6-1-2013

Life cycle cost and assessment model for systems and sources of lighting

Noran Heteba

THE AMERICAN UNIVERSITY IN CAIRO

SCHOOL OF SCIENCES AND ENGINEERING
CONSTRUCTION AND ARCHITECTURAL ENGINEERING DEPARTEMENT

"Life Cycle Cost and Assessment Model for Systems and Sources of Lighting"

By

Noran Heteba

B.Sc. in Construction Engineering, 2009

A thesis submitted to the School of Sciences and Engineering
in partial fulfillment of the requirements for the degree of

Master of Science in Construction Engineering

Under the supervision of

Dr. Samer Ezeldin

Professor, Construction and Architectural Engineering Department

The American University in Cairo, Egypt.

Spring 2013

Statement

“Success is not final, failure is not fatal: it is the courage to continue that counts.”

Winston Churchill

Acknowledgement

First I need to thank God for his guidance and support throughout my whole life and for granting me persistence to overcome all the difficulties and to achieve all my goals.

My deepest gratitude and appreciation goes to my academic supervisor Dr. Samer Ezeldin for giving me the chance to do this research and for his continuous support, guidance, valuable feedback, and optimistic spirit he provided me throughout this research.

My sincere thanks and gratitude goes, also, to Dr. Salah El Haggar for his willingness to give me his valuable time to discuss various aspects in my research and for the sound directions he provided me with.

I would like to thank all SODIC team for every piece of information they provided me with to be able to do this research. I would like, also, to thank my direct managers Eng. Amr Samra – Contracts Director – and Eng. Ahmed Zahran – Project Manager – for their generosity and patience and for giving me the space and time to be able to do my research.

Finally, words cannot express my appreciation to my loving parents for the continuous support and help they are always providing me in my life and for teaching me to believe in myself and in my capabilities.

Abstract

Abstract

This research is concerned with the long-term enhancement of the systems and sources of lighting in Egypt. Lighting is at the top of the residential electricity consumption in Egypt with an estimated 34 percent. Internationally, lighting is only second to HVAC in residential electrical consumption. The methodology of this research is based on Life Cycle Costing (LCC) and Life Cycle Assessment (LCA). This methodology is crystallized through the formulation of an optimization model (LCCA-SSL) which integrates both LCC and LCA methods to help construction stakeholders in the decision making for the most sustainable lighting systems and lighting sources. This implementation can be part of an overall value engineering scheme.

In an attempt to face the global problem of energy consumption, a case study has been selected to compare between two lighting systems; Conventional System and Photovoltaic Solar System, and their corresponding lighting sources; namely, light emitting diodes (LED), high pressure sodium (HPS), and metal halide (MH) within a 10 years period of analysis.

The results showed that the lowest LCC selection is Photovoltaic Solar System using HPS Light Source. The best LCA selection is the Photovoltaic Solar System using LED light source which has the lowest carbon footprint. Consequently, the best integrated alternative between both LCC and LCA is Photovoltaic Solar System using HPS Light Source which has the lowest LCC and the second lowest carbon footprint.

A sensitivity analysis was conducted in order to measure the impact of changing certain variables such as the interest rate, the inflation rate and the period of analysis, where there is uncertainty in their assumption, on the LCC of each of the alternatives. Despite of the similarities

and the breakeven points between some of the alternatives' LCC, Photovoltaic Solar System using HPS as a light source proved to have the least LCC among all the changing variables except for the inflation rate above 35%, where the Conventional System using LED started in beating the Photovoltaic Solar System using HPS to have the lowest LCC among all the other alternatives.

The model proposed in this study is user friendly and can be used by different construction stakeholders to optimize the use of systems and sources of lighting under environmental and long-term constraints.

Table of Contents

List of Figures

List of Tables

Chapter 1
Introduction

Chapter 1: Introduction

1.1 Background

This research is conducted for the purpose of enhancing the competitiveness of the construction industry in Egypt through the application of sustainable measures. One of the areas which constitute the main bulk of economic and environmental impacts was chosen to be the focus of the study. This area is the electricity utilization in lighting (Khasreen et al., 2009). The methods used in this research for the application of sustainable measures on the different sector's lighting are Life Cycle Costing (LCC) and Life Cycle Assessment (LCA). This is performed through the formulation of an optimization model – "LCCA-SSL" – which integrates both LCC and LCA methods to help construction stakeholders in the decision making for the most sustainable lighting systems and lighting sources.

The next sections will clarify the relation between sustainability and the application of LCC and LCA methods by introducing sustainability and its relation with LCC and LCA.

1.2 What is Sustainability?

Sustainability is a concept widely used nowadays after the huge on-going development in the world which has a major negative impact on the environment. According to Poveda in his paper "A Review of Sustainability Assessment and Sustainability/Environmental Rating Systems and Credit Weighting Tools", the definition of Sustainability in the Brundtland Report is "***The development that meets the needs of***

the present without compromising the ability of the future generations to meet their own needs" (Poveda, 2011).

Despite of its importance, sustainability is studied only in the developed countries, while developing countries do not pay much attention to its significance. Consequently, developing countries are suffering from natural resources depleation and lack of affordable alternatives. Accordingly, this leads to the importance of educating people about sustainability in schools, universities as well as awareness campaigns and training courses about sustainability application and its benefits to environment and individuals.

The concept of sustainability was originated in forest giving the meaning of preserving natural resources for the future or never harvest more than what the forest yields in the new growth (Kuhlman et al., 2010). Afterwards, in 1972 the concept was presented in the report of the Club of Rome and gave a very pessimistic view about many natural resources crucial to the human survival, that they shall be exhausted within the next one or two generations (Kuhlman et al., 2010). Therefore, the UN Commission made a report on environment and development to find a way for solving this problem, namely the Brundtland Report named after the UN Commission chairperson (Kuhlman et al., 2010). The Brundtland Report was in 1987; it adopted the sustainability concept and made it well-known (Kuhlman et al., 2010). This report raised the very important question of how to proceed with development with sustainability and accordingly it came up with the term sustainable development giving it the definition stated above (Kuhlman et al., 2010). In 1994, Elkington suggested that sustainability should be divided into three dimensions (Kuhlman et al., 2010). Since then there has been an emergence of two features in the sustainability concept, the first is its division into three dimensions, namely environmental, social, and economic and the second is the distinction between ‘strong’ and ‘weak’ sustainability (Kuhlman et al., 2010). The division of sustainability into weak and strong is also well explained by Paul Etkins in his paper “Environmental sustainability: From environmental valuation to the sustainability gap”. Etkins states that weak sustainability intends that human welfare is not dependant on a specific form of capital and that man-made capital can substitute natural capital but with limitations (Etkins, 2011). However, strong sustainability means that man-made capital and natural capital cannot substitute each other (Etkins, 2011).

According to the United Nations in its Agenda for Development, ***“Development is a multidimensional undertaking to achieve a higher quality of life for all people. Economic development, social development and environmental protection are interdependent and mutually reinforcing components of sustainable development”*** (Kuhlman et al., 2010). However Kuhlman et al. in their paper “What is Sustainability?” opposed the division of the sustainability concept into three dimensions in three points. First, the economic aspect is concerned only with money and this is a very limited view of economics. Second, the gross domestic product (GDP) is intended to measure the welfare of people from only a materialistic view; however it needs to be complemented by other indices such as the human development index. That’s why Kuhlman et al. suggest that the social and economic aspects have to be inter-related and not to be separated. Third, in a three dimensional approach the importance of the environmental aspect in sustainability is undermined when giving it the same weight versus two other aspects; while two dimensional approach gives a 50-50 importance to both dimensions, the socio-economic ‘well-being’ and the environmental.

1.3 Sustainable Development and the Integration between LCC and LCA

After analyzing sustainability and whether it is divided into three dimensions, environmental, economic, and social or only two, environmental and socio-economic ‘well-being’, it is obvious that it has a direct relationship with the application of LCC and LCA. LCC is a ***technique used for the assessment and evaluation of a product/component or a building in general along its whole life in terms of its monetary value*** (“Task Group 4: Life Cycle Costs in Construction”, 2003). Accordingly it tackles the economic pillar of sustainable development. LCA is a ***decision making tool used for evaluating and assessing the environmental impacts of a product/component or a building in general along its whole life*** (“Task Group 4: Life Cycle Costs in Construction”, 2003). Hence, LCA tackles the second pillar of sustainable development which is the environment.

1.4 Problem Statement

Construction industry has a huge environmental and economic impact because of the massive amounts of energy consumption and CO_2 emissions. The energy products and consumption problems are affecting the whole world nowadays. Accordingly, there are different approaches aiming at finding energy saving solutions. In addition to the short-term misconception of stakeholders about buildings’ cost optimization. Several studies were done in order to integrate between life cycle costing and life cycle assessment in construction in order to apply the sustainable development approaches on the construction industry. In addition, optimization models were developed for the purpose of optimizing construction projects' life cycle costs while taking into consideration their environmental impacts. However, these studies are not widely spread and their applications in the developing countries in general and in Egypt in specific are almost nonexistent.

One of the most important components to be studied because of its large amount of energy consumption which affects its life cycle cost and environmental impact is lighting systems and sources. In a study done to find out the most significant environmental impacts in office building in Finland, "electricity use in lighting, HVAC, and power outlets; heat conduction through the structure; manufacture and maintenance of steel, concrete, and paint; water use and waste water generation; and office waste management" came as priority (Khasreen et al., 2009). On the other hand the residential and industrial sectors consume the main bulk of electricity utilization in Egypt with a 39.9% and a 32.7%, respectively, of the total consumption as shown in figure 1.1 (Yassin, n.d).

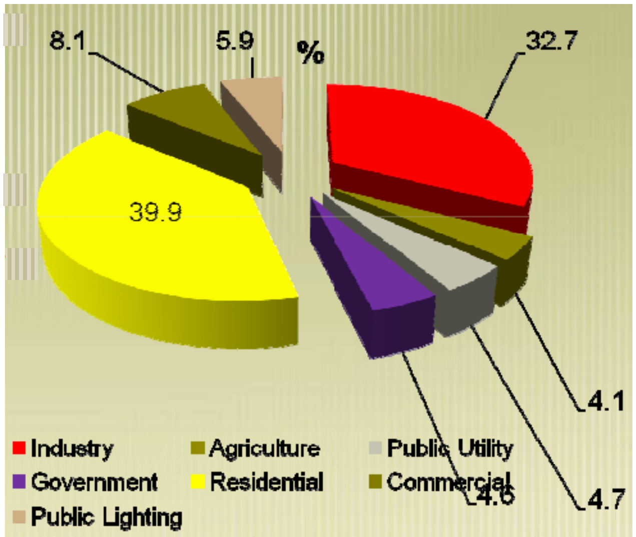


Figure 1.1 – Electrical Energy Consumption Patterns
in Egypt in year 2009/2010 – Dr. Ibrahim Yassin

According to the Center of Climate and Energy Solutions, lighting comes in the second place after space cooling in the residential electricity consumption (refer to figure 1.2).

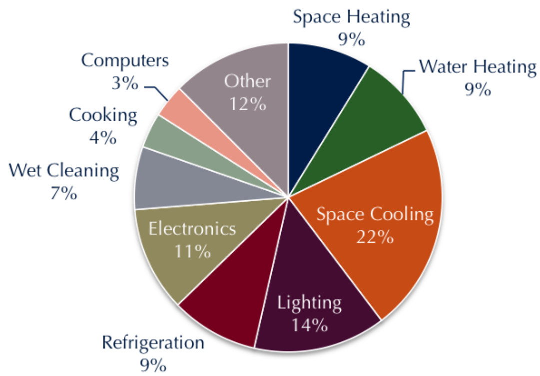


Figure 1.2 – Residential Electricity Consumption by End Use (2010) – Center for Climate and Energy Solutions

On the other hand, according to Surveys conducted in Egypt in year 2000, lighting comes in the first place in energy consumption as shown in figure 1.3 (Yassin, n.d).

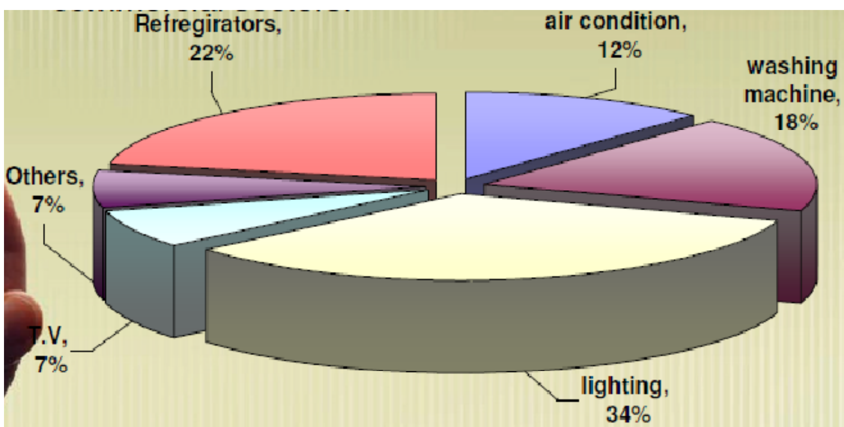


Figure 1. 3– Residential Electricity Consumption in Egypt (2000) – Dr. Ibrahim Yassin

Consequently the development of a new model which integrates life cycle costing and life cycle assessment methods and techniques for the optimization of the use of the most feasible and environmental friendly lighting systems and sources shall enhance the construction industry competitiveness in Egypt.

1.5 Objectives

The main objective of this study is to initiate a simple approach which helps assets/projects' stakeholders in decision-making on the optimum life cycle cost and minimal environmental impacts of lighting systems and sources. The approach shall provide stakeholders with the optimized lighting system and source's life cycle cost and the life cycle assessment methods applicable in Egypt. A software optimization model shall be developed based on the proposed approach to facilitate the calculation process. The main objectives of the developed model could be summarized as follows:

1. Determination of the most economic lighting system and source which can be used in different sectors such as residential, commercial, streets, and office buildings in Egypt.
2. Determination of the most environmental friendly lighting system and source which has the least environmental impacts in terms of energy consumption and CO_2 emissions during its usage phase.
3. Comparison between the conventional lighting system and source and the energy-saving lighting system and source in terms of their life cycle costs, energy consumption and CO_2 emissions.
4. This model shall be finally validated through a case study in Egypt.

1.6 Methodology

Figure 1.4, below, explains the sequence of the methodology of the research starting from the literature review till reaching the final step which is the model validation.

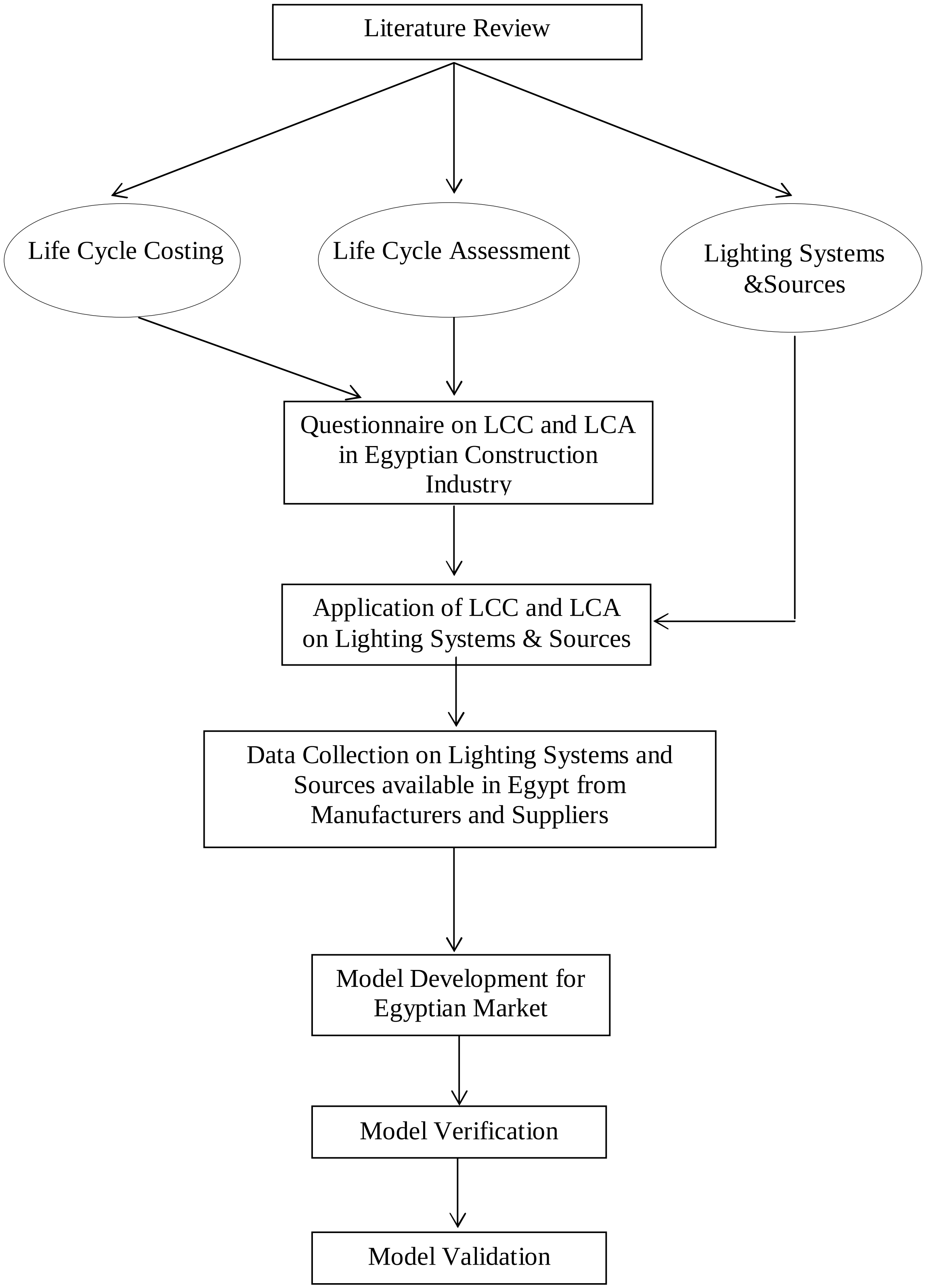


Figure 1.4 – Research Methodology

1.7 Organization of the Thesis

The research consists of six chapters. A brief synopsis of these chapters is described below:

Chapter 2: Literature Review: Presents a literature review on the topics of LCC and LCA; their history, definitions, and methodologies.

Chapter 3: Lighting Systems and Sources: Discusses the current lighting systems and sources; their types, specifications, and applications.

Chapter 4: Methodology and Analysis: Presents the methodology of this research which consists of the questionnaire data collection and analysis and the LCA and LCC methodologies adopted in this research.

Chapter 5: Model Development: Presents the LCCA-SSL model formulation, the equations used, as well as the validation of the model through a real case study of a project in Egypt.

Chapter 6: Conclusion: Concludes the research and summarizes the final results of the case study, as well as giving further recommendations for future research.

Chapter 2
Literature Review

Chapter 2: Literature Review

2.1 Life Cycle Costing in Construction Industry

2.1.1 Background:

Life Cycle Costing (LCC) is a technique used for the assessment and evaluation of a building or an asset in general along its whole life in terms of its monetary value. It is used, mainly, for the comparison between the life cycle costs of two or more alternatives. It can be used in any or all phases of a product/asset ("Life Cycle Costing guideline", 2004). It helps stakeholders in decision making as it compares between different assets' alternatives and concludes which is more economic investment or between different assets' components and gives information on which is more economic along the whole life of the asset. In the Consultancy Study on Life Cycle Energy Assessment of Building Construction, it is stated that LCC is a ***quantitative method which helps in decision making as it gives information about the payback period of a product or an asset as well as the cost of the life cycle of an investment from initial cost to end of life cost including discounting rates of money*** ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007). In general, stakeholders decide on the more economic investment by comparing only between their initial capital investment costs. However, this is misleading as according to Guoguo the costs of operation, maintenance, and rehabilitation of a building make up to 80% of its total life cycle cost (Guoguo, n.d). According to ISO 15686, LCC is defined as ***"A technique which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital costs and future operational costs. In particular it is an economic assessment considering all the projected relevant cost flows over a period of analysis expressed in monetary value. It can be defined as the present value of***

the total cost of an asset over the period of the analysis" ("Task Group 4: Life Cycle Costs in Construction", 2003).

LCC technique goes back to the 1930s by the US government; but there was no real application on buildings till the mid 1960s ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007). It was initially used in North America and then started to be known as a topic of study and research in the 1950s when the Building Research Establishment undertook a research on cost-in-use ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007). The National Institute of Standards and Technology (NIST) Handbook 135 defined LCC in the building sector as "***The total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system over the appropriate Study Period. The Study Period is the length of time period covered by the economic evaluation, which includes both the planning/construction period and the service period.***" ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007). However, it is not much beneficial to calculate the life cycle cost of an asset by its own without comparing it to an alternative investment, especially, when calculating the asset's present value. It may only be beneficial if we are calculating the payback of an asset. In his thesis "Life-Cycle Cost Analysis: A Computer Aided Tool for the Egyptian Construction Industry", Ahmed Ibrahim states that it is not necessary to include all the life cycle costs when comparing between alternatives, only the changeable costs will make sense in the comparison in order to be able to take a decision (Ibrahim, 2001). In order to apply LCC there has to be a known rigid methodology, cost breakdown structure, and an accurate source for the data collection and this is what the next paragraphs will enlighten.

2.1.2 Cost Breakdown Structure:

Normally, the LCC assessment covers the costs of the studied product/ asset from its initial investment cost till its end of life cost. However, the costs to be included in the Life Cycle Costing study differ from one standard to another as they differ among countries and projects. Also, the costs included differ according to the nature of the study. Either it is studying the life cycle cost of a product or an asset by its own, for example, to study its payback period or it is comparing the life cycle cost among two alternative products or assets to decide to invest in which of them. The level of the cost breakdown is dependent on the scope and the purpose of the LCC study ("Life Cycle Costing guideline", 2004)

According to BS ISO 15686 part 5, LCC includes construction costs, operation costs, maintenance costs, end of life costs and finally the environmental costs which is optional (refer to Figure 2.1). It is obvious from literature that there is confusion between the meaning of the whole life cost and the life cycle cost, as in various papers they are considered as one. However, as shown in figure 2.1, according to ISO 15686-5, whole life cost consists of externalities, non-construction costs, life cycle cost (LCC) and income ("Standardised Method of Life Cycle Costing for Construction", n.d).

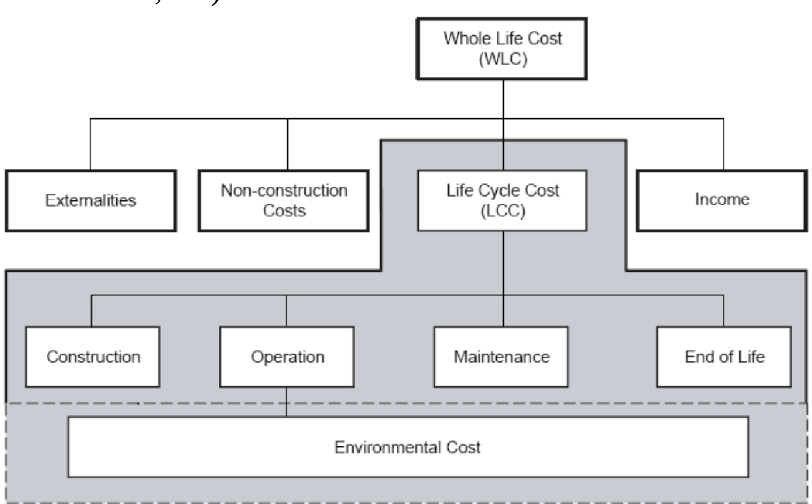


Figure 2. 1 – Life Cycle Costing. "Standardised Method of Life Cycle Costing for Construction". n.d

Cost breakdown structure (CBS) of LCC is customized according to the country it is applied in. For example, occupancy costs, which are not included in the LCC according to ISO 15686-5, are normally included in the LCC in the UK ("Standardised Method of Life Cycle Costing for Construction", n.d). The breakdown of LCC costs including the occupancy costs is shown in Appendix A; this breakdown can be tailored as well according to the country and the type of project.

2.1.2.1 Initial Investment Cost

Initial investment cost reflects all costs of the asset before occupancy. According to the Life Cycle Costing Manual for the Federal Energy Management Program "***The costs incurred in the planning, design, construction and/or acquisition phase of a project are classified as initial investment costs. They usually occur before the building is occupied or a system is put into service***" (Fuller et al., 1996). Construction costs, according to ISO 15686-5, include building works and all costs payable by the client for the building/ asset such as consultancy fees, infrastructure charges, licenses and permits, marketing costs, rights to light costs, project risk register contingency … etc. Construction costs differ according to the type of project. For example, the construction costs of a hospital may include several items which are not to be used in the execution of a residential building and vice versa; this in addition to the method of construction. Initial investment costs are mainly the costs which almost all investors give attention to, though it is about only 20 – 25% of the life cycle cost (refer to the figure 2.2). In order to study LCC of a product/asset, the initial investment cost has to be compared to the net saving and if it is more, then, this investment is feasible. Which means that when we compare two alternatives A & B, A has lower investment cost than B, the net saving of B has to be greater than the additional investment cost of A in order for us to go for investing in B (Fuller et al., 2000)

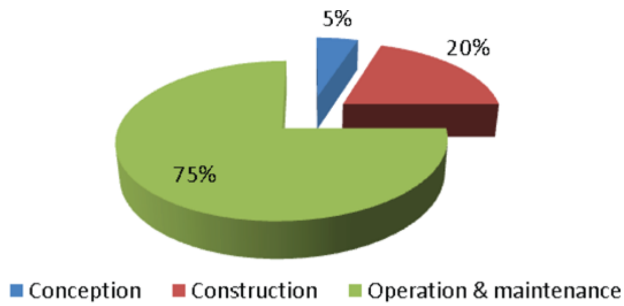


Figure 2. 2 – Life Cycle Cost Breakdown. APOGEE. 2006

2.1.2.2 Operation Costs

Operation costs is defined according to the BCIS and the BSI published document "Standardised Method of Life Cycle Costing for Construction" as ***all the costs operating the building except for the maintenance costs; however these costs are not arising from its occupancy but arising from the asset itself*** ("Standardised Method of Life Cycle Costing for Construction", n.d). Life cycle costing operation costs are those which are directly related to the asset itself; for example, costs of office materials are to be excluded from LCC operation costs ("Life Cycle Cost Analysis Handbook", 1999). Operation costs are periodic costs which include internal and external cleaning, utilities such as electricity, gas, water and drainage … etc, administrative costs such as property management, waste management and disposal, and staff engaged in servicing the building, overhead costs such as insurance, lease, and finally taxes, rates and other local charges payable with owning the building.

2.1.2.3 Maintenance, Replacement and Repair Costs

Maintenance replacement, repair and adaptation of the asset are either scheduled and anticipated costs or unscheduled and unanticipated future costs ("Life Cycle Cost Analysis Handbook", 1999). Maintenance and replacement costs include the scheduled replacements and maintenance of major and minor asset's components, scheduled redecorations, preventative maintenance plans, and refurbishment and adaptation costs excluding those done during construction ("Standardised Method of Life Cycle Costing for Construction", n.d). Maintenance and replacements costs are either done annually or on less frequent basis ("Life Cycle Cost Analysis Handbook", 1999). On the other hand, repair costs are those ***costs kept as allowance for the unscheduled replacements, maintenance and repair costs*** ("Standardised Method of Life Cycle Costing for Construction", n.d).

2.1.2.4 Occupancy Costs

Occupancy costs are not included in the life cycle cost analysis according to ISO 15686-5; they are classified as non-construction costs (refer to figure 2.1) though it is normally included in the life cycle costing calculation in the UK ("Standardised Method of Life Cycle Costing for Construction", n.d). They are ***costs arising from the usage of tenants to the asset such as internal moves, manned security, helpdesk, telephones, IT services, car parking charges, furniture, fittings, and equipment (FF&E) … etc***. ("Standardised Method of Life Cycle Costing for Construction", n.d).

2.1.2.5 End of Life Costs/ Residual Value

According to the BCIS and the BSI published document "Standardised Method of Life Cycle Costing for Construction", end of life costs are ***those costs which are payable at the end of the analysis period***. It is also referred to as the residual value. The residual value is defined as ***"the net worth of a building or building system at the end of the LCCA study period"*** ("Life Cycle Cost Analysis Handbook", 1999). Costs which include those of inspections carried out before demolition, costs of demolition, costs of repair done at the end of the period because of a contractual obligation to return the building on an agreed condition. As well as, costs of values of components of the asset which their life span is still not ended. Finally, the "end of life" term is in almost all LCC calculations not the end of life of the asset, but it is the end of the study period ("Standardised Method of Life Cycle Costing for Construction", n.d).

2.1.2.6 Environmental Costs

Environmental cost is an optional step in the LCC study, which is done when the researcher or the user wants to include the environmental impacts in the LCC study. This is done through integrating LCC with life cycle assessment (LCA) study. There are different ways used in order to integrate between LCC and LCA getting a final environmental cost result. This shall be explained in this chapter in the "Integration between LCC and LCA" section.

2.1.3 Discount Rates

As LCC envisages the estimates of the future costs of products/assets, a discount rate has to be added to the real costs for the accuracy of the results. According to ISO 15686-5 (2006), discount rate is defined as ***"Factor reflecting the time value of money that is used to convert cash flows occurring at different times to a common time"*** (Langdon, 2007).

Discount rate comprises the interest rate of long term investment in bank or government bonds, the interest rate that business would expect as a return for risk and the inflation rate affecting the purchasing power of the currency ("Life Cycle Costing Guideline", September 2004). Discount rate does not reflect the decrease in the value of the asset due to price movements resulting from its degradation by time. However, it reflects the changes of the asset due to the interest rate earned on the money of the asset combined with its value decrease due to inflation. Discount rate is divided into two types: real discount rate and nominal discount rate.

2.1.3.1 Real Discount Rate

Real discount rate takes into account the interest rate of long term investment in bank or government bonds, the interest rate that business would expect as a return for risk, but it excludes the inflation rate affecting the purchasing power of the currency.

2.1.3.2 Nominal Discount Rate

Nominal discount rate takes into account the interest rate of long term investment in bank or government bonds, the interest rate that business would expect as a return for risk, as well as the inflation rate affecting the purchasing power of the currency.

According to the life cycle costing handbook, both real and nominal discount rates give the same result as long as each is included in its corresponding present value calculation. Consequently, the exclusion of the real discount rate to the inflation rate does not mean it is ignoring it. However, it is just excluding it as a matter of simplifying the LCC calculation ("Life Cycle Cost Analysis Handbook", 1999). The decision of using real or nominal discount rate is dependent on the decision of usage of constant dollars or current dollars. Real discount rate is used in calculation when constant dollars are used; on the other hand, nominal discount rate is used in calculation when current dollars are used (Fuller et al., 1996).

In this research the nominal discount rate shall be used because of the instability of the Egyptian industry nowadays which leads to the huge increase in the Egyptian Pound inflation rate.

2.1.3.3 Constant Dollars

Constant dollar, according to "NIST Handbook 135, 1995 edition" is ***dollar with constant purchasing power of a reference year acting as the datum excluding inflation or deflation*** ("Life Cycle Cost Analysis Handbook", 1999).

2.1.3.4 Current Dollars

Current dollar, according to "NIST Handbook 135, 1995 edition" is ***dollar with a fluctuating purchasing power which changes with the changes in price including inflation or deflation*** ("*Life Cycle Cost Analysis Handbook*", 1999).

2.1.4 LCC Application Methodology:

According to Davis Langdon in its project done in 2007 to develop a common European methodology for Life Cycle Costing (LCC) in construction, there has to be a framework for the application of LCC. The findings of this project provide a general framework for the application of LCC across EU without replacing country-specific decision models and approaches. It is divided into 15 generic steps (refer to Table 2.1) which can be tailored on the user's project depending on its size, stage and level of detail required (Langdon, 2007). This framework is based on the core process of LCC (refer to figure 2.3).

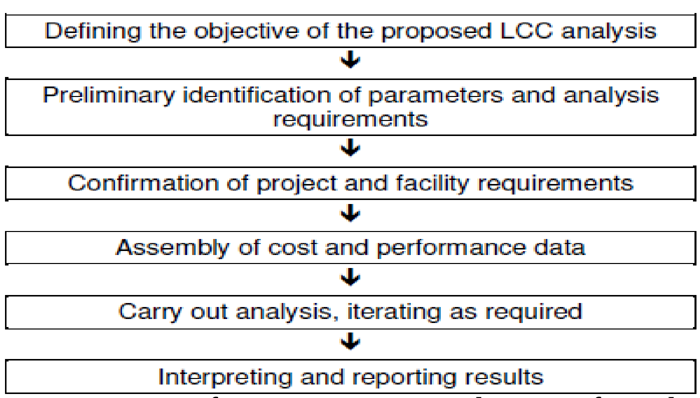


Figure 2. 3 – Core Process of LCC – Davis Langdon – "Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology – Final Methodology". 2007

	STEP	OUTCOME / ACHIEVEMENT
1	Identify the main purpose of the LCC analysis	Statement of purpose of analysis Understanding of appropriate application of LCC and related outcomes
2	Identify the initial scope of the analysis	Understanding of: Scale of application of the LCC exercise Stages over which it will be applied Issues and information likely to be relevant Specific client reporting requirements
3	Identify the extent to which sustainability analysis relates to LCC	Understanding of: Relationship between sustainability assessment and LCC Extent to which the outputs from a sustainability assessment will form inputs into the LCC process Extent to which the outputs of the LCC exercise will feed into a sustainability assessment
4	Identify the period of analysis and the methods of economic evaluation	Identification of the period of analysis and what governs its choice Identification of appropriate techniques for assessing investment options
5	Identify the need for additional analyses (risk/uncertainty and sensitivity analyses)	Completion of preliminary assessment of risks/ uncertainties Assessment of whether a formal risk management plan and/or register is required Decision on which risk assessment procedures should be applied
6	Identify project and asset requirements -	Definition of the scope of the project and the key features of the asset Statement of project constraints Definitions of relevant performance and quality requirements Confirmation of project budget and timescales Incorporation of LCC timing into overall project plan
7	Identify options to be included in the LCC exercise and cost items to be considered	Identification of those elements of an asset that are to be subject to LCC analysis Selection of one or more options for each element to be analysed Identified which cost items are to be included
8	Assemble cost and time (asset performance and other) data to be used in the LCC analysis	Identification of: All costs relevant to the LCC exercise Values of each cost Any on-costs to be applied Time related data (e.g. service life/maintenance data)

Table 2. 1 – LCC Framework – Davis Langdon – “Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology – Final Methodology”. 2007

9	Verify values of financial parameters and period of analysis	Period of analysis confirmed Appropriate values for the financial parameters confirmed Taxation issues considered Application of financial parameters within the cost breakdown structure decided
10	Review risk strategy and carry out preliminary uncertainty/ risk analysis	Schedule of identified risks verified Qualitative risk analysis undertaken – risk register updated Scope and extent of quantitative risk assessment confirmed
11	Perform required economic evaluation	LCC analysis performed Results recorded for use at Step 14
12	Carry out detailed risk/uncertainty analysis (if required)	Quantitative risk assessments undertaken Results interpreted
13	Carry out sensitivity analyses (if required)	Sensitivity analyses undertaken Results interpreted
14	Interpret and present initial results in required format	Initial results reviewed and interpreted Results presented using appropriate formats Need for further iterations of LCC exercise identified
15	Present final results in required format and prepare a final report	Final report issued, to agreed scope and format Complete set of records prepared to ISO 15686 Part 3

Table 2.1 (cont'd) – LCC Framework – Davis Langdon – "Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology – Final Methodology". 2007

2.1.5 LCC Calculation Methods:

After consolidating all the data needed for calculating LCC, such as present and future costs, discount rate, study period, LCC can now be calculated. There are different methodologies for the calculation of the life cycle cost of an asset such as present value which is the most widely used, simple payback, discount payback, equivalent annual cost, internal rate of return, and net saving (refer to table 2.2).

2.1.5.1 The Net Present Value Method:

The present value method is the most important and common method as it compares alternative assets with same lifetimes. It depends on converting all the future and annual cost into present value and this of course requires the involvement of inflation and interest rates.

2.1.5.2 The Simple Payback Method:

The simple payback method calculates the period which the initial investment cost is to be gained by the investor and then the income is considered a profit. It compares the alternative assets in terms of payback periods and the one with the shortest payback period is the one to be chosen. The simple payback method ignores the inflation and interest rates of money.

2.1.5.3 The Discount Payback Method:

The discount payback method is the same as the simple payback period; however, it takes the inflation and interest rates into consideration.

2.1.5.4 The Equivalent Annual Cost Method:

The equivalent annual cost method uses the same steps for calculating the net present worth but it takes a step further which is estimating the costs which will be paid on an annual basis.

2.1.5.5 The Internal Rate of Return (IRR) Method:

The internal rate of return method calculates the rate of return of each alternative taking into consideration the discount rates. The alternative with the highest rate of return is the most profitable (Schade, n.d). The IRR is to be compared against the investor's minimum acceptable rate of return (MARR); if the IRR is higher than the MARR, then the investment is economic (Fuller et al., 1996).

2.1.5.6 The Net Saving (NS) Method:

The net saving method calculates the net amount in present value which the asset is expected to save during the study period (Fuller et al., 1996). The alternative which has higher net saving is the most profitable (Schade, n.d).

Method	What does it calculate	Advantage	Disadvantage	Usable for
Simple payback	Calculate the time required to return the initial investment. The investment with the shortest pay-back time is the most profitable one (Flanagan et al., 1989).	Quick and easy calculation. Result easy to interpret (Flanagan et al., 1989).	Does not take inflation, interest or cash flow into account (Öberg, 2005, Flanagan et al., 1989).	Rough estimation if the investment is profitable (Flanagan et al., 1989).
Discount payback method (DPP)	Basically the same as the simple payback method, it just takes the time value into account (Flanagan et al., 1989).	Takes the time value of money into account (Flanagan et al., 1989).	Ignores all cash flow outside the payback period (Flanagan et al., 1989)	Should be only used as a screening devise not as a decision advice (Flanagan et al., 1989).
Net present value (NPV)	NPV is the result of the application of discount factors, based on a required rate of return to each years projected cash flow, both in and out, so that the cash flows are discounted to present value. In general if the NPV is positive it is worth while investing (Smullen and Hand, 2005). But as in LCC the focuses is one cost rather than on income the usual practice is to treat cost as positive and income as negative. Consequently the best choice between tow competing alternatives is the one with minimum NPV (Kishk et al., 2003).	Takes the time value of money into account. Generates the return equal to the market rate of interest. It use all available data (Flanagan et al., 1989).	Not usable when the comparing alternatives have different life length. Not easy to interpret (Kishk et al., 2003).	Most LCC models utilize the NPV method (Kishk et al., 2003). Not usable if the alternatives have different life length (Flanagan et al., 1989).
Equivalent annual cost (ECA)	This method express the one time NPV of an alternative as a uniform equivalent annual cost, for that it take the factor present worth of annuity into account (Kishk et al., 2003).	Different alternatives with different lifes length can be compared (ISO, 2004).	Just gives an average number. It does not indicate the actual coast during each year of the LCC (ISO, 2004).	Comparing different alternatives with different life's length (ISO, 2004).
Internal rate of return (IRR)	The IRR is a discounted cash flow criterion which determines an average rate of return by reference to the condition that the values be reduced to zero at the initial point of time (Moles and Terry, 1997). It is possible to calculate the test discount rate that will generate an NPV of zero. The alternative with the highest IRR is the best alternative (ISO, 2004)	Result get presented in percent which gives an obvious interpretation (Flanagan et al., 1989).	Calculations need a trail and error procedure. IRR can be just calculated if the investments will generate an income (Flanagan et al., 1989).	Can be only use if the investments will generate an income which is not always the case in the construction industry(Kishk et al., 2003).
Net saving (NS)	The NS is calculated as the difference between the present worth of the income generated by an investment and the amounted invested. The alternative with the highest net saving is the best (Kishk et al., 2003).	Easily understood investment appraisal technique (Kishk et al., 2003).	NS can be only use if the investment generates an income (Kishk et al., 2003).	Can be used to compare investment options (ISO, 2004). But just if the investment generates an income (Kishk et al., 2003).

Table 2. 2 – LCC Calculation Methods – Jutta Schade –"Life Cycle Cost Calculation Models for Buildings". n.d

In this thesis, the Davis Langdon of LCC shall be adopted because of its broad applicability which may fit the topic of this thesis. The results of the LCC shall be based on two calculation methods which are the equivalent annual value and the net present value.

2.1.6 LCC Data Collection

Data collection is an important and a difficult step in the LCC study. Since the LCC study is built on estimation of future data so there has to be a reliable method for data collection for the reduction of uncertainties. According to Schade in his article "Life Cycle Cost Calculation Models for Buildings" the data required for the calculation of LCC can be divided into five groups; occupancy data, physical data, cost data, performance data, and quality data (refer to figure 2.4). In order to collect these data, there are several sources of data collection and estimation such as manufacturers, suppliers, clients, and contractors and this is done through questionnaires and surveys. In addition to engineering cost method, analogous cost method and parametric cost method ("Life Cycle Costing Guideline", September 2004) which are used for cost data collection. The engineering cost method is used on the need of estimating a particular cost element of a product/ asset by examining it, where the detailed capital and operational cost data of the asset under study is available. The analogous cost method is based on historical data from similar built projects with similar components and products. Finally, the parametric cost method is used when some of the costs of the historical asset or the under study asset are known while others are limited to known parameters; these known cost data can be used to develop a mathematical regression or progression formula that can be solved for the cost estimate required ("Life Cycle Costing Guideline", September 2004).

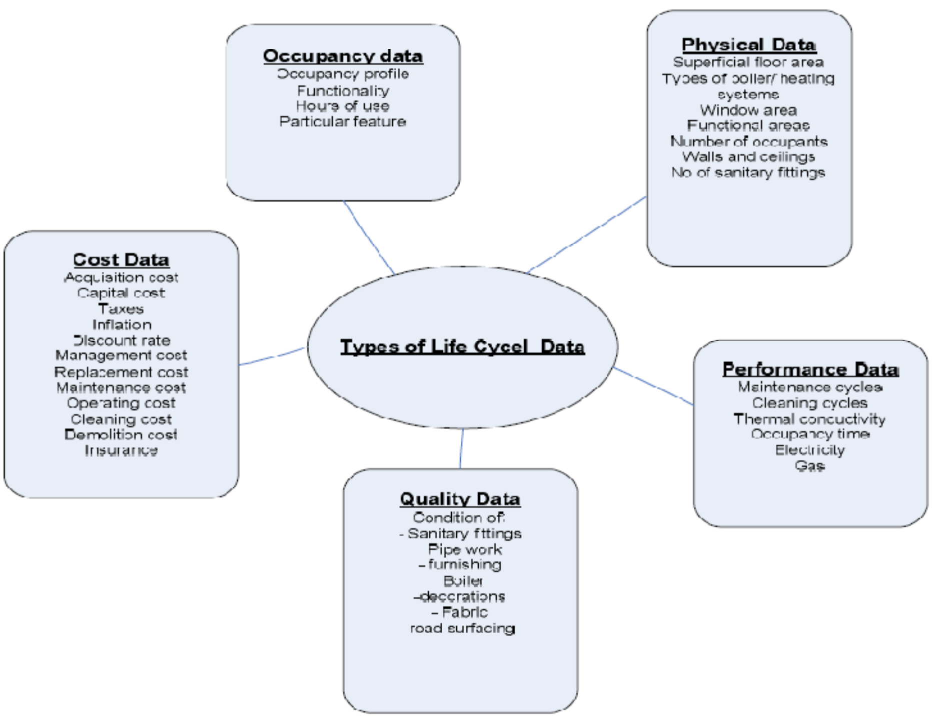


Figure 2. 4 – Types of LCC Data – Jutta Schade – "Life Cycle Cost Calculation Models for Buildings". n.d

2.1.7 Uncertainty of the Results

As LCC deals with future costs and depends on estimation, accordingly it faces a huge amount of uncertainty in data and results. Therefore, in order for the LCC study to have sense and to be beneficial the final result has to be indicative (Tupamaki, 2008). Construction projects life span ranges from 20 to 50 years, as a result, many changes will probably happen such as fuel prices, building products prices and service lives … etc. (Fawcett et al., n.d). This means that the estimation of a detailed and accurate future costs is impossible (Fawcett et al., n.d). In order to overcome the LCC uncertainty problem the life cycle cost of the product/asset has to be a range and not a single value.

2.1.7.1 Probabilistic Results vs. Deterministic Results

Since the 1970s and till recent years the LCC study used to use the deterministic approach (refer to figure 2.5). The deterministic approach incorporates precise data input and yields a single point result for all variables in the product/asset through its study period (Fawcett et al., n.d). Afterwards, the probabilistic approach has taken its way into emergence and since then it is under research. The probabilistic approach encompasses a range of values for life cycle cost. The range of results are calculated using the 3-point estimate method (lowest conceivable value, most likely value and highest conceivable value) in order for the results to be more realistic (Fawcett et al, n.d.).

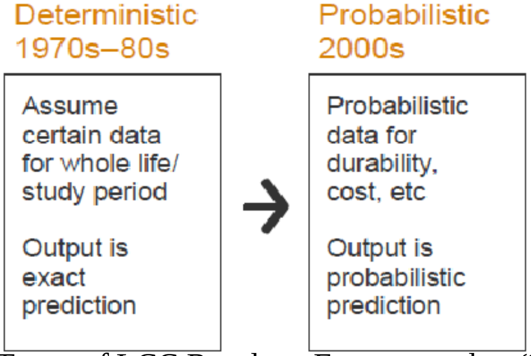


Figure 2. 5 – Evolution of Types of LCC Results – Fawcett et al. – "*Sustainiable Construction Projects: Case Study of Flexible Strategies for Long-Term Sustainability under Uncertainty*"

2.1.8 Modeling of LCC

There is a quite large number of models in market formulated to estimate the LCC of assets. Nevertheless, one of the difficulties faced in adopting the LCC technique in Egypt is the non-existence of a software model which facilitates the calculation of the LCC. Most of the LCC models in market are similar in that they provide estimates of LCC of buildings. However each has different calculation technique and requires different inputs. Examples of software packages are LC-profit, BLCC, EconPack, LEGEP, RELEX LCC, Prototype version of Calcus … etc. (Edvardsen, n.d). In order to promote the use of LCC in Egypt, the LCC model should be characterized by the following:

1. User-friendly; facilitates the estimation of the LCC in terms of not requiring too many and complex input data by the user;
2. Comprehensive; includes all the relevant costs and factors to the LCC of the asset ("Life Cycle Costing Guideline", 2004);
3. Flexible; has an easy access to its database to change the costs and rates which will change with time.
4. Available in the Egyptian Market with its manual and affordable training courses in the large Egyptian construction companies in order to encourage the construction companies to use it.

The LCC Model can be used in Egypt to enhance the economic feasibility of the different sectors' construction projects in the following areas:

1. Construction materials and products such as different types of bricks, wood … etc.;
2. Electrical systems such as lighting systems;
3. Mechanical systems such as HVAC and heating systems.

2.2 Life Cycle Assessment in Construction Industry

2.2.1 Background:

The building sector in comparison to other sectors has the greatest environmental impact during its whole life cycle because of having the longest life span among other industrial products (Sterner, 2002). The building sector is responsible for about 40% of the society's total environmental impact (Jacob, 2001). During the construction phase it consumes up to 40% of energy consumption, 50% of raw materials (Tupamaki, 2008), 25% of wood and trees expenditure, and 16% of fresh water usage (Paulsen, 2001). Consequently, it causes 40% of waste (Tupamaki, 2008), 35% of the world's CO_2 emissions, and 50% of ozone depletion (Paulsen, 2001). On the other hand, during the operation phase, the environmental impact of the building sector does not come to an end. However, it is still causing environmental impact through heating, ventilation, maintenance, and alteration (Sterner, 2002). The reduction of these environmental impacts has become highly needed. The reduction of the greenhouse gases emissions by about 50% before 2100 and the reduction of the CO_2 emissions by 70% before 2030, in order to avoid the increase in temperature by more than 1°C, are essential (Khasreen et al., 2009).

Accordingly, the use of a technique responsible for assessing the environmental impact of a material/product/asset through its life cycle from the acquisition to disposal is inevitable (sterner, 2002); this technique is known as life cycle assessment (LCA). There are other techniques used for environmental impact assessment; however LCA is the most important because it evaluates the life cycle of the asset from the acquisition to disposal. Studies revealed that the operation phase in conventional buildings embodies about 80% to 90% of the life-cycle energy use, while only 10% to 20% is consumed by the material extraction and production and less than 1% through end-of-life treatments (Khasreen et al., 2009).

According to ISO 14040, LCA is defined as ***"assessing the total environmental impact associated with a product's manufacture, use, and disposal and with all actions in relation to the construction and use of a building or other constructed asset throughout its life cycle"*** ("Task Group 4: Life Cycle Costs in Construction", 2003). LCA can be used as a tool for decision-making for purchasing products or implementing designs taking into consideration their environmental impacts. The history of LCA goes back to 1969 when Coca Cola Company performed a multi-criteria study to compare between glass and plastic bottles ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007). Several studies were conducted by the Society of Environmental Toxicology and Chemistry (SETAC) in order to develop an LCA methodology in the late 1980s and the early 1990s. LCA is defined according to SETAC as:

> ***"An objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and material uses and releases to the environment, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing materials; manufacturing, transportation and distribution; use, reuse, maintenance; recycling and final disposal. The life cycle assessment addresses only environmental impacts and not other consequences of human activities such as economic and social effects"*** ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007).

Afterwards, in the late 1990s ISO standard did studies and developed an international standard framework for LCA to facilitate its use. Nevertheless, LCA is more dynamic in manufacturing sectors rather than in the construction sector (“An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments”, 2007). The next paragraphs will explain the framework of LCA, its methodology, and modeling.

2.2.2 LCA Methodology

LCA is one of the best techniques in evaluating products/assets’ environmental impact in the building sector. This is because of its comprehensive study to the environmental impacts of the product/asset from cradle to grave i.e. it covers the raw materials processing, manufacturing, transportation, distribution, use, reuse, maintenance, recycling till its disposal (Khasreen et al., 2009). The international standard framework of LCA is based on the ISO 14040, which divides it into four phases (refer to Figure 2.6): goal and scope definition, inventory analysis, impact assessment, and interpretation.

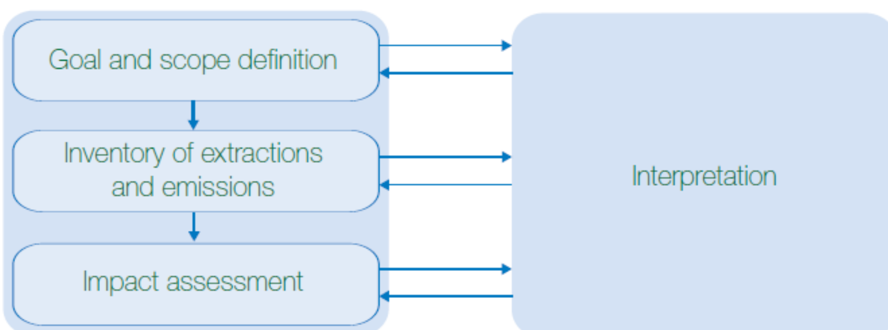


Figure 2. 6 – ISO 14040 LCA Framework – Liu Guoguo – “Integration of LCA and LCC for Decision Making is Sustainable Building Industry”. n.d

2.2.2.1 Goal and Scope Definition

This is the first phase in the framework in which all the process is defined and formatted. Accordingly, this means that this stage is a very important one and should be well formulated concerning what questions will be studied and how the results will be implemented (Sterner, 2002). The goal definition means to whom and for what reason is the LCA study done ("LCA for Construction Product", 2004), for example, will it be carried out for research purpose or in order to prove something … etc. ("Introduction to LCA with SimaPro", 2004). According to the user manual "Introduction to LCA with SimaPro 6" the scope definition here encompasses the functional unit and reference flow, the system boundaries, criteria for inclusion of inputs and outputs, allocation, keeping track of data quality requirements ("Introduction to LCA with SimaPro", 2004). This definition stage should be as much detailed as possible covering the function of the building, its geographical location, the system boundaries meaning a component of the building, a phase in the building life cycle or the whole building life cycle will be studied (Khasreen et al., 2009). It should, also, include the functional units which could be m^2, m^3, number of occupants …etc., the environmental impact categories that should be studied, methodologies of impact assessment, the data requirements, the assumptions, the limitations, the initial data quality requirements, the type of critical review and the type of the report required for the study (Khasreen et al., 2009). Because this stage is mainly reliant on assumptions and because the buildings have long life span, the goal and scope definition phase has to be reviewed and modified after each phase (Khasreen et al., 2009).

2.2.2.2 Inventory Analysis

This phase is considered the body of the LCA process as it is concerned with the data collection. It is the most complex and difficult stage since it involves the collection of all relevant inputs and outputs of energy, mass flow, and emissions to air, water and land (Khasreen et al., 2009). It encompasses the energy of materials and building components, their transportation, wastes emitted, resources consumption, maintenance, replacement, demolition

(Khasreen et al., 2009). The construction phase, construction wastes and the transportation of equipment to site are not to be included in the LCA study (Khasreen et al., 2009).

According to ISO 14044, the inventory analysis procedure involves the data collection, data calculation, data validation, relating data to unit processes and functional unit, and data allocation when the study is involving recycling (Langdon, 2007). The need for allocation changes according to the size of the system boundary; as the system boundary increases, the need for allocation decreases (Khasreen et al., 2009).

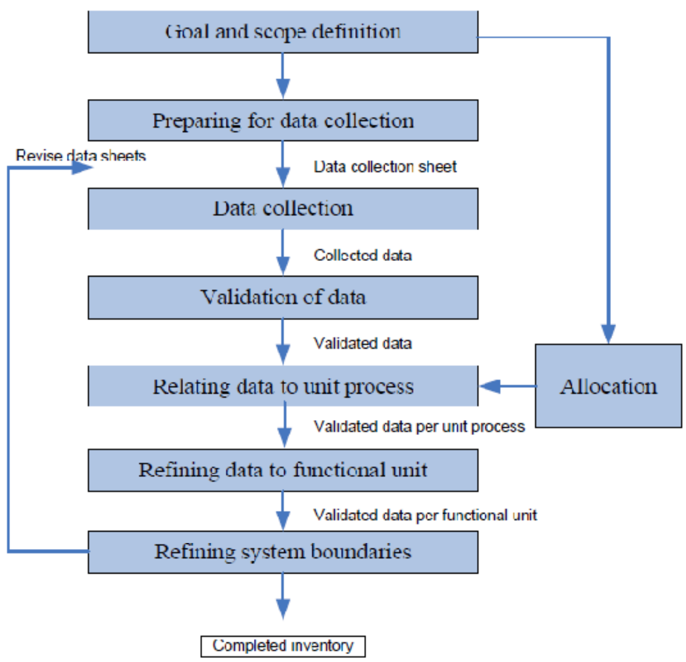


Figure 2. 7 – ISO 14044 LCI analysis procedures – Khasreen et al. – "Life Cycle Assessment and Environmental Impact of Buildings". 2009

Data is divided into two types:

1. Foreground data: very specified data about the product or the system
2. Background data: generic data accompanied with the process such as transportation, energy, materials … etc.

There are different methods for data collection depending on the required data. For example, the foreground data may be collected through questionnaires to suppliers, consultants, or people related to LCA studies and research. However, 80% of the background data can be collected from literature, from databases, from the internet … etc. ("Introduction to LCA with SimaPro", 2004). The nationality of data is a very important concern as methods of construction, production of materials, resources used … etc. change from country to country (Khasreen et al., 2009).

Data quality, accuracy and completeness are very important since the life cycle inventory data drives the study of the LCA and determines its success or failure. Any changes or inaccurate data may lead to wrong results; in addition to that the incompleteness of the data may lead to the change of the goal and scope definition as well as the system boundaries (Khasreen et al., 2009). Thus the choice of a reliable source of data is a must. There may be one or more source of data such as "direct measurements, laboratory measurements, governmental and industrial documents, trade reports and databases, national databases, environmental inventories, consultancies, academic sources, and engineering judgments" (Khasreen et al., 2009)

Figure 2.8, below, shows the inputs and outputs examined by LCA study of a building element (Mundy and Livesey, 2004)

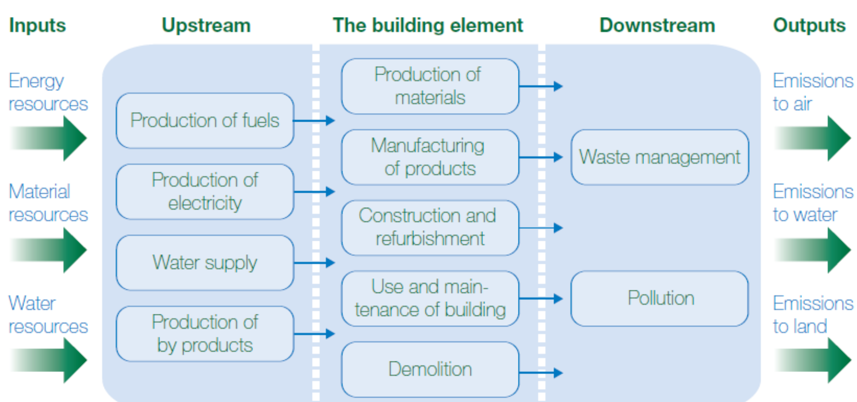


Figure 2. 8 – Inputs and outputs of a building element – Mundy and Livesey – "Life Cycle Assessment for Construction Products"

2.2.2.3 Impact Assessment

This phase is where the inventory data is assessed to evaluate each parameter's environmental impact (Langdon, 2007). According to ISO 14042 the life cycle impact assessment (LCIA) is done for the purpose of "Examine the product system from an environmental point of view using impact categories and category indicators connected with the LCI results. The LCIA also provides information for the life-cycle interpretation phase" (Khasreen et al., 2009). Before starting the main steps of LCIA, it is important to first select and define the impact categories related to buildings which some of them are shown in table 2.3. These impact categories differ from a study of a building to another building according to the goal of the study, the data availability, the significance of the impacts (Khasreen et al., 2009). LCIA is divided into two mandatory study steps which are classification and characterization and other three optional steps which are normalization, weighting, and grouping (Langdon, 2007)

Impact Category	Abbreviation	Definition	LCI data
Global Warming	GW	Increase in earth surface temperature due to release of carbon dioxide, methane, CFCs, etc., which in turn causes polar melt, soil moisture loss, forest loss, etc.	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFC_S) Hydro chlorofluorocarbons ($HCFC_S$) Methyl Bromide (CH_3B_r)
Ozone Depletion	OD	Release of CFCs destroys stratospheric ozone layer, leading to higher ultraviolet radiation and in turn to decrease in harvest crops, skin cancer, etc.	Chlorofluorocarbons (CFC_S) Hydro chlorofluorocarbons ($HCFC_S$) Halons, and Methyl Bromide (CH_3B_r)
Acidification	A	Release of sulphur dioxide and nitrogen oxides leads to acid rain, resulting in dying of forest, damages to nutrients in soils,	Sulphur Oxides (SO_X) Nitrogen Oxides (NO_X) Hydrochloric Acid (HCL) Hydrofluoric Acid (HF)

Impact Category	Abbreviation	Definition	LCI data
		damages to buildings, etc.	Ammonia (NH_4)
Eutrophication	E	Air pollutants, waste water and fertilization in agriculture enriches nutrients in water and land, resulting in algae growth in waters, thus fish dying due to lowered oxygen concentration, and plants prone to diseases and pests, and other problems.	Phosphate (PO_4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO_2) Nitrates, and Ammonia (NH_4)

Table 2. 3 – Environmental Impact Categories – Khasreen et al. – “Life-Cycle Assessment and the Environmental Impact of Buildings: A Review”. 2009 & “An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments. 2007

2.2.2.3.1 Classification

Classification is where each parameter defined in the life cycle inventory phase is assigned to its impact category which was selected and defined previously. For example, emissions of CO_2, NO_2, CH_4 … etc., would be assigned as global warming (“An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments”, 2007), while SO2 would be classified under the “Acidification” impact category (Langdon, 2007).

2.2.2.3.2 Characterization

Because each of the emissions has different degree of the impact category effect, there must be a reference emission where other emissions in the same impact category are to be related to. This process is called Characterization. For example 1 Kg of NO_2 has different degree of global warming than that of CO_2. Accordingly, characterization can be done in this case by converting each greenhouse gas emission an equivalent amount of CO_2 that would lead to the same degree of global warming effect, and the total impact on global warming can be expressed as the sum of the equivalent amounts of CO_2 emitted ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007).

2.2.2.3.3 Normalization

This step is optional in the LCIA study. It is done only for better comprehension of the LCIA results which were calculated in the Characterization step. The total result of each impact category is called impact indicator. For example the impact indicator of global warming of an LCA study of a building is a certain amount of CO_2 emission. This means that for an LCA study of a building/ product, we will have several impact indicators ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007). In order to comprehend the severity of the result we have to relate it to a reference case ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007). For instance, the CO_2 emission in year 2000 is used as a reference case to assess the CO_2 emission in the future. The existing value can be divided by the reference value for obtaining an index value (Langdon, 2007).

2.2.2.3.4 Weighting

This is another optional step in the LCIA, which takes the above results further to facilitate the interpretation of the results. As the impact indicators total results calculated from the normalization step have different effect on the environment, they have to be assigned to weights to indicate the severity of each. For example, global warming has more serious consequences in climate changes than that of ozone depletion; consequently, global warming has to be assigned a higher weight than that of ozone depletion ("An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments", 2007). However, the process of weight assigning is subjective and may lead to controversy. Thus, according to Langdon, "The subjective values of weight are usually acquired from experts in the domain" (Langdon, 2007).

2.2.2.3.5 Grouping

This is the final optional step in the LCIA. Impact categories can be grouped according to their global significance, local significance, geographical relevance, or company priorities … etc. (Langdon, 2007).

2.2.2.4 Interpretation

Interpretation is the final phase in the LCA study. It is considered the presentation of all the previous phases in an analytical way. In this phase all the results are analyzed in a way showing which the prevalent impact category was, the one having the highest environmental impact so that it can be underlined as the most problematic that needs a mitigation solution, the limitations of the study and the recommendation for the future LCA or LCI studies … etc. (Khasreen et al., 2009).

2.2.3 Uncertainty of Data

Because life cycle assessment studies intangible events and impacts, it is exposed to a great extent of uncertainty. Uncertainty may result from the estimation of future environmental impacts or data collected via questionnaires or data incompleteness. Also, sometimes, there happen to be that the collected data doesn't have a characterization factor which leads to ignoring it in the LCA study. Accordingly, it is important to apply a method to deal with this uncertainty problem. However, it is difficult to apply a uniform system to deal with this uncertainty, so Monte Carlo analysis won't be enough. Monte Carlo analysis can be combined with sensitivity analysis to solve the uncertainty issue ("Introduction to LCA with SimaPro", 2004). The sensitivity analysis is done in order to evaluate the magnitude of the assumptions done. So assumptions are evaluated through changing them and recalculate the LCA again. If a product, initially, had a higher load than another product and when changing the assumption, they were reversed; then, an explanation is needed for which is the valid conclusion ("Introduction to LCA with SimaPro", 2004). Eventually, it is concluded that there is no single answer as the LCA study is reliant on the assumptions ("Introduction to LCA with SimaPro", 2004).

2.2.4 Modeling of LCA

There are many models and databases developed for the study of LCA in buildings. Some are done for building products while others are done for materials and others for designs comparisons etc. Table 2.4 shows some of the tools and databases developed for LCA study; some of them have software models. To facilitate the use of LCA in Egypt as well as in any other country, there has to be a model which can be easily accessed with its database which can be modified according to the type of asset studied whether it is a whole building, a product, a material … etc. This model has to calculate the LCA result taking into consideration sensitivity analysis done in order to consider results uncertainty. Eventually, it has to have a cost output to be tangible and more catching to the user. This cost output is either eco-costs or conversion of environmental impacts into costs; and this is what the next section – Integration between LCC & LCA – shall explain.

The LCA model can be used in Egypt for studying the environmental impacts from cradle to grave of the following in order to enhance the sustainability of the Egyptian construction industry:

1. Construction materials and products in different sectors (residential, commercial, industrial …etc.)
2. Electrical systems in different sectors
3. Mechanical systems in different sectors

Database	Country	Function	Type	Level	Software	Website
Athena	Canada	Database + Tool	Academic	whole building design decision	Eco Calculator	www.athenaSMI.ca
Bath data	UK	Database	Academic	product comparison	No	people.bath.ac.uk/cj219/
BEE	Finland	Tool	Academic	whole building design decision	BEE 1.0	-------------------------
BEES	USA	Tool	Commercial	whole building design decision	BEES	www.bfrl.nist.gov/oae/software /bees.html
BRE [3]	UK	Database + Tool	Public	whole building assessment	No	www.bre.co.uk
Boustead	UK	Database + Tool	Academic	product comparison	Yes	www.boustead-consulting.co.uk
DBRI [4] **Database**	Denmark	Database	Public		No	www.en.sbi.dk
Ecoinvent	SL	Database	Commercial	product comparison	No	www.pre.nl/ecoinvent
ECO-it	NL	Tool	Commercial	whole building design decision	ECO-it	www.pre.nl
ECO methods	France	Tool	Commercial	whole building design decision	Under development	www.ecomethods.com
Eco-Quantum	NL	Tool	Academic	whole building design decision	Eco-Quantum	www.ecoquantum.nl
Envest	UK	Tool	Commercial	whole building design decision	Envest	envestv2.bre.co.uk
Gabi	Germany	Database + Tool	Commercial	product comparison	Gabi 4	www.gabi-software.com
IO-database	Denmark	Database	Academic	product comparison	No	---------------------
IVAM	NL	Database	Commercial	product comparison	No	www.ivam.uva.nl
KCL-ECO	Finland	Tool	Commercial	product comparison	KCL-ECO 4.1	www.kcl.fi/eco
LCAiT	Sweden	Tool	Commercial	product comparison	LCAiT	www.ekologik.cit.chalmers.se
LISA	Australia	Tool	Public	whole building design decision	LISA	www.lisa.au.com
Optimize	Canada	Database + tool	---------	whole building design decision	Yes	----------------------
PEMS	UK	Tool	Public	product comparison	Web	----------------------
SEDA	Australia	Tool	Public	whole building assessment	SEDA	----------------------
Simapro	NL	Database + Tool	Commercial	product comparison	Simapro 7	www.pre.nl
Spin	Sweden	Database	Public	product Comparison	No	http://195.215.251.229/Dotnetnuke/
TEAM	France	Database + Tool	Commercial	product comparison	TEAM 3.0	www.ecobilan.com
Umberto	Germany	Database + Tool	Commercial	product comparison	Umberto	www.umberto.de
US LCI data	USA	Database	Public	product comparison	No	www.nrel.gov/lci

Table 2. 4 – LCA Databases and Models – Khasreen et al. – "Life-Cycle Assessment and the Environmental Impact of Buildings: A Review". 2009

2.3 Integration between LCC and LCA

For a better evaluation of an asset and in order to cover its environmental impact as well as its economic one, LCC can be integrated with LCA. As LCC calculates the overall cost of an asset through its lifecycle, LCA integrates it in terms of assessing the asset's environmental impacts through its lifecycle as well. So they both can be integrated in several ways. For example, LCA can come up with environmental measures alternative options and LCC can provide the financial/ economic evaluation of these options or the other way around which means LCC can come up with cost effective alternative options and then LCA would study which of them has less environmental impact (Langdon, 2007).

But here comes the question of how to integrate LCA results, which are environmental indicators, and LCC results which are costs. How to integrate two results of different nature together? According to Guoguo in his paper "Integration of LCA and LCC for decision making in sustainable building industry", there are two methods which can be used to integrate between LCC and LCA (Guoguo, n.d). The first one is to convert LCA impacts into cost by acquiring the market price for elements (emissions) as shown in the example below (Tupamaki, 2008):

Concrete roofing tile, manufactured by Lafarge Roofing Ltd

- Emissions to air (10 properties):
- CO_2 = 0.137kg/kg = 137kg/ton
- European market price for CO_2 = 10EUR/ton
- Environmental impact cost = 1.37EUR/ton = 0.006EUR/tile (@4.3kg)

While the second is to use eco-costs such as:

- Costs of controlling gas emissions;
- Costs of resources used during the extraction and manufacturing of materials;
- Costs of waste disposal;
- Costs of waste treatment;
- Costs of eco-taxes;
- Costs of pollution rehabilitation measures;
- Costs of environmental management.

In this thesis, each of the LCC and LCA shall be addressed separately and there shall be two rankings for the alternatives one for LCC and the other for LCA. Finally, the end-user is to choose which of them he/she shall follow. The reason for this is the transparency of the results for the user for him/her to be able to know the exact LCC of his/her alternatives as well as the separate environmental impacts of each.

Chapter 3
Lighting Systems and Sources

Chapter 3: Lighting Systems and Sources

3.1 Background

Lighting is a kind of equipment or a fixture which emits light in different places such as homes, offices, malls … etc in order to make the surrounding visible. ***"Light is part of the electromagnetic spectrum, which ranges from radio waves to gamma rays. Electromagnetic radiation waves, as their names suggest are fluctuations of electric and magnetic fields, which can transport energy from one location to another"*** ("What is Light? An overview of the properties of light", n.d).The quantity and quality of light affect human's temper, comfort, and productivity (Helal, 2008). Accordingly, one has to take the quantity and quality of lighting into consideration while searching for other alternatives better than conventional lighting in terms of energy consumption and environmental impacts.

3.2 Lighting and Energy Consumption

The world is facing nowadays a huge problem which is energy consumption. Lately, many researchers are directed towards finding methods for saving energy. The problem with energy consumption is the increase of energy prices, the release of carbon emissions in addition to the risk of supply shortage versus people's demand ("The What, Why, and How of Energy Management", n.d).

Energy consumption is mainly distributed among four sectors commercial, residential, industrial and transportation. Electricity has a great impact on energy consumption. Residential sector's electricity utilization encompasses about 38%, commercial sectors about 36% while the industrial sector is about 26% as shown in figure 3.1 ("Electricity Sector Overview", 2011).

One of the main factors in the electricity utilization is lighting as shown in figure 3.2 (Yassin, n.d).

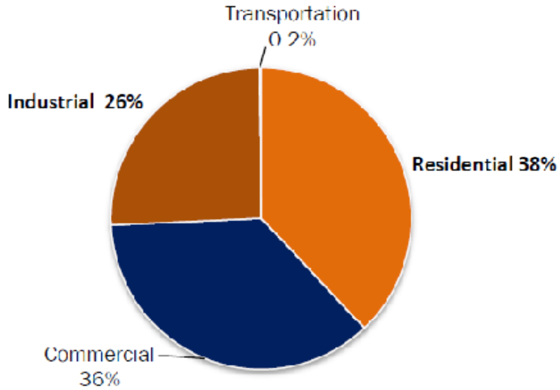


Figure 3. 1 – Retail Sales of Electricity to Ultimate Customers, Total by End Use Sector (2009) – "Electricity Sector Overview". 2011

Lighting consumes more than one third of the total electricity in residential and commercial sectors in Egypt (Helal, 2008). However, according to Dr. Helal in his presentation "Energy Conservation", the new technologies which were developed lately and those which are still to emerge can reduce the energy, environmental impacts and lighting costs by about 30% to 60%, in addition to enhancing the lighting quality.

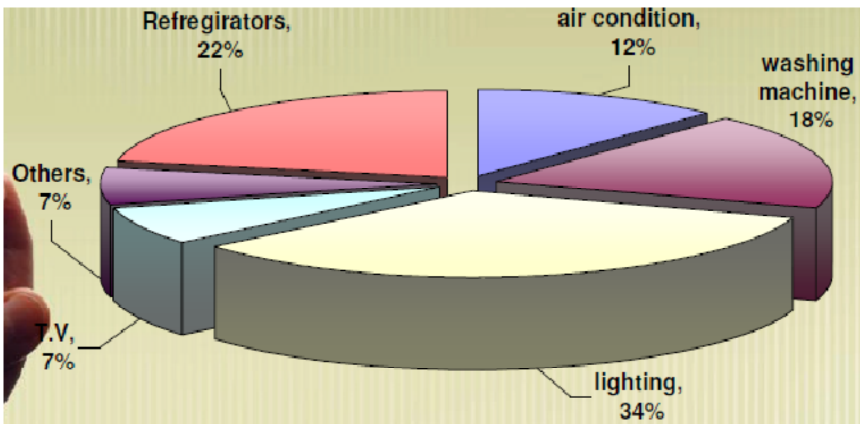


Figure 3. 2 – Residential Electricity Consumption in Egypt (2000) – Dr. Ibrahim Yassin. n.d

3.3 Lighting Performance Measures

To be able to compare the performance of different types of lighting, there should be a kind of measurement for the lighting intensity. There are several measurements for light intensity such as Lux and Lumen. Lux is the amount of light reaching a subject. It is a ***"standardised unit of measurement of the light intensity (which can also be called "illuminance" or "illumination")"*** ("Lux, Lumens & Watts", 2013). One lux is equal to ten foot-candles (Helal, 2008). Below are several examples which can be measured in lux with the amount of lux for each ("Lux, Lumens & Watts", 2013):

1. Outdoor average sunlight ranges from 32,000 to 100,000 lux
2. Moonlight is about 1 lux
3. Warehouse aisles are lit to approximately 100 to 200 lux
4. An office requires about 400 lux
5. At sunset and sunrise (with a clear sky), ambient outdoor light is about 400 lux
6. Building corridors can be lit by about 100 lux

Lumen is another measurement of lighting. It is the amount of light that a bulb produces. It is a ***"standardised unit of measurement of the total amount of light (packets or quanta) that is produced by a light source, such as a bulb or tube"*** ("Lux, Lumens & Watts", 2013). Lumen may be also called Luminous Flux ("Lux, Lumens & Watts", 2013). The lighting intensity of all lamps is measured in lumens (Helal, 2008). Below are some examples of common light sources measurements which can vary somehow in reality ("Lux, Lumens & Watts", 2013):

1. A 400W Metal Halide lamp – for high bay warehouse lighting: 38,000 Lumens
2. A 100W Incandescent bulb – for general task lighting applications: 1,700 Lumens

3. A 32W T5 or T8 Fluorescent tube – for office ceiling lighting:1,600 Lumens
4. A 150W High pressure sodium bulb – for street/area lighting – 12,000 Lumens

There are two types of Lumen, photopic lumen and scotopic lumen. Photopic Lumen is the one measuring the intensity of the outdoor lighting (Helal, n.d). ***It is the amount of light that the human's eye cone requires*** (Helal, n.d). Standard lumen and foot-candle meter is the measurement of photopic lumen (Helal, n.d). Scotopic lumen is the other type of lumen measuring the indoor lighting intensity (Helal, n.d). ***It is the amount of light which the human's eye rods require and it is the one controlling the size of human's eye pupil to enhance its vision*** (Helal, n.d). Scotopic lumen cannot be measured directly with a standard light meter (Helal, n.d).

The amount of lux (light intensity) needed to light up an area of a square meter is equal to the amount of lumen (produced by a bulb) concentrated on that area. This means that 100 lumens which are concentrated on an area of one square meter are resulting in 100 lux of light intensity. However, if those 100 lumens are concentrated over an area of 10 square meters, they will dim the light intensity resulting in 10 lux ("Lux, Lumens & Watts", 2013). Accordingly, if the same amount of lux (100 lux) is needed per one square meter in an area of 10 square meters requires the increase of the number of the lighting fixtures ("Lux, Lumens & Watts", 2013).

Watt is another unit of measurement related to lighting. It measures wattage, which is the ***amount of electricity consumed by the lighting fixture or the amount of power required by a lighting fixture to operate*** ("Lux, Lumens & Watts", 2013). The consumed electricity includes the heat generated by the lighting source, the control system which controls the operation of the lighting fixture, and the energy consumed by the lighting fixture ("Lux, Lumens & Watts", 2013). Luminous efficacy is another term in lighting which is ***the conversion of the electrical power (watt) of a lamp to the amount of light produced (lumen) by a lamp*** ("Lux, Lumens & Watts", 2013). It is measured by lumens per watt (LPW) (Helal, 2008). Below are some examples of luminous efficacy of common light sources used in industry and business ("Lux, Lumens & Watts", 2013):

1. A 400W Metal Halide lamp - used for high bay lighting in warehouses: 95 LPW
2. A 100W Incandescent bulb – used for general task lighting applications: 17 LPW
3. A 32W T5 or T8 Fluorescent tube – used for general office ceiling lighting: 50 LPW
4. A 150W High pressure sodium bulb – used for street/area lighting: 80 LPW

There is another way for lighting fixtures performance rating which is the color rendering index (CRI). CRI is the ability of the lighting fixture to provide colors same as those of the sunlight (Helal, 2008). For instance an incandescent lamp has a CRI of 100 which is approximately similar to that of sunlight (Helal, 2008). At the same time high pressure sodium (HPS) lamp has a CRI of 22 which means it provides very poor colors at the same time.

3.4 Lighting Power Sources

The most common types of lighting systems are either powered by electricity or by solar energy or a hybrid system merging between both. Solar energy as a source of lighting was emergent and was one of the main sources of lighting during the daytime in the early 1900s (Muhs, 2000). However, electrical lighting sources took the lead because of their cost and performance convenience during the whole day (Muhs, 2000). Accordingly, lighting is one of the main consumers of electricity and energy. Consequently, people are now trying to return back to the solar energy as the main source of lighting because of its lower energy consumption, lower operational costs, and less environmental impacts.

Electricity is the traditional method of lighting. It works through burning of fossil fuels in the electricity plant. While burning fuel, steam is generated which, accordingly, gives power to turbines. Turbines are used for rotating huge magnets covered with copper wires. This process generates heat, which is converted to magnetic energy and then to electric energy ("How Electricity gets to your Home", n.d). Electricity then flow through wires to a transformer which elevates the pressure to 756,000 volts to be able to feed long distances ("How Electricity gets to your Home", n.d). Then, this main transformer distributes the electric current through wires to substation transformers which lowers the electric pressure to 2,000 and 13,000 volts ("How Electricity gets to your Home", n.d). At that point, the electric current is distributed through wires and cables to electric pillars which in turn lower the pressure to 120 and 240 volts ("How Electricity gets to your Home", n.d). Finally, through wires and cables the electricity with 120 to 240 volts is distributed to buildings powering lighting systems and other appliances, refer to figure 3.3.

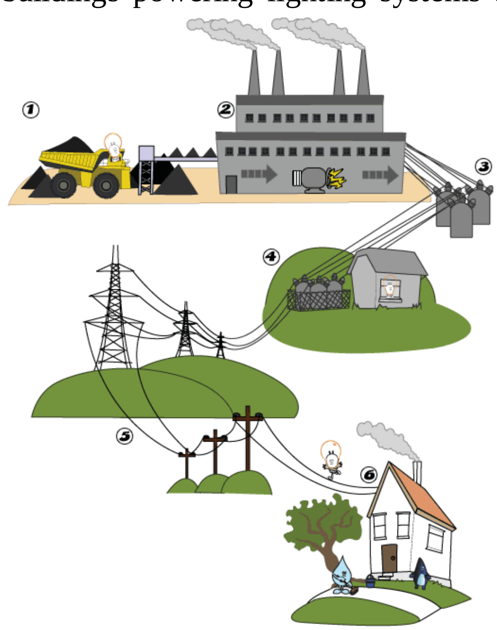


Figure 3. 3 – Conventional Process for Lighting – "How Electricity gets to your Home", n.d

Another, source of power for lighting is solar energy. The amount of sunlight reaching the Earth's crust in the form of radiations is about 174 Peta Watts (Aggeliki, 2011). Part of them is reflected back, while leaving a pure amount of approximately 1000 watt per m^2 energy which can be used ("Solar Lighting", n.d). This amount varies according to weather conditions ("Solar Lighting", n.d). Solar lighting can be used in streets, residential buildings, office buildings, and commercial buildings. Solar lighting is divided into two types, as shown in figure 3.4, a passive solar system and an active solar system ("What's the Difference Between an Active and Passive Solar System?", 2011).

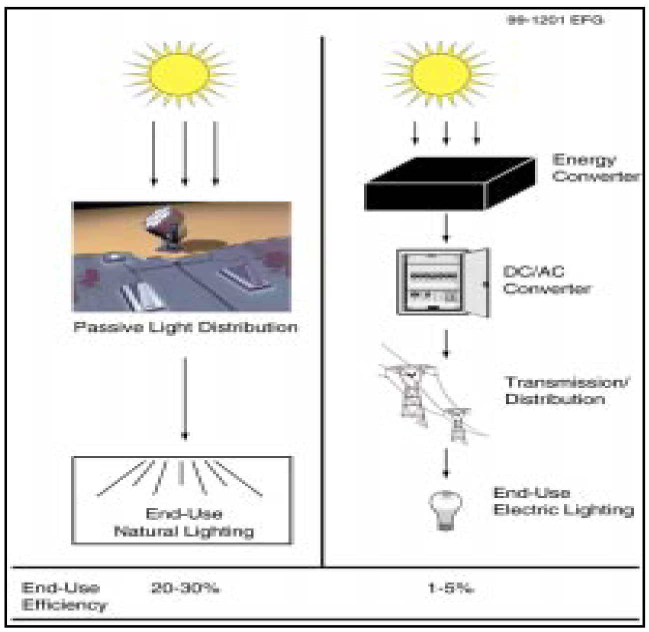


Figure 3. 4 – Different Application of Solar Lighting – Muhs, 2000

Passive solar system is dependent only on daylight which requires special designs for facilitating the entrance of sunlight during daytime such as the installation of skylights, the control of windows sizes, and the setting of the building's orientation ("Passive Solar Lighting", n.d). Passive solar lighting can also be used through gathering the sun light through fiber optics which in turn internally reflect the light and transmit it to the building (Grisé & Patrick, 2002).

Active solar system works through gathering of sun rays and converting them into electricity such as the Photovoltaic Solar System ("What's the Difference Between an Active and Passive Solar System?", 2011). The process of conversion of the solar energy into electricity is called photoelectric phenomenon (Aggeliki, 2011). This process is done through the installation of solar panels which are made of semi conductive material such as silicon (Aggeliki, 2011). These solar panels generate electrons as sun rays fall on them then release them generating current flow. The solar panels are connected to a battery, which stores the energy generated and used to power the lighting fixture, and an AC/DC inverter which converts the DC current to AC current.

A hybrid solar lighting is a newly emergent technology which integrates both the active solar system and the conventional solar system. It fights the problems of both the conventional lighting system (huge energy consumption, large amount of heat and CO_2 emissions … etc) and the passive solar lighting system (low illumination, high equipment costs …etc). Hybrid solar lighting has the advantage of decreasing the energy consumption and the heat waste of conventional lighting systems in addition to working with conventional bulbs such as fluorescent and incandescent ("Hybrid Solar Lighting Illuminates Energy Savings for Government Facilities", n.d). It works through a "roof-mounted solar collector", as shown in figure 3.5. This collector collects the sunlight into a bundle of plastic optical fibers and distributes it to the hybrid luminaires, after removing the infrared light and so has no heat waste as the conventional system ("Hybrid Solar Lighting Illuminates Energy Savings for Government Facilities", n.d), which contains electronic ballast and a daylight control in order to control the amount of light emitted (Muhs, 2000). The removed infrared light can be used in other applications such as heating space, heating water and generating electricity ("Hybrid Solar Lighting Illuminates Energy

Savings for Government Facilities", n.d). The solar collector has a power of lighting eight fluorescent lamps or an area around 93 square meters ("Hybrid Solar Lighting Illuminates Energy Savings for Government Facilities", n.d). During weathers of little sunlight, the hybrid luminaires through their sensors control the intensity of the artificial light to reach the needed illumination ("Hybrid Solar Lighting Illuminates Energy Savings for Government Facilities", n.d).

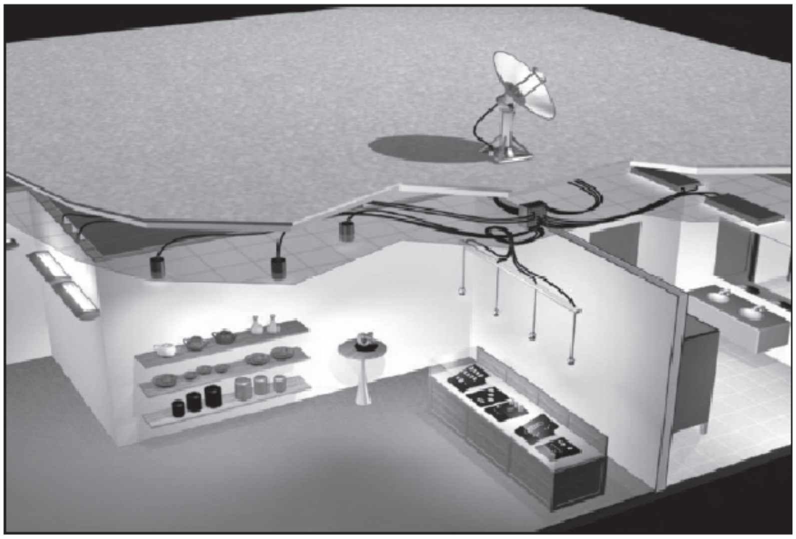


Figure 3. 5 – Conceptual Illustration of the Hybrid Solar Lighting – "Hybrid Solar Lighting Illuminates Energy Savings for Government Facilities", n.d

3.5 Lighting Sources Types

There are four basic types of lighting sources as shown in figure 3.6 which are incandescent, fluorescent, high intensity discharge (HID), and low pressure sodium (LPS) (Helal, 2008). Each of these is divided into several types with different features and different usage. This in addition to the newly emergent lighting source named Lighting Emitting Diodes (LED).

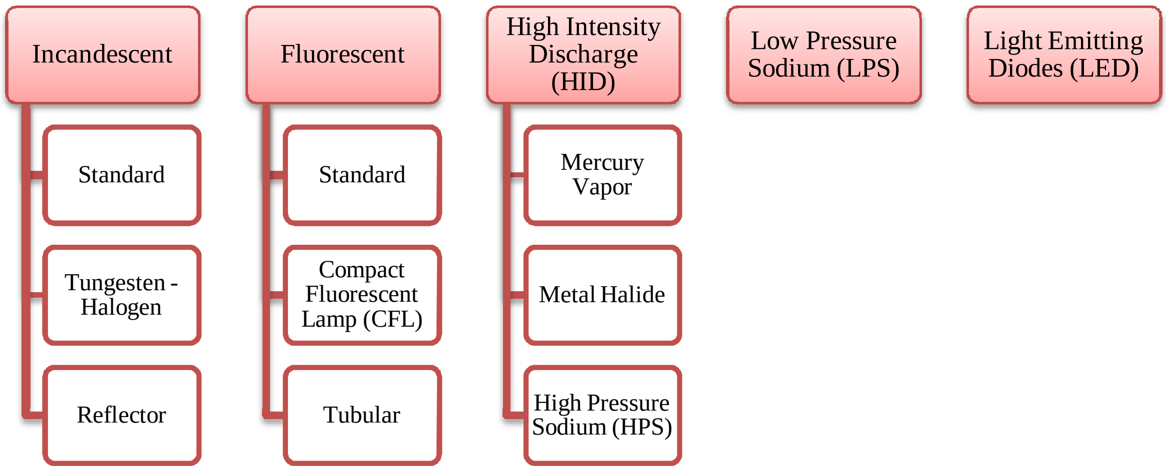


Figure 3. 6 – Types of Lighting Sources

3.5.1 Incandescent Bulbs

Standard Incandescent is the most common type of lighting used in the residential sector (Helal, 2008). Though as mentioned earlier, incandescent light has CRI which is similar to the CRI of sunlight, it is the least efficient of light sources. It produces light with only 15% of the energy emitted and the rest is emitted as heat (“Energy-Efficient Lighting”, n.d) because its technique of lighting is through heating of a filament to produce light. Though incandescent light is the cheapest of light sources, it is the most expensive to operate (Helal, 2008). There are other two common types of incandescent which are Tungsten-Halogen and Reflector.

3.5.2 Fluorescent Bulbs

Fluorescent lighting is another common lighting source which is produced through conduction of an electric current with mercury and inert gases (Helal, 2008). It is used in indoor lighting and it has higher efficiency than that of incandescent lighting (Helal, 2008) as it uses 25% or 35% of the energy used by incandescent lamp to give the same amount of illumination

("Fluorescent Lighting", 2011). It has different types such as compact fluorescent lamp (CFL) and tubular fluorescent lamp

3.5.3 High Intensity Discharge (HID)

High Intensity Discharge (HID) lighting bulbs provide a very high efficient lighting compared to other lighting sources ("High Intensity Discharge Lighting", 2011). HID requires electric arc to produce light ("High Intensity Discharge Lighting", 2011). As fluorescent, HID needs ballast to start the electric arc for the HID to produce light, which results in delaying the lamp for a few seconds till it produces the light (Helal, 2008). HID can save up from 75% to 90% energy when compared to incandescent light ("High Intensity Discharge Lighting", 2011). There are three common types of HID which are the Mercury Vapor (MV), Metal Halide (MH), and the High Pressure Sodium (HPS) (Helal, 2008).

3.5.4Low Pressure Sodium (LPS)

Low Pressure Sodium (LPS) lamps have more energy efficiency than that of the HID lamps ("High Intensity Discharge Lighting", 2011). It is not considered of the HID family as it does not work with the same arc technique; however, its operating technique is a bit similar to that of fluorescent ("Telling the Differences Between Different Light Sources", n.d).

3.5.5 Light Emitting Diodes (LED)

Light Emitting Diodes (LED) is the newest type of energy efficient lamps. It has a very different technique than other conventional lighting sources which were described above. LED is a semiconductor device that works through the application of electric current which causes electrons to flow from the diode's positive side to its negative side ("LED Lighting", 2012). The excess energy emitted while the electrons orbit produce photons of light ("LED Lighting", 2012). LED has to have a constant source of power which is controlled and regulated by a driver for the LED to produce the suitable amount of light without being damaged. LED can emit different colors which mean that they can be used in various areas indoors and outdoors, residential and commercial (“LED Lighting”, 2012). It can emit white light in 3 ways, refer to figure 3.7, phosphor conversion in which a phosphorous sheet is used in front of the normal LED to convert light color to white, or by RGB system in which the multiple monochromatic LEDs (red, green, and blue) is mixed to produce the white light, or through a hybrid method which combines the phosphorous method with the RGB method to produce the white color (“LED Basics”, 2013).

LED has the longest lifetime of all the above-mentioned light sources which ranges from 40,000 to 100,000 hrs (“Energy Efficient Lighting System (Industries, Public Utilities & Residential Buildings)”, n.d). In addition to saving energy from 82% to 93% compared to the conventional lighting sources (“Energy Efficient Lighting System (Industries, Public Utilities & Residential Buildings)”, n.d).

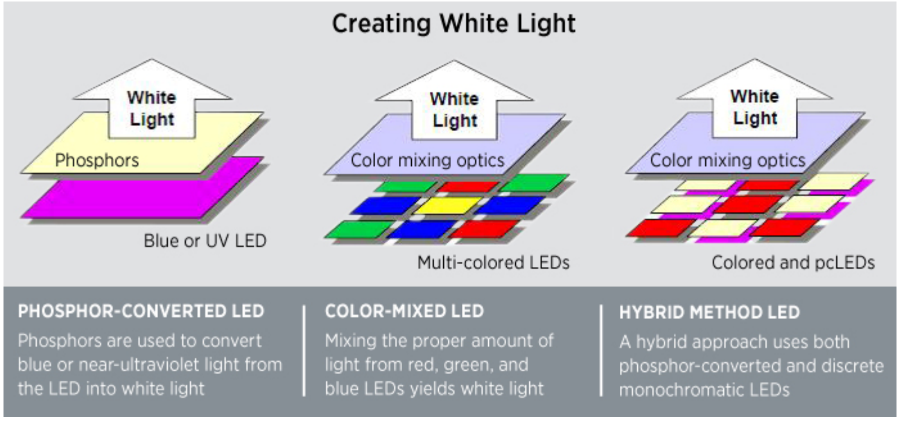
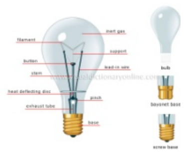
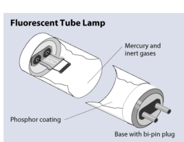
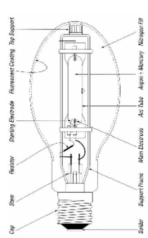


Figure 3. 7 – LED White Light Emission Techniques – “LED Lighting”. 2012

LED light is different from other light sources in that it is direct current (DC) driven. For this reason it is the most convenient light source to be used with solar lighting systems as it does not need the conversion of the DC of the solar lighting into and AC to operate (Hazra, 2011).

3.6 Comparison between the Light Sources

Table 3.1, below, shows a summarized comparison between the characteristics of the different lighting sources.

Type		Picture	Color Temperature (Kelvin)	Lumen per Watt	CRI	Lifetime (hr)	Gear (Yes/No)	Application
Incandescent	Standard		2500-2700	12	More than 90	1000	No	General lighting, homes, restaurants, emergency lighting
	Tungsten -Halogen		3000-3200	18		2000-4000	No	Flood lighting, exhibitions, stadiums, construction areas
	Reflector					2000-4000	No	Homes, restaurants, emergency lighting
Fluorescent	Standard		2700-6000	80	More than 80	5000	Yes	Homes, offices, shops, hospitals
	CFL			60		6000-15000	Yes	
	Tubular			60		6000-15000	Yes	
High Intensity Discharge (HID)	Mercury Vapor		2200	30-65	40-60	16000-24000	Yes	Factories, car parking, floodlighting

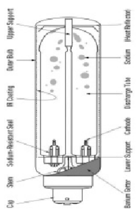
	Metal Halide		3000-20000	65-115	More than 60	5000-20000	Yes	General lighting, gymnasiums, factories, hallways, and retail displays
	High Pressure Sodium		1900-2200	50-90	More than 60	16000-24000	Yes	General lighting, factories, warehouses, streets
LPS	Low Pressure Sodium		2200	50-90	40-60	12000-18000	Yes	Roadways, tunnels, canals, streets
LED	LED		2700-10000	65-160	65-95	40000-10000	Yes	General lighting indoors and outdoors

Table 3. 1 – Lighting Sources Comparison – “3Brothers Company Data Sheet”. n.d & “Energy Efficient Lighting System (Industries, Public Utilities & Residential Buildings)” n.d

3.7Different Sectors Lighting Requirements

Table 3.2 shows the lighting requirements for the most common areas in different sectors.

Residential		
Area	**Lumens/m^2 needed**	**Light Temperature (K)**
Bedroom	100	2700-3200
Living Room	100	2700-3200
Hallway	100	2700-3200
Bathroom	100	2700-3200
Dining Room	200	2700-3200
Kitchen	200	2700-3200
Office	500	5500-6000
Commercial		
Area	**Lumens/m^2 needed**	**Light Temperature (K)**
Store	200	5500-6000
Restaurants	200	2700-3200
Hallway	100	2700-3200
Bathroom	100	2700-3200
Kitchen	200	2700-3200
Office	500	5500-6000
Office Building		
Area	**Lumens/m^2 needed**	**Light Temperature (K)**
Office	500	5500-6000
Meeting Room	300	5500-6000
Hallway	100	2700-3200
Bathroom	100	2700-3200
Kitchen	200	2700-3200
Factory		
Area	**Lumens/m^2 needed**	**Light Temperature (K)**
Manufacturing Area	200	5500-6000
Office	500	5500-6000
Meeting Room	300	5500-6000
Hallway	100	2700-3200
Bathroom	100	2700-3200
Kitchen	200	2700-3200
Street		
Area	**Lumens/m^2 needed**	**Light Temperature (K)**
Street Lighting	Depends on a Specs	5500-6000

Table 3. 2 – Lighting Requirements – “Egyptian Code for Electrical Works” 2012 & “Guide to buying the right lamp – Understanding Light Color Temperature”. n.d

Table 3.3 explains the different lighting color temperatures and their applications.

Lamp Color Name	Apparent Color Temperature (Kelvin)	Characteristics and Examples	Common Adjectives Used to Describe the Light	Best Location
Warm White	2700-3200K	Similar to incandescent bulb, yellowish light best for accentuating skin tones and color of wooden objects	Friendly, warm, inviting, intimate, relaxing	Best for areas that need low light intensity like Bedrooms, lounges, restaurants, office lobbies, boutiques, reception area etc.
Natural White	4000-4500K	Similar to early morning sunlight, Xenon lamp for automotive use	Neat and clean, Natural tone	Best choice for high light intensity applications like Surgical lights, indoor photography, Laundry, Office etc.
Day White	5500-6000K	Typical day light, Flash light	Crisp light, efficient, brightly lit, natural outdoor	Retail stores, Factories, Printing, artist studio, Schools, Offices, indoor grow lights, photography
Cool White	7000-7500K	Best contrast but least flattering to the skin, may need mixing with light from a warm white lamp.	Bright light, bluish light	Special applications needing high light intensity and good color rendition like art Galleries, museums, showcases for precious stones and jewelry

Table 3. 3 – Lighting Color Temperature Requirements – “Guide to buying the right lamp – Understanding Light Color Temperature” n.d

Chapter 4
Methodology and Analysis

Chapter 4: Methodology and Analysis

4.1 Introduction

The research methodology is divided into three parts. Part 1 is a data collection about the extent of the application of the LCC and LCA in Egypt, the most important costs to be included in an LCC study and the most area of concern (mechanical works, electrical works … etc.) for an LCC study. This part is performed through a questionnaire distributed on a sample of 20 Construction Engineers. Part 2 is the framework of the LCA study which shall be adopted in this research. Part 3 is the framework of the LCC study which shall be applied in this research. The application of the LCA and the LCC framework shall be applied on a real case study in Chapter 5.

4.2 Questionnaire Organization and Data Collection

A generic questionnaire was designed on the LCA and LCC of buildings in Egypt and was distributed on a sample of 20 Construction Engineers, six engineers with work experience ranging from 5 to 10 years, five engineers from 10 to 15 years, five engineers from 15 to 20 years, two engineers from 25 to 30 years and two engineers from 30 to 35 years, in thirteen large scale construction companies in Egypt whose annual revenue is more than EGP 1,000,000 for the purpose of:

1. Measuring the extent of the construction market’s knowledge about the application of LCC and LCA;
2. Presenting the costs which can be included in an LCC study of buildings in Egypt;

3. Determining which area can be the most area of concern in the LCC study so as to focus on in the research.

The questionnaire was divided into FIVE parts:

Part 1 of the questionnaire collected information about the respondent, his/her company, and his/her extent of knowledge about LCC.

Part 2 of the questionnaire was directed towards asking about the respondent's previous experience on the application of LCC in his company or in other previous companies he/she has worked in.

Part 3 asked questions about the barriers facing the application of LCC and LCA and the availability of software calculating LCC and LCA. This was to support the idea of the importance of the presence of a software model facilitating the application of LCC and LCA.

Part 4 focused deeper on the application of LCC for buildings in Egypt by proposing rating questions about the costs which should be included when applying LCC to buildings in Egypt.

An optional question was included requiring the respondent to state a real project which he/she has applied LCC or LCA in. This question was chosen for the purpose of picking a case study which can be useful in the model validation.

The last part of the questionnaire was about the LCA. It was focusing on the extent of knowledge and application of the respondents towards LCA, and if they have applied LCA before.

A blank copy of the questionnaire is included in Appendix B. The raw data of the responses is included in Appendix C.

4.3 Questionnaire Results and Analysis:

The sample is evenly distributed among Owners, Consultants, Project Management Offices, Contractors, and Others (Multi-disciplinary Companies and Risk Consultants). Figure 4.1 show the distribution of the 20 respondents among the different construction companies' types.

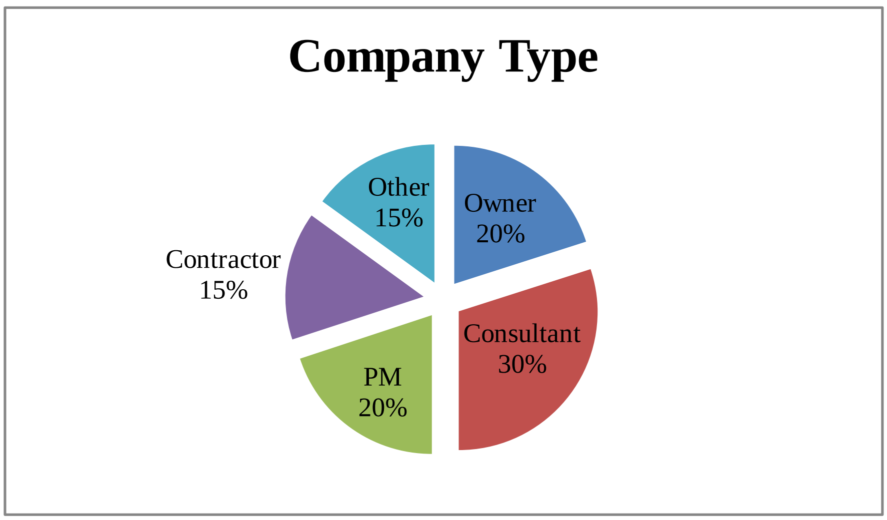


Figure 4. 1 – Respondents' Company Type

The question addressing the respondent's participation in any project throughout his past experience which applies LCC was a Yes or No question and followed by an "If Yes" question what was the project and where was it. This question revealed that 13 respondents out of 19 (for this question as there was one with no response) representing 68% of the respondents have worked before in a project that applied LCC as shown in figure 4.2. Out of the 13 respondents, 12 answered the "If Yes" question. Out of the 12 answers, only 7 projects were in Egypt and the others were outside Egypt.

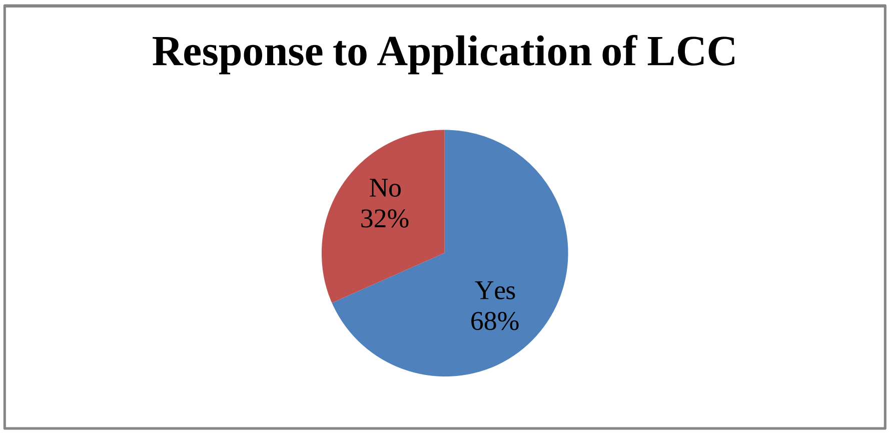


Figure 4. 2 – Respondents' Application of LCC

Then, a question was addressing the most common method used in the calculation of LCC. Figure 4.3 shows the frequency of each of the methods usage in the LCC calculation. It is obvious that though the methods frequencies of usage are similar, the Net Present Value method took the lead as the most commonly used method for this sample of construction engineers.

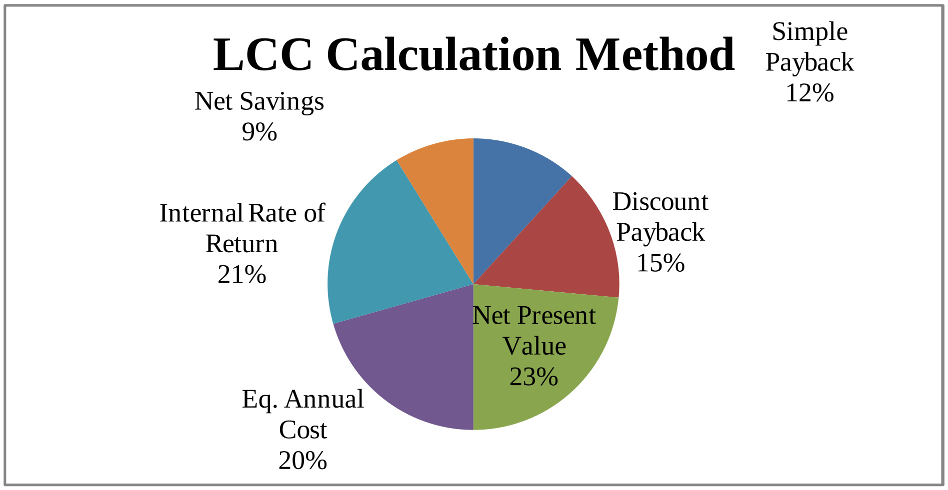


Figure 4. 3 – LCC Calculation Method

Figure 4.4 shows the respondents' opinion in the relation between the type of contract and the application of LCC. It is shown that 58% of the respondents claim that the type of contract doesn't influence the decision of applying LCC on a project. The other respondents who chose "Yes" were asked which type of contract would require the application of LCC but it gave very similar results as shown in table 4.1. This means that LCC can be applied on all types of contract. However, it is more logical that BOT and PPP contracts may require LCC application more than the other types of contracts because of its concession period which, in most cases, starts from design of the project till its end of investment.

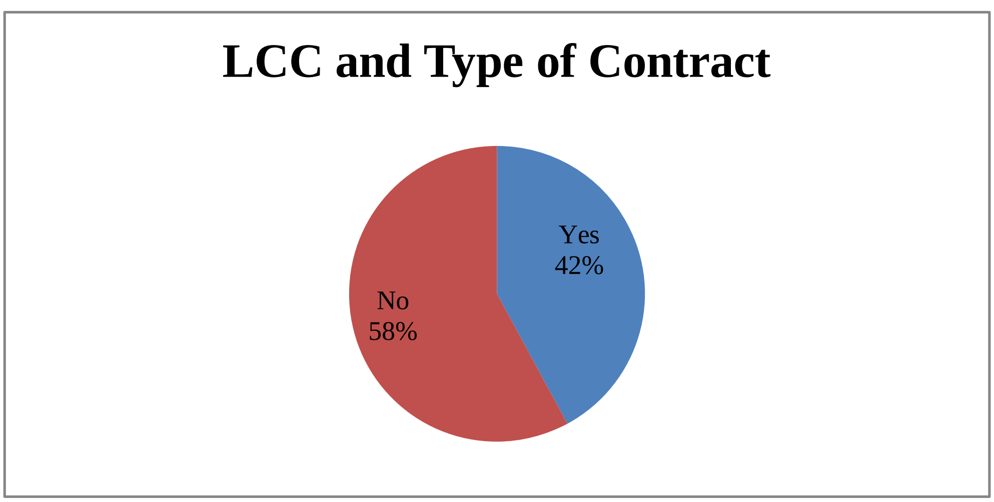


Figure 4. 4 – LCC and Type of Contract

Type of Contract	Frequency	Percentage
Unit Price	4	27%
Lump Sum	3	20%
Cost Plus	2	13%
BOT	3	20%
PPP	3	20%

Table 4. 1 – Percentages of each Contract in relation to the Application of LCC

Furthermore, a question addressing the relation between the LCC application and the size of project was asked. As shown in figure 4.5, 53% stated that LCC shall be applied for projects' size more than LE 1,000,000 with the claim that small projects may not require huge budgeting studies such as lifecycle costs.

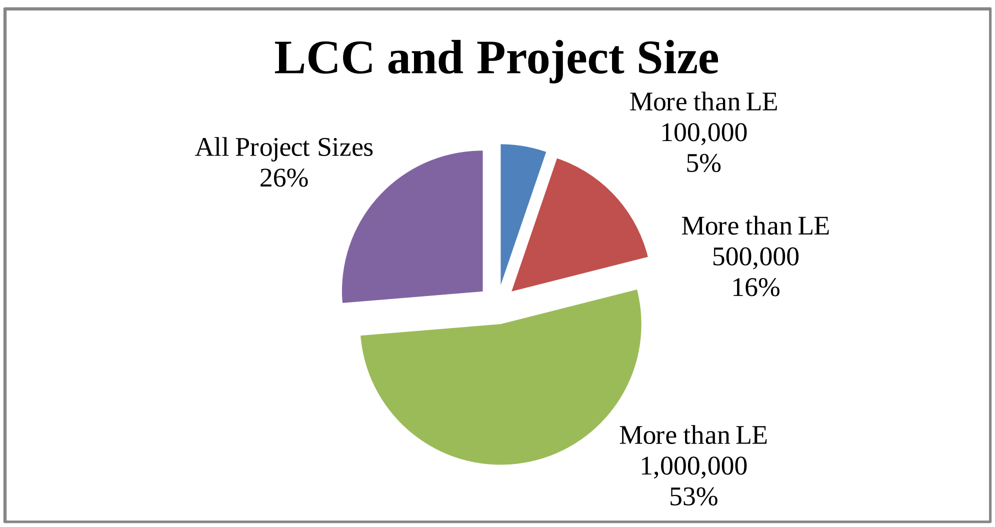


Figure 4. 5 – LCC and Size of Project

Lack of data and difficulty in predicting future costs were the most two important problems facing the application of LCC in the point of view of 76% of the respondents. Though only 10% of the respondents chose that one of the difficulties of LCC application is the lack of presence of software model, it may be argued that the other difficulties listed in table 4.2 can be solved with the presence of software. A software model which organizes the steps of the LCC application and contains the calculation methods of LCC shall encourage the users to apply LCC and shall facilitate its application as well.

Problems Facing LCC Application	Frequency	Percent
Lack of data	13	43%
Difficult to predict future costs	10	33%
No Software	3	10%
Time Constraints	4	13%
Others	0	0%

Table 4. 2 – Problems Facing LCC Application

The previous claim, that the software model is important and its presence shall facilitate to the users the application of LCC on projects, is supported with the "Yes or No" question which addresses the issue of the presence of an LCC software model. The answer was that 79% of the respondents as shown in figure 4.7 below have no software model used for calculating LCC.

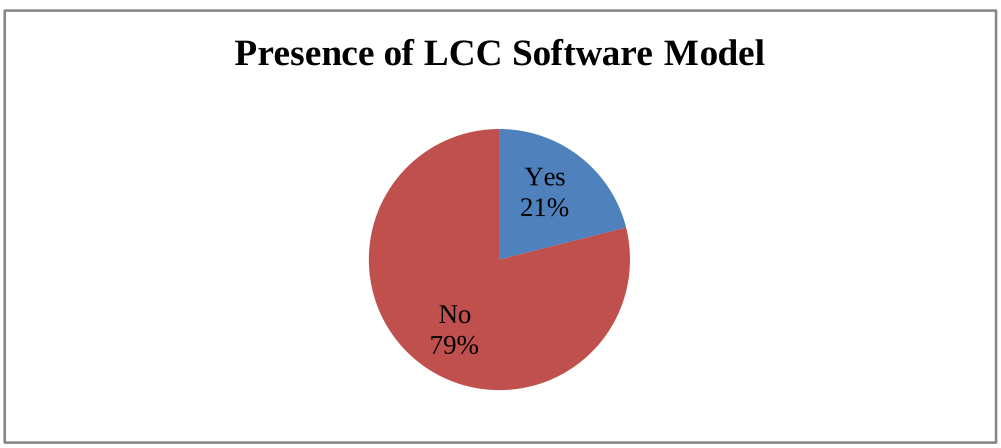


Figure 4.6 – Presence of LCC Software Model

Concerning the nature of the LCC result, 74% of the respondents preferred that it should be a probabilistic result. This answer is logical as 80% of the lifecycle costs of the project are estimated for a period which may reach more than 20 years in the future. Thus the costs are affected by changeable inflation rates and unpredicted risks, which means that a probabilistic result may be more descriptive.

As the LCC costs may change according to the country it is applied in, two rating questions were offered to the respondents to know which lifecycle costs may be applied for buildings in Egypt (1 is considered the least important and 5 is the most important). The first question was addressing the general costs such as construction costs, operation costs, maintenance costs, occupancy costs, and end of life/end of investment costs. Table 4.3 shows the rating of these costs according to the points of view of Construction engineers' sample. All the five general costs are given a rating above 3 which means that they are all important. However, the two most important are the maintenance costs and the operation costs. This answer is logical as the running costs of any project consume about 80% of the project's lifecycle cost.

Costs to include in buildings LCC in Egypt	
	Rate
Maintenance costs	4.16
Operation costs	3.95
End of life/ end of investment costs	3.53
Construction costs	3.5
Occupancy costs	3.16

Table 4. 3 – Costs to include in buildings LCC study in Egypt

The second question was going deeper into the details of each of the five lifecycle costs above for two purposes. One is to let the respondent recognize which costs exactly are considered under each of the five general costs so as to refine the ratings given above as much as possible. The second purpose is to identify which of the costs shall be included in the LCC study for buildings in Egypt from the point of view of the respondents.

Table 4.4 shows the rating of the construction costs or the initial investments costs. There are 6 of the initial investment costs are rated below 3, which means these costs can barely be considered in the initial investment costs of the LCC of building in Egypt. These costs are the water adoption, masonry works, foundations, transportation charges, excavation, and Special client costs – launch events and associated marketing costs. Such costs can be excluded from the LCC study in Egypt as they are constant costs and do not incorporate many alternatives. On the other hand, plumbing, electrical and mechanical works come on the top of the list of the most important initial investment costs for the LCC study of buildings in Egypt.

Initial Investment Costs		
No.	**Cost**	**Rate**
1	Plumbing works	3.72
2	Electrical works	3.63
3	Mechanical works	3.50
4	Finishing works	3.45
5	Electricity adoption	3.39
6	Licenses and permits	3.39
7	Structural costs (concrete and steel reinforcement)	3.37
8	Land acquisition	3.35

9	Architectural design costs	3.33
10	Consultancy fees	3.17
11	Light adoption	3.13
12	Structural design costs	3.11
13	Gas adoption	3.11
14	Planning costs	3.00
15	Water adoption	2.94
16	Masonry works	2.83
17	Foundations	2.80
18	Transportation charges	2.50
19	Excavation	2.47
20	Special client costs – launch events and associated marketing costs	2.29

Table 4. 4 – Initial Investment Costs of LCC study of Buildings in Egypt

Table 4.5 shows the rating of the operation costs in LCC of buildings in Egypt. The rating demonstrates that property management and property insurance are the most important to be considered in the operation costs, this is logical to an extent as there are different systems in building property management and property insurance which are treated as different alternatives. Waste management/disposal costs, gas fees, water fees, external cleaning and internal cleaning's rating are below 3 which means they carry less weight in the LCC study. The waste management and cleaning costs have to an extent a number of different criteria if building components are considered. However, if a whole building is considered and not its specific components, which is the case in this questionnaire, there are no alternatives are considered, so it may be logical, somehow, to exclude them from the operation costs of LCC for buildings in Egypt. What is considered illogical and contradicts with what was shown in the initial investment costs is the electricity fees. As for the building components, there are many energy saving alternatives which can influence the electricity fees such as HVAC or natural ventilation, solar lighting or electric power lighting … etc. Though, electricity fees cost is given a rate of 3 which is also considered important, it was expected to come on top of the operation costs list.

Operation Costs		
No.	**Cost**	**Rate**
1	Property management	3.68
2	Property insurance	3.61
3	Rent	3.29
4	Staff engaged in servicing the building	3.28
5	Taxes	3.17
6	Electricity fees	3.00
7	Waste management/ disposal	2.94
8	Gas fees	2.88
9	Water fees	2.59
10	External cleaning	2.39
11	Internal cleaning	2.00

Table 4. 5 – Operation Costs of LCC study of Buildings in Egypt

Table 4.6 shows the rating of maintenance and replacement costs. As shown in the table, all the costs are considered important as they all taking an above 3 rate except for redecorations. This rating can be considered logical because redecorations in many cases may be considered as optional and not an obligatory scheduled or unscheduled action.

Maintenance and Replacement Costs		
No.	**Cost**	**Rate**
1	Major replacements	4.11
2	Unscheduled replacement, repairs, and maintenance	3.32
3	Refurbishment and adaptation	3.16
4	Minor replacement, repairs, and maintenance	3.00
5	Redecorations	2.68

Table 4. 6 – Maintenance and Replacement Costs of LCC study of Buildings in Egypt

Though ISO 15686 does not consider occupancy cost as an item of the LCC, in the UK it is normally included in the LCC. For that reason it was included in this questionnaire for the respondents to rate it in case of Egypt. In the general costs rating question, occupancy costs were given a rating of 3.16; though its rating is above 3, it is rated as the lowest among the other 4 general LCC costs. However, when the costs of the occupancy costs were detailed as shown below in table 4.7, respondents were able to have a clearer view for the general term “Occupancy Costs”. Consequently, out of 17 costs, only 3 were given an above 3 rate. Because IT services, occupant’s furniture, fitting, and equipment, and internal plants and landscaping barely have alternative criteria for projects in the same sector such as residential, commercial, office building … etc. It is can be more logical to exclude occupancy costs from the LCC of buildings in Egypt and abide by the cost breakdown structure of LCC in ISO 15686.

Occupancy Costs		
No.	**Cost**	**Rate**
1	IT services	3.65
2	Occupant's furniture, fittings and equipment (FF & E)	3.33
3	Internal plants and landscaping	3.25
4	Manned security	2.94
5	Car parking charges	2.71
6	Hospitality	2.69
7	Telephones	2.63
8	Vending	2.56
9	Porters	2.47
10	Catering	2.44
11	Post room – mail services – courier services	2.44
12	Reception and customer hosting	2.40
13	Library services	2.38
14	Stationary and reprographics	2.31
15	Help desk	2.25
16	Internal moves	2.00

Table 4. 7 – Occupancy Costs of LCC study of Buildings in Egypt

Lastly, table 4.8 shows the end of life or end of investment costs in LCC rating for buildings in Egypt. The demolition and reinstatement to meet contractual requirements were given rates of 3.84 and 3.44 respectively, which mean that in the respondents' points of view they are important to be included in the LCC study of buildings in Egypt. However, disposal inspections were given a lower rate of 2.94 which is considered not important to be included in the LCC as it falls below 3. Though disposal inspections may be considered as an important cost to be added in the LCC because of the huge variety of disposal inspections criteria which may be considered in case of buildings, this rating may be interpreted as that many of the respondents reacted with the disposal costs as they are due to the “End of Life” of the building and not the “End of Investment in the building. In that case, it may be logical, to an extent, to exclude the disposal inspections costs from the end of life costs. However, disposal inspections costs are important to be included in the LCC study of building in Egypt.

End of Life/ End of Investment Costs		
No.	**Cost**	**Rate**
1	Demolition	3.84
2	Reinstatement to meet contractual requirements	3.44
3	Disposal inspections	2.94

Table 4. 8 – End of Life/End of Investment Costs of LCC study of Buildings in Egypt

Finally, it was shown from the results that the application of LCC is familiar among the sample of respondents as 68% of the respondents have worked before in projects applying LCC. However, the rate of the application of the LCC in Egypt needs to be improved as out of the 68% only 58% of the respondents’ projects applying LCC were in Egypt.

Based on literature and the rating questions, maintenance and operation costs are the most considerable in an LCC study as maintenance costs took a rate of 4.16 out of 5. On the other hand, operation costs took a rate of 3.95. Construction costs/initial investment costs were also one of a great importance with a rating of 3.5. Out of the initial investment costs, Pluming Works, Electrical Works, and Mechanical Works were the most important in the LCC study as they took ratings of 3.72, 3.63, and 3.5 respectively. Consequently, the main focus of this thesis is to study the LCC and LCA of one of these phases, which is the Electrical phase. Lighting is one of the most important contributors in the Electrical phase in all sectors (residential, commercial, office buildings … etc) in terms of costs, energy consumption and environmental impacts. Consequently, this research will focus on the study of LCC and LCA of lighting systems and sources in Egypt.

In the LCA part of the questionnaire, it started by a question addressing the extent of the application of the LCA. Accordingly, a Yes or No question was raised to identify the respondent's application of LCA in his/her previous experience; figure 4.7 shows the extent of application of LCA.

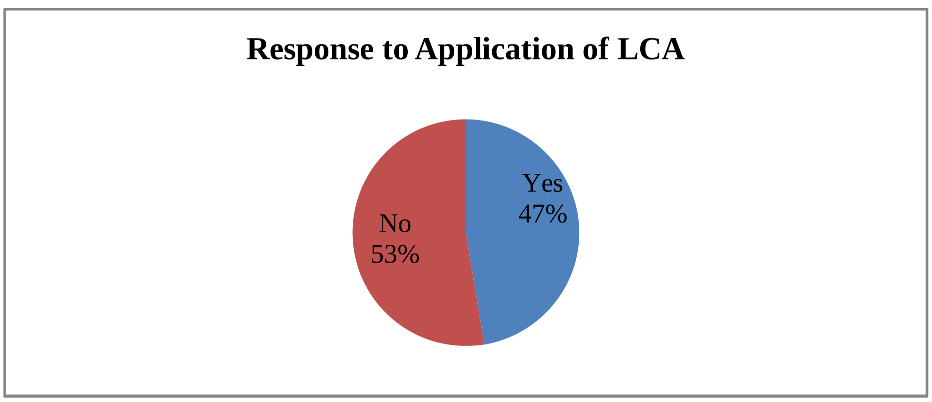


Figure 4. 7 – Respondents' Application of LCA

Then, a question addressing presence of LCA software was raised. It showed that 75% of the respondents have no software used to facilitate the application of the LCA, as shown in figure 4.8.

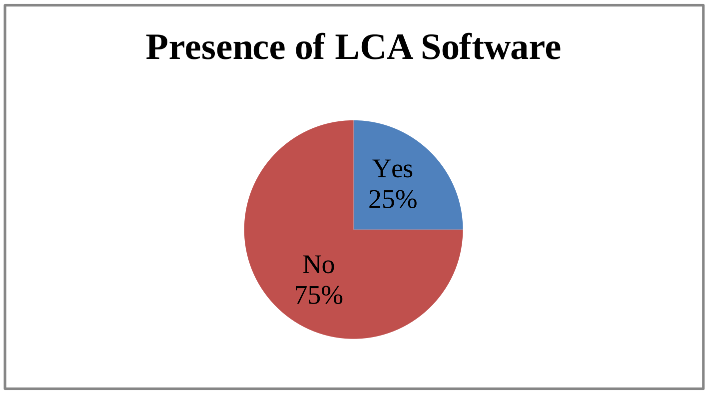


Figure 4. 8 – Presence of LCA Software

To identify the reasons that respondents do not resort to the application of LCA in their project, a multiple choice question including 4 obstacles, which may face the application of LCA, was addressed. Figure 4.9 shows the results of this question which revealed that the main problem is the lack of data, representing 60% of the responses. This answer is logical as one of the main problems in the application of LCA in general is the lack of data. Accordingly, the presence of software linked with database shall push the application of LCA forward.

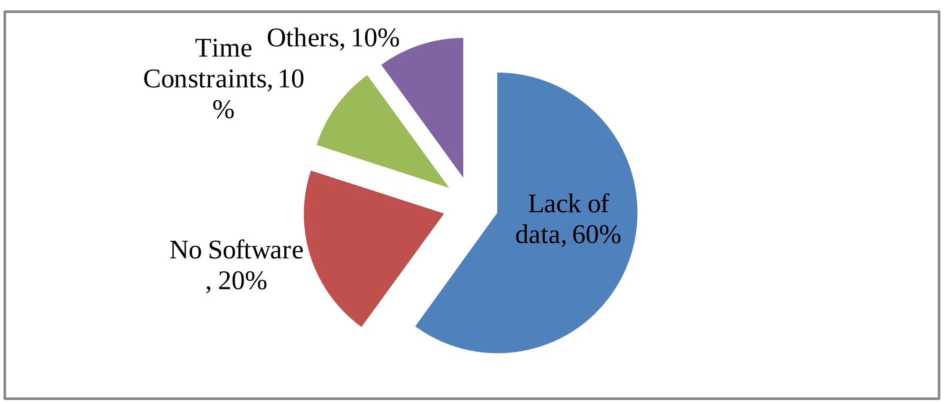


Figure 4. 9 – Obstacles of the application LCA

In a nutshell, it was obvious from the questionnaire results, the LCA part, that the application of LCA is not highly common in Egypt. LCA is not popularly applied in

Egypt because of the absence of software which facilitates the application of LCA as well as the lack of environmental data. Based on the questionnaire 75% claimed that they have no software used in the application of LCA as well as 60% stated that the lack of data is one of the barriers to the application of LCA. Accordingly, this thesis shall take one of the most important factors of environmental impacts and most easy for application by the end-user which is the energy consumption. From the energy consumption data, the model shall calculate the amount of CO_2 emissions in kg.

4.4 Life Cycle Assessment (LCA) Methodology:

As per ISO 14040 LCA consists of four stages which are goal and scope definition, inventory of extractions and emissions, impact assessment, and interpretation.

4.4.1 Goal and Scope Definition

The goal of carrying out LCA study is for research purpose in order to find out which lighting electricity power generation alternative and which light source alternative are more sustainable. The targeted audience of the LCA study is the end-user. The scope is as defined in the points below:

1. **The functional unit:** “To light a specific area” is the functional unit used in this analysis as the study compares the energy consumption of different light systems and sources in addition to the CO_2 Emissions which is dependent on the energy consumption. Details on the application shall be provided in Chapter 5.
2. **The system boundaries:** The boundaries in this research are divided into two parts. One is Cradle to Grave which is related to the source of power for lighting such as conventional electricity, photovoltaic solar energy … etc. The other is

gate to gate which is concerned with the lighting sources (lamps) because it is focusing only on the operation phase. Based on the claim of the European Lamp Companies Federation, lamps are different than all other products as 90% of their environmental impacts are concentrated in the usage phase and most of them are because of their energy consumption. Figure 4.10 shows the percentages of the environmental impacts in each phase in the lamp lifecycle.

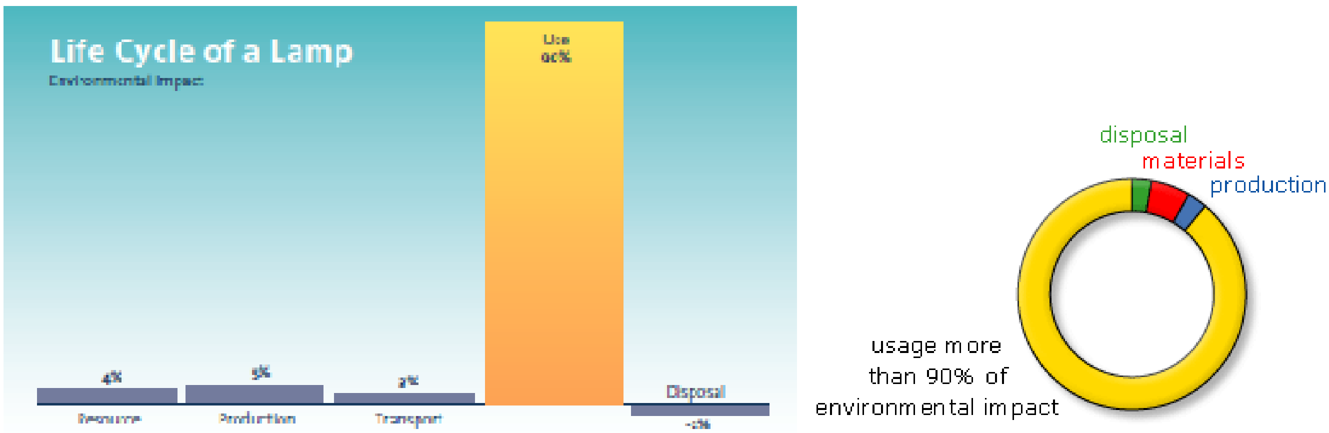


Figure 4. 10 – Lamp Environmental Impacts during Lifecycle
– "About Lamps and Lighting", 2009.

3. **The environmental impact categories:** The LCA study in this research incorporates only Global Warming Potential, and the energy consumption in the operation phase as it causes the largest environmental impacts of the whole lifecycle of lighting systems ("Chapter 7: Life Cycle Analysis and Life Cycle Costs", 2012).

4. **The data requirements:** The required data for the LCA study of the lighting electricity generation system is acquired from SimaPro Software. The used calculation method in the software is Global Warming Potential. The output data

is represented as an amount of kg CO_2 equivalent per kWh for each alternative. The required data for the LCA study of the light source is related only to the end-user energy consumption in the usage phase. The energy Consumption in kWh is then multiplied by the output of the SimPro to give the amount of equivalent CO_2 emissions in kg.

5. **The assumptions:** The study is taking the energy consumption of the end-user only caused by lighting source he/she is using. The equivalent CO_2 emissions are assumed to be those converted from the energy consumption by the factor produced by the SimaPro as mentioned in the previous step. To calculate the equivalent amount of CO_2 emission of each electricity generation system using SimaPro, the values used in Spain were taken as an assumption to the nearest amounts of emissions in Egypt.
6. **The limitations:** The study does not include the raw material extraction, manufacturing, transportation, and disposal phases of the lighting source. In addition to the energy consumption of the main electricity station and any other emissions which may be caused by energy consumption.

4.4.2 Life Cycle Inventory

The required data for the LCA study of the lighting electricity generation system is acquired from SimaPro Software. The used calculation method in the software is Global Warming Potential. The output data is represented as an amount of kg CO_2 equivalent per kWh for each alternative. The required data for the LCA study of the light source is related only to the end-user's energy consumption in the usage phase. The energy Consumption in kWh is then multiplied by the output of the SimPro to give the amount of equivalent CO_2 emissions in kg. To calculate the equivalent amount of CO_2 emissions of each electricity generation system using SimaPro, the values used in Spain were taken as an assumption to the nearest amounts of emissions in Egypt.

4.4.3 Impact Assessment

The Study addresses only the Global Warming Potential (GWP) which is represented by an amount of CO_2 emissions in kg equivalent. The resulted amount of CO_2 contains other emissions of gases, which result in Global Warming, that have been converted to its equivalent amount of CO_2 in kg. For example, 1 kg CH_4 is equivalent to an amount of 42 kg CO_2 ("Introduction to LCA with SimaPro", 2004)

4.4.4 Interpretation

The results, basically, will direct the user to the usage of an alternative that leads to less energy consumption and less CO_2 emissions. This is encountered through a ranking of the energy consumption and CO_2 emissions of each of the alternatives in an ascending order.

4.5 Life Cycle Costing (LCC) Methodology:

The methodology adopted in this research is that formulated by Davis Langdon in 2007 as it was developed with a generic approach to be available for application in any country without changing each country's perspective and approaches (Langdon, 2007). Langdon LCC framework consists of 15 steps as indicated in table 2.1 in Chapter 2 (Langdon, 2007). The tailoring of the framework to fit this research concerning lighting systems and sources in Egypt is shown below:

1. **<u>Identify the main purpose of the LCC analysis:</u>** The purpose of the LCC analysis in this research is to support decision making through the financial assessment of different lighting alternatives which have been selected as having the less environmental impacts and the less energy consumption.

   The LCC here is applied through a model which requires the user to input all the detailed information related to the costs of the lighting alternatives, which this study encompasses, during its lifecycle. The future costs related to operation, maintenance and disposal are assumed by the user through historical information from similar lighting components used in similar projects and through data collection from the lighting systems and sources' suppliers.

   The output of the model shall be:

   - LCA is done in terms of energy consumption and CO_2 emissions in the use phase for all the alternatives in the model. The output ranks all the included alternative light sources:
   - LCC analysis is performed for selected feasible alternatives. The output provides the following ranking:

LCA ranking of the alternatives LCC ranking of the alternatives

2. **<u>Identify the initial scope of the analysis:</u>** The scale of the application of LCC is limited to an individual component in assets in different sectors which is lighting. The LCC is to be applied for all stages in the lifecycle of the lighting starting from the initial investment till the end of life/disposal of the lighting source. The analysis boundaries are to be defined by the user as an input whether he/she needs to do the comparison along the asset life in which the lighting system will be included or for only a certain period of analysis.

   If the user needs to exclude any cost from the analysis a zero value is used. The output shall be in terms of equivalent annual costs and present value.

3. **<u>Identify the extent to which sustainability analysis relates to LCC:</u>** As explained in the previous step, LCC and LCA are addressed separately. The user shall identify the lighting alternatives he/she needs to include in the study of LCC. Then the model shall show an output of 2 rankings; one for LCC according to cost effectiveness and the other for the same alternatives but according to their environmental performance. Finally, the user makes the final decision.

4. **<u>Identify the period of the analysis and the methods of economic evaluation:</u>** The period of analysis shall be defined as an input by the user whether it is a specific period of time within the physical life of the lighting system or the whole physical life of the lighting system. Accordingly, the user will insert two discount rates the interest rate for this period and the percentage of prices escalation. The methods to be used are the annual equivalent value (AEV) and the net present value (NPV)

5. **<u>Identify the need for additional analysis (risk/uncertainty and sensitivity analyses):</u>** Sensitivity analysis will be incorporated in the LCC study in order to

measure the impact and the significance of changing certain variables, where there is uncertainty in their assumption, on the LCC of lighting such as:

- Inflation rate
- Interest rate
- Period of analysis

For each of the above variables, three values shall be added one which the expected value, one is lower than expected value, and one is higher than expected value. These values are chosen based on “careful assessment of the underlying risks rather than by arbitrary plus/minus percentages” (Langdon, 2007).

6. **Identify the project and asset requirements:** In this research, the study is concerned with only component in the project/ asset which is lighting. In addition, the model is focused only on lighting systems and sources in different sectors. Accordingly, what shall be relevant in this research is the identification of the lighting requirements as they differ according to the sector and area such as lumen/m^2, CRI, temperature. The model is comprehensive and shall be relevant for different lighting systems and sources alternatives. It can be used in the pre-design stage, design stage, and even in the usage phase.

7. **Identify options to be included in the LCC exercise and cost items to be considered:** The user in the LCC study of lighting systems is to use the model to identify the needed alternatives to be included in his/her study from a set of alternatives. First, he/she is to choose his/her desired lighting systems such as

conventional lighting system, photovoltaic solar lighting system, passive solar lighting system …etc. Afterwards, the user is to choose from another set of lighting sources alternatives for each of the previously selected lighting systems. Figure 4.11 shows the most commonly used lighting sources alternatives:

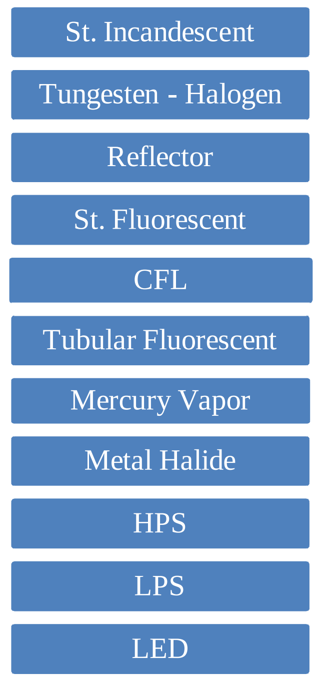


Figure 4. 11 – Lighting Sources Set of Alternatives

The user has also access to identify and include any other alternative he/she may need and that is not included in the set of alternatives identified in the model.

8. <u>Assemble cost and time (asset performance and other) data to be used in the LCC analysis:</u> There are four main costs to be included in the LCC study for lighting systems:

- Initial Cost:
  - <u>Lighting System Cost:</u>

1. Lighting System Initial Cost
2. Lighting System Design Cost
3. Lighting System Installation Cost

- Luminaire Cost
  1. Number of Luminaire
  2. Price per Luminaire
- Lamp Cost
  1. Number of Lamps
  2. Price per Lamp
- Gear Cost
  1. Number of Gears
  2. Price per Gear

➢ Energy Cost:
- Number of Luminaires in the area to be lit
- Price of Electricity (c/KWh)
- Annual Burning Hours (h)
- Power of Luminaire, Lamp, Ballast (W)

➢ Replacement, Maintenance and Disposal Costs
- Group Replacement Cost:
  1. Annual Burning Hours (h)
  2. Price per Lamp
  3. Burning Time between Group Replacements

4. Cost for Replacing per lamp when done at one time including disposal cost.
5. Proportion of Lamps Failing before Group Replacement Time (Early Burnouts)
6. Portion of the Lamp Cost of the Early Burnouts that is charged against Group Replacement

- <u>Spot Replacement Cost:</u>
  1. Annual Burning Hours (h)
  2. Price per Lamp
  3. Lamp Life (h)
  4. Cost of Replacing per Lamp when done individually including disposal cost
- <u>Gear Replacement Cost</u>
  1. Ballast Life (h)
  2. Annual Burning Hours (h)
  3. Period of Analysis (year)
  4. Price per Gear
  5. Replacement Cost per Gear
- <u>Solar System – Battery Replacement Cost</u>
  1. Battery Life
  2. Period of Analysis
  3. Price per Battery
  4. Replacement Cost per Battery

  - Solar System Maintenance Cost per Year

- Service Cost:
  - Number of Lamps
  - Work Costs of Cleaning per Lamp
  - Material Costs of Cleaning per Lamp
  - Cleaning Intervals
  - Period of Analysis

All the above costs are dependent on variables such as inflation rate, interest rate, period of analysis … etc. Accordingly, these variables are included in the calculations.

9. **Verify values of financial parameters and period of analysis:** This step shall be applied in the case study section (Chapter 5).
10. **Review risk strategy and carry out preliminary uncertainty/ risk analysis (optional):** N/A
11. **Perform required economic evaluation:** This step shall be applied in the case study section (Chapter 5).
12. **Carry out detailed risk/ uncertainty analysis (optional):** N/A
13. **Carry out sensitivity analysis (optional):** This step shall be applied in the case study section (Chapter 5).
14. **Interpret and present initial results in required format:** Results are given first in a table for each alternative showing the present value of each cost: initial cost, energy cost, replacement, maintenance and disposal costs, and service cost as well as the

equivalent annual value of the energy cost, replacement, maintenance and disposal costs, and service cost. In addition to the energy consumption in KWh and CO_2 emissions in an annual basis and per the whole period of analysis. Detailed illustration is provided in chapter 5.

15. **Present final results in required format and prepare a final report:** The final result is represented as two tables one ranking the alternatives according to their LCC net present value, while, the other is ranking the alternatives according to energy consumption per period of analysis. Detailed illustration is provided in chapter 5.

Chapter 5
Model Development and Validation
(LCCA-SSL)

Chapter 5: Model Development and Validation

5.1 Model Development

The LCCA-SSL is a model developed to facilitate the process of life cycle costing and life cycle assessment calculation. It is developed on Microsoft Office Excel. It permits the user to compare between lighting systems and lighting sources up to 6 alternatives. The alternatives for the lighting systems which the user can compare between are the conventional lighting system and the photovoltaic solar lighting system. On the other hand, the user can compare between a set of 14 types of lighting bulbs. However, the user has the opportunity to enter any other alternative than those given in the model by choosing “Other” and enter the data of his lighting system/source alternative.

5.1.1 Model Organization

The model consists of two modules. The first module is named “Lighting Design Decision Support”, while the second module is named “LCC & LCA Calculation”. The first module helps the user to know how many light bulbs he/she may need to light up a specific area. The user, first, chooses the sector he/she needs to light up, as shown in figure 5.1. Afterwards, he/she chooses the area he needs in this sector. For example, if the user chooses the residential sector, he/she, then, has to choose in the residential sector the area he/she needs whether it is a bedroom, kitchen, living room … etc. Accordingly, the model will show the lighting requirements for this area such as the lumens/m^2, the lumens, and the light temperature in Kelvin. Furthermore, the user has to choose the light bulb he/she needs to use from the set of the 14 alternatives offered and the model in turn shall show up the light temperature and the CRI of the chosen light bulb. Moreover, the user shall choose the wattage of the chosen light bulb from a set of offered wattages for each light bulb in the model or he may type a different wattage for the light bulb he needs to use and in this case he is required to type also the lumen of this light bulb wattage. Based on the lumens/m^2 required, the lumens produced by the chosen light bulb wattage as well as the area inserted by the user, the model calculates the number of bulbs the user may need to light up the area.

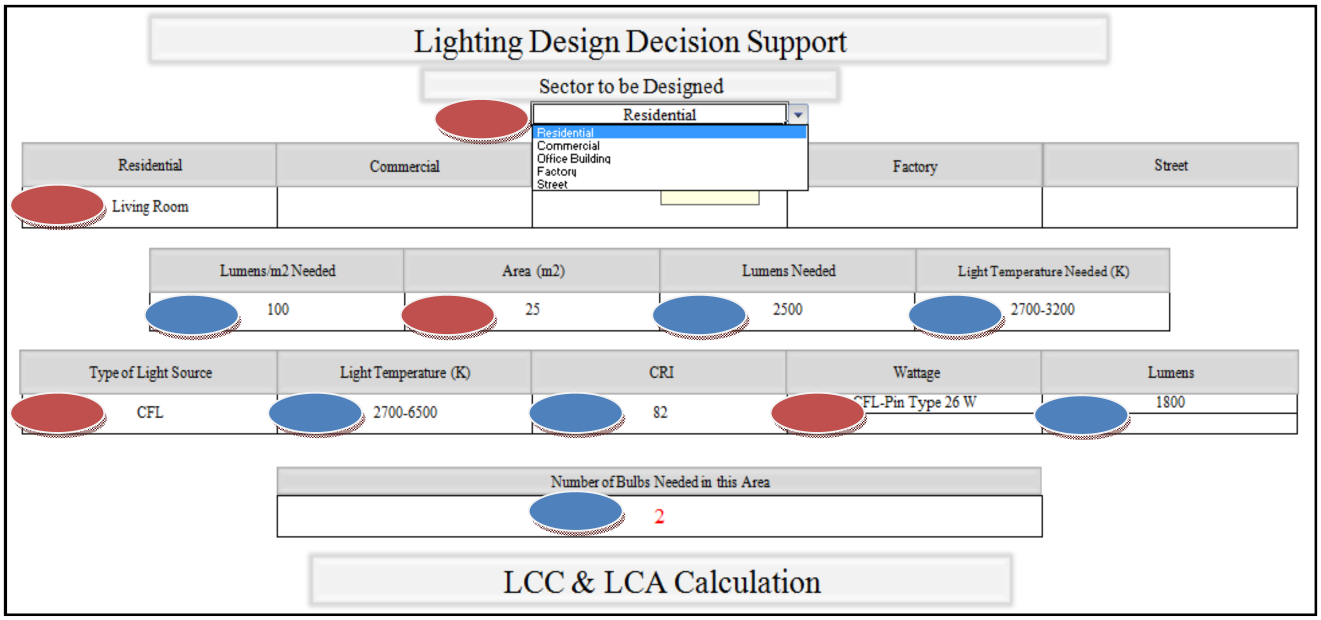


Figure 5. 1 – Lighting Design Decision Support

Input Data by User

Output Data which will show up automatically based on the User input

After finishing this module, the user has to click the “LCC & LCA Calculation” Tab to go for the second module which calculates the life cycle costs and assessment based on several inputs given by the user. Though, the number of bulbs is one of the inputs which is required to be inserted by the user in the LCC Calculation module, it is not reflected directly in the second module from the first module. The reason behind that the two modules are not linked with each other is that the lumens/m^2 required to light up a specific area is based on several factor such as the color of the room, the age of the user who may need more light in a specific area … etc. However, the lumens/m^2 offered by the model is considered as the standard, which based on the user’s requirements may increase or decrease.

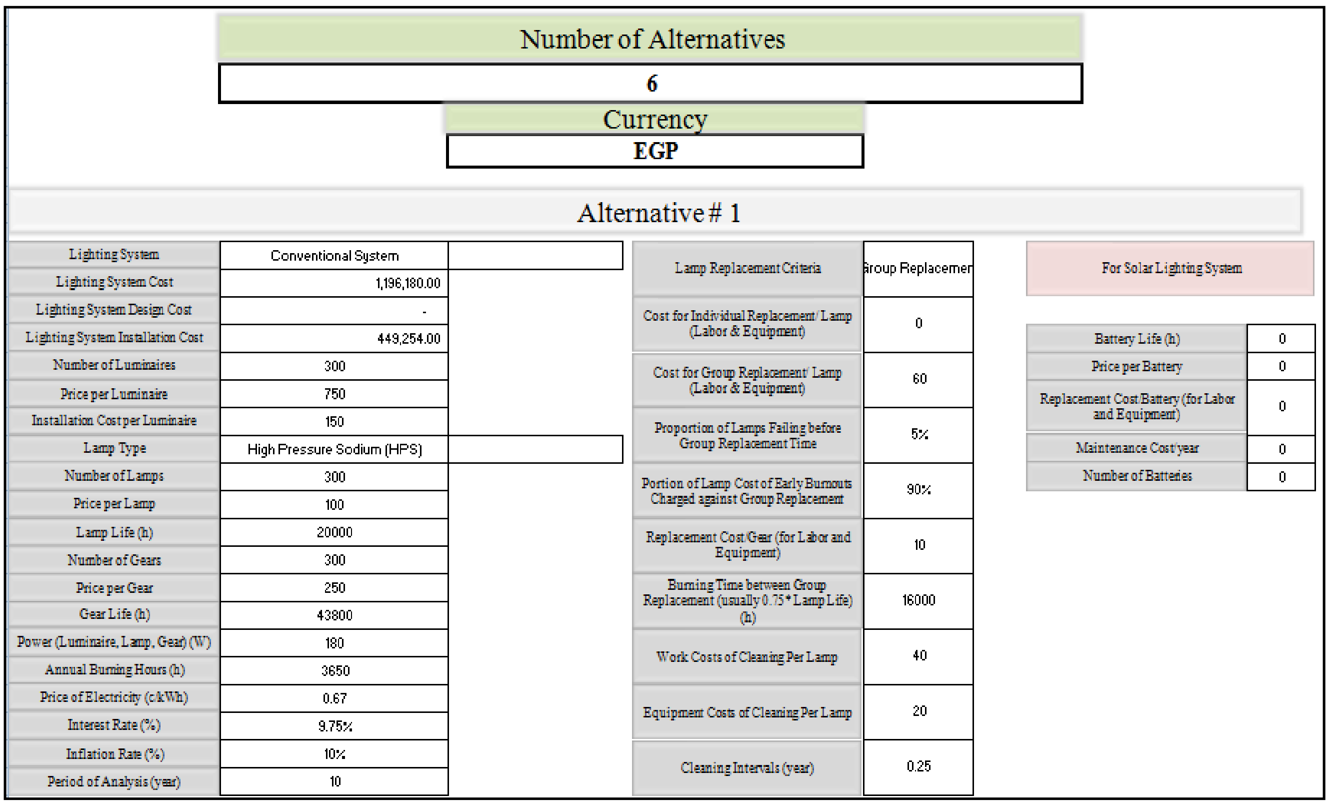
Finally, from the input data inserted by the user, the model calculates the lifecycle costs and lifecycle assessment (Energy Consumption and CO_2 Emissions) of the chosen alternatives. Then, it gives in the “Results Interface” two ranks one for the LCC and the other for the LCA.

5.1.2 Model Inputs

As illustrated above, the inputs of module 1 are the sector, the type of area in this sector, area needed to be lighten up, the type of light bulb and finally the bulb’s wattage and lumens (if the light bulb’s wattage is not in the set of chosen wattages).

The second module which is concerned with the LCC and LCA calculation is the bulk of this model. It can be used in any sector, as the data which is required to be inserted is generic and has nothing focusing on a specific sector. Figure 5.2 shows the data required to be inserted by the user for the LCC and the LCA calculation of each alternative.

The input data required from the user is either selected from a dropdown menu or typed. The data to be selected from a dropdown menu are, the number of alternatives, the currency, the lighting system (Conventional System, Photovoltaic Solar System, Other), the lamp type (a set of 14 lighting bulbs), and finally the lamp replacement criteria (Group Replacement, Spot Replacement). In case the user chose "Other" he/she has to write the name of the Alternative.



Number of Alternatives
6

Currency
EGP

Alternative # 1

Lighting System	Conventional System	
Lighting System Cost	1,196,180.00	
Lighting System Design Cost	-	
Lighting System Installation Cost	449,254.00	
Number of Luminaires	300	
Price per Luminaire	750	
Installation Cost per Luminaire	150	
Lamp Type	High Pressure Sodium (HPS)	
Number of Lamps	300	
Price per Lamp	100	
Lamp Life (h)	20000	
Number of Gears	300	
Price per Gear	250	
Gear Life (h)	43800	
Power (Luminaire, Lamp, Gear) (W)	180	
Annual Burning Hours (h)	3650	
Price of Electricity (c/kWh)	0.67	
Interest Rate (%)	9.75%	
Inflation Rate (%)	10%	
Period of Analysis (year)	10	

Lamp Replacement Criteria	Group Replacemen
Cost for Individual Replacement/ Lamp (Labor & Equipment)	0
Cost for Group Replacement/ Lamp (Labor & Equipment)	60
Proportion of Lamps Failing before Group Replacement Time	5%
Portion of Lamp Cost of Early Burnouts Charged against Group Replacement	90%
Replacement Cost/Gear (for Labor and Equipment)	10
Burning Time between Group Replacement (usually 0.75 * Lamp Life) (h)	16000
Work Costs of Cleaning Per Lamp	40
Equipment Costs of Cleaning Per Lamp	20
Cleaning Intervals (year)	0.25

For Solar Lighting System	
Battery Life (h)	0
Price per Battery	0
Replacement Cost/Battery (for Labor and Equipment)	0
Maintenance Cost/year	0
Number of Batteries	0

Figure 5. 2 – Input Data for the LCC and LCA Calculation

The data to be typed by the user are listed below:

1. Lighting System Cost
2. Lighting System Design Cost
3. Lighting System Installation Cost
4. Number of Luminaires
5. Price per Luminaire
6. Installation Cost/Luminaire
7. Number of Lamps (maybe the one calculated in Module 1 or another as the preference of the user)
8. Price per Lamp
9. Lamp Life (hours)
10. Number of Gears (i.e. Ballast or Driver)
11. Price per Gear
12. Gear Life (hours)
13. Power of Luminaire, Lamps, and Gears (Watt)
14. Annual Burning Hours (hour)
15. Price of Electricity (Cost per Kilo Watt Hour)
16. Interest Rate (%)
17. Inflation Rate (%)
18. Period of Analysis (Year)
19. Cost of Labor and Equipment for Individual Replacement per Lamp including disposal costs (in case of Spot Replacement)
20. Cost of Labor and Equipment for Group Replacement per Lamp including disposal costs (in case of Group Replacement)
21. Proportion of Lamp Failing before Group Replacement (from 0 to 1) (in case of Group Replacement)
22. Portion of Lamp Cost of Early Burnouts Changed against Group Replacement (from 0 to 1) (in case of Group Replacement)
23. Burning Time between Group Replacements (usually its around 0.75 of the Lamp Life) (in case of Group Replacement)
24. Work Cost of Cleaning per Lamp
25. Material Cost of Cleaning per Lamp
26. Cleaning Intervals per Period of Analysis (number of times per Period of Analysis)
27. Battery Life (hour) (in case of Solar Lighting System)
28. Price per Battery (in case of Solar Lighting System)
29. Cost of Labor and Equipment for Battery Replacement (in case of Solar Lighting System)
30. Maintenance Cost per Year (in case of Solar Lighting System)
31. Number of Batteries (in case of Solar Lighting System)

The input data are used to calculate LCC and LCA. The LCC is divided into four Costs:

1. Initial Costs
2. Energy Costs
3. Replacement, Maintenance and Disposal Costs
4. Service Costs

The initial Cost includes, as shown in figure 5.3, the lighting system costs, the luminaire costs, the lamp costs, and the gear costs.

1. Lighting System Cost= Initial Cost + Design Cost + Installation Cost

   (eq. 5.1)

2. Luminaire Cost= Number of Luminaires x (Price per Luminaire + Luminaire Installation Cost)

   (eq. 5.2)

3. Lamp Cost= Number of Lamps x Price per Lamp

   (eq. 5.3)

4. Gear Cost= Number of Gears x Price per Gear

   (eq. 5.4)

So, Total Initial Cost= 1 + 2 + 3+ 4

(eq. 5.5)

Initial Costs							
Lighting System Cost (Present Value)							
	Alt. # 1			Alt. # 2			
	High Pressure Sodium (HPS)			LED			
	Conventional System			PhotoVoltaic Solar System			Con
Lighting System Initial Cost	1,196,180.00			1,734,892.65			
Design of Lighting System Cost	-			-			
Lighting System Installation Cost	449,254.00			173,489.27			
Lighting System Cost (Present Value)	1,645,434.00			1,908,381.92			
Luminaire Cost (Present Value)							
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6	
	ressure Sodiun	LED	LED	ressure Sodiun	Metal Halide	Metal Halide	
Number of Luminaires	300	300	300	300	300	300	
Price per Luminaire	750	0	750	0	750	0	
Luminaire Installation Cost (c/Luminaire)	150	0	150	0	150	0	
Luminaire Cost (Present Value)	270,000.00	-	270,000.00	-	270,000.00	-	
Lamp Cost (Present Value)							
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6	
	ressure Sodiun	LED	LED	ressure Sodiun	Metal Halide	Metal Halide	
Number of Lamps	300	300	300	300	300	300	
Price per Lamp	100	3000	3000	100	40	40	
Lamp Cost (Present Value)	30,000.00	900,000.00	900,000.00	30,000.00	12,000.00	12,000.00	
Gear Cost (Present Value)							
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6	
	ressure Sodiun	LED	LED	ressure Sodiun	Metal Halide	Metal Halide	
Number of Gears	300	0	0	300	300	300	
Price per Gear	250	0	0	250	160	160	
Gear Cost (Present Value)	75000	0	0	75000	48000	48000	
Total Initial Cost (Present Value)	2,020,434.00	2,808,381.92	2,815,434.00	2,013,381.92	1,975,434.00	1,968,381.92	

Figure 5. 3 – Initial Costs of LCC Calculation

As shown in figure 5.4, Annual Energy Costs variables are the number of luminaires, power of luminaire, annual burning hours, and price of electricity (cost per Kilo Watt Hour). It is calculated as follows:

Annual Energy Cost= ((Number of Luminaires x Power of Luminaire)/1000) x Annual Burning Hours x Price of Electricity. (eq. 5.6)

Energy Cost (Annual Value)						
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6
	ressure Sodiun	LED	LED	ressure Sodiun	Metal Halide	Metal Halide
Number of Luminaires	300	300	300	300	300	300
Power of Luminaire (Lamp+Ballast) (W)	180	70	70	180	250	250
Annual Burning Hours (h)	3650	3650	3650	3650	3650	3650
Price of Electricity (c/kWh)	0.67	0	0.67	0	0.67	0
Annual Energy Cost	132,057.00	-	51,355.50	-	183,412.50	-

Figure 5. 4 – Annual Energy Costs of LCC Calculation

Replacement Costs include lamp replacement costs, gear replacement costs (in case of the presence of a gear), and battery replacement and annual maintenance costs (in case the source of power is solar energy). There are two different criteria for lamp replacement which the user has to choose from; group replacement and spot replacement. Group replacement means replacing all the lamps one at a time, as at a certain point of time before the end of lamp lifetime, the lamp does not work with its full efficiency (lumen depreciation) due to pollution, usage, less frequent cleaning … etc. On the other hand, spot replacement means replacing the lamps when they burnout. Figure 5.5 shows the variables used in each of the lamp replacement criteria.

Lamp Spot Replacement Cost (Annual Value)						
	Alt. # 1 High Pressure Sodium (HPS)	Alt. # 2 LED	Alt. # 3 LED	Alt. # 4 High Pressure Sodium (HPS)	Alt. # 5 Metal Halide	Alt. # 6 Metal Halide
Annual Burning Hours (h)	1	1	1	1	1	1
Price per Lamp	0	0	0	0	0	0
Lamp Life (h)	1	1	1	1	1	1
Cost for Replacing/Lamp when done individually (for Labor and Equipment) including Disposal Cost	0	0	0	0	0	0
Spot Replacement Intervals	1	1	1	1	1	1
Period of Analysis (yr)	10	10	10	10	10	10
Number of Lamps	300	300	300	300	300	300
to be Replaced within the analysis period	0	0	0	0	0	0
Spot Replacement Cost	**0**	**0**	**0**	**0**	**0**	**0**
Annual Spot Replacement	**0**	**0**	**0**	**0**	**0**	**0**
Lamp Group Replacement Cost (Annual Value)						
	Alt. # 1 High Pressure Sodium (HPS)	Alt. # 2 LED	Alt. # 3 LED	Alt. # 4 High Pressure Sodium (HPS)	Alt. # 5 Metal Halide	Alt. # 6 Metal Halide
Annual Burning Hours (h)	3650	3650	3650	3650	3650	3650
Price per Lamp	100	3000	3000	100	40	40
Burning Time between Group Replacement (usually 0.75* Lamp	16000	45000	45000	16000	4000	4000
Cost for Replacing/Lamp when done at one time (for Labor and Equipment) including Disposal Cost	60	60	60	60	60	60
Proportion of Lamps Failing before Group Replacement Time (i.e Early Burnouts)	0.05	0.05	0.05	0.05	0.05	0.05
Portion of Lamp Cost of the Early Burnouts that is Charged against Group Replacement	0.9	0.9	0.9	0.9	0.9	0.9
Number of Lamps	300	300	300	300	300	300
Period of Analysis (yr)	10	10	10	10	10	10
Group Replacement Cost	**48,004.55**	**918,135.05**	**918,135.05**	**48,004.55**	**30,001.85**	**30,001.85**
Group Replacement Intervals	4	12	12	4	1	1
replacement within the analysis period	**2**	**0**	**0**	**2**	**10**	**10**
Annual Group Replacement	**9,600.91**	**-**	**-**	**9,600.91**	**30,001.85**	**30,001.85**

Figure 5. 5 – Annual Lamp Replacement Costs

Annual Spot Replacement Calculation

1. The spot replacement cost is calculated as shown below:

   Cost of Lamps + Cost of Replacing =

   (Number of Lamps x Price per Lamp) **+** (Number of Lamps x (Cost for Replacing per Lamp when done at individually (for Labor and Equipment) including Disposal Cost)

   (eq. 5.7)

2. The Spot replacement intervals is calculated as shown in eq. 5.8:

   Round down of (Lamp Life / Annual Burning Hours)

   (eq. 5.8)

3. The number of spot replacements within the period of analysis, eq. 5.9:

   Round down of (Period of Analysis / Spot Replacement Intervals)

   (eq. 5.9)

4. Annual Spot replacement cost, eq. 5.10:

   (Spot Replacement Cost x Number of Spot Replacements within the Period of Analysis) / Period of Analysis

   (eq. 5.10)

Annual Group Replacement Calculation

1. The group replacement cost is calculated as shown in eq. 5.11:

Cost of Lamps + Cost of Replacing as a group + Cost of Lamps to Replace Early Burnouts + Cost of Replacing Early Burnouts =

(Number of Lamps x (1- Proportion of Lamps Failing before Group Replacement Time) x Price per Lamp) + (Number of Lamps x (1- Proportion of Lamps Failing before Group Replacement Time) x (Cost for Replacing per Lamp when done at one time (for Labor and Equipment) including Disposal Cost) + (Number of Lamps x Proportion of Lamps Failing before Group Replacement Time x Portion of Lamp Cost of the Early Burnouts that is Charged against Group Replacement) + (Number of Lamps x Proportion of Lamps Failing before Group Replacement Time x (Cost for Replacing per Lamp when done at one time (for Labor and Equipment) including Disposal Cost)

(eq. 5.11)

2. The group replacement intervals is calculated as shown in eq. 5.12:

   Round down of (Burning Time between Group Replacement / Annual Burning Hours)

   (eq. 5.12)

3. The number of group replacements within the period of analysis, eq. 5.13:

   Round down of (Period of Analysis / Group Replacement Intervals)

   (eq. 5.13)

4. Annual group replacement cost, eq. 5.14:

   (Group Replacement Cost x Number of Group Replacements within the Period of Analysis) / Period of Analysis

   (eq. 5.14)

Annual Gear Replacement Calculation

The annual gear replacement cost, figure 5.6, is calculated as shown below:

Gear Replacement Cost (Annual Value)						
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6
	High Pressure Sodium (HPS)	**LED**	**LED**	**High Pressure Sodium (HPS)**	**Metal Halide**	**Metal Halide**
Ballast Life (h)	43800	0	0	43800	43800	43800
Annual Burning Hours (h)	3650	0	0	3650	3650	3650
Ballast Replacement Intervals	**12**	**1**	**1**	**12**	**12**	**12**
Number of Gears	300	0	0	300	300	300
Period of Analysis (yr)	10	1	1	10	10	10
Price per Ballast	250	0	0	250	160	160
Number of times the Ballast is to be Replaced within the analysis period	**0**	**1**	**1**	**0**	**0**	**0**
Replacement Cost/Ballast (for Labor and Equipment)	10	0	10	10	10	10
Annual Ballast Replacement Cost	-	-	-	-	-	-

Figure 5. 6 – Annual Gear Replacement Costs

1. The gear replacement intervals, eq. 5.15:

   Gear Life/Annual Burning Hours

   (eq. 5.15)

2. Number of gear replacements within the period of analysis, eq. 5.16:

   Round down (Period of Analysis/Gear Replacement Intervals)

   (eq. 5.16)

3. The Annual Gear Replacement Cost, eq. 5.17:

   Number of Gear Replacements within the Period of Analysis x Number of Gears x (Price per Gear + Replacement Cost per Gear)/Period of Analysis

   (eq. 5.17)

Annual Solar System Battery Replacement Calculation

The final cost in the replacement costs is included when the source of lighting power is the solar energy which includes the annual battery replacement cost and the annual maintenance cost. As Shown in figure 5.7, the annual replacement cost of solar lighting system battery is very similar to that of the gear replacement.

Solar System - Battery Replacement Cost (Annual Value)						
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6
	High Pressure Sodium (HPS)	LED	LED	High Pressure Sodium (HPS)	Metal Halide	Metal Halide
Battery Life (h)	1	70080	1	70080	1	70080
365*24 (h)	8760	8760	8760	8760	8760	8760
Battery Replacement Intervals	**1.000**	**8.000**	**1.000**	**8.000**	**0.000**	**8.000**
Period of Analysis (yr)	1	10	1	10	1	10
Price per Battery	0	2145.4885	0	2145.4885	0	2145.4885
Number of times the Battery is to be Replaced per Period of Analysis	**1**	**1**	**1**	**1**	**8760**	**1**
Number of Batteries	0	300	0	300	0	300
Replacement Cost/Battery (for Labor and Equipment)	0	10	0	10	0	10
Annual Battery Replacement Cost	**-**	**64,664.66**	**-**	**64,664.66**	**-**	**64,664.66**
Solar System - Maintenace Cost (Annual Value)						
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6
	High Pressure Sodium (HPS)	LED	LED	High Pressure Sodium (HPS)	Metal Halide	Metal Halide
Maintenance Cost/yr	**0**	**1000**	**0**	**1000**	**0**	**1000**
Total Replacement Costs (Annual Value)	**9,570.00**	**65,664.66**	**-**	**75,234.66**	**29,940.00**	**95,604.66**

Figure 5. 7 – Annual Solar System Battery Replacement Costs

1. The battery replacement intervals, eq. 5.18:

   Battery Life in Hours/ (365 days x 24 hours)

   (eq. 5.18)

2. The number of battery replacements within the period of analysis, eq. 5.19:

   Round down (Period of Analysis in Years/ Battery Replacement Intervals)

   (eq. 5.19)

3. Annual battery replacement cost, eq. 5.20:

   Number of Battery Replacements within the Period of Analysis x Number of Batteries x (Price per Battery + Replacement Cost per Battery)/Period of Analysis

   (eq. 5.20)

Finally, the annual replacement cost shall be the addition of all the above annual replacement costs and the annual maintenance cost (in case of solar system), eq. 5.21:

Annual Lamp Replacement Cost (Spot or Gear) + Annual Gear Replacement Cost + Annual Battery Replacement Cost (in case of solar system) + Annual Maintenance Cost (in case of solar system)

(eq. 5.21)

The final cost in the life cycle costing calculation is the service cost. The service costs, as shown in figure 5.8, include the annual lamp cleaning costs.

Service Cost (Annual Value)						
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6
	High Pressure Sodium (HPS)	LED	LED	High Pressure Sodium (HPS)	Metal Halide	Metal Halide
Number of Lamps	300	300	300	300	300	300
Work Costs of Cleaning per Lamp	40	40	40	40	40	40
Equipment Costs of Cleaning per Lamp	20	20	20	20	20	20
Period of Analysis (yr)	10	10	10	10	10	10
Cleaning Intervals	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**	**0.25**
Annual Service Cost	**72,000.00**	**72,000.00**	**72,000.00**	**72,000.00**	**72,000.00**	**72,000.00**

Figure 5. 8 – Annual Service Costs

The annual lamp cleaning cost is calculated as follows:

1. The number cleaning times within the period of analysis is calculated:

   Period of Analysis (years)/Cleaning Intervals

   (eq. 5.22)

2. The annual cleaning cost:

   Number of Cleaning Times within the period of Analysis x Number of Lamps x (Work Costs of Cleaning per Lamps + Material Costs of Cleaning per Lamps)/ Period of Analysis

   (eq. 5.22)

For the LCA, there are calculation formulas, one for the energy consumption (kWh) and the other is the conversion of this energy consumption into CO_2 emissions (kg).

The annual energy consumption:

Power of Luminaire (W) x Number of Luminaires x Annual Burning Hours / 1000

(eq. 5.23)

The annual CO_2 emissions:

Annual Energy Consumption (kWh) x CO_2 Factor of the lighting system (kg/kWh)

(eq. 5.24)

5.1.3 Model Outputs

There are two outputs for the LCCA-SSL, the LCC and the LCA. In the LCC part, the results are calculated by two methods the first is the equivalent annual value, which is calculated for all the LCC costs except for the initial costs, and the net present value (NPV), which is the initial costs (present value) in addition to the conversion of the annual costs to present value incorporating interest rate (%) and inflation rate (%) through the following equation:

NPV = A x ((1-(1+NDR)^(-n))/NDR)

(eq. 5.25)

Where, A is the Equivalent Annual Value

n is the period of analysis

NDR is the Net Inflation Discount Rate, which is calculated as follows:

NDR= ((1 + Interest Rate (%)) / (1 + Inflation Rate (%))) -1

(eq. 5.26)

The LCA result is classified into two results; one is the Annual Energy Consumption (Kilo Watt per Hour) and the other is the Annual CO_2 Emissions (kg). The annual energy consumption cost is calculated, through the variables shown in figure 5.9, by equation 5.23.

Energy Consumption (kWh)						
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6
	Conventional System	PhotoVoltaic Solar System	Conventional System	PhotoVoltaic Solar System	Conventional System	PhotoVoltaic Solar System
	High Pressure Sodium (HPS)	LED	LED	High Pressure Sodium (HPS	Metal Halide	Metal Halide
Number of Luminaires	300	300	300.00	300.00	300	300
Power of Luminaire (Lamp+Ballast) (W)	180	70	70.00	180.00	250	250
Annual Burning Hours (h)	3650	3650	3,650.00	3,650.00	3650	3650
1000	1000	1000	1000	1000	1000	1000
Annual Energy Consumption (kWh)	197,100.00	76,650.00	76,650.00	197,100.00	273,750.00	273,750.00

Figure 5. 9 – Annual Energy Consumption

The Annual CO_2 Emissions is calculated by multiplying the annual energy consumption with the factor of amount of CO_2 emissions per 1 KWh for each lighting systems alternative as shown in equation 5.24. This factor is calculated using SimaPro7 Software. Figure 5.10 shows the calculation of CO_2 emissions.

CO_2 Emissions						
	Alt. # 1	Alt. # 2	Alt. # 3	Alt. # 4	Alt. # 5	Alt. # 6
	Conventional System	PhotoVoltaic Solar System	Conventional System	PhotoVoltaic Solar System	Conventional System	PhotoVoltaic Solar System
	High Pressure Sodium (HPS)	LED	LED	High Pressure Sodium (HPS	Metal Halide	Metal Halide
Conversion of 1 kWh to kg CO_2	0.97096292	0.050941545	0.97096292	0.050941545	0.97096292	0.050941545
Annual CO_2 Emissions (kg)	191,376.79	3,904.67	74,424.31	10,040.58	265,801.10	13,945.25

Figure 5. 10 – Annual CO_2 Emissions

The LCCA-SSL can calculate up to six alternatives. The model's results of LCC and LCA are shown in figure 5.11.

Alternative # 1

Conventional System — High Pressure Sodium (HPS)

LCC	Present Value	Annual Value
Initial Costs	2,020,434.00	-
Energy Costs	1,337,228.31	132,057.00
Replacement and Disposal Costs	96,907.21	9,570.00
Service Costs	729,082.43	72,000.00
Total	4,183,651.94	213,627.00
LCA	**Energy Consumption (KWh)**	**CO_2 Emissions (kg)**
Annual	197,100.00	191,376.79
Total Per Period of Analysis	1,971,000.00	1,913,767.92

Alternative # 2

PhotoVoltaic Solar System — LED

LCC	Present Value	Annual Value
Initial Costs	2,808,381.92	-
Energy Costs	-	-
Replacement and Disposal Costs	664,929.81	65,664.66
Service Costs	729,082.43	72,000.00
Total	4,202,394	137,664.66
LCA	**Energy Consumption (KWh)**	**CO_2 Emissions (kg)**
Annual	76,650.00	3,904.67
Total Per Period of Analysis	766,500.00	39,046.69

Alternative # 3

Conventional System — LED

LCC	Present Value	Annual Value
Initial Costs	2,815,434.00	-
Energy Costs	520,033.23	51,355.50
Replacement and Disposal Costs	-	-
Service Costs	729,082.43	72,000.00
Total	4,064,549.66	123,355.50
LCA	**Energy Consumption (KWh)**	**CO_2 Emissions (kg)**
Annual	76,650.00	74,424.31
Total Per Period of Analysis	766,500.00	744,243.08

Go to Final Result

Alternative # 4

PhotoVoltaic Solar System — High Pressure Sodium (HPS)

LCC	Present Value	Annual Value
Initial Costs	2,013,381.92	-
Energy Costs	-	-
Replacement and Disposal Costs	761,837.01	75,234.66
Service Costs	729,082.43	72,000.00
Total	3,504,301.35	147,234.66
LCA	**Energy Consumption (KWh)**	**CO_2 Emissions (kg)**
Annual	197,100.00	10,040.58
Total Per Period of Analysis	1,971,000.00	100,405.79

Alternative # 5

Conventional System — Metal Halide

LCC	Present Value	Annual Value
Initial Costs	1,975,434.00	-
Energy Costs	1,857,261.54	183,412.50
Replacement and Disposal Costs	303,176.78	29,940.00
Service Costs	729,082.43	72,000.00
Total	4,864,954.74	285,352.50
LCA	**Energy Consumption (KWh)**	**CO_2 Emissions (kg)**
Annual	273,750.00	265,801.10
Total Per Period of Analysis	2,737,500.00	2,658,010.99

Alternative # 6

PhotoVoltaic Solar System — Metal Halide

LCC	Present Value	Annual Value
Initial Costs	1,968,381.92	-
Energy Costs	-	-
Replacement and Disposal Costs	968,106.58	95,604.66
Service Costs	729,082.43	72,000.00
Total	3,665,570.92	167,604.66
LCA	**Energy Consumption (KWh)**	**CO_2 Emissions (kg)**
Annual	273,750.00	13,945.25
Total Per Period of Analysis	2,737,500.00	139,452.48

Figure 5. 11 – Model Results

Finally, the user can click the tab "Go to Final Result" which is shown in figure 5.11 to direct him/her to the final result summary. The final result summarizes the results of the alternatives into two charts and two ranking tables; one for LCC and one for LCA as shown in figure 5.12.

LCC Rank

Rank	Alternative	Present Value	Annual Value
4	Alternative 1	4,183,651.94	213,627.00
5	Alternative 2	4,202,394.15	137,664.66
3	Alternative 3	4,064,549.66	123,355.50
1	Alternative 4	3,504,301.35	147,234.66
6	Alternative 5	4,864,954.74	285,352.50
2	Alternative 6	3,665,570.92	167,604.66

LCA Rank

Rank	Alternative	Total Energy Consumption (KWh)	Total CO_2 Emissions
5	Alternative 1	1,971,000.00	1,913,767.92
1	Alternative 2	766,500.00	39,046.69
4	Alternative 3	766,500.00	744,243.08
2	Alternative 4	1,971,000.00	100,405.79
6	Alternative 5	2,737,500.00	2,658,010.99
3	Alternative 6	2,737,500.00	139,452.48

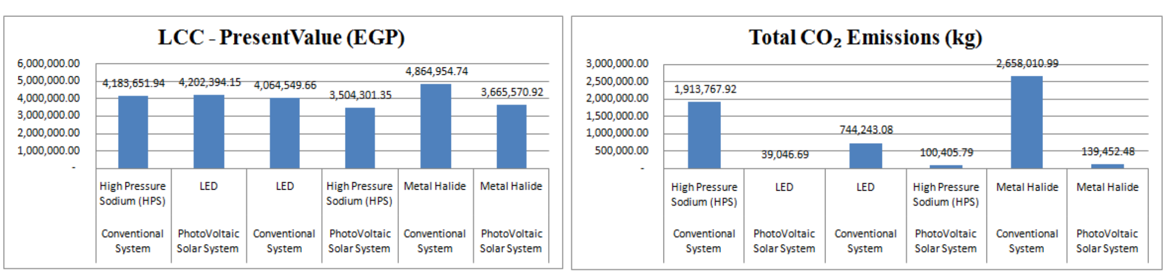


Figure 5. 12– Model Final Result

5.2 Model Validation

After developing the model, it has to be validated, which means to be checked if it is workable on a real case study. Real data has to be inserted to check the equations and the workability of the model.

5.2.1 Case Study – MIVIDA Project

MIVIDA is a residential compound in fifth Settlement - New Cairo. MIVIDA is owned by EMAR, the Project Manager is TURNER, the Cost Consultant is EUROPTIMA. The project is divided into work packages; each has its Main Consultant and Main Contractor. It consists of residential units such as villas, townhouses, apartments as well as hotels, retail malls and office buildings. It has a total area of 3.6 km^2.

Figure 5. 13 – MIVIDA Master Plan

The component in MIVIDA Project which encompasses an LCC study was the lighting systems of the compound's street network. The LCC study incorporated two alternatives of lighting systems, the conventional lighting system and the photovoltaic solar lighting system as well as three alternatives of lighting sources, LED lamps, high pressure sodium lamps (HPS), and metal halide (MH) lamps. The LCC study tackles four main costs for each alternative, initial cost, energy cost, maintenance and replacements costs, and service cost.

5.2.2 MIVIDA Case Study – LCC Methodology

As illustrated in Chapter 4, Davis Langdon Framework was adopted in this study. It consists of 15 steps which are formulated basically for whole asset alternatives and not for specific components in the asset (Langdon, 2007). However, the framework was tailored to fit in this research.

1. **Identify the main purpose of the LCC analysis:** The purpose of the LCC analysis in this research is to help in decision making through the financial assessment of different two street lighting systems alternatives, conventional lighting system and passive solar lighting system and three lighting sources alternatives, LED lamps, HPS lamps, and MH lamps.
2. **Identify the initial scope of the analysis:** The scale of the application of LCC is limited to an individual component in residential compound "MIVIDA" which is street lighting systems and sources. The LCC study tackles four main costs for each alternative; initial cost, energy cost, maintenance and replacements costs, and service

cost for a period of analysis of 10 years. The LCC output shall be in terms of equivalent annual costs and net present value.

3. **<u>Identify the extent to which sustainability analysis relates to LCC:</u>** LCC and LCA each shall be tackled separately. From the energy data, the energy consumption shall be calculated and consequently, the CO_2 emissions shall be calculated as well.

4. **<u>Identify the period of the analysis and the methods of economic evaluation:</u>** The period of analysis shall be 10 years. The methods to be used are the annual equivalent value (AEV) and the net present value (NPV)

5. **<u>Identify the need for additional analysis (risk/uncertainty and sensitivity analyses):</u>** Sensitivity analysis will be incorporated in the LCC study in order to measure the impact and the significance of changing certain variables, where there is uncertainty in their assumption, on the LCC of lighting such as:
    - Inflation rate
    - Interest rate
    - Period of analysis

6. **<u>Identify the project and asset requirements:</u>**
    - Lighting Intensity: 6000 lumens (150W HPS = 250W MH = 60W LED)
    - Operating Hours per day: 10 hours/day
    - Number of Lighting Poles: 300 (30m spacing between lighting poles)
    - Lighting Pole Length: 6m

7. **<u>Identify options to be included in the LCC exercise and cost items to be considered:</u>** The alternatives are conventional lighting system and photovoltaic solar

lighting system. The study incorporates three lighting sources alternatives for each lighting system alternative to reach the most feasible and sustainable alternative, as shown in figure 5.14. The costs to be included are initial cost, energy cost, replacement and maintenance cost, and service cost.

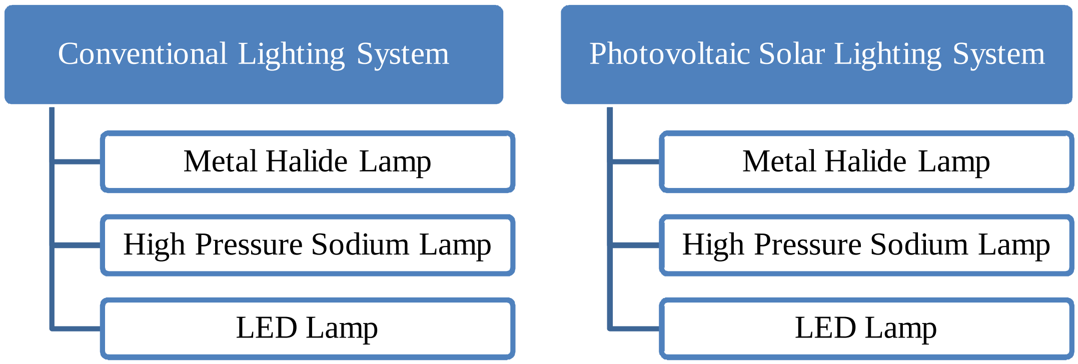


Figure 5. 14 – Lighting Systems and Sources Alternatives

8. **Assemble cost and time (asset performance and other) data to be used in the LCC analysis:** Figures 5.15, 5.16, 5.17, 5.18, 5.19 and 5.20 show the costs and all the input data for each alternative. The data were collected from different suppliers such as Hi-Tech Lighting Company (for the conventional lighting system), Foresight Trading and Linuo Solar Thermal Group (for photovoltaic lighting system).

Alternative # 1

Lighting System	Conventional System
Lighting System Cost	1,196,180.00
Lighting System Design Cost	-
Lighting System Installation Cost	449,254.00
Number of Luminaires	300
Price per Luminaire	750
Installation Cost per Luminaire	150
Lamp Type	High Pressure Sodium (HPS)
Number of Lamps	300
Price per Lamp	100
Lamp Life (h)	20000
Number of Gears	300
Price per Gear	250
Gear Life (h)	43800
Power (Luminaire, Lamp, Gear) (W)	180
Annual Burning Hours (h)	3650
Price of Electricity (c/kWh)	0.67
Interest Rate (%)	9.75%
Inflation Rate (%)	10%
Period of Analysis (year)	10

Lamp Replacement Criteria	Group Replacement
Cost for Individual Replacement/ Lamp (Labor & Equipment)	0
Cost for Group Replacement/ Lamp (Labor & Equipment)	60
Proportion of Lamps Failing before Group Replacement Time	5%
Portion of Lamp Cost of Early Burnouts Charged against Group Replacement	90%
Replacement Cost/Gear (for Labor and Equipment)	10
Burning Time between Group Replacement (usually 0.75* Lamp Life) (h)	16000
Work Costs of Cleaning Per Lamp	40
Equipment Costs of Cleaning Per Lamp	20
Cleaning Intervals (year)	0.25

For Solar Lighting System	
Battery Life (h)	0
Price per Battery	0
Replacement Cost/Battery (for Labor and Equipment)	0
Maintenance Cost/year	0
Number of Batteries	0

Figure 5. 15 – Conventional System – HPS (Alternative 1) Input Data

Alternative # 2

Lighting System	PhotoVoltaic Solar System
Lighting System Cost	1,734,892.65
Lighting System Design Cost	-
Lighting System Installation Cost	173,489.27
Number of Luminaires	300
Price per Luminaire	0
Installation Cost per Luminaire	0
Lamp Type	LED
Number of Lamps	300
Price per Lamp	3000
Lamp Life (h)	50,000
Number of Gears	0
Price per Gear	0
Gear Life (h)	-
Power (Luminaire, Lamp, Gear) (W)	70
Annual Burning Hours (h)	3650
Price of Electricity (c/kWh)	0
Interest Rate (%)	9.75%
Inflation Rate (%)	10%
Period of Analysis (year)	10

Lamp Replacement Criteria	Group Replacement
Cost for Individual Replacement/ Lamp (Labor & Equipment)	0
Cost for Group Replacement/ Lamp (Labor & Equipment)	60
Proportion of Lamps Failing before Group Replacement Time	5%
Portion of Lamp Cost of Early Burnouts Charged against Group Replacement	90%
Replacement Cost/Gear (for Labor and Equipment)	0
Burning Time between Group Replacement (usually 0.75* Lamp Life) (h)	45000
Work Costs of Cleaning Per Lamp	40
Equipment Costs of Cleaning Per Lamp	20
Cleaning Intervals (year)	0.25

For Solar Lighting System	
Battery Life (h)	70,080.00
Price per Battery	2,145.49
Replacement Cost/Battery (for Labor and Equipment)	10
Maintenance Cost/year	1000
Number of Batteries	300

Figure 5. 16 – Photovoltaic System – LED (Alternative 2) Input Data

Alternative # 3

Lighting System	Conventional System
Lighting System Cost	1,196,180.00
Lighting System Design Cost	-
Lighting System Installation Cost	449,254.00
Number of Luminaires	300.00
Price per Luminaire	750.00
Installation Cost per Luminaire	150.00
Lamp Type	LED
Number of Lamps	300.00
Price per Lamp	3,000.00
Lamp Life (h)	50,000.00
Number of Gears	-
Price per Gear	-
Gear Life (h)	-
Power (Luminaire, Lamp, Gear) (W)	70.00
Annual Burning Hours (h)	3,650.00
Price of Electricity (c/kWh)	0.67
Interest Rate (%)	9.75%
Inflation Rate (%)	10%
Period of Analysis (year)	10

Lamp Replacement Criteria	Group Replacement
Cost for Individual Replacement/ Lamp (Labor & Equipment)	0
Cost for Group Replacement/ Lamp (Labor & Equipment)	60
Proportion of Lamps Failing before Group Replacement Time	0.05
Portion of Lamp Cost of Early Burnouts Charged against Group Replacement	0.9
Replacement Cost/Gear (for Labor and Equipment)	10
Burning Time between Group Replacement (usually 0.75* Lamp Life) (h)	45,000.00
Work Costs of Cleaning Per Lamp	40
Equipment Costs of Cleaning Per Lamp	20
Cleaning Intervals (year)	0.25

For Solar Lighting System	
Battery Life (h)	0
Price per Battery	-
Replacement Cost/Battery (for Labor and Equipment)	0
Maintenance Cost/year	0
Number of Batteries	0

Figure 5. 18 – Conventional System – LED (Alternative 3) Input Data

Alternative # 4

Lighting System	PhotoVoltaic Solar System
Lighting System Cost	1,734,892.65
Lighting System Design Cost	-
Lighting System Installation Cost	173,489.27
Number of Luminaires	300.00
Price per Luminaire	-
Installation Cost per Luminaire	-
Lamp Type	High Pressure Sodium (HPS)
Number of Lamps	300.00
Price per Lamp	100.00
Lamp Life (h)	20,000.00
Number of Gears	300.00
Price per Gear	250.00
Gear Life (h)	43,800.00
Power (Luminaire, Lamp, Gear) (W)	180.00
Annual Burning Hours (h)	3,650.00
Price of Electricity (c/kWh)	-
Interest Rate (%)	9.75%
Inflation Rate (%)	10%
Period of Analysis (year)	10

Lamp Replacement Criteria	Group Replacement
Cost for Individual Replacement/ Lamp (Labor & Equipment)	0
Cost for Group Replacement/ Lamp (Labor & Equipment)	60
Proportion of Lamps Failing before Group Replacement Time	0.05
Portion of Lamp Cost of Early Burnouts Charged against Group Replacement	0.9
Replacement Cost/Gear (for Labor and Equipment)	10
Burning Time between Group Replacement (usually 0.75* Lamp Life) (h)	16,000.00
Work Costs of Cleaning Per Lamp	40
Equipment Costs of Cleaning Per Lamp	20
Cleaning Intervals (year)	0.25

For Solar Lighting System	
Battery Life (h)	70,080.00
Price per Battery	2,145.49
Replacement Cost/Battery (for Labor and Equipment)	10
Maintenance Cost/year	1000
Number of Batteries	300

Figure 5. 17 – Photovoltaic System – HPS (Alternative 4) Input Data

Alternative # 5

Lighting System	Conventional System
Lighting System Cost	1,196,180.00
Lighting System Design Cost	-
Lighting System Installation Cost	449,254.00
Number of Luminaires	300.00
Price per Luminaire	750.00
Installation Cost per Luminaire	150.00
Lamp Type	Metal Halide
Number of Lamps	300.00
Price per Lamp	40.00
Lamp Life (h)	5,000.00
Number of Gears	300.00
Price per Gear	160.00
Gear Life (h)	43,800.00
Power (Luminaire, Lamp, Gear) (W)	250.00
Annual Burning Hours (h)	3,650.00
Price of Electricity (c/kWh)	0.67
Interest Rate (%)	9.75%
Inflation Rate (%)	10%
Period of Analysis (year)	10

Lamp Replacement Criteria	Group Replacement
Cost for Individual Replacement/ Lamp (Labor & Equipment)	0
Cost for Group Replacement/ Lamp (Labor & Equipment)	60
Proportion of Lamps Failing before Group Replacement Time	5%
Portion of Lamp Cost of Early Burnouts Charged against Group Replacement	90%
Replacement Cost/Gear (for Labor and Equipment)	10
Burning Time between Group Replacement (usually 0.75* Lamp Life) (h)	4,000.00
Work Costs of Cleaning Per Lamp	40
Equipment Costs of Cleaning Per Lamp	20
Cleaning Intervals (year)	0.25

For Solar Lighting System	
Battery Life (h)	0
Price per Battery	0
Replacement Cost/Battery (for Labor and Equipment)	0
Maintenance Cost/year	0
Number of Batteries	0

Figure 5. 20 – Conventional System – MH (Alternative 5) Input Data

Alternative # 6

Lighting System	PhotoVoltaic Solar System
Lighting System Cost	1,734,892.65
Lighting System Design Cost	-
Lighting System Installation Cost	173,489.27
Number of Luminaires	300.00
Price per Luminaire	-
Installation Cost per Luminaire	-
Lamp Type	Metal Halide
Number of Lamps	300.00
Price per Lamp	40.00
Lamp Life (h)	5,000.00
Number of Gears	300.00
Price per Gear	160.00
Gear Life (h)	43,800.00
Power (Luminaire, Lamp, Gear) (W)	250.00
Annual Burning Hours (h)	3,650.00
Price of Electricity (c/kWh)	-
Interest Rate (%)	9.75%
Inflation Rate (%)	10%
Period of Analysis (year)	10

Lamp Replacement Criteria	Group Replacement
Cost for Individual Replacement/ Lamp (Labor & Equipment)	0
Cost for Group Replacement/ Lamp (Labor & Equipment)	60
Proportion of Lamps Failing before Group Replacement Time	5%
Portion of Lamp Cost of Early Burnouts Charged against Group Replacement	90%
Replacement Cost/Gear (for Labor and Equipment)	10
Burning Time between Group Replacement (usually 0.75* Lamp Life) (h)	4,000.00
Work Costs of Cleaning Per Lamp	40
Material Costs of Cleaning Per Lamp	20
Cleaning Intervals per Period of Analysis	0.25

For Solar Lighting System	
Battery Life (h)	70080
Price per Battery	2,145.49
Replacement Cost/Battery (for Labor and Equipment)	10
Maintenance Cost/year	1000
Number of Batteries	300

Figure 5. 19 – Photovoltaic System – MH (Alternative 6) Input Data

9. **Verify values of financial parameters and period of analysis:** All the costs, variables, and period of analysis have been revised.

10. **Review risk strategy and carry out preliminary uncertainty/ risk analysis (optional):**N/A

11. **Perform required economic evaluation:** The LCC calculation is performed by calculating the annual value for the 10 years period of analysis for each of the energy cost, replacement and maintenance cost, and the service cost. Then converting the annual value into present value through the equation 5.25.

12. **Carry out detailed risk/ uncertainty analysis (optional):**N/A

13. **Carry out sensitivity analysis (optional):** A sensitivity analysis was conducted to know the effect of changing the inflation rate, the interest rate, and the period of analysis on the LCC of the two different alternatives.

    Figure 5.21 and table 5.1 show the effect of changing the inflation rate on the LCC of the conventional system and the photovoltaic solar system using three types of lamps, HPS, LED, MH. It is obvious that for the six alternatives as the inflation rate increases, the LCC values increases, though the trend of the increase differ from an alternative to another leading to several breakeven points. At the 5% inflation the photovoltaic HPS and photovoltaic MH are almost the same. However, as the inflation rate increases, the gap between them increases leaving photovoltaic MH with a significant higher NPV LCC. While conventional LED, photovoltaic LED and conventional LED are almost the same at 5% and 10% inflation, as the inflation reaches 15% the conventional LED lowers significantly till it becomes the least NPV LCC out of the six alternatives at 40% inflation. Photovoltaic LED as well lowers significantly after the 15% inflation till it beats the photovoltaic MH after 30% inflation (breakeven point). Conversely, the conventional HPS NPV LCC increases significantly as the inflation rate exceeds the 15% till it becomes the second highest alternative of the six starting from the 15% inflation. The conventional MH has the highest NPV LCC from the beginning till the end through its NPV LCC increases significantly with the increase of the inflation rate than all the other five alternatives. The photovoltaic HPS seems to be the most feasible as the inflation rate increases and the conventional LED comes to be the second feasible alternative and may become the first if the inflation rate increases more than 35%.

Inflation Rate	**LCC - PV**					
	HPS -Conv.	**HPS-Ph.V**	**LED-Conv.**	**LED-Ph.V**	**MH-Conv.**	**MH-Ph.V**
5%	3,708,827.13	3,177,045.59	3,790,369.65	3,896,409.45	4,230,706.98	3,293,039.14
10%	4,183,651.94	3,504,301.35	4,064,549.66	4,202,394.15	4,864,954.74	3,665,570.92
15%	4,807,669.79	3,934,383.01	4,424,878.80	4,604,521.23	5,698,487.27	4,155,154.62
20%	5,627,177.12	4,499,198.68	4,898,090.22	5,132,624.86	6,793,145.08	4,798,112.88
25%	6,701,468.79	5,239,615.22	5,518,422.79	5,824,915.59	8,228,131.36	5,640,966.47
30%	8,105,976.63	6,207,621.27	6,329,433.42	6,730,002.91	10,104,204.26	6,742,896.72
35%	9,936,032.23	7,468,920.65	7,386,169.80	7,909,319.99	12,548,703.03	8,178,697.60
40%	12,311,351.40	9,106,023.17	8,757,759.93	9,440,013.65	15,721,538.22	10,042,294.20

Table 5. 1 – Inflation Rate Variance and LCC - NPV

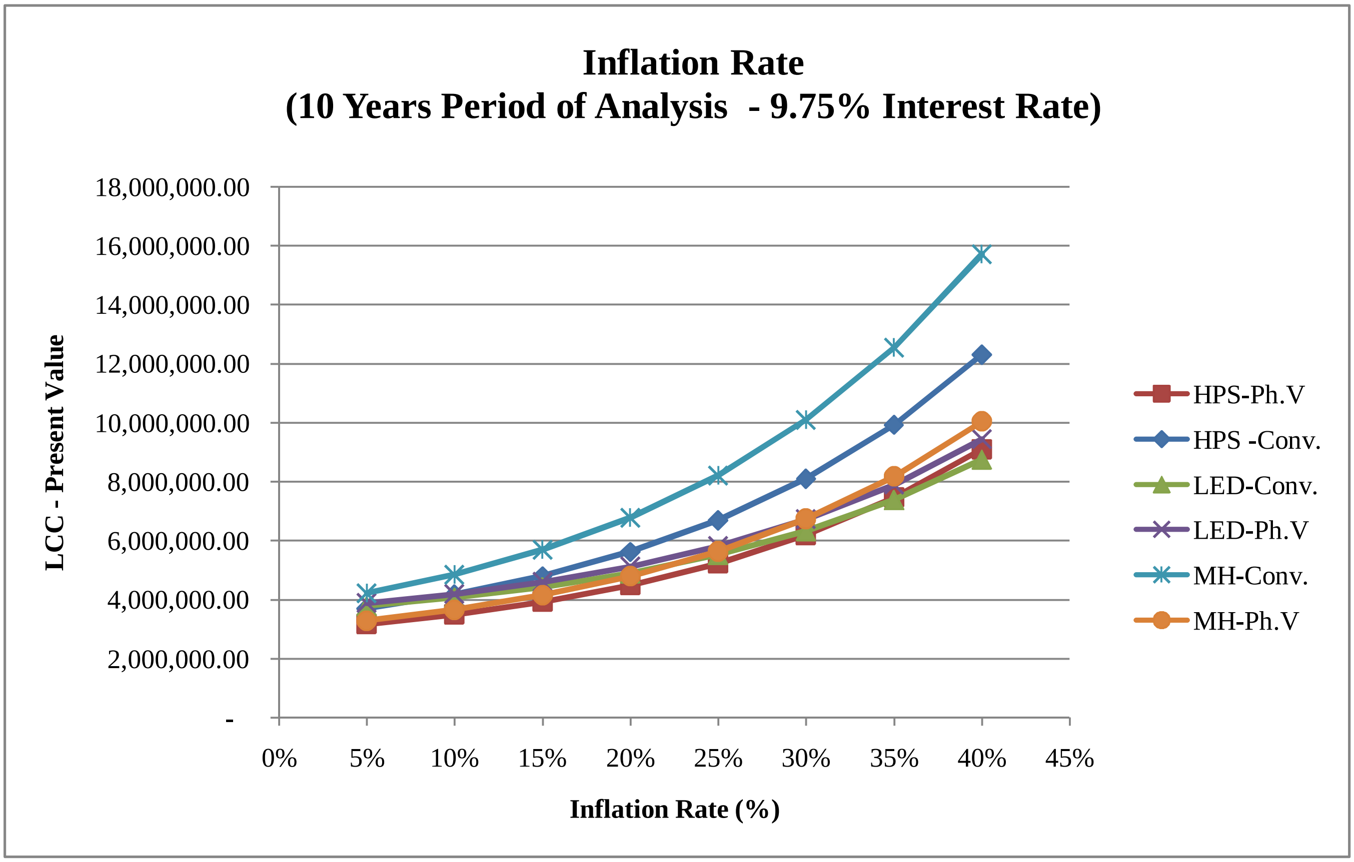


Figure 5. 21 – Inflation Rate Variance and LCC - NPV

Figure 5.22 and table 5.2 show the effect of changing the interest rate on the LCC of the conventional system and the photovoltaic solar system with the same three lamp types mentioned above. In contrast to the case of the inflation rate, the NPV LCC decreases as the interest rate increases. The photovoltaic HPS and the photovoltaic MH have the lowest NPV LCC at 5% interest and then they start to converge as the interest increases till they overlap at the 25% interest and then become almost the same at 35% interest rate which shows that if the interest rate increases than 40% (breakeven point), the photovoltaic MH NPV LCC may become lower than that of the photovoltaic HPS. While conventional LED NPV LCC is lower than that of conventional HPS at the 5% interest rate, the breakeven point is around the 13% interest, where the conventional LED NPV LCC at 5% falls between that of the conventional LED and the conventional HPS, it reaches the breakeven point with the higher (conventional HPS) at 15% interest and continues to diverge till it becomes significantly higher. On the other hand, it reaches the breakeven point with the lower (conventional LED) around 40% interest rate. The conventional MH at 5% interest has the highest NPV LCC of all the other alternatives till reaching breakeven points around 25% interest and decreases than that of the photovoltaic LED and the conventional LED. Moreover, its trend of decreasing shows that it may beat those of the conventional HPS, the photovoltaic HPS and the photovoltaic MH if the interest rate increases a bit more than 40% interest. Finally, the photovoltaic HPS proves to have the most feasible NPV LCC from the beginning till the end and the photovoltaic MH comes to be the second feasible alternative.

Interest Rate	**LCC - PV**					
	HPS -Conv.	**HPS-Ph.V**	**LED-Conv.**	**LED-Ph.V**	**MH-Conv.**	**MH-Ph.V**
5%	4,804,276.48	3,932,044.29	4,422,919.39	4,602,334.53	5,693,954.65	4,152,492.34
9.75%	4,183,651.94	3,504,301.35	4,064,549.66	4,202,394.15	4,864,954.74	3,665,570.92
15%	3,707,032.78	3,175,808.90	3,789,333.53	3,895,253.14	4,228,310.17	3,291,631.34
20%	3,385,950.01	2,954,514.26	3,603,929.42	3,688,342.27	3,799,423.51	3,039,720.46
25%	3,150,732.93	2,792,399.42	3,468,107.07	3,536,764.62	3,485,232.04	2,855,176.94
30%	2,974,321.49	2,670,814.24	3,366,241.10	3,423,082.26	3,249,590.26	2,716,770.38
35%	2,839,138.27	2,577,644.11	3,288,181.71	3,335,968.04	3,069,019.12	2,610,710.11
40%	2,733,494.69	2,504,833.11	3,227,179.51	3,267,889.63	2,927,905.60	2,527,825.67

Table 5. 2 – Interest Rate Variance and LCC - NPV

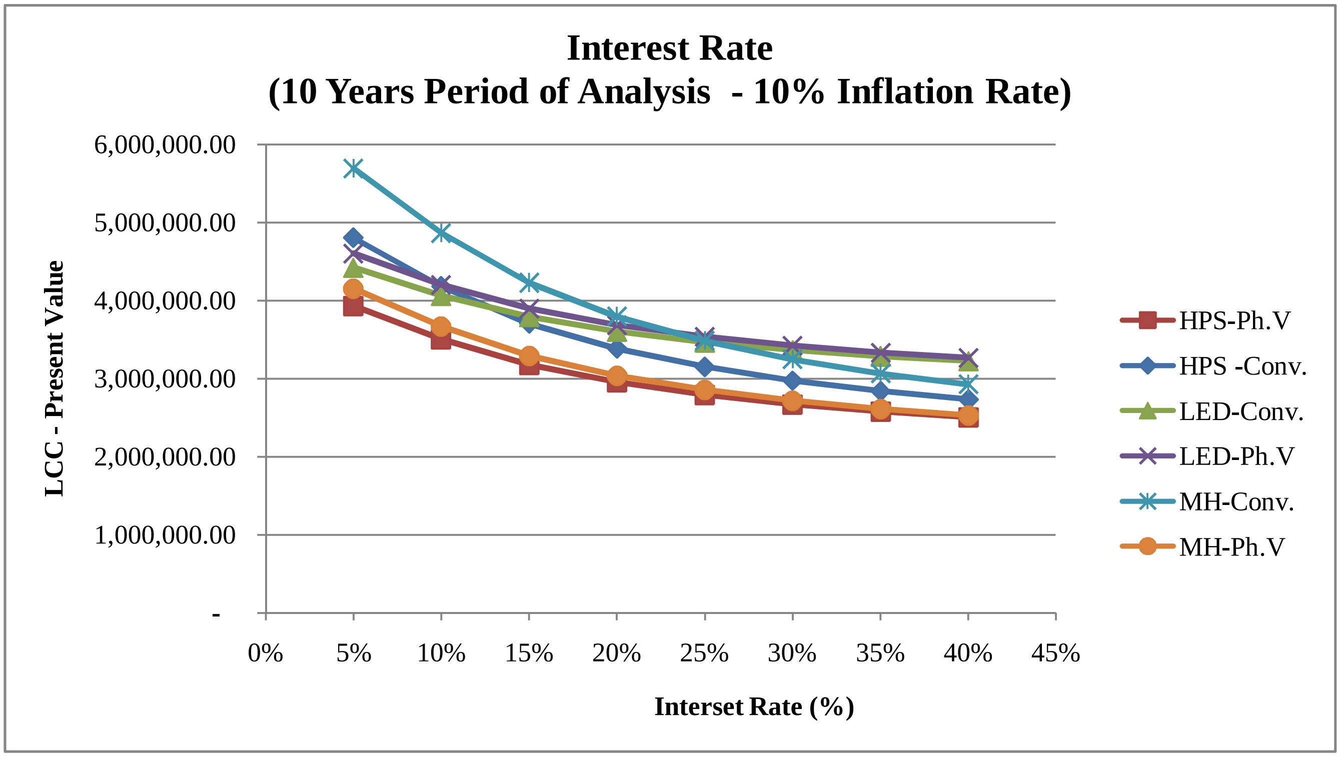


Figure 5. 22 – Interest Rate Variance and LCC - NPV

Figure 5.23 and table 5.3 show the effect of changing the period of analysis on the LCC of the conventional system and the photovoltaic solar system with three types of lamps. Similar to the case of the inflation rate, as the period of analysis increases, the NPV LCC increases. The photovoltaic HPS and the photovoltaic MH start almost the same at 5 years period of analysis, while the photovoltaic MH continues to increase with a higher rate but it remains at the 40 years period of analysis the nearest to the photovoltaic HPS (the one with the least NPV LCC). However, the four other alternatives (conventional HPS, conventional LED, photovoltaic LED, and conventional MH) start with very small difference in the NPV LCC at 5 years period of analysis. Then, the conventional MH diverges significantly and remains increasing with a constant trend. On the other hand, the conventional HPS increases with a constant trend as well but not as steep as that of the conventional MH that it remains in the same range with the other two alternatives (photovoltaic LED and conventional LED). These two are adopting a zigzag trend of increasing and decreasing till the conventional LED become the lowest of the four alternatives starting from 30 years period of analysis while returning back to increase again. Finally, the photovoltaic HPS proves to have the most feasible NPV LCC from the beginning till the end.

Period of Analysis	LCC - PV					
	HPS -Conv.	**HPS-Ph.V**	**LED-Conv.**	**LED-Ph.V**	**MH-Conv.**	**MH-Ph.V**
5	3,095,890.54	2,429,061.80	3,436,439.20	3,175,883.81	3,411,976.25	2,486,609.93
10	4,183,651.94	3,504,301.35	4,064,549.66	4,202,394.15	4,864,954.74	3,665,570.92
15	5,363,295.63	4,012,737.39	5,630,171.85	5,512,432.00	6,386,496.86	4,251,417.84
20	6,525,558.05	5,158,436.71	6,278,079.97	6,564,155.68	7,873,212.40	5,454,056.58
25	7,732,179.30	6,348,334.09	7,874,431.59	8,568,971.87	9,429,475.25	6,723,021.08
30	8,871,794.70	6,801,074.27	8,542,634.06	8,980,352.38	10,950,706.56	7,283,706.94
35	10,024,444.45	7,932,804.38	9,218,440.72	10,070,213.11	12,489,340.80	8,524,620.08
40	11,322,182.35	9,209,427.15	10,859,387.10	12,129,994.84	14,099,030.68	9,833,226.33

Table 5. 3 – Period of Analysis Variance and LCC - NPV

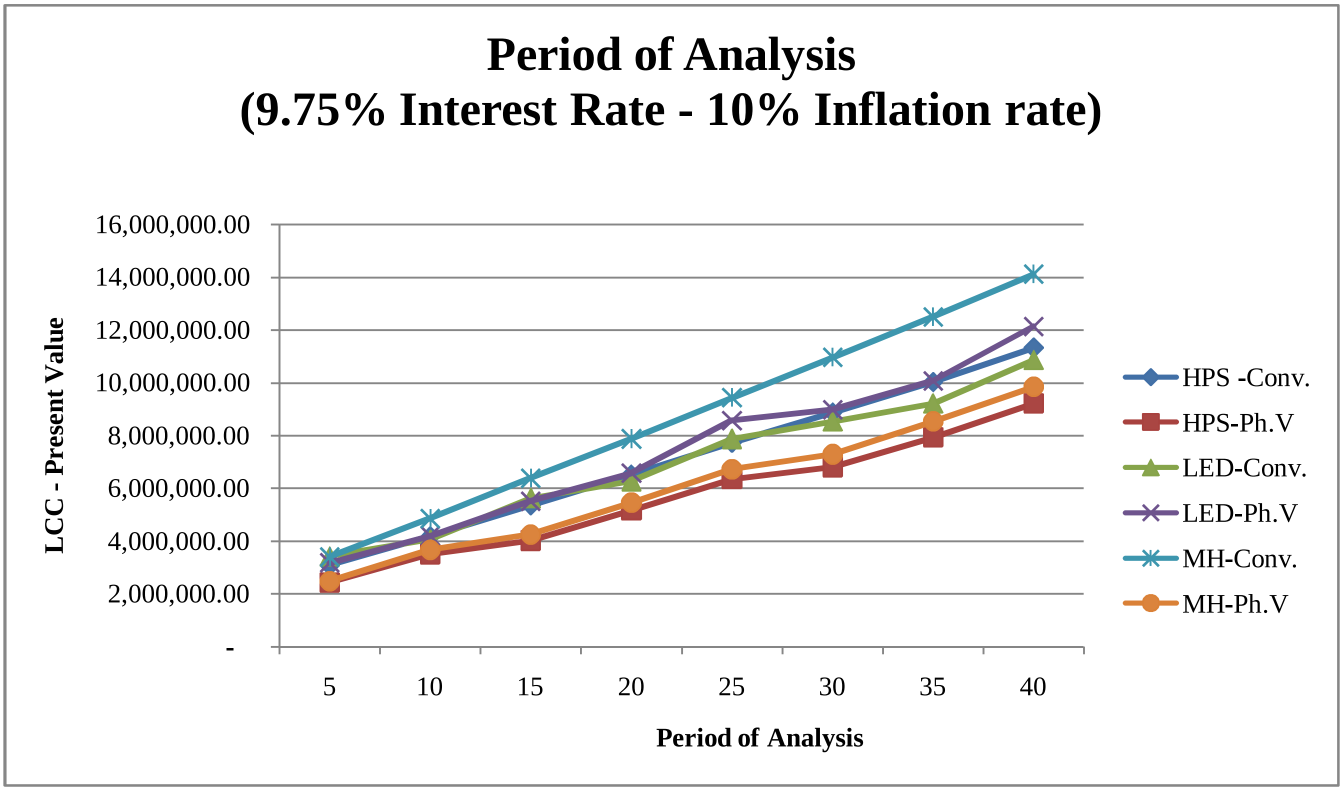


Figure 5. 23 – Period of Analysis Variance and LCC - NPV

14. **Interpret and present initial results in required format:** As shown in figure 5.24, results are given first in a table for each alternative showing the present value of each cost: initial cost, energy cost, replacement, maintenance and disposal costs, and service cost as well as the equivalent annual value of the energy cost, replacement, maintenance and disposal costs, and service cost. In addition to the energy consumption (kWh) and CO_2 Emissions (kg) in an annual basis and per the whole period of analysis.

Alternative # 1

Conventional System		
High Pressure Sodium (HPS)		
LCC	Present Value	Annual Value
Initial Costs	2,020,434.00	-
Energy Costs	1,337,228.31	132,057.00
Replacement and Disposal Costs	96,907.21	9,570.00
Service Costs	729,082.43	72,000.00
Total	4,183,651.94	213,627.00
LCA	Energy Consumption (KWh)	CO_2 Emissions (kg)
Annual	197,100.00	191,376.79
Total Per Period of Analysis	1,971,000.00	1,913,767.92

Alternative # 2

PhotoVoltaic Solar System		
LED		
LCC	Present Value	Annual Value
Initial Costs	2,808,381.92	-
Energy Costs	-	-
Replacement and Disposal Costs	664,929.81	65,664.66
Service Costs	729,082.43	72,000.00
Total	4,202,394	137,664.66
LCA	Energy Consumption (KWh)	CO_2 Emissions (kg)
Annual	76,650.00	3,904.67
Total Per Period of Analysis	766,500.00	39,046.69

Alternative # 3

Conventional System		
LED		
LCC	Present Value	Annual Value
Initial Costs	2,815,434.00	-
Energy Costs	520,033.23	51,355.50
Replacement and Disposal Costs	-	-
Service Costs	729,082.43	72,000.00
Total	4,064,549.66	123,355.50
LCA	Energy Consumption (KWh)	CO_2 Emissions (kg)
Annual	76,650.00	74,424.31
Total Per Period of Analysis	766,500.00	744,243.08

Go to Final Result

Alternative # 4

PhotoVoltaic Solar System		
High Pressure Sodium (HPS)		
LCC	Present Value	Annual Value
Initial Costs	2,013,381.92	-
Energy Costs	-	-
Replacement and Disposal Costs	761,837.01	75,234.66
Service Costs	729,082.43	72,000.00
Total	3,504,301.35	147,234.66
LCA	Energy Consumption (KWh)	CO_2 Emissions (kg)
Annual	197,100.00	10,040.58
Total Per Period of Analysis	1,971,000.00	100,405.79

Alternative # 5

Conventional System		
Metal Halide		
LCC	Present Value	Annual Value
Initial Costs	1,975,434.00	-
Energy Costs	1,857,261.54	183,412.50
Replacement and Disposal Costs	303,176.78	29,940.00
Service Costs	729,082.43	72,000.00
Total	4,864,954.74	285,352.50
LCA	Energy Consumption (KWh)	CO_2 Emissions (kg)
Annual	273,750.00	265,801.10
Total Per Period of Analysis	2,737,500.00	2,658,010.99

Alternative # 6

PhotoVoltaic Solar System		
Metal Halide		
LCC	Present Value	Annual Value
Initial Costs	1,968,381.92	-
Energy Costs	-	-
Replacement and Disposal Costs	968,106.58	95,604.66
Service Costs	729,082.43	72,000.00
Total	3,665,570.92	167,604.66
LCA	Energy Consumption (KWh)	CO_2 Emissions (kg)
Annual	273,750.00	13,945.25
Total Per Period of Analysis	2,737,500.00	139,452.48

Figure 5. 24 – Initial Results

It is concluded from the initial results that the Photovoltaic Solar System is more economic than the Conventional system with all lamp types except for LED. The reason for the higher lifecycle cost of LED Photovoltaic Solar System than that of the LED Conventional System returns back to that LED lamp is an energy saver i.e. leading to the lowest annual energy costs among other lamp types in the conventional system. Consequently, its low annual energy cost has beaten the replacement and maintenance costs of the photovoltaic solar system. However, when comparing LCA results, it is obvious that CO_2 emissions of the photovoltaic solar system is much lower than that of the conventional system as the photovoltaic solar system has an amount of 0.050941545 kg/kWh CO_2 equivalent while the conventional system has an amount of 0.97096292 kg/kWh CO_2 equivalent. The amount of CO_2 equivalent for each lighting system alternative was calculated using SimaPro 7 Software. Therefore, the lamp type of the least energy consumption shall be the best with the photovoltaic solar system in terms of CO_2 emissions.

15. <u>Present final results in required format and prepare a final report:</u> The final result is two charts for LCC and LCA as well as two tables; one ranking the alternatives according to their LCC net present value, while the other is ranking the alternatives according to their energy consumption per period of analysis as shown in figures 5.25 and 5.26 respectively.

LCC Rank

Rank	Alternative	Present Value	Annual Value
4	Alternative 1	4,183,651.94	213,627.00
5	Alternative 2	4,202,394.15	137,664.66
3	Alternative 3	4,064,549.66	123,355.50
1	Alternative 4	3,504,301.35	147,234.66
6	Alternative 5	4,864,954.74	285,352.50
2	Alternative 6	3,665,570.92	167,604.66

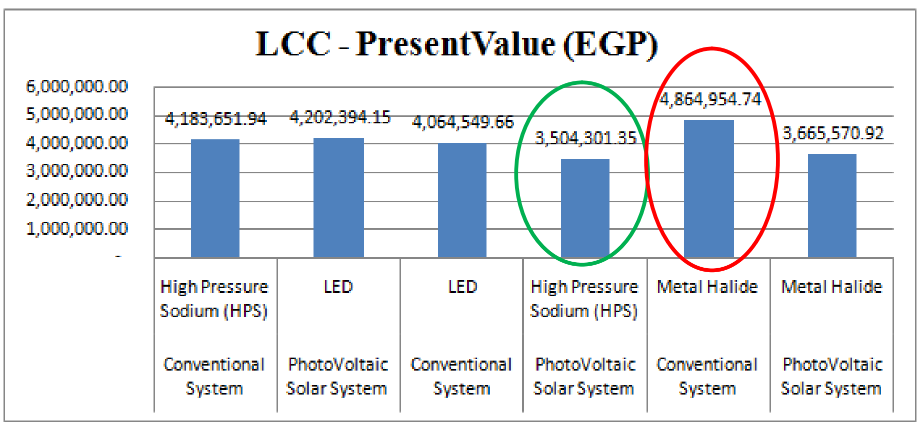


Figure 5. 25 – Final LCC Results

The final LCC result shows that the most economic alternative among the six is the Photovoltaic Solar System using HPS Light Source which has an NPV LCC of EGP 3,504,301.35 while the highest NPV LCC is that of the Conventional System using MH Light Source which is EGP 4,864,954.74. However, when comparing the light sources alternatives of the Photovoltaic Solar System, it is found that the least feasible alternative is that of LED though it has the longest lifetime and so the least energy costs. This result returns back to the reason of the large gap between the LED lamp cost and other conventional lamps costs such as HPS and MH.

5.2.3 MIVIDA Case Study – LCA Methodology

As illustrated in Chapter 4, ISO 14040 LCA Framework was adopted in this study. It consists of 4 stages (“Introduction to LCA with SimaPro”, 2004).

1. **Goal and Scope Definition**

The goal of the LCA study is to find out which lighting system and light source have the lowest carbon footprint out of six alternatives (2 lighting systems and 3 lighting sources) for MIVIDA Project street network. The targeted audience of the LCA study is the end-user/ the owner of MIVIDA “EMAAR”. The scope is as defined in the points below:

1. **The functional unit:** “To light MIVIDA Street Network” is the functional unit used in this analysis as the study.
2. **The system boundaries:** The boundaries in this research are divided into two parts. One is Cradle to Grave which is related to the source of power for lighting such as the Conventional Electricity and the Photovoltaic Solar Energy. The other is gate to gate which is concerned with the lighting sources (lamps) because it is focusing only on the use phase.
3. **The environmental impact categories:** The LCA study in this research incorporates only Global Warming Potential, and the energy consumption in the

operation phase as it causes the largest environmental impacts of the whole life cycle of lighting systems ("Chapter 7: Life Cycle Analysis and Life Cycle Costs", 2012).

4. **The data requirements:** The required data for the LCA study of the lighting electricity generation system is acquired from SimaPro Software. The used calculation method in the software is Global Warming Potential. The output data is represented as an amount of kg CO_2 equivalent per kWh for each alternative. The required data for the LCA study of the light source is related only to the end-user energy consumption in the usage phase. The energy Consumption in kWh is then multiplied by the output of the SimPro to give the amount of equivalent CO_2 emissions in kg.
5. **The assumptions:** The study is taking the energy consumption of the end-use only caused by lighting source it is using. The equivalent CO_2 emissions are assumed to be those converted from the energy consumption by the factor produced by the SimaPro as mentioned in the previous step. To calculate the equivalent amount of CO_2 emission of each electricity generation system using SimaPro, the values used in Spain were taken as an assumption to the nearest amounts of emissions in Egypt.
6. **The limitations:** The study does not include the raw material extraction, manufacturing, transportation, and disposal phases of the lighting source. In addition to the energy consumption of the main electricity station.

2. <u>Life Cycle Inventory</u>

The required data for the LCA study of the lighting electricity generation system is acquired from SimaPro Software. The used calculation method in the software is Global Warming Potential. The output data is represented as an amount of kg CO_2 equivalent per kWh for each alternative. The required data for the LCA study of the light source is related only to the end-user's energy consumption in the usage phase. The energy Consumption in kWh is then multiplied by the output of the SimPro to give the amount of equivalent CO_2 emissions in kg. To calculate the equivalent amount of CO_2 emission of each electricity generation system using SimaPro, the values used in Spain was taken as an assumption to the nearest amounts of emissions in Egypt.

3. Impact Assessment

The Study addresses only the Global Warming Potential (GWP) which is represented by an amount of CO_2 emissions in kg equivalent. The resulted amount of CO_2 contains other emissions of gases, which result in Global Warming, that have been converted to its equivalent amount of CO_2 in kg. For example, 1 kg CH_4 is equivalent to an amount of 42 kg CO_2 ("Introduction to LCA with SimaPro", 2004)

4. Interpretation

The final result of the LCA, figure 5.26, shows that the most sustainable alternative with the lowest carbon footprint, 39,046.69kg, is the Photovoltaic Solar System using LED light source in a ten-year period of analysis. The reason for that is the low energy consumption of the LED as 60W LED Lamp replaces a 150W HPS Lamp and 250W MH Lamp. Accordingly, the least sustainable alternative having the highest carbon footprint, 2,658,010.99kg, is the Conventional System using MH light source in a ten-year period of analysis.

LCA Rank

Rank	Alternative	Total Energy Consumption (KWh)	Total CO_2 Emissions
5	Alternative 1	1,971,000.00	1,913,767.92
1	Alternative 2	766,500.00	39,046.69
4	Alternative 3	766,500.00	744,243.08
2	Alternative 4	1,971,000.00	100,405.79
6	Alternative 5	2,737,500.00	2,658,010.99
3	Alternative 6	2,737,500.00	139,452.48

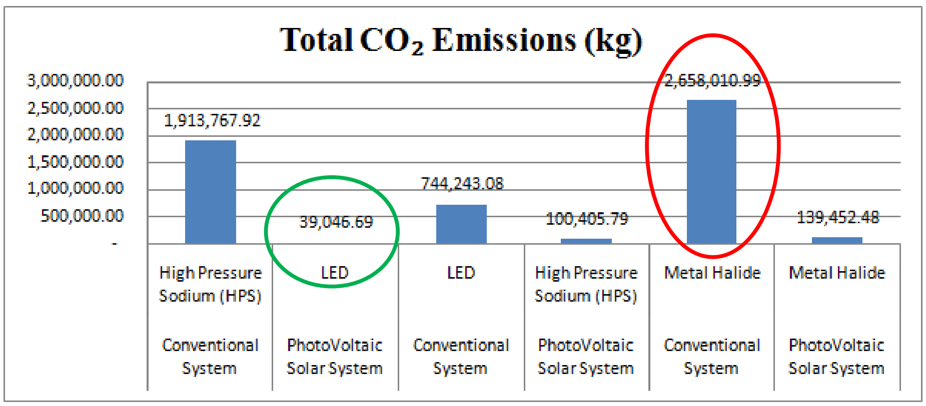


Figure 5. 26 – Final LCA Results

Finally, as the most economic alternative does not match with the most sustainable alternative, the results shall be integrated i.e. the most feasible alternative with the second most sustainable alternative. The reason for the preference for choosing the most feasible alternative and then the second sustainable one and not vice versa is that the end-user shall always go with the lowest cost and not the lowest environmental impact. Consequently the best alternative shall be Photovoltaic Solar System using HPS light source with an NPV LCC of EGP 3,504,301.35 and a Carbon Footprint of 100,405.79kg.

Chapter 6
Conclusions and Recommendations

Chapter 6: Conclusions and Recommendations

6.1 Conclusions

This research has adopted two techniques for the purpose of enhancing the competitiveness of the construction industry in Egypt through the application of sustainable measures which are life cycle costing (LCC) and life cycle assessment (LCA). The research methodology consisted of literature review and development of a questionnaire, followed by the model development, verification and validation.

A questionnaire was formulated and distributed among a sample of 20 construction engineers whose work experience ranges from 5 to 33 years. The target of this questionnaire was to measure the extent of the application of the Egyptian construction market to the LCC and the LCA, to present the most important costs which have to be included in an LCC study of buildings in Egypt, and to determine the most area of concern in the LCC study to focus on in this research. The questionnaire results showed that the application of LCC is familiar among the sample of respondents as 68% of the respondents have worked before in projects applying LCC. However, the rate of the application of the LCC in Egypt needs to be improved as out of the 68% only 58% of the respondents' projects applying LCC were in Egypt. In addition it showed that the application of LCA is less common in Egypt. Only 47% of the sample of respondents claimed that they have worked before in projects applying LCA. The reason behind that is the absence of software which facilitates the application of LCA as well as the lack of environmental data. Based on the questionnaire, 75% said that they have no software used in the application of LCA as well as 60% claimed that the lack of data is one of the barriers to the application of LCA.

The results of the questionnaire's rating questions showed that maintenance and operation costs are the most considerable in an LCC study. As maintenance costs took a rate of 4.16 out of 5. On the other hand, operation costs took a rate of 3.95. Construction costs/initial investment costs were also one of a great importance with a rating of 3.5. Out of the initial investment costs, Pluming Works, Electrical Works, and Mechanical Works were the most important in the LCC study as they took ratings of 3.72, 3.63, and 3.5 respectively.

Consequently, the main focus of this thesis was to formulate a model (LCCA-SSL) calculating the LCC and LCA of the most important contributors in the construction/maintenance phases in all sectors which is lighting. The LCCA-SSL Model was applied on MIVIDA Project in New Cairo. The aim of the model was to find the most economic and environmental friendly lighting system and lighting source for MIVIDA's road network. The road network consisted of 300 light poles each is 6m high and the spacing between the light poles equal to 30m. The study incorporated six alternatives, two different electricity generation lighting systems which are the Conventional System and the Photovoltaic Solar System and their corresponding lighting sources which are LED, HPS and MH. The study was performed for a ten-year period of analysis, 9.75% interest rate and 10% inflation rate.

The results showed that the best LCC selection is Photovoltaic Solar System using HPS Light Source which has an NPV LCC of EGP 3,504,301.35 and the best LCA selection is the Photovoltaic Solar System using LED light source which has a carbon footprint of 39,046.69kg. However, the best integrated alternative between both LCC and LCA is Photovoltaic Solar System using HPS Light Source which has the lowest LCC of EGP 3,504,301.35 and the second lowest carbon footprint of 100,405.79kg.

A sensitivity analysis was conducted to measure the significance of changing each of the aforementioned assumptions on the final result. While changing the inflation rate from 5% to 30%, the interest rate from 5% to 40% and the period of analysis from 5 years to 40 years, the Photovoltaic Solar System using the HPS light source proved to have the least LCC among all the other alternatives. However, when the inflation rate reached 35%, the Conventional system using the LED light source proved to have the lowest LCC among the other alternatives.

Finally, the LCCA-SSL Model is user friendly and can be used by stakeholders in decision making about the most sustainable lighting system and source. The proposed model is based on generic LCC and LCA frameworks which can be applied on a whole asset or any component therein. Accordingly, the model has a flexibility to be tailored for any asset's LCC and LCA study which can be a part of an overall value engineering scheme.

6.2 Recommendations

As the whole world is facing an energy consumption problem, this thesis made an attempt in one of the phases which has a large contribution in energy consumption. However, lighting in the electrical phase is not the only contributor to the energy consumption problem.

Accordingly, the LCCA-SSL can be more developed to include other energy consumption contributors systems such as HVAC and heating systems in different sectors (residential, commercial, industrial … etc.).

In addition to linking the LCCA-SSL Model to a database which shall broaden the LCA study to include the systems' environmental impacts from cradle to grave rather than the operation phase only.

Furthermore it would be more realistic if the LCCA-SSL Model gave a probabilistic result rather than a deterministic one because almost all the phases of the LCC and LCA study are dependent on estimation.

Lastly, the inclusion of risks factors and contingency costs would, also, be a plus to the LCCA-SSL model and to the soundness of the LCC results.

References

References

1. "3Brothers Company Datasheet". 28 March 2013
2. "About Lamps and Lighting". European Lamp Companies Federation. 2009 http://www.elcfed.org/
3. Aggeliki K. "All You Need to Know About Photovoltaic and Solar Panel Technology"Bright Hub. 25 October 2011 http://www.brighthub.com/environment/renewable-energy/articles/126036.aspx?cid=parsely_rec
4. "An Introduction to Life Cycle Energy Assessment (LCEA) of Building Developments" *Consultancy Study on Life Cycle Energy Assessment of Building Construction.* March 2007 http://www.emsd.gov.hk/emsd/e_download/pee/LCA_manual.pdf
5. "Color Temperature Chart" Light Bulbs Direct. Date accessed 1 April 2013 http://www.lightbulbsdirect.com/page/001/CTGY/ColorTemp
6. Edvardsen, Dag Fjeld. "Overview report on LCC approaches, tools and indicators" date accessed 3 September 2012 http://immovalue.e-sieben.at/pdf/immvalue_report_d4.1.pdf
7. "Egyptian Code for Electrical Works". 2012
8. Ekins, Paul. "Environmental sustainability: From environmental valuation to the sustainability gap" SAGE. 2011 http://connection.ebscohost.com/c/articles/66816575/environmental-sustainability-from-environmental-valuation-sustainability-gap
9. "Electricity Sector Overview" *Climate TechBook.*Pew Center on Global Climate Change. June 2011 http://www.c2es.org/docUploads/ElectricitySectorOverview.pdf
10. "Electricity Emissions in the United States" *Electricity Overview.* Center for Climate and Energy Solutions. Web. 2 Mar 2013. http://www.c2es.org/technology/overview/electricity
11. "Energy efficient light bulbs should have already replaced your old fashioned incandescent bulbs" SBI. Date accessed 9 March 2013. http://www.green-the-world.net/energy_efficient_light_bulbs.html
12. "Energy Efficient Lighting System (Industries, Public Utilities & Residential Buildings)".*Training Programme on Energy Efficient Technologies for Climate Change Mitigation in Southeast Asia.* UNEP.Date accessed 1 March 2013. http://www.unep.org/climatechange/mitigation/sean-cc/Portals/141/doc_resources/TrainingEEtechnologies/EE%20Lighting_Asthana.pdf
13. "Energy-Efficient Lighting".*Energy Answers for Business.*APS Business Center.Date accessed 1 March 2013. http://www.distributiongroup.com/articles/Lighting.pdf

14. Fawcett, William. And HannesKreig. "Sustainable Construction Projects: Case Study of Flexible Strategies for Long-Term Sustainability under Uncertainty" date accessed 8 September 2012
http://cileccta.eu/sites/default/files/downloads/Sustainiable%20Construction%20Projects%20Case%20Study%20of%20Flexible%20Strategies.pdf
15. "Fluorescent Lighting" *Energy Basics.*US Department of Energy. 31 May 2011
http://www.eere.energy.gov/basics/buildings/fluorescent.html
16. Fuller, Sieglinde K. and Stephen R. Petersen. "Life-Cycle Costing Manual for the Federal Energy Management Program" February 1996
http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf
17. Fuller, Sieglinde K. and Amy S. Boyles. "Life-Cycle Costing Workshop for Energy Conservation in Buildings: Student Manual" *United States Department of Energy Federal Energy Management Program.*April 2000
http://fire.nist.gov/bfrlpubs/build00/PDF/b00069.pdf
18. Grisé. William and Patrick. Charles. "Passive Solar Lighting Using Fiber Optics" Journal of Industrial Technology. November 2002
http://atmae.org/jit/Articles/grise122002.pdf
19. "Guide to buying the right lamp – Understanding Light Color Temperature". *My LED Lighting Guide.Your Guide to Energy Efficient LED Lighting.* One Green Earth. Date accessed 1 April 2013.
http://www.myledlightingguide.com/article.aspx?articleid=37
20. Guoguo, Liu. "Integration of LCA and LCC for decision making in sustainable building industry"date accessed 8 September 2012
https://gin.confex.com/
21. "Halogen Light" Taojindi.com.23 March 2010
http://en.518ad.com/selling/MoreDetails.aspx?p=47&id=2009021609165537 17
22. Halonen, Lisa. "Chapter 7: Life Cycle Analysis and Life Cycle Costs". *Guidebook on Energy Efficient Electric Lighting for Building*.IEA International Energy Agency ECBCS Energy Conservation in Buildings and Community Systems. 11 October 2012
http://lightinglab.fi/IEAAnnex45/guidebook/
23. Hazra, O. "Solar Powered Exterior LED Lighting Systems: Considerations for Federal Facility Managers". *US Department of Energy*.Pacific Northwest National Laboratory. August 2011
http://www1.eere.energy.gov/femp/pdfs/ssl_lighting_systems.pdf
24. Helal, Mohammed. "Energy Conservation" 2008
25. Helal, Mohammed."Pupil Lighting Measure".FutekThe Energy Savers. Date accessed 8 March 2013
http://www.futeklighting.com/education.asp?page=1
26. "High Intensity Discharge Lighting" *Energy Basics.*US Department of Energy. 31 May 2011
http://www.eere.energy.gov/basics/buildings/high_intensity_discharge.html
27. "How Electricity gets to your Home"Electricity Guide. Date accessed 31 March 2013

http://www.electricity-guide.org.uk/science.html

28. "Hybrid Solar Lighting Illuminates Energy Savings for Government Facilities". *Technology Focus a New Technology Demonstration Publication*. Federal Energy Management Publication. Date accessed 18 March 2013 http://www1.eere.energy.gov/femp/pdfs/tf_hybridsolar.pdf
29. Ibrahim, Ahmed "Life Cycle Cost Analysis: A Computer Aided Tool for the Egyptian Construction Industry" Thesis, American University in Cairo. 2001
30. "Incandescent Lighting" *Energy Basics.*US Department of Energy. 2 June 2012 http://www.eere.energy.gov/basics/buildings/incandescent.html
31. "Introduction to LCA with SimaPro". Product Ecology Consultants. September 2004 http://www.pre-sustainability.com/download/manuals/UserManual.pdf
32. Khasreen, MohamadMonkiz and Phillip F.G. Banfill, and Gillian F. Menzies "Life-Cycle Assessment and the Environmental Impact of Buildings: A Review" 18 September 2009 http://www.rpd-mohesr.com/uploads/custompages/sust..pdf
33. Kuhlman, Tom and John Farrington. "What is Sustainability" Sustainability. 1 November 2010 http://www.mdpi.com/2071-1050/2/11/3436/pdf
34. Langdon, Davis. "Development of a Promotional Campaign for Life Cycle Costing in Construction" 19 January 2010 http://ec.europa.eu/enterprise/sectors/construction/files/compet/life_cycle_costing/100119_development_of_a_promotional_campaign_en.pdf
35. Langdon, Davis. "Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology – Final Review" May 2007 http://ec.europa.eu/enterprise/sectors/construction/files/compet/life_cycle_costing/literat_review_en.pdf
36. Langdon, Davis. "Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology – Final Methodology" May 2007 http://ec.europa.eu/enterprise/sectors/construction/files/compet/life_cycle_costing/common_methodology_en.pdf
37. Langdon, Davis. "Life cycle costing (LCC) as a contribution to sustainable construction: a common methodology – Final Guidance" May 2007 http://ec.europa.eu/enterprise/sectors/construction/files/compet/life_cycle_costing/guidance_en.pdf
38. "LED Basics" *Solid State Lighting*.US Department of Energy. 19 February 2013 http://www1.eere.energy.gov/buildings/ssl/sslbasics_ledbasics.html
39. "LED Lighting" *Energy Basics.*US Department of Energy. 12 March 2012 http://www.eere.energy.gov/basics/buildings/led.html
40. "Life Cycle Costing Guideline" *New South Wales Treasury*. September 2004 http://www.treasury.nsw.gov.au/__data/assets/pdf_file/0005/5099/life_cycle_costings.pdf
41. "Light Bulb Market" Lee Group Marketing. Date accessed 9 March 2013.

http://www.lightbulbmarket.com/65%20watt%20br30%20130%20volt%20philips%20reflector%20flood%20light%20bulb

42. "Long Life Circline Fluorescent Bulbs" Bulborama Leaders in Long Life Light Bulbs and Energy Saving Lighting Supplies. Date accessed 9 March 2013. http://www.bulborama.com/Long-Life-Circline-Fluorescent-Bulbs-c119/
43. "Lux, Lumens &Watts".Green Business Light.The UK's Leading Installer of Energy Saving Industrial Lighting. 2013 http://www.greenbusinesslight.com/page/119/Lux-lumens-and-watts
44. "Mercury Vapor Lamp".LampTech. 25 August 2003 http://www.lamptech.co.uk/Documents/M1%20Introduction.htm
45. Muhs, Jeff. "Design and Analysis of Hybrid Solar Lighting and Full-Spectrum Solar Energy Systems".Oak Ridge National Laboratory. July 2000 http://www.ornl.gov/~webworks/cpr/v823/pres/106523_.pdf
46. Mundy, Jo and Katie Livesey "Life Cycle Assessment for Construction Products: an introductory guide for manufacturers and specifiers" Forestry Commission. 2004 http://www.forestry.gov.uk/pdf/FCMS018.pdf/$file/FCMS018.pdf
47. "Passive Solar Lighting",*Alternative Energy Solutions*. Solar Innovations. Date accessed 15 April 2013 http://www.solarinnovations.com/solar-energy-products/passive-solar-lighting/
48. Paulsen, Jacob "Life cycle assessment for building products – The significance of the usage phase" Thesis, Sweden. 2001
49. Pode, Ramchandra; Diouf, Boucar.Solar Lighting. Dordrecht: Springer, 2011. Ebook Library. Web. 10 Mar. 2013. http://lib.aucegypt.edu/search~S2?/.b2088918/.b2088918/1,1,1,B/l856~b2088918&FF=&1,0,,1,0
50. Poveda, Cesar A. "A Review of Sustainability Assessment and Sustainability /Environmental Rating Systems and Credit Weighting Tools" Journal of Sustainable Development. December 2011 http://www.ccsenet.org/journal/index.php/jsd/article/view/12535/9104
51. Schade, Jutta. "Life Cycle Cost Calculation Models for Buildings" date accessed 23 July 2012 http://www.inpro-project.eu/media/LCC_for_buildings_Levander_Schade_Stehn.pdf
52. "Solar lighting" ebay. Date accessed 30 March 2013 http://popular.ebay.com/home-living/solar-lighting.htm
53. "Standardised Method of Life Cycle Costing for Construction". *The UK Supplement to ISO 15686 Part 5 -Life cycle costing for buildings and constructed assets.*BCIS and the British Standards Institute. Date accessed 7 January 2013 http://www.ciria.org/service/membership_options/AM/ContentManagerNet/ContentDisplay.aspx?Section=membership_options&NoTemplate=1&ContentID=6436
54. Sterner, Eva. "Green Procurement of Buildings – Estimation of Life-Cycle Cost and Environmental Impacts" Thesis. 2002 http://epubl.ltu.se/1402-1544/2002/09/LTU-DT-0209-SE.pdf
55. "Task Group 4: Life Cycle Costs in Construction" *Final Report.* 1 July 2003

http://www.ceetb.eu/docs/Reports/LCC%20FINAL%20REPORT-2.pdf

56. "Telling the Differences Between Different Light Sources". International Dark-Sky Association (IDA).Date accessed 3 March 2013 http://www.darksky.org/assets/documents/is032.pdf
57. "The Low Pressure Sodium Lamp".LampTech.19 November 2011 http://www.lamptech.co.uk/Documents/SO%20Introduction.htm
58. "The What, Why, and How of Energy Management".*Energy Lens Energy Management Made Easy*. BizEE. Date accessed 19 March 2013 http:www.energylens.com/articles/energy-management/
59. Tupamaki, Olavi. "Total LCC and Probabilistics" *The 25th International Symposium on Automation and Robotics in Construction*. 26-29 June 2008 http://www.iaarc.org/publications/fulltext/6_sec_074_Tupamaki_Total.pdf
60. "Types of Light Sources and Light Bulbs" American Lighting Association. 2011 http://www.americanlightingassoc.com/lighting-fundamentals/light-sources-light-bulbs.aspx
61. "Visual Dictionary Online" *Merriam Webster*.Ikonet.com. 2013 http://visual.merriam-webster.com/house/electricity/lighting/incandescent-lamp.php
62. "What's the Difference Between an Active and Passive Solar System?" ECO Outfitters. The Source for Sensible Energy. 27 October 2011 http://www.ecooutfitters.net/blog/2011/10/whats-the-difference-between-an-active-and-passive-solar-system/
63. "What is Light? An overview of the properties of light".ANDOR Technology. Date accessed 8 March 2013 http://www.andor.com/learning-academy/what-is-light-an-overview-of-the-properties-of-light
64. "What is Lamp" Electrapk Free Tutorials-Classifieds-Forum-Job Services. 21 May 2012 http://electrapk.com/what-is-lamp/
65. Yassin, Ibrahim. "Market Development of Compact Fluorescent Lighting in Egypt".GEF UNDP. Energy Efficiency Improvement in Egypt. Date accessed 8 March 2013 http://www.enlighten-initiative.org/portal/Portals/26107/documents/ConferenceMaterial/MiddleEast_NorthAfrica/Market%20Development%20of%20Compact%20Fluorescent%20Lamps%20in%20Egypt.pdf

Appendices

Appendix A

Appendix A: Life Cycle Costs Breakdown Structure

Serial	Initial Investment Costs
1	Land acquisition
2	Planning costs
3	Structural design costs
4	Architectural design costs
5	Excavation
6	Foundations
7	Structural costs (concrete and steel reinforcement)
8	Masonry works
9	Mechanical works
10	Electrical works
11	Plumbing works
12	Finishing works
13	Transportation charges
14	Consultancy fees
15	Special client costs – launch events and associated marketing costs
16	Water adoption
17	Electricity adoption
18	Gas adoption
19	Light adoption
20	Licenses and permits
21	Others

Serial	Operation Costs
1	Rent
2	Internal cleaning
3	External cleaning
4	Water fees
5	Electricity fees
6	Gas fees
7	Property management
8	Staff engaged in servicing the building
9	Waste management/ disposal
10	Property insurance
11	Taxes
12	Others

Serial	Maintenance and Replacement Costs
1	Major replacements
2	Minor replacement, repairs, and maintenance
3	Unscheduled replacement, repairs, and maintenance
4	Redecorations
5	Refurbishment and adaptation
6	Others

Serial	Occupancy Costs
1	Internal moves
2	Reception and customer hosting
3	Manned security
4	Help desk
5	Telephones
6	Post room – mail services – courier services
7	IT services
8	Library services
9	Catering
10	Hospitality
11	Vending
12	Occupant's furniture, fittings and equipment (FF & E)
13	Internal plants and landscaping
14	Stationary and reprographics
15	Porters
16	Car parking charges
17	Others

Serial	End of Life/ End of Investment Costs
1	Disposal inspections
2	Demolition
3	Reinstatement to meet contractual requirements
4	Others

Appendix B

Appendix B: Questionnaire

Questionnaire

Name	:	
Position	:	
Years of Experience	:	
Telephone #	:	
Company	:	

Introduction

Life Cycle Costing (LCC) is a technique used to assist decision takers/ investors to settle on a design method, item, construction method, product … etc among other alternatives of the same nature. This is done through comparing the Life Cycle Costs of each alternative and choosing the lowest. In case of comparing an asset to an asset, for example, a building to a building, not all activities need to be included only activities with different life cycle costs, since including activities which are typical in all alternatives and having the same costs is considered non-sense in terms of comparison. Since Life cycle cost breakdown structure differs from country to country and from project to project. And since LCC can be integrated with Life Cycle Assessment (LCA) in order to minimize the environmental impact of products or construction processes. The target of this questionnaire is to utilize the experience of the valued respondents in tailoring the life cycle cost breakdown structure to fit to residential buildings in Egypt, collecting data about the application of LCA in residential buildings in Egypt, as well as, measuring the extent of the usage of LCC and LCA techniques in the construction industry of Egypt.

1. Respondent's Company Type:
    - Owner ( )
    - Consultant ( )
    - Project Manager ( )
    - Contractor ( )
    - Others ( ) Please specify, ______________________
2. The average annual volume of work of your company:
    - LE 50,000 to 100,000
    - LE 100,000 to 1,000,000
    - LE 100,000 to 10,000,000
    - More than LE 10,000,000
3. Have you ever worked in a project which applies LCC?
    - Yes
    - No

    If "Yes", what was the project and where was it?

    ____

    ____

    ____
4. What is the method your company uses to calculate LCC?
    - Simple payback ( )
    - Discount payback method ( )
    - Net present value ( )
    - Equivalent annual cost ( )
    - Internal rate of return ( )
    - Net saving ( )
5. Does the type of contract of the project affect the application of LCC?
    - Yes
    - No

    If "Yes", which of the following types of contract require the application of LCC?
    - Unit price contracts ( )

- o Lump sum contracts ( )
- o Cost plus contracts ( )
- o BOT contracts ( )
- o PPP contracts ( )
- o Others ( ) please specify, ____________________

____

6. For which size of projects should LCC be applied on?
   - o More than LE 100,000 projects ( )
   - o More than 500,000 projects ( )
   - o More than 1,000,000 projects ( )
   - o All projects' sizes ( )
7. Is there any software model your company uses for conducting LCC?
   - o Yes ( )
   - o No ( )

   If "yes", please specify ____
8. What are the problems faced when conducting LCC?
   - o Lack of data ( )
   - o It is not easy to predict future costs ( )
   - o No software model available ( )
   - o Time constraints due to short design and construction period ( )
   - o Others ( ) please specify

   ____
9. What are the costs which have to be included in the application of LCC in residential buildings in Egypt?

   (1: Least important – 5: Most important)

	1	2	3	4	5
Land acquisition					
Construction costs					

Maintenance costs					
Operation costs					
Occupancy costs					
En of life/ end of investment costs					

10. **Rate** the below costs according to their importance in the calculation of Life Cycle Costing of residential buildings in Egypt:

(1: Least important – 5: Most important)

Initial Investment Costs					
	1	2	3	4	5
Land acquisition					
Planning costs					
Structural design costs					
Architectural design costs					
Excavation					
Foundations					
Structural costs (concrete and steel reinforcement)					
Masonry works					
Mechanical works					
Electrical works					
Plumbing works					
Finishing works					
Transportation charges					
Consultancy fees					
Special client costs – launch events and associated marketing costs					
Water adoption					
Electricity adoption					

Gas adoption					
Light adoption					
Licenses and permits					
Others					

If “Others”, please specify:

____

____

____

Operation Costs					
	1	2	3	4	5
Rent					
Internal cleaning					
External cleaning					
Water fees					
Electricity fees					
Gas fees					
Property management					
Staff engaged in servicing the building					
Waste management/ disposal					
Property insurance					
Taxes					
Others					

If “Others”, please specify:

____

____

____

Maintenance and Replacement Costs					
	1	2	3	4	5
Major replacements					
Minor replacement, repairs, and maintenance					
Unscheduled replacement, repairs, and maintenance					
Redecorations					
Refurbishment and adaptation					
Others					

If "Others", please specify:

____

____

____

Occupancy Costs					
	1	2	3	4	5
Internal moves					
Reception and customer hosting					
Manned security					
Help desk					
Telephones					
Post room – mail services – courier services					
IT services					
Library services					
Catering					
Hospitality					
Vending					
Occupant's furniture, fittings and equipment (FF & E)					

Internal plants and landscaping					
Stationary and reprographics					
Porters					
Car parking charges					
Others					

If "Others", please specify:

____

____

____

End of Life/ End of Investment Costs					
	1	2	3	4	5
Disposal inspections					
Demolition					
Reinstatement to meet contractual requirements					
Others					

If "Others", please specify:

____

____

____

11. In your point of view, which is more preferable for the accuracy of the final result of the life cycle cost?
    - Deterministic Result ( )
    - Probabilistic Result ( )
12. Do you add risk/contingency % in the calculation of the life cycle cost of residential buildings in Egypt?

- Yes ( )
- No ( )

13. Can you state an actual case where you applied LCC?
    - Project Title:

    - Project Type:

    - On which phases were the LCC applied:

    - What was the method used:

        i. Simple payback ( )
        ii. Discount payback method ( )
        iii. Net present value ( )
        iv. Equivalent annual cost ( )
        v. Internal rate of return ( )
        vi. Net saving ( )
    - What was the result of the application of the LCC?

14. Have you ever included Environmental Costs (Life Cycle Assessment/LCA) in the calculation of LCC?
    - Yes ( )
    - No ( )

    If "Yes", what is the life cycle inventory data do you depend on?
    - Data formulated by your company ( )

- o Data from literature review and tailoring it to your country and your project ( )
- o Others ( ) please specify

____

____

____

15. Is there any software model your company uses for conducting LCA?
    - o Yes ( ) please specify ____________________________
    - o No ( )
16. What are the problems faced when conducting LCA?
    - o Lack of data ( )
    - o No software model available ( )
    - o Time constraints due to short design and construction period ( )
    - o Others ( ) please specify

      ____
17. Can you state an actual case where you applied LCA?
    - o Project Title:
    - o Project Type:
    - o On which phases were the LCA applied:
    - o From where did you get the life cycle inventory data:
    - o What was the result of the application of the LCA?

Appendix C

Appendix C: Questionnaire Responses

Serial	Name	Position	Years of Experience	Company
1	Adel Anwar	Technical Office Manager	26	ECG
2	Ahmed Wahid	Senior Quantity Surveyor	10	Qatar PM
3	Khaled Osman	Project Controls Manager	18	Qatar PM
4	Osama Eid	Project Manager	31	Qatari Diar
5	Senthel Bala	Senior Quantity Surveyor	17	CCC
6	Ramy Raaft	Senior Manager - Development	15	GSSG Holding
7	Amira Labib	Director	13	DG Jones & Partners
8	Mona Mabrouk	Senior Quantity Surveyor	7	Gleeds Construction Consultancy Egypt
9	Ahmed Nasr	Senior Quantity Surveyor	7	Gleeds Construction Consultancy Egypt
10	Hesham Mahmoud	Director of Cost Control	15	SODIC
11	Antonie De Klerk	Senior Project Surveyor	14	Davis Langdon - an AECOM Company
12	Tawheid Fahmy	Landscape Manager	19	AUC - Facilities & Operations Dept.
13	Osama Zayed	Director of Construction Services	33	AUC - Facilities & Operations Dept.
14	Said Lebian	Project Manager	25	Europtima
15	Waleed Salaheldin	Project Controls Engineer	8	Turner Construction Company
16	Wael Fadl	Electrical Technical Manager	13	Consukorra Co.
17	Yassmine Thabet	Planner Engineer	7	Mott Macdonald
18	Vinod Sampong	Contracts Manager/Cost Controller	9	Mott Macdonald
19	Ayman Sabet	Quality Manager	5	ISS International security and safety systems
20	Francis Kwashie	Project Risk Consultant	10	DS+A

Multiple Choice Questions

Coding:

Q1	
Answer	Code
Owner	1
Consultant	2
PM	3
Contractor	4
Other	5

Q2	
Answer	Code
LE 50,000 to 100,000	1
LE 100,000 to 1,000,000	2
LE 100,000 to 10,000,000	3
More than 10,000,000	4

Q3,Q5,Q7,Q12,Q14, Q15	
Answer	Code
Yes	1
No	2

Q4	
Answer	Code
Simple Payback	1
Discount Payback	2
Net Present Value	3
Eq. Annual Cost	4
Internal Rate of Return	5
Net Savings	6

Q6	
Answer	Code
More than LE 100,000	1
More than LE 500,000	2
More than LE 1,000,000	3
All Project Sizes	4

Q8	
Answer	Code
Lack of data	1
Difficult to predict future costs	2
No Software	3
Time Constraints	4
Others	5

Q11	
Answer	Code
Deterministic	1
Probablistic	2

Q16	
Answer	Code
Lack of data	1
No Software	2
Time Constraints	3
Others	4

		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q11	Q12	Q14	Q15	Q16
ID #	Name	Company Type	Company Annual Work Vol.	Used LCC before	Method for LCC Calc.	Type of Contract & LCC	Size of Project for LCC	Software for LCC	Problems facing LCC	LCC Type of Results preferred	Apply Risk in LCC	Used LCA before	Software for LCA	Problems facing LCA
1	Adel Anwar	2	4	1	2	2	3	2	1,2,4	1	1	1	2	1
2	Ahmed Wahid	3	4	2	1	2	1	2	1	1	1	2	2	1,2
3	Khaled Osman	3	4	1	1,5	1	3	2	1	2	1	2		1
4	Osama Eid	1	4	2	5	1	2	1	2	1	1	1	1	3
5	Senthel Bala	4	4	1	5	2	3	2	2	2	1	1	2	1
6	Ramy Raaft	1	4	1	2,3,5	1	4	2	1	2	1	2	2	1,2
7	Amira Labib	5		1	2,3		3	2	1,4	1	1	2	2	4
8	Mona Mabrouk	2	3		6	2			1,3					
9	Ahmed Nasr	2	3	2	3,5	1	3	2	2	2	1	2	2	4
10	Hesham Mahmoud	1	4	2	5	1	3	2	1	2	1	2	1	1
11	Antonie De Klerk	5	4	1	1,2,3,4	1	3	2	1,2	2	2	1	2	1
12	Tawheid Fahmy	3	2	1	1	2	2	1	2	2	1	1	1	1
13	Osama Zayed	1	4	1	4	2	4	2	1	1	2	2	2	1
14	Said Lebian	2	4	1	2	2	3	2	1,2	2	2	2		
15	Waleed Salaheldin	3	4	1	3,4,5	1	4	2	1,3	2	1	2	2	1,2,3
16	Wael Fadl	4	4	2	4	2	4	2	3,4	2	1	1		
17	Yassmine Thabet	2	4	1	3,6	2	4	1	4	2	1	1	1	3
18	Vinod Sampong	2	4	1	3	2	3	2	1,2	2	1	1	2	1,2
19	Ayman Sabet	4	2	2	6	1	2	2	2	2	2	1	2	
20	Francis Kwashie	5	4	1	3	2	3	1	1,2	2	1	2	2	1

Rating Questions

Q9

Costs to include in buildings LCC in Egypt

	1	2	3	4	5	Number	Rate
Land acquisition	5	4	9	8	40	20	3.3
Construction costs	2	4	18	16	30	20	3.5
Maintenance costs	1	2	9	12	55	19	4.16
Operation costs		6	9	20	40	19	3.95
Occupancy costs	3		24	28	5	19	3.16
End of life/ end of investment costs	1	8	15	8	35	19	3.53

Q10

Initial Investment Costs							
	1	**2**	**3**	**4**	**5**	**Number**	**Rate**
Land acquisition	4	4	12	12	35	20	3.35
Planning costs		12	24	8	10	18	3.00
Structural design costs		10	21	20	5	18	3.11
Architectural design costs		10	15	20	15	18	3.33
Excavation	5	10	9	8	10	17	2.47
Foundations	4	10	15	12	15	20	2.80
Structural costs (concrete and steel reinforcement)	2	2	21	24	15	19	3.37
Masonry works	1	12	21	12	5	18	2.83
Mechanical works	1	8	12	24	25	20	3.50
Electrical works	2		21	16	30	19	3.63
Plumbing works		4	18	20	25	18	3.72
Finishing works	2	2	24	16	25	20	3.45
Transportation charges	4	8	24	4	5	18	2.50
Consultancy fees	2	4	24	12	15	18	3.17
Special client costs – launch events and associated marketing costs	6	10	6	12	5	17	2.29
Water adoption	3	10	12	8	20	18	2.94
Electricity adoption	1	10	12	8	30	18	3.39
Gas adoption	2	12	9	8	25	18	3.11
Light adoption	1	12	9	8	20	16	3.13
Licenses and permits	1	4	27	4	25	18	3.39
Others							

Operation Costs							
	1	**2**	**3**	**4**	**5**	**Number**	**Rate**
Rent	4	2	6	24	20	17	3.29
Internal cleaning	7	10	15	4		18	2.00
External cleaning	3	16	15	4	5	18	2.39
Water fees	3	8	21	12		17	2.59
Electricity fees	3	6	18	12	15	18	3.00
Gas fees	2	8	18	16	5	17	2.88
Property management		6	12	32	20	19	3.68
Staff engaged in servicing the building	1	8	12	28	10	18	3.28
Waste management/ disposal	2	8	18	12	10	17	2.94
Property insurance		4	21	20	20	18	3.61
Taxes	2	8	15	12	20	18	3.17
Others							

Maintenance and Replacement Costs							
	1	**2**	**3**	**4**	**5**	**Number**	**Rate**
Major replacements	1	2	9	16	50	19	4.11
Minor replacement, repairs, and maintenance	3	8	18	8	20	19	3.00
Unscheduled replacement, repairs, and maintenance	1	4	27	16	15	19	3.32
Redecorations	4	8	21	8	10	19	2.68
Refurbishment and adaptation	3	4	18	20	15	19	3.16
Others							

Occupancy Costs							
	1	**2**	**3**	**4**	**5**	**Number**	**Rate**
Internal moves	5	16	9	4		17	2.00
Reception and customer hosting	3	10	15	8		15	2.40
Manned security	1	12	12	20	5	17	2.94
Help desk	3	18	3	12		16	2.25
Telephones	3	10	12	12	5	16	2.63
Post room – mail services – courier services	1	16	18	4		16	2.44
IT services		4	18	20	20	17	3.65
Library services	4	10	12	12		16	2.38
Catering	3	14	15	12		18	2.44
Hospitality	3	6	18	16		16	2.69
Vending	2	10	21	8		16	2.56
Occupant's furniture, fittings and equipment (FF & E)	1	6	18	20	15	18	3.33
Internal plants and landscaping	1	12		24	15	16	3.25
Stationary and reprographics	2	16	15	4		16	2.31
Porters	2	18	12		5	15	2.47
Car parking charges	3	10	12	16	5	17	2.71
Others							

End of Life/ End of Investment Costs							
	1	**2**	**3**	**4**	**5**	**Number**	**Rate**
Disposal inspections		14	18	16	5	18	2.94
Demolition	1	2	18	12	40	19	3.84
Reinstatement to meet contractual requirements	1	4	21	16	20	18	3.44
Others							

“If Yes” Questions

Q3

ID #	Name	Used LCC before	project	location
1	Adel Anwar	1	Qatari Diar Project	Egypt
3	Khaled Osman	1	Jumeira Beach Residence	Dubai
5	Senthel Bala	1	Railway Project	Ireland
6	Ramy Raaft	1	Dubai Mall The Address Hotel Adera Project	Dubai Dubai Egypt
7	Amira Labib	1	City stars	Egypt
11	Antonie De Klerk	1	-	
12	Tawheid Fahmy	1	AUC New Campus	Egypt
13	Osama Zayed	1	AUC New Campus	Egypt
14	Said	1	Mivida Project	Egypt
15	Waleed Salaheldin	1	Mivida Project	Egypt
17	Yassmine Thabet	1	Most Projects	Dubai & London
18	Vinod Sampong	1	Hill Street foot bridge	Coventry
20	Francis Kwashie	1	Highway reconstruction	London

Q5

ID #	Name	Type of Contract & LCC	Contract		
3	Khaled Osman	1	Lump Sum	BOT	PPP
4	Osama Eid	1	Unit Price	Cost Plus	
6	Ramy Raaft	1	Unit Price	Cost Plus	
9	Ahmed Nasr	1	Unit Price	Lump Sum	
10	Hesham Mahmoud	1	BOT	PPP	
11	Antonie De Klerk	1	PPP		
15	Waleed Salaheldin	1	Lump Sum	BOT	
19	Ayman Sabet	1	Unit Price		

Type of Contract	Frequency	Percentage
Unit Price	4	27%
Lump Sum	3	20%
Cost Plus	2	13%
BOT	3	20%
PPP	3	20%