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Greenometer-7: A Tool to Assess the Sustainability of a Building's Life Cylce at the Conceptual Design Phase

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GREENOMETER-7: A TOOL TO ASSESS THE SUSTAINABILITY OF A BUILDING'S LIFE CYCLE AT THE CONCEPTUAL DESIGN PHASE

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To my Parents, Wife and Son

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ABSTRACT

This study presents a tool that has been developed to measure and subsequently improve the sustainability performance of a building over its entire life-cycle while still at the conceptual design stage. This forecasting tool is called GREENOMETER-7.

GREENOMETER-7 is a LCA tool and it evaluates the projected building at two levels: micro- and macro-assessment. The micro-assessment level provides in-depth analysis of the building products, components, and operations; however, the macro-assessment level measures the sustainability performance of the building as a whole and covers areas that are not applicable at the product or component level. Both levels consist of categories and indicators. The micro-assessment level has 12 categories that fall into the following major areas: energy, water and wastewater, resources, contaminants, and economics. The macro-assessment level of GREENOMETER-7 has 7 categories. They are location, land use and land value, stormwater, heat-island and landscaping, water and wastewater, energy, resources, and environmental indoor quality (EIQ). The tool uses a 7-degree scale (0 to 6) to express sustainability performance, where 0 means extremely unsustainable, 3 means neutral and 6 means highly sustainable. The output is a score from 0 to 6 for the micro- and macro-assessment levels as well as for their categories and indicators.

The micro-assessment level has three phases: inventory, impact assessment and interpretation. The inventory phase has two steps: hierarchy-analysis and “N” determination. The impact assessment phase has two steps: profiling and synthesis. Also, the interpretation phase has two steps: ranking and valuation (weighting). On the other hand, the macro-assessment level has two phases: inventory and interpretation. The inventory phase has two steps: macro-survey and macro-profile. The interpretation phase has two steps: ranking and valuation (weighting).

The LEED scoring system is the predominant green building rating system in the United States. USGBC is in the process of incorporating life cycle assessment (LCA) into LEED. GREENOMETER-7 can be utilized to justify LEED credits and for forecasting the LEED certification level of the building at the conceptual design stage. By utilizing the tool to justify LEED credits it also ensures incorporating LCA into LEED.

A case study has been conducted to demonstrate the application of the tool. A proposed one-story residential building in Columbus, Ohio was selected for this case study. Both the micro- and macro-assessment levels have been conducted. The tool has been also used to forecast the LEED certification level of the projected building.

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INTRODUCTION

1.1 Background

The world today is facing many environmental issues. The scale of environmental problems has increased from local and regional to global. Unplanned and unsustainable development, rapid industrialization, urbanization, and other technological developments have contaminated air, water and soil quality and therefore have interfered with the basic needs of the society. Public awareness of environmental issues such as global warming, acid rain and ozone depletion has increased substantially over the last few years (Harris, 1999, Sonnemann, 2004).

While buildings provide countless benefits to society, they also have significant impacts on the environment. In the U.S. alone approximately 1.8 million residential buildings and 170,000 commercial buildings are constructed every year (U.S. EPA, 2004). In the life cycle of a building various natural resources are consumed - including energy resources, water, land, and minerals - and many kinds of pollutants are released back to the environment. These environmental inputs and outputs result in significant environmental consequences including global warming, acidification, air pollution, resource depletion, and waste disposal (Li, 2006, Harris, 1999). Some of the facts that need to be highlighted include the following:

- The building sector's energy consumption is significantly high in comparison to other sectors. In the U.S., buildings account for 39 percent of the total primary energy consumption and 70 percent of the electricity consumption (Wang, 2005a). According to the EIA Annual Review, the residential sector in the U. S. consumed 21.054 Quadrillion Btu in 2006, which represents around 21 percent of the total energy consumption for that year (Energy Information Administration, 2007a). In the U.S. 85 percent of the total energy is obtained from fossil fuel (Reilly, 1997). We are at or near the midpoint of oil extraction while world demand for oil is rising sharply and it is expected that between 2010 and 2020, oil prices will skyrocket as production falls and demand begins to exceed supply (Kibert, 2005).

- Building constriction is believed to consume a round half of all the resources taken from nature (Assefa, 2007). Building construction also consumes around 25 percent of the virgin wood (Public Technology Inc., 1996).

- In the U.S. building related construction and demolition debris total approximately 136 million tons per year accounting for nearly 60 percent of the total non-industrial waste generation. Approximately 43 percent of construction and demolition debris is generated from residential buildings (U.S. EPA, 2004).

- The built environment contributes to global warming by the release of greenhouse gases into the atmosphere both directly as a result of energy and indirectly by the use of manufactured products. It is estimated that the built environment accounts for about 40 percent of world greenhouse gas emissions (Assefa, 2007, Reilly, 1997). Recently, the level of carbon in the atmosphere took its largest jump (3 parts per million) since measurements began (Kibert, 2005).

- Moreover, about 52 percent of SO_2 and 20 percent of NO_x are produced in the U.S. because of building-related energy consumption (Wang, 2005a).

- In 1992, the U.S. EPA estimated that nearly one out of every 15 homes had radon concentrations above the EPA recommended action level. Radon is the second leading cause of lung cancer and is estimated to be responsible for an estimated 21,000 deaths per year (U.S. EPA, 2004).

- In the U.S., people spend about 90% of their time indoors. Sick Building Syndrome (SBS) and Building-Related Illness (BRI) refer to the two major classes of problems associated with building health. Sources of indoor air pollution may include combustion sources, building materials and furnishing, household cleaning, maintenance, etc (Kibert, 2005).

- In many parts of the word fresh water is an increasingly scarce resource. It is estimated that one person in six on Earth is without safe drinking water and about 2.4 billion people lack adequate sanitation (Kibert, 2005). Buildings account for 16 percent of the water used annually worldwide (Public Technology Inc., 1996). In the U.S. building occupants use 12.2 percent of the total water consumed, of that total, 25.6 percent is used by commercial buildings and 74.4 percent by residential buildings (U.S. EPA, 2004).

The population is expected to grow to as much as 9 billion people by the year 2050 (Janssen, 1992). This increase in population is expected to put more pressure on the environment. Without people adopting sustainable practices, environmental concerns will grow faster. Sustainability is defined as satisfying the need of the present generation without compromising the needs for future generation (Sonnemann, 2004). It takes into account environmental, economic and social aspects. Applying sustainable development concepts to the design, construction, and operation of buildings can enhance both the economic well-being and environmental health of communities around the world (Public Technology, Inc, 1996).

Giving their environmental, economic and social impacts, buildings are clearly a significant and major part of the sustainable development debate. Sustainable (green) building is a recent design philosophy that requires the consideration of energy, resources depletion and waste emissions during its whole life cycle in addition to minimizing cost and creating a healthy environment for people (Wang, 2005a). During the design of a sustainable building, environmental determinants are only one of the determinants besides many others such as cost, comfort, aesthetics, technical, functional, or legal requirements (Kotaji, 2003). A sustainable building should be constructed of materials that minimize life cycle environmental impacts such as global warming, resources depletion, and human toxicity.

A comprehensive and effective building assessment tool is required to design sustainable buildings and to provide comprehensive assessment of building performance across a broader range of environmental considerations using a set of criteria and targets. This tool can be used for the complex evaluation of the complex and expanded building life cycle. Environmental building assessment methods provide measures of progress towards sustainability, and they contribute significantly to the understanding of the relationship between buildings and the environment. In order for environmental building assessment tools to be useful as design tools and for the most effective way to achieve sustainability, they must be introduced as early as possible even before a design is conceptualized (Ding, 2008, Banaitiene, 2008). In a building's life cycle, the conceptual design phase has significant influence on the overall performance when many potential design alternatives are generated and environmentally evaluated in order to obtain the most sustainable solution (Banaitiene, 2008, Wang, 2005).

1.2 Problem Statement

To reduce the impacts of buildings on the environment and to prompt sustainability, there is a need for effective and objective building environmental assessment tools which can be used for the evaluation of the building complex and expanded life cycle. The ideal building assessment tool has the following characteristics:

- It is implemented at the conceptual design phase, early enough where modification in the design is possible and economically feasible and where the life cycle consequences of the build on the environment are mostly determined. Most of a building's material, energy, and environmental loadings are likely to be committed at this stage (Center for Design at RMIT University, 2001, Kibert, 2005).

- It considers the whole life cycle of the building because all stages generate environmental impact (Public Technologies, Inc, 1996, Kotaji, 2003).

- It is developed in accordance with LCA principles where designers can choose the combination of alternatives that reduce the building's life cycle environmental impact (Lloyd, 2005, Zhang, 2006).

- It demonstrates an in-depth coverage of both bad and good criteria associated with building performance.

- It is easy-to-use with reasonable time, effort, and cost. It does not require huge amount of information to be assembled and analyzed (Ding, 2008).

- It can be used by the designer to produce buildings with low environmental impact and healthy indoor environments (Assefa, 2007).

- It provides a comprehensive assessment of the environmental characteristics of a building using a wide set of criteria. It incorporates the whole spectrum of environmental criteria such as global warming, resources depletion, and human toxicity. Moreover, it captures the complex web-like relationship between a building's construction and operation and its impacts on human health and the environment (Trusty, 2002, Ding, 2008).

- Besides environmental issues, it covers other concerns such as financial, social, technical, aesthetical, and legal aspects. It has the ability to satisfy several conflicting criteria (Kotaji, 2003, Sinou, 2006).

- It pays special attention to the financial issues because when building is too expensive it is usually labeled economically unattractive. Environmental issues and financial considerations should go hand in hand as part of the evaluation framework (Ding, 2008).

- It provides a clear objective function and has the ability to show designers where effort can be best prioritized (Trusty, 2002).

- It employs building simulation, where the performance of a proposed building is usually investigated by exploring design changes that provide incremental improvement measured against single criteria such as reduced energy consumption and/ or improved thermal comfort (Soebarto, 2001).

Unfortunately, there are many challenges that make the development of such an ideal assessment tool not an easy task. Some of these challenges include the following:

- A comprehensive tool is most likely to contain many complicated parameters, which make it not attractive to the design community. If the time, effort, and cost that are required to input and process the data are excessive, this problem may jeopardize its usefulness. Balancing between completeness and simplicity of use is one of the challenges in developing an effective and efficient environmental building assessment tools (Ding, 2008, Soebarto, 2001).

- It is a difficult task to balance among several conflicting criteria, especially economic and environmental performance, and at the same time satisfy the needs of all stockholders. Efforts to optimize a single performance criterion may affect other performance criteria (Lloyd, 2005, Wang, 2005, Ding, 2008).

- Scientifically defensible methods are not available to measure all indicators. While energy consumption and waste generation can be measured, other aspects of environmental performance, such as the effect of indoor air quality on the occupants' health, are substantially more difficult to assess quantitatively. Assessment methods will be used only if they are straightforward to use, scientifically defensible, and use environmentally relevant indicators (SETAC, 2002, Harris, 1999).

- All stages in the life cycle of a building generate environmental impacts and must therefore be analyzed. However, buildings have extremely long lifetimes- often more than 50 years- and it is difficult to predict the impacts during this extended life cycle, where the building may undergo many changes. Reduction in the environmental impact requires designers to use long-range planning horizons. To evaluate the life cycle of a building is a very complex and wide ranging problem (Banaitiene, 2008, Lloyd, 2005, Kotaji, 2003)

- Evaluating the environmental consequences of a specific building is difficult because every building is a unique, complex system of interrelated building materials, components and subsystems (Lloyd, 2005)

- Weighting is the most complex and subjective area of environmental impact and there is no standard method for weighting one indicator against another. The weighting of various indicators against each other is not possible in an objective way for different reasons. One reason is that experts have difficulties in agreeing on the relative importance of different effects. Another reason is that the importance may vary geographically. There is at present neither a consensusbased approach nor a satisfactory method to guide the assignment of weighting (Ding, 2008, Harris, 1999)

- There is no established set of indicators and targets. A number of environmental considerations such as global warming, ozone depletion, acid rain, energy consumption, depletion of resources, recycling potential, embodied energy, and health impact are considered to be of major importance and would therefore be included in most environmental assessment methods. Other important effects could be considered insignificant and are ignored (Harris, 1999).
- Geographical difference is another challenge, what could be important in one region could be less important in another and verse versa.
- Many participants (designer, client, contractor, etc.) are all involved in the building's life cycle and it is not an easy task to satisfy the needs of all (Banaitiene, 2008).

During the last decade, the building sector has witnessed the development of two types of environmental assessment tools: criteria scoring systems and LCA-based tools. LCA-based tools use LCA methodology and work at the level of whole building; however, they could be regionally specific and they may use different modeling approaches. Examples of the LCA based tools include Envest in the UK, EcoQuantum in the Netherland, and ATHENA in North America (Trusty, 2002, Assefa, 2007, Kotaji, 2003). Scoring systems are based on criteria scoring on a scale ranging from small to large environmental impact. Some scoring systems that have been developed and adopted include LEED in the U.S., BREEAM in U.K, CASBEE in Japan, and SBTool in Canada and other countries (Lee, 2006, Assefa, 2007). Despite their usefulness in contributing towards a more sustainable building, these tools have limitations that may hamper their future usefulness and effectiveness in the context of assessing the environmental performance of buildings. Some of these limitations are applicable to both types and some of them are more specific for one type over the other.

General limitations that are applicable to both the scoring and the LCA-based tools include the following:

- They are not complete and some of them only include few parameters. The investigation showed that none of the methods seem to incorporate all the parameters involved, especially the economic and social aspects (Sinou, 2006).

- They do not include the economic aspects which is critical because if the cost is high the sustainable building will be labeled economically unattractive (Wang, 2005).

- Most of them have some complexity. Even experienced users require significant time in preparing objective assessments.

- There is an absence of a clear objective function that needs to be optimized (Trusty, 2002)

- Most environmental building assessment methods were developed for local use and do not allow for national or regional variations (Ding, 2008)

- They are not available at the conceptual design stage where the life cycle consequences of the build on the environment are mostly determined. The opportunity to reduce the building's environmental impact decreases substantially after it has been designed and built. The most effective way of achieving sustainability in a project is to consider and to incorporate environmental issues at a stage even before a design is conceptualized (Ding, 2008, Lloyd, 2005).

- Simulation is not supported in most tools. When using simulation, the performance of a proposed building is usually investigated by exploring design changes (Soebarto, 2001).
- The weighting step is always subjective, which questions the tools credibility.
- They only consider negative criteria; they don't give credit for positive impacts.

Some of the limitations that are specific to the scoring tools include the following:

- They are a type of subjective scoring systems. The subjective nature of the scoring system sometimes makes it difficult for those models to provide in-depth results (Zhang, 2006).
- Many effects are considered insignificant and are ignored by some tools (Harris, 1999).
- They don't cover the whole life cycle of the building. An analysis that excludes any of the stages is limited because all stages generate environmental impacts (Public Technology, Inc, 1996).
- They are not based on LCA-methodology, which demonstrates an in-depth coverage of environmental impacts.

- The scoring systems have a system of assigning point values to a number of selected parameters on a scale ranging from small-to-large environmental impact. They provide an on/ off analysis with no in-depth information (Assefa, 2007)

Building LCA tools reported so far have several problems or limitations:

- They are limited to a few parameters; it has been recommended that researchers develop a more complete tool that will include as many parameters as possible and at the same time keep it attractive to the designer community (Sinou, 2006). For example, ATHENA indicators are primary energy, global warming potential, solid waste, air pollution index, and water pollution index.

- The LCA tools that are currently available are not widely utilized by most stakeholders. The reason behind that could be because the time, effort, and expense that are required to input and process the data are generally excessive (Soebarto, 2001).

- LCA is a complex process because it is cradle-to-grave analysis, which makes such tools unattractive to designers (UNEP, 1996).

- Most of the buildings' LCA tools remain in the inventory analysis stage (e.g. identifies inputs such as energy consumption or outputs released back to the environment such as green house gas emissions) (Li, 2006).

It is clear that there is a need for a tool that can overcome many of the limitations and challenges. A tool that can be effectively used in the conceptual phase to improve buildings' performance. This research is an attempt to make contribution in this direction.

1.3 Research Objective

The objective of this research is to develop an easy-to-use and comprehensive tool that can be used by the designer who is not an LCA expert to measure the sustainability of a building life cycle while still at the conceptual design where different design options can be evaluated with minimum effort. The goal is to overcome the limitations of the available tools and also to address important issues that were not considered before. Another objective is to show how the tool can be utilized by other tools and certification systems such as LEED so that the unique features of the tool can be inherited. Finally, a case study will be used to demonstrate how the developed tool works. The features and capabilities of the proposed tool are discussed in more detail in the next section.

1.4 Tool Features

The proposed tool will be developed to insure that it has the following features and capabilities:

- It considers all stages of the building's life cycle based on the fact that all stages generate environmental impacts and must therefore be analyzed.

- It is a gate-to-gate analysis tool. It only considers what is inside the boundaries of the building site. The alternative cradle-to-grave analysis requires intensive data, not only for the life cycle of the building, but it begins from initial extraction of raw materials from the earth to demolition and waste management. Limiting the analysis to what is inside the boundaries of the building site, saves time and effort looking for extensive information.

- Although it is developed in accordance with the principles of LCA, important features from the scoring systems are also integrated. It is an attempt to combine the advantage of both tool types.

- It works at both the whole building level and the product level to provide a comprehensive and accurate sustainability picture. Designing a sustainable building requires the matching of materials and products, regardless of their impacts at the material or product level.

- It is comprehensive and covers several environmental criteria to prevent shifting issues from one area to another. The ultimate goal from an environmental perspective is to minimize the flows from and to the environment, the use of natural resources of all kinds, and emissions to air, land, and water throughout the building complete life cycle.

- As a sustainable tool, in addition to environmental considerations, it measures health, social and economic aspects over the whole life cycle. It pays special attention to the economic factor because sustainable practices can not be implemented if they are not economically feasible.

- It considers both good and bad indicators and it is not limited only to the negative impacts. Available tools only consider negative criteria such as consumption of energy and release of greenhouse gas, but none gives credit for adopting a sustainable practice such as the use of renewable energy.

- This tool is for use at the conceptual design phase because decisions made at this stage have considerable impacts on building performance and because it is the stage where the life cycle consequences of the build on the environment are mostly determined. Most of a building's material, energy, and environmental loadings are likely to be committed during the conceptual or design phase. Implementing changes on an existing building may be impractical, difficult, or expensive to facilitate (Ding, 2008).

- It employs simulation, where the performance of a proposed building can be investigated by exploring design changes that provide incremental improvement measured against every change. Also it answers the what if question.

- It is a user-friendly and designer-oriented. Although it is comprehensive and has many parameters, the designer is only required to provide reasonable information so that the analysis can be accomplished utilizing realistic time, cost and effort.

- It is sensitive to the geographical differences, the general form of the tool is a template that can be customized and adjusted so that it becomes regionally specific.

- The building's overall performance could be presented by providing an array of numbers or it could be taking another step further to generate a single number (using the 7-degree scale of 0 to 6). A single number representing a score for the building has advantage of being easy to understand (Kibert, 2005).

- It communicates the results in an easy to understand way.

1.4 Methodology

To achieve the stated objective, this research has employed the following methodology:

- An extensive literature review has been conducted to identify previous work in this field and to identify limitations and challenges.
- The tool has been developed to overcome the shortcomings and limitations identified through an extensive literature review.
- A correlation has been established with LEED standards, where the new tool can be used for forecasting and justification of LEED points.
- Profiles have been developed for selected building materials and products from different categories.
- A case study has been employed to demonstrate the application of the tool.

1.5 Organization of the Dissertation

The dissertation is organized as the following:

- Chapter 2 provides a literature review about building environmental performance assessment tools, scoring rating systems, life cycle assessment (LCA) of building products, LCA of whole buildings, building environmental performance indicators, and weighting (valuation) methods.
- Chapter 3 introduces the tool and provides in-depth information about the tool's micro- and macro-assessment level as well as the correlation with LEED.
- Chapter 4 is the analysis and results, profiles have been developed for common building materials, products, and equipment that cover the major areas in building and construction.
- Chapter 5 introduces a case study to demonstrate the application of the tool. In this chapter, GREENOMETER-7 is used to measure the environmental performance and sustainability of a single-story residential house.
- Chapter 6 ends the dissertation with a summary and suggestions for future work.

CHAPTER II

LITERATURE REVIEW

2.1 LCA-Based Building Assessment

Building performance is now a major concern of professionals in the building industry and environmental building performance assessment has emerged as one of the major issues in sustainable construction. More comprehensive building assessment methods are required to assess building performance across a broader range of environmental considerations and to provide a comprehensive assessment of the environmental characteristics of a building using a common set of criteria. During the last decade, the building sector has witnessed the development of two types of environmental assessment tools. The first group of these tools is purely based on criteria scoring. The second group includes those tools that are based on life cycle assessment (LCA) methodology. A number of building environmental assessment methods from both types were developed in various parts of the world, but there are more examples noticeable from the scoring system type (Assefa, 2007, Ding, 2008).

The development of LCA in the building sector is accelerating; and it is used in this sector in two different ways: for the assessment of building products or for the assessment of the whole building. Using LCA for the assessment of building products and materials will be covered in another section. LCA is considered one of the tools to help achieve sustainable building practices. By integrating LCA into the building design process, the designer can evaluate the life cycle impacts of building materials, components, and systems and choose the combination that reduces the building's life cycle environmental impact (Lloyd, 2005). They have been developed to evaluate how successful any development is with regards to balancing the environmental, economic, social, and technical aspects (Ding, 2008). Examples of whole building LCA-based tools are ATHENA (North America), ENVIST (UK), and ECO-QUANTUM (Netherland) (Assefa, 2007, Kotaji, 2003).

Some of the building performance assessment methods were developed based on the principles of life cycle assessment (LCA) methodology. According to ISO, LCA is divided into four steps: goal and scope definition, inventory analysis, impact analysis, and interpretation. The product under study in the case of building assessment is the building itself. The functional unit for building LCA is the whole building over one stage or over its entire life cycle. The whole life cycle of the building should be taken into account. The life cycle of the building spans from the extraction of the materials for construction to final demolition of the building. The Building life cycle can be divided into 3 stages: construction, operation, and demolition. The total of the stages should reflect the total life cycle. The building is broken down to the product level. For each product the LCA is carried from cradle-to-grave. The product LCA results are added together resulting in the LCA of the whole building. Impact Assessment is the step in which quantitative results of the inventory analysis are evaluated and aggregated into environmental loads (Kotaji, 2003, Zhang, 2006).

The LCA-based methods, compared with the criteria scoring methods, demonstrate an in-depth coverage of environmental impacts and they are most useful in the conceptual design stage. Unfortunately, building LCA tools reported so far have several problems or limitations. To evaluate the life cycle of a building it is a complex and wide range problem. Buildings have extremely long lifetime, often more than 50 years. It is difficult to predict the life cycle "from-cradle-to-grave" During this life span; the building may undergo many changes. Moreover, most of the buildings LCA examples remain in the inventory analysis stage e.g. identifies inputs such as energy consumption or outputs released back to the environment such as green house gas emissions (Zhang, 2006, Li, 2006, Banaitiene, 2008).

Another approach is to integrate LCA tools into criteria scoring systems. This integration will yield significant benefits, not only in improved understanding and crediting of environmental performance, but also in reducing assessment complexity and cost (Trusty, 2002). The USGBC adopted the concept of integrating LCA into LEED, and this approach is expected to grow more in the future. On September 19, 2004 a meeting was convened in Washington D.C. by the USGBC to begin the process of determining how best to integrate LCA into LEED. Six Working groups have been established to develop recommendations to USGBC. At the end of 2006, the U.S. Green Building Council's Life Cycle Assessment Working Groups have developed initial recommendations for incorporating life cycle assessment of buildings materials as part of the continuous improvement of LEED (GreenBuildings.com, 2007, USGBC, 2006a, USGBC, 2006b).

2.1.1 ATHENA

ATHENA is an example of building assessment based on life cycle assessment. It was developed by the Athena Institute in Canada. Athena Institute is a non-profit organization that seeks to improve the sustainability of buildings through the implementation of LCA, they have offices in Canada and the United States. ATHENA Impact Estimator for Buildings is the only software tool in North America that evaluates whole buildings and assemblies based on LCA methodology (The Athena Institute, 2007). ATHENA software is a LCA tool that focuses on the assessment of whole buildings or building assemblies such as walls, roofs, or floors. Using the software, architects can assess and compare the environmental implications of designs for both for new buildings and major renovations. It incorporates ATHENA's databases, which covers many of the structural and envelope systems typically used in residential and commercial buildings. Athena software enables users to describe a building in architectural terms, and then provides LCA-based environmental evaluations of alternative designs and material choices. ATHENA is for use at the conceptual design phase and it provides (without weighting) summary for embodied energy use, global warming potential, solid waste emissions, pollutants to air, pollutants to water, and natural resources use. A comparison dialogue feature allows the side-by-side comparisons of several alternative designs. The output of ATHENA provides cradle-to-grave and region specific results of design (Kibert, 2005).

2.2 Criteria Scoring Systems

Criteria scoring systems are the second type of building assessment tools that are used to assess whether a building is performing adequately. They are intended to foster more sustainable building design, construction and operation by promoting and making possible a better integration of environmental concerns with economic, social and other criteria. The ultimate goal is to model the environmental impacts of whole buildings (Trusty, 2002). The focus of the criteria scoring systems seems mainly to be on issues regarding energy, site, water, materials, and quality of indoor environment. The major principles of sustainable buildings are: reduce resource consumption, reuse resources, use recycled resources, protect nature, eliminate toxicity, apply life cycle costing, and focus on quality (Sinou, 2006, Kibert, 2005). Most green building criteria scoring systems deal in one way or another with site selection, the efficient use of energy and water resources during operation, recycling and reuse of water and materials, waste management during construction and operation, indoor environmental quality, passive heating, cooling, and ventilation, and the selection of environmentally preferable materials. The criteria scoring system needs to be able to clearly communicate an overall performance rating and be sufficiently universal to facilitate comparison of performance across the various regions and building types. Some of the common criteria scoring systems are SBTool (Sustainable Building Tool) which is an international project coordinated from Canada, LEED a method developed in the USA with a world wide application, CASBEE a method developed in Japan, and BREEAM a method developed in the UK (Fowler, 2006, Sinou, 2006, Lee, 2006, Assefa, 2007).

Criteria scoring systems are types of subjective scoring systems. They have a system of assigning point values to a number of selected parameters on a scale ranging from small to large environmental impact. There are two different approaches to describe the building's overall performance: a single number or an array of numbers. A single number representing a score for the building has the advantage of being easy to understand, however, the array approach provides more detail. LEED is an example of the assessment methodologies that adopted the single number approach while SBTool is an example of that uses the array approach. SBTool uses a relatively large quantity of information to assess the building. The LEED standard provides a single number that determines the building's assessment or rating, based on an accumulation of points in various impact categories, which are then totaled to obtain a final score. If a single number is used to score a building the system must convert the many different units describing the building's resources and environmental impacts (energy use, water consumption, land area footprint, materials, waste quantities, and recycled materials) into a series of numbers that can be added together to produce a single overall score which may be described on a scale ranging from poor to excellent. Alternatively, a building assessment system can utilize an array of numbers that depict the building's performance in major areas, such as global worming potential, energy consumption, and waste generation, an overall score could be obtained after weighting aggregation (Kibert, 2005, Wang, 2005, Assefa, 2007).

The scoring systems have relatively wide coverage of environmental aspects and they generally capture the complex web-like relationship between a building's construction and operation and its impacts on human health and the environment, but the subjective nature of the scoring system sometimes makes it difficult for those models to provide in-depth results. Moreover, there is an absence of a clear objective function that needs to be optimized (Zhang, 2006, Trusty, 2002).

2.2.1 LEED

LEED (Leadership in Energy and Environmental Design) is a criteria scoring system that has been developed by the U.S. Green Building Council (USGBC) in the United States for developing high-performance, sustainable buildings. The USGBC is a non-profit organization committed to expanding sustainable building practices and its mission is to transform the way buildings and communities are designed, built and operated, enabling an environmentally and socially responsible, healthy, and prosperous environment that improves the quality of life. LEED scoring systems are available for commercial new buildings, commercial existing buildings, commercial interior, core & shell, schools, retail, healthcare, neighborhood, and homes (USGBC, 2007).

The LEED scoring system has emerged in recent years with a high level of visibility and increasing market acceptance and it is the predominant building assessment standard in the United States. The LEED standard provides a single number that determines the building's assessment or rating, based on an accumulation of points in various impact categories, which are then totaled to obtain a final score. Applicant building must satisfy a number of performance credit points to qualify for certified, silver, gold, or platinum certification. LEED addresses specific environmental building related impacts using a whole building environmental performance approach. The major categories of criteria include: sustainable site (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor air quality (IQ), and innovation and design process (ID). Each category has its own number of prerequisites and credits. (Kibert, 2005, USGBC, 2005b).

USGBC is in the process of incorporating LCA into the LEED rating systems. The USGBC Life Cycle Assessment working group has been established at the end of 2004 to develop recommendations to USGBC on how best to integrate LCA into LEED. USGBC Life Cycle Assessment working group has developed initial recommendations for incorporating LCA of building materials into LEED. The recommendations included short and long term implementation strategies as well as technical details regarding LCA methodology. The LCA working group's recommendation for an initial approach is to undertake LCA of the assemblies that constitute a building's structure and envelope. The assemblies will be ranked according to their environmental impact, with LEED credits awarded accordingly. The reports of working group A and working group B were released at the end of 2006. It was recommended to use a regional energy grid approach not national average and energy related emissions. Working group A agreed on the following long-term objective for the integration of LCA into LEED: to routinely and credibly apply LCA to support integrated design and ensure environmental performance at the whole building level, taking into account the complete building life cycle and subject to defined criteria. Also they recommended awarding credit for selecting highly ranked products based on the use of LCA, and making decisions based on the use of an LCA tool by the design team. One of the recommendations for Group B was to use TRACI as the approach for the life cycle impact assessment stage of LCA. TRACI method contains 10 impact categories including global warming potential (GWP), ozone depletion potential (ODP), photochemical oxidation potential (PCOP), acidification potential, eutrophication, health toxicity potential (cancer), health toxicity potential (non-cancer), health toxicity potential (criteria pollutants), ecotoxicity potential, and fossil fuel use (GreenBuildings.com, 2007, USGBC, 2006a, USGBC, 2006b).

2.2.2 BREEAM

BREEAM (Building Research Establishment Environmental Assessment Method) was launched in the UK in 1990 to provide an environmental assessment and labeling scheme for buildings. It was developed by BRE Ltd., the national building research organization of UK. BREEAM is the oldest building assessment method. BREEAM criteria scoring system assesses the performance of the building in the following areas: energy efficiency, water, materials, land use, health and wellbeing, pollution, management, and transport. Credits are awarded in each area according to performance. A set of weighting factors then enables the credits to be added together to produce a single overall score. The building is then rated on a scale of PASS, GOOD, VERY GOOD or EXCELLENT rating. It evaluates the environmental performance of buildings in both the design phase as well as existing buildings. BREEAM versions for buildings, according to the building type, include industrial, ecohome (Code for Sustainable Homes), multi-residential, court, prisons, offices, and retail. The designer completes a form, where all the environmental parameters considered by the method are evaluated (PRE, 2007).

2.2.3 SBTool

The SBTool software (formally known as GBTool) has been developed as part of the international Green Building Challenge (GBC) process that has been under development since 1996 by International Initiative for a Sustainable Built Environment (iiSBE) and participating teams from more than 20 countries. The first version of GBTool was developed and completed in 1998. The latest version is SBTool 2007. GBC is an international collaborative effort to develop a building environmental assessment tool that exposes and addresses controversial aspects of building performance and from which the participating countries can selectively draw ideas to either incorporate into or modify their own tools (iiSBE , 2007a, Chang, 2007).

The assessment elements of SBTool are classified into three levels of factors: The highest level is called performance issues, the second level is called categories, and the third level is called criteria. At the top level there are seven performance issues: site selection and project planning, energy and resource consumption, environmental loading, indoor environmental quality, functionality and controllability of building systems, long-term performance, and social and economic aspects. Each issues is subdivided into categories at the second level, there are a total of 29 categories. Each category is subdivided into criteria at the third level; there are a total of 125 criteria (Chang, 2007). SBTool covers a wide range of sustainable building issues within the three major areas of environment, social, and economic sectors. A distinguished feature of SBTool is that it is designed as a generic framework, and requires a third party to adjust it to suit the unique conditions applicable to certain building types in various regions. Third parties are expected to adjust the default weights and benchmarks throughout the system. It places emphasis on the ability to have the system reflect the relative importance of performance issues in a particular region and to establish regionally relevant benchmarks. By replacing the generic benchmarks with the regional benchmarks, users can ensure that the system is relevant to their local conditions. The tool is split into three parts: module A (settings) includes benchmarks and weights that are established by a third party to suite local conditions. All benchmarks and weighting factors defined by the third party in Module A are automatically copied to Module B and Module C to be used by designers. Module B (project) allows designers to provide information about the site and project characteristics. Model C (evaluation) is used by designers to carry out self-assessments of any of the building life cycle stages and it takes its values for weights and benchmarks from Module A that has been calibrated by the third party. Users of Modules B and C can't change the settings that have been established by a third party in Module A (iiSBE, 2007b).

Weighting is used to generate scores from one level to the other. Category scores are obtained through aggregating the weighted scores of constituent criteria. Issue scores are obtained through aggregating the weighted scores of constituent categories. The overall building score is obtained through the weighted scores of issues. The weighting value, from the lower level to the overall building, is a total of 100%. The analytical hierarchy process is used for weighting. Weighting factors are established by a third party in each region to reflect the varying importance of issues in that region. If a criteria is not applicable to region, the criterion weight is set to zero and all weights in the applicable category are re-distributed amongst other criteria that remain active (Chang, 2007, iiSBE, 2007a).

Benchmarks are of two types: numeric values and text form. In all cases the scoring of criteria uses a liner scale from -1 to +5, in which 0 represents the benchmark for the minimum acceptable performance level, 3 represent good practice and 5 represents best practice. The scores -1 is given to indicate levels of unsatisfactory (negative) performance that are clearly below the benchmark. Normally, the performance levels tied to each score vary by location and often by building type, which is why SBTool requires local third parties to establish regionally relevant benchmarks. In the case of numeric parameters, scoring is done by setting two numeric values at the 0 and +5 levels, and then the slope of the line is used to define numeric values for the -1 and +3 performance levels. It is more subjective in the case of text-based parameters. Default text benchmark statements are provided to describe a range of conditions from negative (-1) to best practice (+5) (Lee, 2006, iiSBE, 2007a).

SBTool allows the assessment to be carried out at various phases of the life cycle of a building including pre-design, design, construction and operation. The results of the assessment during the operations phase may be useful for certification purposes. Since the tool provides consistency in the high-level issues and second level categories, the results are comparable across the four assessment phases.

2.3 LCA of Building Products

Building for Environmental and Economic Sustainability (BEES) is an example LCA tools for building products from cradle-to-grave, i.e. from the acquisition of raw materials to the final disposal of the product. All stages of the life of a product are analyzed: raw material acquisition, manufacturing, transportation, installation, and waste management. BEES tool has been developed by the National Institute of Standards and Technology

(NIST). It provides data about air pollutants, indoor air quality, ecological toxicity, and human health for each material and product. Up to 12 environmental impacts are measured across the life cycle stages of the product: global warming, acid rain, resource depletion, indoor air quality, solid waste, eutrophication, ecotoxicity, human toxicity, ozone depletion, habitat alteration, water intake and smog. These environmental impacts are assessed according to the TRACI method that was developed by It allows for side-by-side comparison of building products for the purpose of selecting cost effective and environmentally preferable products. It also allows for weighting so that the environmental and economic performance of the product can be combined into a single performance score (Kotaji, 2003, Kibert, 2005, Assefa, 2007, Lippiatt, 2007a, Lippiatt, 2007b).

LCA of products consists of four interdependent elements: goal definition and scoping, inventory analysis (LCI), impact assessment (LCIA), and improvement assessment/interpretation (Ghassemi, 2002, Freeman, 1995, SETAC, 1993b).

- Goal definition and scope: identifying the purpose of conducting the LCA, and identifying the boundary of the system to be studied.
- Inventory analysis (LCI): quantifying the energy and materials input to the system, and quantifying the outputs consequently released such as air emissions, solid waste disposal, and wastewater discharge.
- Impact assessment (LCIA): assessing the impacts on human health and the environment associated with environmental releases, and energy and material use (LCI results).

- Improvement assessment/ Interpretation: evaluating opportunities available to bring about environmental improvements and suggesting methods to reduce environmental impacts and energy and materials use along the life cycle.

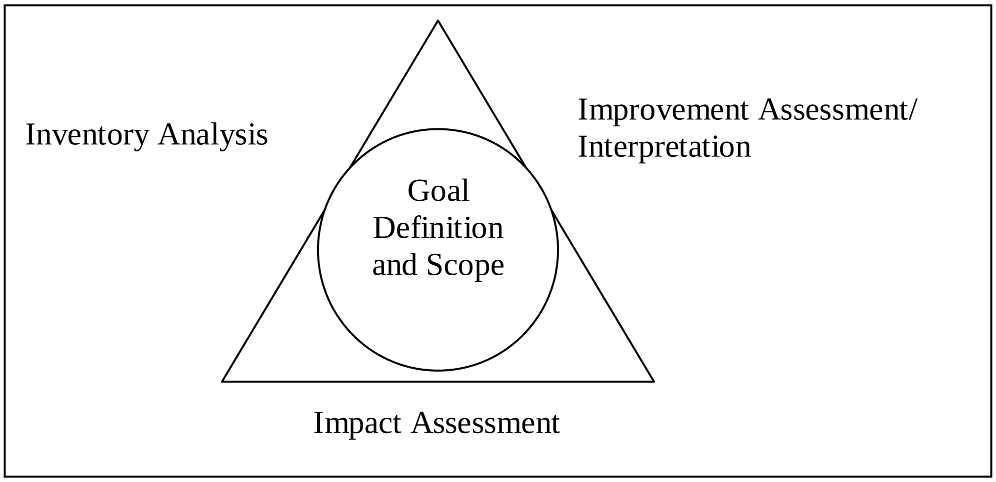

Figure 1: Life Cycle Assessment Elements

2.3.1 Goal Definition and Scoping

This is an essential step in any LCA study. In this step the following issues need to be defined and/ or questions need to be answered (Bishop, 2000, Ghassemi 2002):

- The purpose of the study (why is the study being conducted?)
- The audience (to whom are the results intended?)
- The subject of the study (which product, process or activity is to be studded?)
- The scope of the study (what level of details and reliability are required?)
- The system, boundary conditions, methodology and assumptions
- The expected products of the study, and
- The functional unit.

The goal should be stated unambiguously, together with the reason for carrying out the study. The functional unit has to be clearly defined, also it should be measurable and relevant to input and output data. Functional unit is the amount of product, material or service to which the LCA is applied. Examples of functional units are: the packaging used to deliver a given volume of material A, the paint to cover 100 m^2, the transportation mean to travel a specific distance, printing a specific number of pages. All LCI data for the system are normalized to the functional unit, e.g. 0.45 kg carbon dioxide release per packaging for 1,000 litter of material A.

A key consideration is whether the results of the study will be used internally by the company or weather the results will be communicated externally. An internal study will have different requirements from an external one. Internal studies are done for one of the following reasons: to select between alternative materials, to check the environmental impact of a change (material, process, etc), to discover any potential negative environmental aspects of a product, to reduce cost, to perform a competitive impact assessment with an alternative, brainstorming for improvements, or strategic planning. On the other hand external studies could be done for the following reasons: marketing, informing customers and consumers.

2.3.2 Inventory Analysis (LCI)

Inventory analysis is a systematic, objective, stepwise procedure for quantifying the inputs (energy and materials used) and the outputs (environmental releases to air, water and land, noise, radiation, etc.) for the entire life cycle of the system (product, process, or activity) (Bishop, 2000). LCI consists of the following steps:

- Defining the boundary of the system and dividing it into subsystem (if needed)
- Gathering data for each subsystem

- Creating a computer model
- Analyzing and preparing the results for the impact assessment element.

The system is separated from its surrounding (the system environment) by a system boundary. The system environment is the source of all the inputs to the system and the sink of all outputs from the system. The system can be represented by a box. The outline of the box represents the system boundary and separates the system from its surroundings. A flow chart can be developed to show how the subsystems are interlinked, data should be gathered using this flow chart. Each system should be mass and energy balanced. Inputs should equal outputs including wastes.

It is usually desirable to divide the system into a series of subsystems before collecting the data, and then the analyst should collect data for each subsystem. Once data collected for each step in the system being analyzed, certain calculations are necessary to put the data into the desired format for entry into a computer model. Computer modeling can be done by using spreadsheets or more sophisticated software. LCI produces a list containing the quantities of pollutants released to the environment and the amount of energy and material consumed.

Data collection is the most time consuming task in LCA and perhaps the process is complex and difficult. Other parties will need to be involved, most of whom will have only limited or no interest in the LCA. All LCIs have data variability, data uncertainties and data gaps. The most recent data should always be used. Sensitivity analysis may be carried out to test the effect on the results and possible limitations on the conclusions. Data collection sources include (SETAC, 1991, Sunnemann,2004):

- Electronic databases (provided by commercial or public software)

- Literature data (scientific papers, reports, LCA, etc).
- Unreported data (from manufacturers, laboratories, suppliers, etc)
- Engineering calculations (calculated or estimated)

When dealing with a system involving multiple products allocation procedures are needed. The material releases and resource use must be allocated (distributed) to the different products in the inventory process. If the system is only one product, then there is no allocation problem because all the environmental loads must be assigned to that system.

2.3.3 Life Cycle Impact Assessment (LCIA)

LCA without LCIA is not LCA. Most of the time, it is impossible to evaluate the results of life cycle and make improvement based on LCI alone. LCIA converts the results from LCI to a set of common impact measures that allow interpretation of the total environmental effects of the system being evaluated. LCIA should direct LCI data collection and not vice versa. LCIA is necessary in addition to LCI because results from LCI are too complex and does not allow direct conclusions concerning how to make improvements.

LCIA is defined as a technical quantitative and/ or qualitative process to characterize and assess the environmental and human health effects associated with the use of resources and environmental releases identified in the inventory component (SETAC, 1993a). A stressor is defined as any physical, chemical or biological conditions that can induce an impact. A single stressor may be associated with multiple impacts. LICA is for estimating the potential impacts not the actual impacts. Actual impacts might be addressed by other tools such as risk assessment.

Some impacts are not easily modeled because of the level of understanding of the environmental mechanism is low; other impacts are critical but are difficult to model quantitatively. LCIA must be fully based on natural science; the results must be reproducible and independent on the analyst who performs the study (Udo de Haes, 2000). In general, LCIA practice is moving more toward using more sophisticated models e.g. models that consider fate and transportation, however, difficulties and limitations in LCIA should not discourage practitioner from conducting impact assessments. Some of LCIA limitations are (SETAC, 1997a, U.S.EPA , 1993a):

- Data availability limitation
- Modeling and resource limitation
- Complexity of the natural systems
- It can’t include all possible environmental and resource categories
- It can’t analyze systems and categories in an equivalent manner
- It can’t approach most categories in a technical detailed manner

Basic LCA assumptions are inconsistent with the process of most ecological effects (Owens, 1996):

- LCA assumes process respond in a strictly linear manner, while many processes are nonlinear.
- LCA assumes all processes do not have a threshold, thus only a zero emission would then have zero impact. Yet many processes have thresholds, and many releases don’t lead to an effect if it is less than the threshold.

There is a need to increase the level of standardization and the ultimate goal is develop a generic procedure for LCIA with a number of options for different applications.

For each impact category, the following procedure is proposed in ISO 14042 (UNEP, 2003):

- Identification of the category endpoints (areas of protection)
- Definition of the indicator for given category endpoints.
- Identification of the model and the characterization factors.

Areas of protection (AoP) are defined as classes of category endpoint e.g. human health, natural environment and natural resources. Both midpoint and endpoint approaches might be used together to provide more information.

The conceptual framework of LCIA is composed of mandatory elements and optional elements (UNEP, 2003). The mandatory elements are:

- Selection of impact categories, indicators and models
- Classification: the process of assignment and initial aggregation of data from inventory studies to impact categories (e.g. greenhouse gases) within the endpoint categories
- Characterization: the analysis and estimation of the magnitude of potential impacts on human health and the environment for each impact category.

The optional elements are:

- Normalization: calculating the magnitude of category indicators relative to reference values. (All impact scores are related to a reference situation)

- Grouping: assigning of impact categories to groups of similar impacts or ranking categories in a given hierarchy e.g. high, medium and low priority.
- Valuation: the assignment of relative weights to different impact categories to reflect the relative seriousness of the different impact categories.

2.3.3.1 Classification

Classification is the process of assignment and initial aggregation of data from inventory studies to impact categories (e.g. greenhouse gases) within the endpoint categories. The overall purpose of the classification phase is to organize and possibly aggregate inventory items into impact categories that provide a more useful and manageable set of data. In this step inventory data need to be classified into the relevant impact categories, some items from LCI have influence on more than one environmental mechanism and are assigned to more than one impact category (Ghassemi, 2002). For example, oxides of nitrogen, NOx, is a source of acid precipitation also acts as catalyst in the formation of ground level ozone.

Environmental problems do not take place in separate chains, leading to single effects; most of the time are part of complex network. A stressor could cause parallel, serial, indirect, or combined (SETAC, 1993a). Parallel impacts are two or more impacts caused by the same stressor e.g. SO2 could cause toxic and acidifying effects. Serial impacts refer to two or more types of impacts which are caused one after the other by the same stressor, e.g. Chromium (VI) could cause ecotoxicity impacts and thereafter cause human toxicity impacts. Indirect impacts are impacts that are caused by a stressor that is induced by the same stressor in question so it is indirect impact, e.g. the Aluminum toxicity induced by the acidification effect of NOx. Combined impacts are impacts which are caused by a combination of two or more stressors and does not occur with only on of them, e.g. the formation of ground level ozone by the reaction of NOx and CxHx. Impacts can be classified based on different criteria; the most common are input vs. output related categories, local vs. global categories, and midpoint vs. endpoint (damage) categories. Input categories refer to environmental impacts associated with material and energy input to the system while output categories corresponds to damage due to emissions. Impact categories could be classified into three different space groups: global impacts, regional impacts, and local impacts. Midpoint categories include global warming, acidification, and stratospheric ozone depletion. Common endpoint categories are human health, ecological health and resource depletion. Endpoint (damage) categories are also called areas of protection (AoP).

For any chosen classification, impact categories must meet the following criteria (SETAC, 1996):

- Completeness: the list should include all relevant environmental problems
- Independence: the categories should be independent as much as possible in order to avoid double counting.
- Practicality: the list should for practical reasons not contain too many categories.

For each impact category the following procedure is proposed by ISO 14042 (Sonnemann, 2004):

- Identification of the category endpoints
- Definition of the indicator for given category endpoints

- Identification of appropriate LCI results that can be assigned to the impact category.
- Identification of the model and the characterization factors.

Internationally recognized organizations including SETAC and UNEP are in the process of attempting to develop default impact categories list. There are thousands of chemicals and materials which can be categorized in the impact assessment stage of a LCA, but are not currently included in the classification stage. In most current burdens lists only a few of the legislatively regulated materials and chemicals such as those on the U.S. EPA TRI (Toxic Release Inventory) are included. The LCIA stage should direct the LCI stage and not verse versa. Only emissions anticipated to cause impacts should be included. Table 1 includes most common impact categories (mostly midpoint categories) and the relevant inventory items for each.

Table 1: Common Life Cycle Impact Categories (source: U.S. EPA, 2006d)

Impact Category	Relevant Inventory Items
Global Warming	Carbon dioxide (CO_2) Nitrogen dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFCs) Hydrochloroflourocarbons (HCFCs) Methyl Bromide (CH_3Br)
Stratospheric Ozone Depletion	Chlorofluorocarbons (CFCs) Hydrochloroflourocarbons (HCFCs) Halons Methyl Bromide (CH_3Br)
Acidification	Sulfur Oxides (SO_x) Nitrogen Oxides (NO_x) Hydrochloric ACID (HCl) Hydrofluoric Acid (HF) Ammonia (NH_3)
Eutrophicaton	Phosphate (PO_4^{2-}) Nitrogen Oxide (NO) Nitrogen Dioxide (NO2) Nitrates Ammonia (NH3)
Photochemical Smog	Non-methane hydrocarbon (NMHC)
Aquatic Toxicity	Toxic chemical with a reported lethal concentration to fish
Terrestrial Toxicity	Toxic chemicals with a reported lethal concentration to rodents
Human Health	Total releases to air, water, and soil.
Resource Depletion	Quantity of minerals used Quantity of fossil fuels used
Land Use	Quantity of disposed of in a landfill

2.3.3.2 Characterization

Characterization is the process in which quantification of the impacts takes place. This process should be based on scientific knowledge about environmental mechanisms. The result of the characterization step is an environmental profile consisting of the impact indicator scores for the different impact categories.

In the characterization models many assumptions and simplifications are made because environmental mechanisms are often very complex and extended. As discussed before, environmental mechanisms could be parallel, serial, indirect, or combined. For the purpose of characterization models theses mechanisms are simplified to help develop an overall view of the environmental impacts of human activities (Ghassemi, 2002). Typically, in modeling a “non-threshold” assumption is used. Some stressors may cause more than one type of impact. This should explicitly be taken into account in the establishment of characterization factors. One should be aware of the risk of double counting. For serial and indirect impacts there is no risk of double counting, because the effects occur one after the other (SETAC, 1993b). Characterization models translate LCI data to impact descriptors, for example translate carbon dioxide emission into global warming. Usually characterization is two steps: First each of the input and output LCI results are converted to impact using the characterization model, second the converted results are often aggregated or added together into the category indicator.

There are several alternative approaches to characterization that differ in their breadth and depth. These methods range from simple generic that examine loading directly to more complex approaches that estimate environmental exposure and link that exposure to effects on human and the environment. The five characterization approaches in a hierarchical order of increasing complexity are (Bishop, 2002):

- loading (less is better)
- Equivalency
- Inherent Chemical properties (Toxicity, Persistence and Bioaccumulation)
- Generic exposure and effect
- Site-specific exposure and effect

The inventory data needed for all five approaches vary greatly in magnitude and difficulty. Presently much attention is given to development and use of equivalency assessment approach.

Loading (Less is Better) Approach

This approach is an aggregate based on the qualitative masses or energy units of inventory data. It is a simple method that assumes that there is a direct relationship between loading (or consumption) and environmental or health or health impact “less is better”. It uses data directly from LCI which can be summed as a measure of the impact e.g. energy and water use. When applying this method it is assumed that less loading of contaminants to the environment (or use of resources) will result in some gain in environmental quality. The advantages of using the loading approach are: convenience and ease of use, areas of reduction in environmental loading can be identified; chemical loadings for different products can be compared. Simplicity is the strength of this approach. In the loading approach, all emissions of a given substance are summed up throughout the life cycle.

This method is strongly debated for its ability to discriminate between processes with emissions causing concentration below and above a threshold value. Moreover, this approach can't be used to model all types of impact. The lack of linkage between loadings ad effects and absence of any quantification of the consequence of the loading is a major drawback (SETAC, 1993b). For example, this approach is acceptable for energy but using grams to compare toxicity of substances can be misleading due to relative difference in toxicity potency or persistence among chemicals.

Equivalency Approach

In this approach the inventory data having common mechanisms are aggregated on the basis of equivalency factors. Equivalency factor is a factor which expresses the contribution of a stressor (e.g. atmospheric emission of CFC-11) to the chosen impact categories (e.g. global warming) based upon impact mechanisms that directly relate the inventory data to the chosen receptor (midpoint or endpoint). Equivalency factors have been developed for different impacts e.g. global warming potential (GWP), Ozone Depletion Potential (ODP), and Acidification Potential (AP). The equivalency approach consists of multiplying the inventory data by the appropriate equivalency factors, then expressing the inventory data in equivalency units. In the equivalency form the data can be aggregated within each impact category (Owens, 1996).

LCI results in equivalency units = equivalency factor x LCI result ………………….. (1)

In algebraic terms:

$y = a \cdot x$ ……………………………………...……………………………………….. (2)

Equivalency approach assumes a linear relationship between the amount of an emitted compound and its resulting impact. Typically this relation reflects a curve not a straight line.

Inherent Chemical Properties (Toxicity, Persistence, and Bioaccumulation) Approach

In this approach inventory data are aggregated based on inherent chemical properties associated with the material emitted such as toxicity, carcinogenicity, persistence, and bioaccumulation.

Generic Exposure and Effects Approach

This approach is designed to estimate potential impacts based on generic environmental and human health exposure and effect information.

Site Specific Exposure and Effect Approach

This approach is used to determine the actual impacts based on site-specific fate, transport and impact information. It is a complex approach and only possible when detailed site-specific information is available, e.g. emission values, ambient concentrations, exposure pathways, and duration and fluctuation in exposure. Some believe that this level is beyond LCA.

For each impact category the first task is to select relevant receptors in a given impact chain. The receptor does not need to be the highest order impacts in the impact chain, it could be midpoint as well as endpoint. For instance change in climate may be chosen as a receptor (midpoint), even though climate effects will be an intermediate impact engendering further impacts along the chain.

When emitted, a compound is distributed in the environment. The distribution can be restricted to one environmental compartment or partitioning between compartments (air, water, soil) can also take place depends on the properties of the compound and those of the specific environment (Potting, 1999). Because of dispersion within one compartment, most emissions will be diluted to some degree. In some cases, however, accumulation takes place because of bioaccumulation, or physical and chemical processes like sedimentation and deposition. The compound may be immobilized through irreversible binding or very strong adsorption. Also it may be removed from the environment to some degree by chemical or biological degradation.

2.3.3.3 Valuation (Weighting)

Valuation is the qualitative or quantitative step in which the relative importance of the different impact categories are weighted in relation to each other. Each impact category is weighted according to the relative seriousness of that problem. The prioritizing between different impact categories depends on the values applied by the person or the panel of experts who want(s) to weight the impact. To varying degrees valuation occurs at multiple points throughout the entire LCA process. Many LCA applications require that the final result consists of a single figure or environmental index which allows direct comparison of different products or options for reducing environmental impacts. Once the scores for each impact category have been multiplied by their appropriate weighting factors, all the scores can be added together to provide an overall environmental index (SETAC, 1993a, Volkwein, 1996).

Valuation is highly subjective and controversial process. The assignment of relative weights to the categories is inherently subjective and not purely scientific task. There is a high demand for the development of a generally applicable set of weighting factors, which can be applied for all types of products or services. A generic weighting set is an array of pre-calculated valuation factors for LCA impact categories revised from time to time. The advantages of generic sets of valuation factors include (SETAC, 1993a, SETAC 1996):

- Using generic weighting factors will allow for comparison of the outcome of two or more LCA studies due to reproductively.
- A weighting procedure is time and money consuming, developing a generic set for a certain time range is cheaper.
- LCA results using generic weighting sets are easier to comprehend, since the procedures for setting the weights are clearly documented.

However, the desirability for the general set of weighting factors is not generally accepted. According to ISO 14042, weighting is not allowed for comparative assertions disclosed to the public, but the results can be weighted afterwards outside the ISO umbrella. Weighting can be conducted in three ways (Udo de Haes, 1999, Vogtlander, 2000):

- Weight the negative value of the damage (impact)
- Weight the required effort to prevent the damage
- Weight the required effort to repair the damage

The third option is not the desired option from the sustainability point of view. So weighting can be conducted according to the first (impact) or second (prevention) options.

Various methods have been suggested to conduct the valuation. These methods are classified into one of the following (Sonnemann, 2004, Pennington, 2004):

- Distance to target methods (where weighting results are related to target levels)
- Willingness-to-Pay Method and other Monetary methods (all methods which have a monetary measure involved in the weighting factors)
- Panel methods (a group of methods where the relative importance of damages, impact categories or interventions is derived from a group of people through surveys).
- Proxy methods
- Technology abatement methods
- Social and expert methods

For example, the Eco-Indicator 99 method uses a panel weighting approach, while the EDIP 97 method uses a distance-to-target method applying potential reduction targets (Dreyer, 2003). It is of great importance that theses approaches are optimized and standardized as much as possible. The relative desirability for these methods depends on various criteria like completeness, transparency, content and practicality, objectivity, and repeatability. Transparency refers to the extent to which a method is easy to understand and reproduce. Practicality includes the level of simplicity and cost of applying the method. Comprehensiveness indicates that the approach must be capable of deriving weights for at least the most important impacts (Powell, 1996).

Distance-to-Target (DtT) Methods

Several weighting methods relate the weighting factors to some sort of target. These methods are called distance-to-target (DtT) methods. The underlying premise is that a correlation exists between the seriousness of an effect and the distance between the current and target levels. For example, if acidification must be reduced by a factor of 5 and global warming by a factor of 10 to achieve sustainability then global warming is considered as twice as serious. The targeted reduction factors are the relative. Targets could be politically or scientifically based. Targets could be standards or scientifically derived sustainable levels (Walz, 1996). The equation is:

$$Wi = 1/ Ti \quad (3)$$

Where,

wi is the weighting factor and Ti is the target.

The targets are always assumed to be equally important. The method ranks impacts as being more important the farther away socity is from achieving the desired standard for that pollutant. A disadvantage of the DtT approach is that the emission standards may be based on what is politically achievable rather than what is scientifically desirable (Powell, 1996).

Willingness to Pay (WtP) Method

The principle of monetization is to attach monetary values to each impact category. All contributions to these impacts are translated into numbers with the same unit e.g. $. Monetization method is used as an umbrella term for all methods that have a monetary measure as the unit for weighting factors. Within the monetary method a number of methods can be further distinguished such as willingness to pay (WtP), damage costs, cost-benefit analysis, damage shadow costs, and emission prevention costs (SETAC, 1996). WtP is the amount of money a consumer would be willing to spend to secure an environmental benefit. An example may be the costs of reducing emissions to a decided emission limit. The marginal cost for removing the pollutant to the emission limit can be seen as the monetary value the society puts on the pollutant. A society's WtP may be derived from political and governmental discussions. Another way of deriving a social price is to look at green taxes. If there are taxes on emissions, theses taxes may be seen as the society's WtP for that specific pollutant (SETAC, 1996, SETAC, 2002, U.S. EPA, 1995).

Panel Methods

Panel methods are increasingly important. Panels can play a role in establishing a generally applicable set of weighting factors. It is recommended to form the panel from a cross section of interested parties, possibly with different view points. It can include environmental consumers, and business groups, who reflect the relevant scientific and social options. A disadvantage of this approach is that the results are non-repeatable (Powell, 1996, SETAC, 2006).

Proxy Methods

These methods use one or a few quantitative measures stated to be indicative for the total environmental impact to generate the weighting factors. These methods do not give a comprehensive picture of the environmental impacts (SETAC, 1996).

Technology Abatement Methods (Environmental Control Costs)

These methods lean on the technological options for reducing environmental burden. The weights from the environmental control cost are derived from the expenditure necessary to control environmental damage that is control costs. If it cost $2 to control one unit of pollutant A and $1 top control pollutant B, then A has a weight twice than of B (Powell, 1996).

2.3.3.4 Grouping

Grouping is a qualitative or semi-quantitative process that involves sorting and/ or ranking. In some cases it is useful to group impact categories that are conceptually related e.g. grouping impact categories that relate to human health. Farther than grouping the ISO 14043 standard suggests that the impact categories may be ranked on an ordinal scale (e.g. low, medium, or high priority). Ranking could be used to select or screen a set of impact categories. For example, if global effects are decided to be significantly more important than local effects, then we may only select global impact categories for further consideration (SETAC, 2002).

2.3.3.5 Normalization

Normalization is an optional element within impact assessment which is relating all impact scores to a reference value. The normalized score (Ni) is calculated by dividing the impact score (Si) by the reference value (Ri), as the following (SETAC, 1996):

$$Ni = Si/ Ri \qquad (4)$$

Normalization can be performed at different phases of LCA structure: after LCI, after LCIA, or as part of valuation (SETAC, 1996). The reference value could be developed based on geographical scale, temporal scale, distance to political target, or environmental quality objectives (EQO) (Erlandsson, 2003). EQO indicate environmentally acceptable conditions that can be regarded as ecologically sustainable. In order to apply EQO it is necessary that the critical load is expressed as a mass flow, which is then can be used for normalization of the most common impact categories. The environmental critical loads should not be exceeded.

2.3.4 Interpretation

The objective of the interpretation step is to identify opportunities to reduce energy use, resources consumption or environmental emissions throughout the entire life cycle of the product, process, or activity. In this step the results of the LCI and LCIA steps are analyzed, conclusions are reached and findings are presented. Tables and graphical displays are used as tools for communicating the results. Prioritizing the recommendations is an essential step in the interpretation step. Among the straightforward and efficient ways to establish prioritization is to rank each recommendation on a +/- scale where ++ being the most desirable score and – being the least desirable score. As the interpretation stage is currently defined in ISO 14043, it includes the identification of significant issues raised by LCI and LCIA, a quality evaluation of the results from the LCI and LCIA and conclusions and recommendations (Bishop, 2002, Graedel, 1998).

2.4 Analytical Hierarchy Process (AHP)

It is more often the case that people are asked to make decisions that will satisfy several, potentially conflicting, interests. Environmental and natural management problems are by nature, multiobjective, fitting environmental quality against economic and other consideration. For most such problems there exists a hierarchy of objectives, subojectives, and sub-subobjectives and so on. Multiobjective decision problems can be classified into two general categories (Revelle, 1997):

(1) Problems for which the potential alternatives are predefined (discrete), and

(2) Problems for which the alternatives are not predefined (continuous).

There are separate multiobjective methods to deal with these two different categories of problems. In predefined (discrete) problems, the selection is from a list of known alternatives. Methods to deal with decisions with known alternatives are referred to as multiple criteria decision making (MCDM) methods. MCDM methods include: the analytical hierarchy process (AHP) and the simple multattribute rating technique (SMART) (Revelle, 1997). For both AHP and SMART methods, a decision maker's preferences are an integral part of the solution process. Discrete quantitative methods require information on the priorities of decision makers as well as on the scores of the criteria (Janssen, 1992).

The analytic Hierarchy Process (AHP) is a systematic procedure for demonstrating a problem with predefined alternatives in a hierarchical structure, based on the values of the decision maker(s). The AHP organizes basic reasoning by decomposing a problem into its constituent parts and then using simple pairwise comparison to develop priority ranking in each level of the hierarchy. The AHP does not need the conversion of objectives into common unit or the creation of unitless indices. Fundamentally, the AHP works by developing priorities for alternatives and the criteria used to judge the alternatives. The aim of AHP is to derive quantitative weights from qualitative statements on the relative importance of criteria obtained from comparison of all pairs of criteria (Janssen, 1992). Three important components of the AHP are (Yang, 1997):

- Problem decomposition: the problem is decomposed into elements (which are grouped on different levels to form a hierarchy) and each element is further decomposed into sub-element until the lowest level of the hierarchy.

- Comparative Analysis: pairwise comparison between elements at each level to measure the relative importance.
- Synthesis of priorities: the priority weights of elements at each level will be computed using eigenvector.

Decomposition

The creation of the hierarchy is one of the most valuable steps in the AHP because it can guarantee the inclusion of all objectives in the evaluation process. The construction of the hierarchy preserves the relationships among objectives and subobjectives. There is no limit to the number of layers in a hierarchy, for example, the subobjective could own sub-objectives. The top level of hierarchy represents the overall objective, the lowest level enumerates the alternatives under consideration and the intermediary levels are attributes and subatributes to be considered in satisfying the overall objective (Revelle, 1997, Climaco, 1997).

Comparative Analysis

The AHP employs a pairwise comparison to determine the relative weights or priorities of the decision maker for the objectives and the alternatives. Comparisons can be made according to preference, importance, or likelihood which ever is most appropriate for the element considered. For each pair of objectives on the same branch of every level of the objective hierarchy, the decision maker is asked to indicate the intensity of his or her preferences for one objective with respect to the second in the form of a number. The scale for comparison among pairs of elements consists of verbal judgments ranging from equal to extreme (1, 3, 5, 7, 9). Saaty proposed the following nine-point scale to express difference in importance (Janssen, 1992): 1 for equally important, 3 for moderately more important, 5 for strongly more important, 7 for very strongly more important and 9 for extremely more important. Intermediate values (2,4,6,8) can be used if it is too difficult to choose between two successive classes. The criteria are compared pairwise with respect to their importance. The notation used for these comparisons is aij, where the value of aij is the degree to which i is preferable to j. These pairwise comparisons can be represented as a matrix A, where in the matrix each value aij indicates how more important row heading i is than column heading j. An element is equally important when compared with itself, so where the row of A and column of A meet insert 1. Elements of the matrix diagonal are always unity.

Since the comparisons are assumed to be reciprocal, the decision maker needs only to answer (n(n-1)/2 comparisons. We need n-1 pairwise comparison judgments so that each element is represented in the data at least once (Saaty, 1990). If quantitative data is available the comparison values can be the ratio of the scores themselves.

Synthesis of Priorities

Once a pairwise comparison is generated, the AHP derives the weights or priories for the relevant elements by solving for the principal eigenvector of the matrix. The relations between the weights wi and judgment aij are simply given by the following equation (Saaty, 1980):

$$w_i/w_j = a_{ij} \qquad (5)$$

Associated with a square matrix are its eignvector and corresponding eignvalues. The eigenvector provides the priority ordering, and the eignvalue is a measure of the consistency of the judgment. The principal eignvector becomes the vector of priorities when normalized (Saaty, 1990):

$$Aw = \lambda max\ w \qquad \text{……(6)}$$

By convention, the comparison of strength (priorities) is always of an activity appearing in the column on the left against an activity appearing in the row on the top. The normalized principal right eigenvector of the matrix represents the priority values of those criteria. Assume that n activities are being considered. Let C1, C2, ………., Cn be the set of activities. The quantified judgment on pairs of activities Ci, Cj are represented by an n-by-n matrix, A= aij (i,j =1, 2, ……, n). The pairwise comparison of four activities:

$$\begin{array}{ccccc} & C1 & C2 & C3 & C4 \\ C1 & 1 & a_{12} & a_{13} & a_{14} \\ C2 & \frac{1}{a_{12}} & 1 & a_{23} & a_{24} \\ C3 & \frac{1}{a_{13}} & \frac{1}{a_{14}} & 1 & a_{34} \\ C4 & \frac{1}{a_{14}} & \frac{1}{a_{24}} & \frac{1}{a_{34}} & 1 \end{array} \qquad \text{……(7)}$$

Thus the matrix A has the form

$$\begin{bmatrix} 1 & a12 & & a1n \\ \frac{1}{a12} & 1 & & \\ & & & \\ \frac{1}{a1n} & & & 1 \end{bmatrix} \qquad \text{……(8)}$$

Now we need to assign weighting factors w1, w2, ……wn for C1, C2, …..Cn. For perfect consistency, the relation between the weights wi and the judgment aij are given by

$\frac{wi}{wj} = aij$ for i,j = 1,2, , n. To obtain the weights w=(w1, w2, …., wn) based on A is an eigenvalue problem:

$$Aw = \lambda max\ w \quad \text{(9)}$$

Where,

λmax is the largest or principal eigenvalue of A. The calculation process can be summarized as following (Solnes, 2003):

1. Each factor is compared with all other factors on a numerical scale according to importance to obtain the weights, wi, to be associated with each factor, form the comparison matrix A.
2. For each of A's columns, divide each entry by the sum of entries of the corresponding column. This yield a new normalized matrix in which the sum of each column vector is 1.0
3. By forming the average value of all elements in a raw, an estimate of the best value for the vector of the weights is obtained.
4. Check the consistency of the solution obtained in 3. Aw= λmax w, λmax should not differ much from n.
5. Repeat the same process for each of the factors for all the alternatives to obtain the scores or values of the utility functions.

Consistency

The eignvalue is a measure of the consistency of the judgment. Consistency means that if apple is twice as preferable as orange and orange is three preferable as banana, then apple must be six times as preferable as banana (Saaty 1990). Complete consistency implies that relationship of the type aij = aik . akj hold for all sets of three criteria. When all pairwise comparisons in the judgment matrix A are absolutely consistent, then Aw=nw, where w is an eigenvector of associated eigenvalue n (Schmoldt, 2001). Because the matrix multiplication occurs on the right, w is called a right eigenvector. As judgment become inconsistent, small changes occur in the aij, and A becomes inconsistent, then multiple eigenvectors and eignvalue solutions exist for Aw = λmax w. The largest eigenvalue remains close to n as long as changes in the aij are small and A does not become too inconsistent. The closer λmax is to n (the number of activities in the matrix) the more consistence is the result. The degree of inconsistency can be expressed by the consistency index (CI) , CI= λmax- n/n-1. CI is equivalent to the standard deviation of the evaluation error and the mean deviation of each comparison element aij from the true ones. The consistency index of a randomly generated reciprocal matrix from the scale 1 to 9, with reciprocals forces is called random index (RI). The following table gives the order of the matrix (first raw) and the average RI:

1	2	3	4	5	6	7	8	9	10	11	12	13	14
0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57

The ratio of CI to the average RI for the same order matrix is called the consistency ratio (CR). A consistency ratio of 0.10 or less is considered acceptable (Saaty, 1990).

After all pairwise comparisons for all A matrices are determined to be sufficiently consistent, the weight of each objective is calculated. The weights are then used to calculate the score of each alternative. The alternative score is calculated by first multiplying each value by its appropriate weight followed by summing of the weighted scores for all criteria. The AHP method can not only be used to assess weights but can also be used to assess the performance of alternatives by pairwise comparison of the alternatives. The AHP method is relatively simple and straightforward to use, available as computer software package (expert choice), and it is flexible enough to handle a wide Varity of problem types.

2.5 Assessment Indicators

2.5.1 Global Warming (Climate Change)

Global warming or the greenhouse effect is the effect of increasing temperature in the lower atmosphere. Greenhouse gases are called like this because they trap heat in the atmosphere in much the same way that glass helps to trap solar energy in a greenhouse. The mechanism that causes global warming effect consists essentially of infrared absorption in the spectral region between 10n and 15 um. Most of the Earth's atmosphere is transparent to both incoming (ultraviolet) and outgoing (infrared) radiation, but some trace gases, notably water vapor (H_2O),carbon dioxide (CO_2), methane (CH_4), nitrous dioxide (N_2O), and chlorofluorocarbons have molecular structures that absorb outgoing IR-radiation resulting in the greenhouse effect. For a substance to be regarded as a global warming contributor, it must be a gas at normal temperature and either be able to absorb infrared radiation and be stable in the atmosphere with long residence time or be of fossil origin and converted to CO2 in the atmosphere (Ghassemi, 2002). The criteria for classification of a substance as making a direct contribution to man-made global warming are that at normal temperature and pressure it is a gas which absorbs infrared radiation or is broken down to CO2; remain present for a period which enables its effect to be of some significance. The expected contribution to warming from a greenhouse gas is calculated on the basis of a knowledge of it's specific IR absorption capacity and expected lifetime in the atmosphere (Houschild, 2001). Global warming potential (GWP) developed by IPCC (International Panel on Climate Change) are generally used for characterization. Global warming potential is calculated for substances using carbon dioxide as a reference.

$$\mathbf{GWP_i} = \frac{\textbf{Contribution from i to global } \boldsymbol{warming} \textbf{ over x years}}{\boldsymbol{Contribution} \textbf{ from } \mathbf{CO_2} \textbf{ to global warming over x years}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The IPCC figures are calculated for three time horizon, 20, 100, and 500 years (SETAC, 1996). Total GWP is calculated by multiplying a substance mass emission (mi) by its GWP and adding them together:

$$GWP = \sum_i^n (m_i \; x \; GWP_i) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Secondary and tertiary effects of global warming have been identified such as increasing sea level and instability in climate. Because the average troposphere lifetime of all greenhouse gases exceeds the tropospheric mixing time (about a year), it is not important where the emissions occur (global impact). It is recommended to use the longest time horizon (500 years) in LCIA in order to take into account possible negative effects for future generations.

2.5.2 Stratospheric Ozone Depletion

Decomposition of the stratospheric ozone layer will cause increased incoming UV-radiation leading to impacts on humans such as increased levels of skin cancer, cataracts and decreased immune defense but also impacts on natural organisms and ecosystems. The decomposition of ozone is enhanced by the stratospheric input of anthropogenic halogenated compounds most notably the family of compounds known as chloroflurocarbons (CFCs). CFCs are nonreactive, nonflammable, nontoxic, noncorrosive molecules whose properties are ideally suited for purpose such as refrigeration, air conditioning, manufacturing foam cleaning electronics, and propelling the contents of aerosol cans. For a substance to be considered as contributing to ozone depletion, it must (Ghassemi, 2002):

1. be a gas at normal atmospheric temperature
2. contain chlorine or bromine
3. be stable within the atmosphere for several years

Ozone depletion potentials (ODP) have been proposed by the World Meteorological Organization (WMO) for a number of halogenated compounds. The ozone depletion potential (ODP) is calculated by multiplying the amount of the emission (Q) by the equivalency factor (EF).

$$ODP = Q.EF \quad \text{...(12)}$$

The equivalency factor is defined as (Ghassemi, 2002):

$$\mathbf{EF_{ODP}} = \frac{\text{calculated global ozone depletion caused by substance i}}{\text{calculated global ozone depletion caused by CFC}-11} \quad \text{............................(13)}$$

CFC was chosen as reference substance because it has been well studied and has been one of the most important ozone depletion substances (Hauschild, 1998).

2.5.3 Photochemical Smog

Photo-oxidant formation is the formation of reactive chemical compounds such as ozone by the action of sunlight on certain primary air pollutants in the presence of nitrogen oxide (NO_x) . Exposure of human to ozone may result in eye irritation respiratory problems, and chronic damage of the respiratory system. Exposure of plants to ozone may result in damage of the leaf surface, leading to damage of the photosynthetic function, dieback of the leaves and finally the whole plant (Jensen, 1997). Photochemical ozone formation proceeds through the following four steps (Bruijn, 2002):

1. Reaction between VOCs or CO and OH to form peroxy radicals
2. The peroxy radicals oxidize NO to NO_2
3. NO_2 is split by sunlight with formation of NO and release of oxygen atoms
4. Oxygen atoms react with molecular oxygen to form ozone.

For VOC to form peroxy radicals on atmosphere oxidation it must contain oxygen and double bounds. The photochemical ozone formation can be quantified by using photochemical ozone creation potential (POCP) for organic compounds. POCPs for organic compounds are expressed as ethylene (C_2H_4) equivalents i.e. their impacts are expressed relative to the effect of C_2H_4 (Jensen, 1997).

$$\text{Photochemical Ozone Formation} = \sum_i \text{POCP}_i \cdot m_i \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (14)$$

Where,

mi is the mass of substance i released.

2.5.3 Acidification

Acidifying pollutants have a wide variety of impacts on soil, groundwater, surface waters, biological organisms, ecosystems and materials. The major acidifying pollutants are SO_2 and NO_x. Substances are considered to have acidification effect if they result in:

1. Supply or release of hydrogen ions (H^+) in the environment
2. Leaching of the corresponding anions from the concerned system.

The acidifying substances from the troposphere are added to exposed systems by (Houschild,1998):

1. Dry deposition; i.e. deposition of air-borne substances in the form of particles or gases on vegetation or soil and water surface.

2. Wet deposition (acid rain), i.e. the dissolving of air-borne substances in water and their deposition in terrestrial or aquatic systems in precipitation.

The acidification potential (AP) can be estimated as SO2 equivalents (Jensen, 1997).

$$\text{Acidification} = \sum_i \text{AP}_i \cdot \text{m}_i \quad \text{(15)}$$

Where,

mi is the mass of substance i released.

$$AP_i = \frac{n}{2MW} X64.06 = \frac{n}{MW} X32.03 \quad \text{(16)}$$

Where,

MW is the molecular weight of the substance emitted,

n is the number of hydrogen ions released in the recipient as a result of conversion of the substance, and

64.04 g/mol is the gram molecular weight of SO_2.

The acidification potential expresses the largest possible contribution to acidification by the substance.

2.5.4 Eutrophication

Eutrophication (or nutrient enrichment) of aquatic and terrestrial ecosystems can be caused by surplus nitrogen, phosphorus and degradable organic substances. The primary effect of surplus nitrogen and phosphorus in aquatic ecosystems is growth of algae (Jensen, 1997). The secondary effect is decomposition of dead algae and organic anthropogenic organic substances. The decomposition of organic material is an oxygen consuming process leading to decreasing oxygen saturation and sometimes anaerobic conditions (Jansen, 1997). Eutrophication is generally measured using the concentration of Chlorophyll-a in the water (Ghassemi, 2002). Eutrophication potential (EP) measured as a characterization factor to assess and aggregate the intervention for the impact category eutrophication.

$$Eutrofication = \sum_i EP_i X m_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

The reference substance PO_4^{3-} is used to create eutrophication potentials. EPs are based on the average chemical composition of aquatic organisms $C_{106}H_{263}O_{110}N_{16}P$. One mole of biomass requires 16 moles of N and 1 mole of P. The contribution to eutrophication of P is 1. The contribution to eutrophication of N is 1/16. One mole of P contributes as much to the formation of biomass as 16 moles of N (Bruijn, 2002) .

2.5.5 Resource Depletion

Depletion of resources occurs when materials and energy are added as inputs to a process. We are more concerned about nonrenewable resources such as minerals and fossil fuels than renewable resources such as agricultural crops and wind energy. Abiotic resources are natural resources such as iron ore, crude oil, and wind energy which are regarded as non-living. Three types of abiotic resources can be distinguished: deposits, funds, and flows. Deposits such as mineral ores and fossil fuel are considered to be limited resources because they are not renewable within a relevant time horizon. Funds are resources that are can be regenerated within human lifetime like groundwater and soil. Flows are resources that are constantly regenerated, such as winds, river water and solar energy (Jensen, 1997, Bruijn, 2002).

$$Abiotic\ Depletion = \sum_i ADP_i X\ m_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

2.5.6 Land Use

A distinction is often made between land occupation and transformation i.e. changing its quality. Land occupation (in m^2 /y) leads to an increase in land competition. Land transformation (in m^2) changes the quality of the land itself as well as that of the surrounding area or region (Bruijn, 2002).

$$\text{Land Competiotion} = \sum_s U_s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(19)}$$

where Us is the land use of state s attributable to the functional units expressed in m^2/yr.

2.5.7 Human Toxicity

This impact category covers the impact on human health of toxic substances present in the environment. The potential effect on humans depends on the actual emission and fate of the specific substances emitted to the environment. A few important examples of man-made toxic impacts on humans can be cited (Houschild, 1998):

1. Metals such as lead, cadmium and mercury, which are emitted from a large number of different processes and which cause acute and especially chronic effects of various kinds.
2. Persistent organic substances (i.e. substances of low degradability) such as PCBs (polychlorinated biphenyls), PAHs (polycyclic aromatic hydrocarbons), and dioxins, which accumulate in adipose tissue and which cause various adverse effects.
3. Organic substances which emulate the female sex hormone estrogen on sensitive receptors in large quantities as plasticizes in PVC.

4. Volatile organic compounds, oxides of sulfur and nitrogen oxides, which are emitted from combustion processes and which cause effects in persons with respiratory ailments.

Humans are exposed to the impacts of pollutants in the environment in a number of different ways. Direct exposure can occur via: inhalation and ingestion of polluted groundwater, surface water and soil. Indirect-exposure can also occur via ingestion of plants which have been exposed to pollution. The classification of a substance as toxic is based on the following properties (Houschild, 1998):

1. Toxicity (determined empirically in animal experiments)
2. Persistence (determined empirically in biodegradability tests)
3. Bioaccumulation potential (determined empirically or estimated on the basis of the substance octanol-water partitioning coefficient

Human toxicity potential (HTP) can be determined by

$$HTP_i = \sum F_i x\, T_i x I_r x E_r \quad \ldots\ldots\ldots\ldots \text{(20)}$$

where,

Fi : a fate factor, representing media transport of substance i

T_i : the transfer factor, the fraction of substance i transferred from final compartment to exposure route, r

Ir : an intake factor, representing human intake via exposure route r

Er: an effect factor, representing the toxic effect of intake of a substance I via exposure route r

2.5.8 Ecotoxicity

This impact category covers the impacts of toxic substances on aquatic, terrestrial, and sediment ecosystems. Ecotoxicological impacts depend on exposure to and effects of chemical and biological substances. The ecotoxicity potential (ETP) can be determined by (Braijn, 2002):

$ETP_i = \sum F_i x E_i$ ……………………………………………………………… (21)

where,

Fi : a fate factor, representing intermedia transport of substance i

E_i : an effect factor, representing the toxic effect of exposure of a given ecosystem to substance i.

CHAPTER III

TOOL DEVELOPMENT

3.1 Overview

The GREENOMETER-7 is a building assessment tool that is intended to be used at the conceptual design phase to measure and improve the sustainability of the building over its entire life cycle. A sustainable building reserves resources (energy, water, and materials), reduces waste and pollutants generation, and has minimum impact on human health and the environment over its entire life cycle; moreover, it provides occupants with a comfortable environment and it is affordable. Many sectors are involved in sustainable building design including the environmental, economic, social, and health sectors. The aim of building assessment tools, including GREENOMETER-7, is to integrate as many factors from the various sectors in an optimal way to assist designers in producing sustainable buildings. GREENOMETER-7 considers all stages of the building life cycle in the assessment.

As the name implies, GREENOMETER-7 is a meter to measure building sustainability. GREENOMETER-7 measures the sustainability of the building at two levels: micro-assessment and macro-assessment. The two levels include a total of more than 100 indicators that cover various sustainability determinants with concentration on the environmental, economic, and human health determinants. GREENOMETER-7 uses a 7-degree scale in measuring sustainability. The seven degrees are 0, 1, 2, 3, 4, 5, and 6; where 0 means highly unsustainable, 3 means neutral (the benchmark), and 6 means highly sustainable (Figure 2). Both the micro- and macro-assessment levels have categories and indicators, and these categories and indicators are ranked using the 7-degree scale. The micro-assessment level generates a sustainability micro-score and the macro-assessment level generates a sustainability macro-score. Both scores are used to obtain the building overall sustainability score (Figure 3).

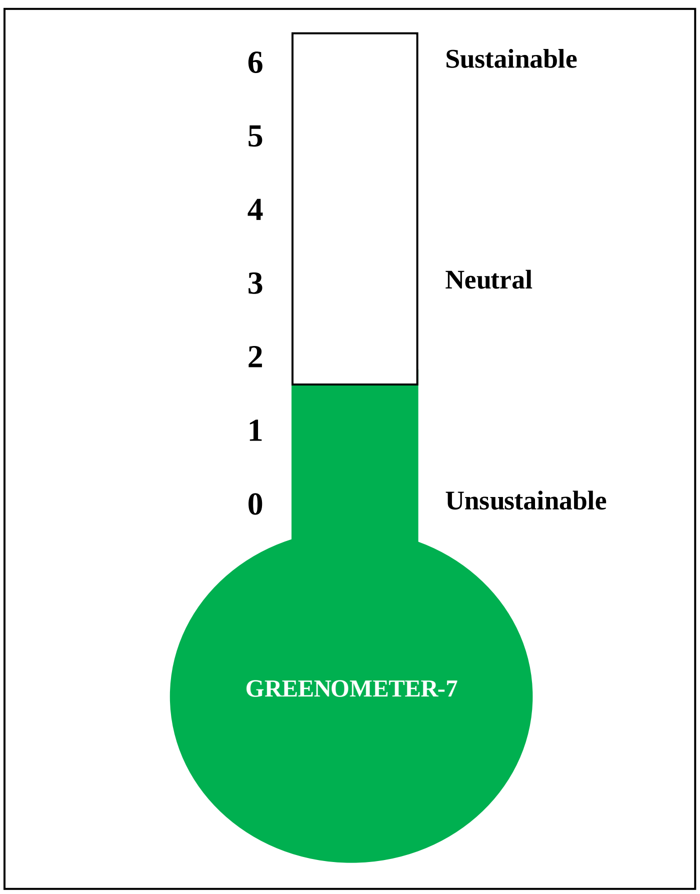

Figure 2: The 7-degree scale of GREENOMETER-7

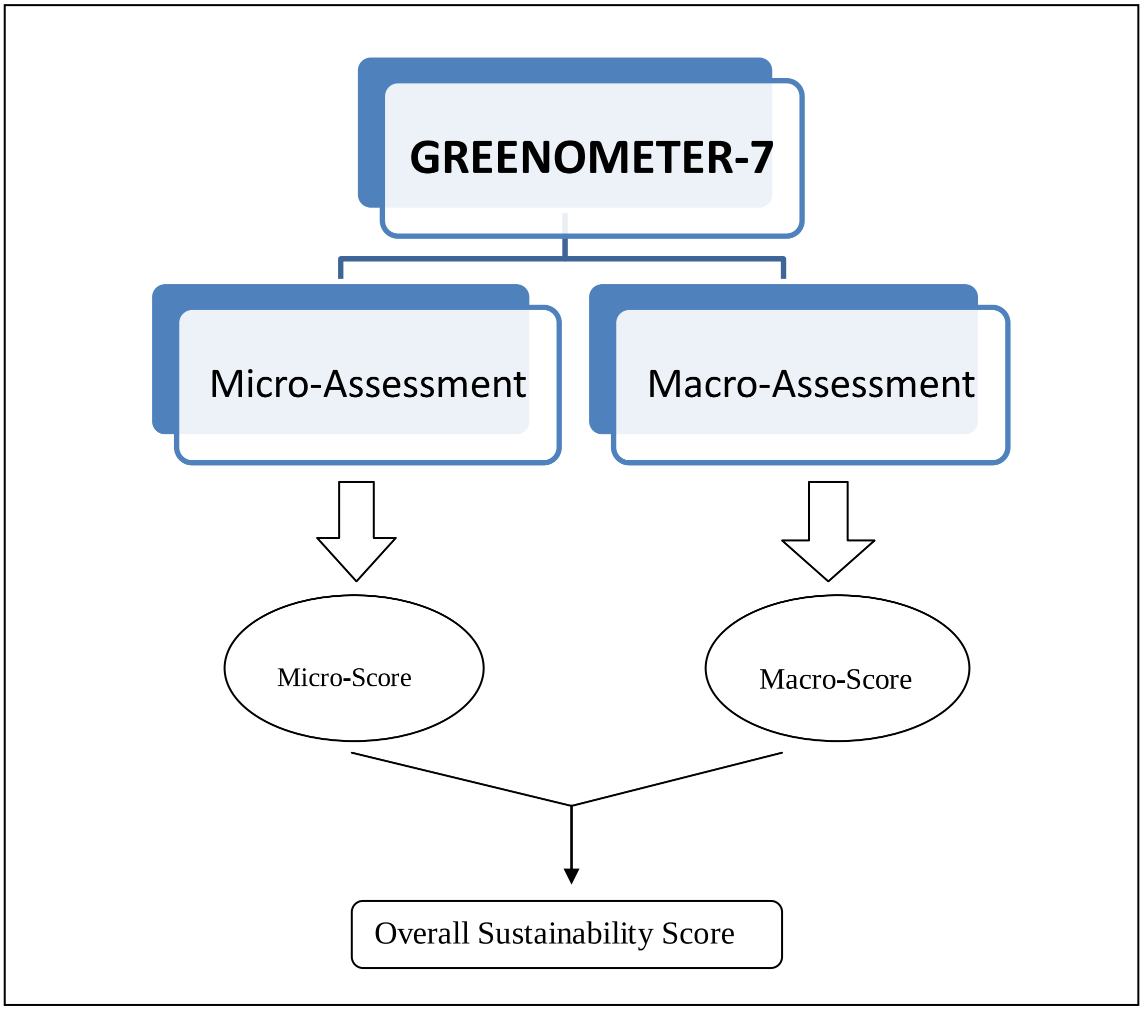

Figure 3: Flowchart of GREENOMETER-7 levels and scores

In order for a building assessment tool to be useful, it needs to be introduced as early as possible. Making changes before the building is built is easier and less expensive to implement. On the other hand, making changes on an existing building can be impractical, expensive and/ or difficult to implement. GREENOMETER-7 is intended to be used in the conceptual design phase to offer the designer more flexibility to suggest and implement as many changes as needed. Buildings have an extremely long lifetime, often more than 50 years. The conceptual design phase is where most of building materials, energy, environmental loadings, and other consequences are committed. Although the impacts of the building on the environment are not the same for all stages of its life cycle, all of theses stages generate impacts and must be analyzed when assessing the sustainability of the building. Using the tool in an early stage allows for improvements, it allows the designer to explore different options and alternatives in materials, systems, and design methods with minimum effort and cost. It uses simulation to estimate the life cycle sustainability of a proposed building. It allows the designer to make changes in materials and design (preferably one at a time) and track the impact on the overall score and sub-scores. Also it allows for identifying the reasons factors responsible for unacceptable scores.

GREENOMETER-7 can be used to evaluate different types of buildings (residential, office building, commercial, institutional). A general sustainability tool is presented here as a template; then, if needed, it can be customized for specific application. For example, the following sustainability assessment tools could be derived from the template GREENOMETER-7 tool:

- GREENOMETER-7 [Residential]: for residential buildings
- GREENOMETER-7 [Office Building]: for office buildings
- GREENOMETER-7 [Commercial]: for commercial buildings
- GREENOMETER-7 [Institutional]: for institutional buildings

This chapter covers the micro-assessment level of GREENOMETER-7, while the macro-assessment level is covered in the next chapter.

3.2 Micro-Assessment

3.2.1 Rules and Principles

GREENOMETER-7 is a tool to measure the sustainability of a building over its entire life cycle, its micro-assessment level is bound by three rules:

- **Gate-to-Gate Assessment (space boundary)**

The tool treats the building site as a system. The assessment is only limited to what is inside the boundaries of the site (system); this why it is called "gate-to-gate" assessment. The only exception to the gate-to-gate rule is in the case of selecting among alternatives. The selection needs to be based on cradle-to-grave assessment of the products. After selecting the best alternative, only the impacts inside the boundaries of the site are considered in GREENOMETER-7. Gate-to-gate assessment makes it easier for the analyst. Only information about the impacts of the product and equipment inside the boundaries of the site are required. The cradle-to-gate analysis is sophisticated and it requires gathering a larger amount of data, since it is not limited to what happens inside the boundaries of the site. GREENOMETER-7 recommends that the selection between alternative building products and materials is carried out based on a cradle-to-grave LCA analysis. After the best alternative is selected, only the impacts inside the boundaries of the site are considered in using the GREENOMETER-7 to measure the building sustainability.

By not incorporating the impacts outside the boundaries of the site, the tool does not ignore these impacts; any impacts caused by activities outside the boundaries of the site are the responsibility of another site. By limiting the assessment to what happens inside the boundaries of the site, it encourages accountability. The owner (or operator) of the building is only accountable for decision he/ she makes. Even though it may seem that everybody is responsible for the sustainability of his/ her site, these decisions may indirectly make improvement on other sites. When selecting among alternatives, cradle-to-grave assessment is required to insure sustainable products are selected. By selecting sustainable products and materials, the designer may not allow unsustainable products and activities coming from other sites to enter the site boundaries, and these decisions indirectly encourage other sites to make their products and services more sustainable in order to market them.

- **Stage Assessment (time boundary)**

GREENOMETER-7 is a building life cycle assessment tool. It considers all stages of the building life cycle. The building life cycle is divided into three stages: construction, operation (including renovation), and demolition. The total stages must equal the life cycle of the building. By making the analysis stage-oriented, it ensures that there is no double counting, and at the same time it allows for evaluating and studying the sustainability of each stage separately. Also, it will allow for presenting the results separately for each stage. The improvements applicable to one stage may not be applicable to another. Since it is a quantitative tool, it is important to know the duration of the impact. The duration of each life cycle stage provides the timing boundary for the assessment.

- **Assessment Class (class boundary)**

GREENOMETER-7 micro-assessment level requires everything to be expressed in terms of one of five available assessment classes for the assessment to be conducted. The five assessment classes are E, L, U, M, and O.

E: for products, material, and equipment entering (E) the site

L: for products, materials, and equipment leaving (L) the site

U: for using (U) the products and equipment for the time period between E and L

M: for maintenance (M) operations on the materials and equipment

O: for other (O) operations that can't be assigned to one of the other assessment classes.

More than one assessment class may apply to the products, materials or equipment. For example, carpet has two assessment classes: E and L. Assessment class E is applicable when the carpet is first installed because it is entering the site. However, assessment class L is applicable when the carpet is removed because it is leaving the site. A washer is an equipment example; it has three assessment classes (E, L, and U). Assessment class E is applicable when the washer is first installed because it is entering the site. Assessment class L is applicable when the washer is removed at its end of service because it is leaving the site. Electricity and water consumption in the use phase are accounted for in the U assessment class.

In summary, the assessment by GREENOMETER-7 micro-assessment level is bound by three questions:

- Only inside the boundaries of the site (where?)
- The duration of a life cycle stage (when?)
- The assessment class (What?)

In addition to the previous rules, the development of GREENOMETER-7 has been guided by the principles of life cycle assessment (LCA), sustainability and multi-objective optimization.

- **Life Cycle Assessment (LCA)**

GREENOMETER-7 has been developed based on the principles of life cycle assessment (LCA). The product in this case is the building itself. LCA requires assessing the environmental impacts of a product from a cradle-to-grave perspective, i.e. from the acquisition of raw materials to the final disposal of products. It begins from initial extraction of raw materials from the earth to final disposal including manufacturing, transport, use, reuse, and recycling. GREENOMETER-7 also requires assessing the building over its entire life cycle, from construction to demolition. LCA consist of four stages: goal definition and scope, inventory analysis, impact assessment, and interpretation. GREENOMETER-7 has similar stages, but it is conducted at two levels: macro-assessment and micro-assessment. Both assessment levels have inventory and interpretation steps. The micro-assessment phase has a profiling step instead of the impact assessment step in LCA.

- **Sustainable Development**

GREENOMETER-7 adopted the principles of sustainable development in identifying the assessment indicators. Sustainable development has three pillars: environmental, economical and social. Similarly, GREENOMETER-7, considers and balances among factors from the environmental, economical, health, and social sectors. A tool that is focused on the environmental sector only is not effective. Designing an environmentally responsible building does not help the environment if the building is not affordable.

- **Multi-Objectives Optimization**

Designing a sustainable building is a problem characterized by multiple objectives. During the design of a building, environmental, economic, and social determinants are involved. It is the aim of the designer to integrate all these determinants in an optimal way in the design to achieve the required building sustainability level. Multi-objective optimization models can assist in green building design. The concept of multi-objective optimization has been used in selecting the categories and attributes for GREENOMETER-7.

3.2.2 Structure

The micro-assessment level has three phases: inventory, impact assessment, and interpretation (Figure 4). The inventory phase has two steps: hierarchy-analysis and "N" determination. The impact assessment phase has two steps profiling and synthesis. The interpretation phase has two steps ranking and valuation (weighting).

In this section the steps of the micro-assessment level will be discussed in more details. The steps of the macro-assessment level will be discussed in the next chapter.

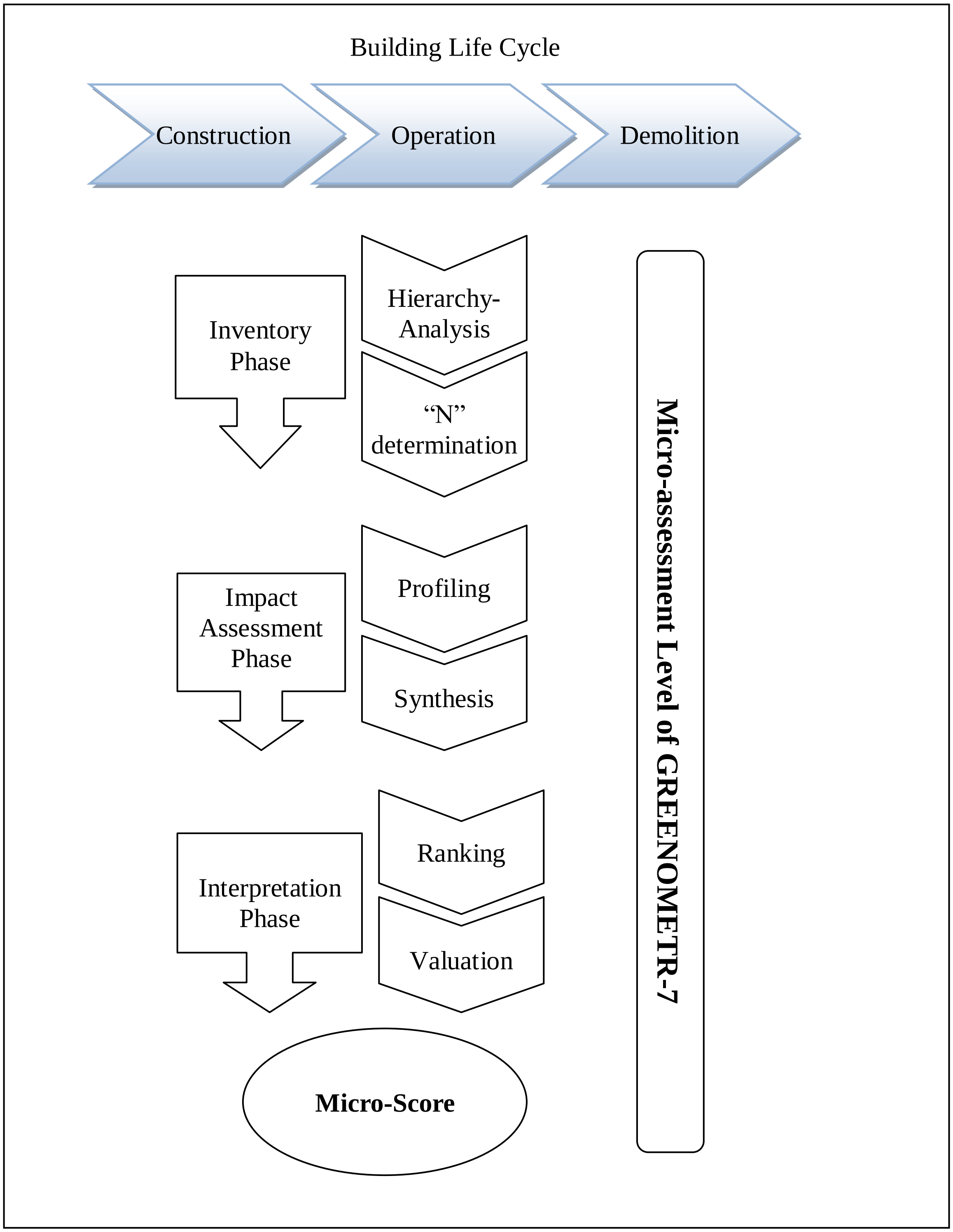

Figure 4: Flowchart of the micro-assessment level of GREENOMETER-7

3.2.2.1 Hierarchy-Analysis

Hierarchy-analysis is the first step in the micro-assessment level, and it is one of two steps in the inventory phase. The goal of this step is to express everything that needs to be considered in terms of one of the five assessment classes (E, L, U, M, and O). A hierarchy-analysis needs to be conducted for each life cycle stage separately. For simplicity, each life cycle stage could be divided into activities, and the activities are expressed on terms of the assessment classes (Figure 5). Considering the expanded life of the building, it is a challenge to count for every major activity that has impacts in all life cycle stages. The designer may have to project for activities that are expected to happen 50 to 100 years, later such as demolition. The building life cycle stages are construction, use (including maintenance and renovation) and demolition. The building life cycle is divided into stages and each stage can be divided into activities. It is critical to include all major activities because if an activity is missing it will not be considered for in the final assessment. The designer expresses each activity into the assessment classes E, L, U, and if needed M and O. The output of this step is a list of the assessment classes of each life cycle stage that may be sub-listed under activities for each stage. The actual assessment is conducted later only for the assessment classes by developing a profile for each. The stages and their activities are assessed indirectly by combining the applicable assessment classes in the synthesis step. The activity assessment is conducted by combining the profiles of all of its assessment classes. The stage assessment is conducted by combining the profiles of all of its activities. The life cycle micro-assessment (building micro-profile) is conducted by combining the profiles of all the stages.

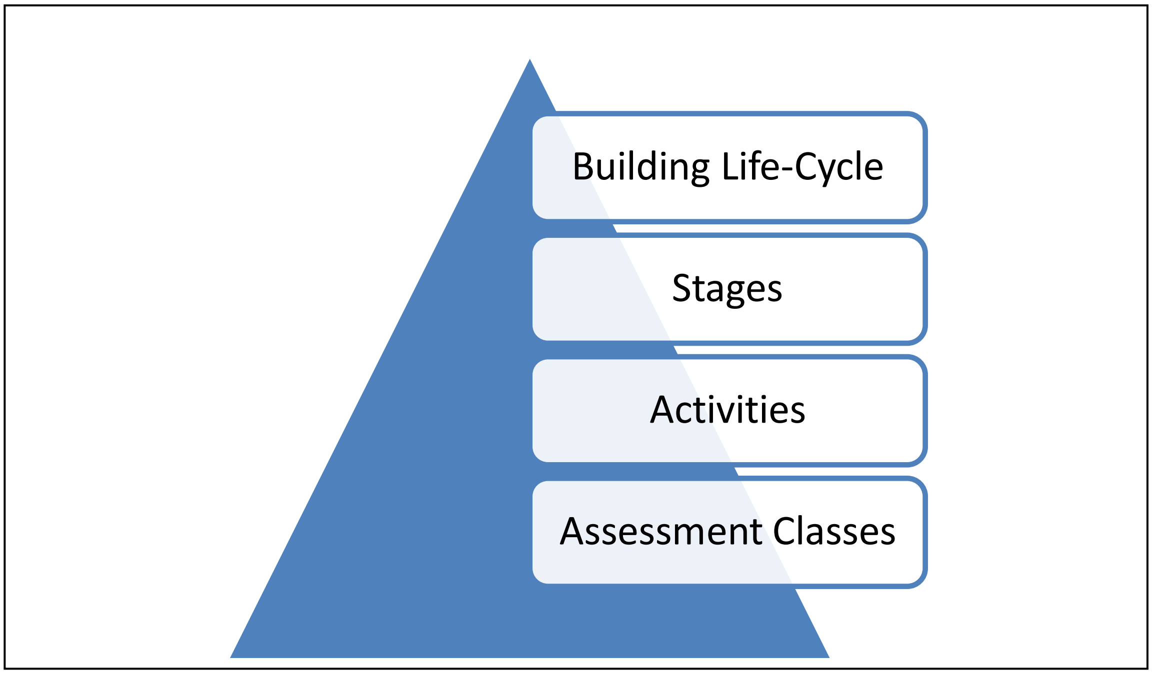

Figure 5: The hierarchy analysis of the micro-assessment level of GREENOMETR-7

3.2.2.2 "N" Determination

In the hierarchy-analysis step the designer develops a list of all the assessment classes of each life cycle stage. In the "N" determination, the second step in the inventory phase, the designer determines the number of functional units applicable for each assessment class identified in the hierarchy-analysis step. This number is called "N". The N value is used in the synthesis step to develop profiles for the activities and stages. It is helpful to know the functional unit for each assessment class before gathering the information so that the designer knows exactly in what unit the data should be provided (i.e., in weight, volume, area). For example, the functional unit for assessment classes E and L for carpet is one square meter. To find N, the designer needs to determine the area of the building that needs to be carpeted. In this case N is the total area of the building since the functional unit is one square meter. The output of this phase is N value for each assessment class identified in the hierarchy-analysis step.

3.2.2.3 Profiling

At this point the designer has developed a comprehensive list of all assessment classes at each life cycle stage (hierarchy-analysis). In the profiling step a profile is developed (or selected from a database, if available) for each assessment class identified in the hierarchy analysis step. It is recommended that a database be developed for the common assessment classes to save time for the designer when conducting the analysis. New profiles need to be developed for the ones with no profile in the database. The actual assessment is conducted only for the assessment classes in the profiling step. The activity profile is obtained by combining the profiles of all of its assessment classes. The stage profile is obtained by combining the profiles of all the activities of that stage. The building profile is obtained by combining profiles its life cycle stages. There are five types of assessment classes: E, L, M, U, and O (Figure 6).

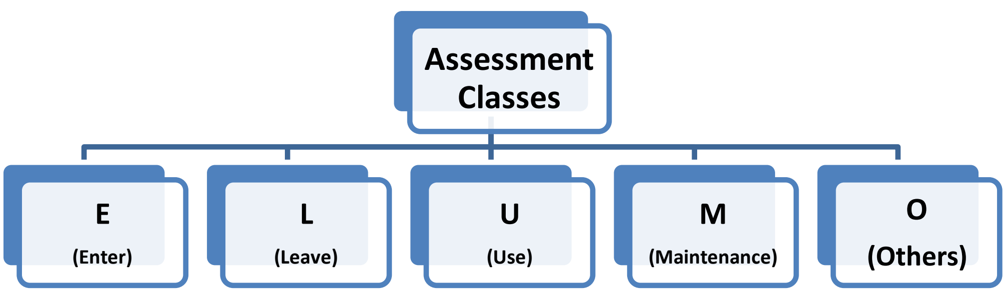

Figure 6: The types of assessment classes at the micro-level of GREENOMETR-7

The profile consists of a list of 11 categories. Each category has its own indicators and attributes. The profiles of different assessment classes are consistent; they have the same categories in the same order so that they can be combined in the synthesis step. The categories are as follows: electricity, fossil fuel, water and wastewater, resources input, resources output, contaminants output-captured, contaminants output-disposal, contaminants output- air, contaminants output- water, contaminants output –soil, and economics.

A functional unit has to be selected for each assessment class in each life cycle stage. The profile has a variable called “N” that represents the number of the functional units applicable in each life cycle stage. If the life cycle is divided into activities, N is the number of functional units applicable to each activity. The value of N is determined for all assessment classes in the inventory. When N is substituted in the synthesis step, the profile indicators and attributes are multiplied by the N value. For example, if 500 kg of material A has been used in the construction phase, then, the value of N will be 500 assuming that the functional unit is 1 kg of material A. Different assessment classes are expected to have different functional units. For example, the functional unit for the E and L assessment classes for carpet can be selected as one square meter while the functional unit for the U profile for the washer can be selected as one hour of operation. The output of this phase is a profile for all assessment classes identified in the hierarchy-analysis phase.

Assessment class X is only considered when the designer is selecting among alternatives to ensure that the decision is based on cradle-to-gate life cycle assessment. Assessment class X considers the impacts (good and bad) of a product outside the boundaries of the site. For products and materials it is recommended to combine the E and L classes in addition to the X assessment class of the alternatives before comparing them (cradle-to-grave assessment). For example, when selecting between two different carpet types, a cradle-to-grave LCA needs to be conducted for each alternative. The LCA is the combination of the E, L, and X classes. On the other hand, for equipment it is recommended to combine the E, U, and L assessment classes in addition to the X assessment class of the alternatives before comparing them. For example, to select between alternative washers, a cradle-to-grave LCA needs to be conducted for each alternative. The LCA is a combination of the E, L, U, and X classes.

- ***Assessment Class E***

Assessment class E reflects the impacts of materials, products, and equipment entering the building site. In profiling E, the attributes are given values for only the time frame from the moment the product/ process/ equipment enters the boundaries of the building site to the point it is completely installed. Any impact from the time it is completely installed until just before it is removed is accounted for in assessment class U. Since it is a gate-to-gate assessment, the focus here is only on what happens inside the boundaries of the site. Any impact outside the boundaries of the site is another site's responsibility. All materials and products have E and L assessment classes and some of them have U and M assessment classes. All equipment has E, U, and L assessment classes; some of them may have M assessment class. So, all materials, products, and equipment have E assessment classes. In the profile the value for each attribute is expressed per one functional unit, i.e. if the functional unit is 100 kg of product A, then each attribute will be assigned a value associated with using the 100 kg. The N value, to be determined in the inventory step, reflects the number of functional units of product "A" that have been used for a specific activity (in one stage) and the value of each attribute will be multiplied by the N value. Functional units for products and materials can be expressed in weight units (e.g. kg or lb), volume units (e.g. letter or gallon), or number of pieces. Functional units for equipment can be expressed by the number of units. N is assigned an initial value of 1 (default) in the assessment class profile. The actual value of N is determined in the inventory step and it is substituted in the synthesis step, where the attributes values are multiplied by N. For example, in the aluminum siding E assessment class (E-siding-aluminum), the functional unit is 1 m2 and the aluminum attribute is assigned 1.63 kg. If 2,000 functional units of aluminum siding are expected to be used in the construction phase, then the N value for this assessment profile is 2,000. Assessment class E gives designers the opportunity to evaluate the impacts of products, materials, and equipment entering the building site from different perspectives including emission of contaminants, health impacts on the building occupants, cost of the materials, consumption of resources, and toxic chemicals introduced to the building. A second example is a printer entering the site. The printer has E, U and L assessment classes and the functional unit could be used as one printer. For example, if the price for one printer is $200, the value of the cost attribute for E-printer becomes $200. When 5 printers are purchased, the N value will be 5 and the cost attribute becomes $1000. The E profile for the printer considers important attributes like the energy use, air emissions, cost, and resources use. On the other hand, the L profile provides information about complementary information like recycling versus landfill, cost of disposal, and solid waste generation.

- ***Assessment Class L***

Assessment class L reflects the impacts of the materials, products, and equipment when leaving the building site (exiting the boundary of the building site). Usually, each material, product, and equipment has E and L assessment classes, but these assessment classes may not be applicable in the same building life cycle stage. In profiling assessment class L, attributes are given values to cover the time frame from the point the material, product, or equipment is uninstalled until it is taken out of the boundaries of the site. Assessment class L usually occurs in the demolition stage, and sometimes in the operation stage.

In selecting among alternatives, designers will find that assessment class L has the same importance as other classes. A product may have minimum environmental impact in the construction phase when the product enters the site (i.e. sustainable assessment class E), but has a major impact when it is removed at its end of life (i.e. unsustainable assessment class L). Assessment class L gives designers the opportunity to evaluate the product when it leaves the site from different perspectives such as air emissions, generation of solid waste, recycling, cost of removal. For example, in assessment class L for carpet (i.e. removing the carpet at its end of service), it involves important attributes such as removal cost, landfill versus recycling, and energy use. Similar to assessment class E, assessment class L is expressed per functional unit. In the generic profile for assessment class L, a default value of one is given to N, where N is the number of functional units that are applicable to a specific activity in a specific stage in the life cycle of the building. Attributes are given values associated with one functional unit of the product or material removed from the site. We can select 1 m2 as the functional unit for the L assessment class for carpet (L-Carpet). If the weight of each square meter of the removed carpet is 3 kg and it is sent to the landfill, a value of 3.0 kg is assigned to the solid waste generation attribute. If 200 m2 is expected to be removed in a renovation activity, the N value will be 200. By multiplying each attribute value by N in the synthesis step, the solid waste generation value for L will become 600 kg. For a complete picture about the sustainability of products, materials, or equipment, it is critical to evaluate all applicable assessment classes. For example, two products may seem competitive. However, the L assessment class for each may show that one of them goes to the landfill while the other is recycled when leaving the site. Considering the printers example, it is estimated to replace 5 printers in the building operation phase. If the five printers are the same, the same L profile can be used, otherwise different printers require different L assessment classes. For two printers if printer "A" is recyclable and printer "B" is not, then in the case of printer "A" the solid waste generation attributes will be assigned 0 value. In selecting equipment for the building the designer needs to consider assessment classes E, L, in addition to U and M if applicable for all equipment in the design phase. From sustainability point of view, the designer needs to consider what could happen 50 or 100 years from today.

- ***Assessment Class U***

Assessment class U accounts for the impacts from using the materials, products, and equipment in the time frame between E and L. Assessment class U is usually more applicable for equipment. The functional unit for the U assessment class is usually selected as a unit of time such as 1 hour or one day, and the attributes are assigned values accordingly. N is the estimated use time (number of functional units) of the equipment or material for a specific activity in one life cycle stage. For example, if 1 hour of operation was selected as the functional unit for the printer and it consumes 0.05 kwh of electricity per each hour of operation, the value of the electricity consumption attribute will be 0.05 kwh. If we operated the printer for 2000 hours in the operating phase, the value of the electricity consumption attribute becomes 100 when substituting the N value in the synthesis step.

- ***Assessment Class M***

Assessment class M is to count for the impact of products and equipment maintenance. M was listed in an assessment class other than assessment class U because maintenance is not a routine activity, and it may require different functional unit than U. In the printer example, the functional unit of U could be selected as one hour of use. Otherwise, the functional unit of M could be selected as one occurrence of maintenance. In profiling assessment class M, resources use, wastewater generation, cost, solid waste generation, and emissions to air need to be considered.

- ***Assessment Class O***

Assessment class O is to count for any impact that can not be covered under E, L, M and U. It is mainly for profiling human activities that do not fall under one of the other assessment classes. Profiling O is similar to U, but it does not involve equipment, most of the time it has a time functional unit too. The objective of adding the O assessment class is to ensure that all major impacts are counted for inside the boundaries of the site in each stage of the building life cycle.

- ***Assessment Class X***

Assessment class X is used only when comparing between alternatives, it is not considered in the synthesis step, and it is not directly involved with GREENOMETER-7. The goal is to inform the designer about the impacts of the products and equipment outside the boundaries of the site, and to consider these impacts when selecting between two alternatives. Assessment outside the boundaries of the site is only used to make the selection between the alternatives to insure that the decision was based on cradle-to-grave assessment. GREENOMETER-7 is a gate-to-gate analysis (site oriented), and does not use the data from assessment class X after the selection has been made. The profile of X has the same categories and attributes as other assessment classes; except that it account for impacts resulting from the functional unit outside the boundaries of the site.

3.2.2.4 Synthesis

As stated before the actual assessment is only conducted for the assessment classes in the profiling step. Assessments for higher levels (activity, stage, life cycle) are conducted indirectly by combining the applicable assessment classes. This process is called synthesis; which is similar to hierarchy-analysis but in the opposite direction (from lower level to higher level). Synthesis can be conducted at three levels: from assessment class to activity, from activity to stage, and from stage to the building whole life cycle (Figure 7). The N value identified in the inventory phase is only used in the first synthesis level. Synthesis at the first level involves combining the profiles of the activity after multiplying them by their N values. Synthesis at the second level involves combining the activity profiles obtained from the previous synthesis level to generate a stage profile. Finally, the building micro-profile is obtained by combining the profiles of all its life cycle stages. The output of this step is activity profiles for all activities, stage profiles for all building life cycle stages, and micro-profile for the whole life cycle of the building. The profiles at all levels are consistent with the assessment class profile; each profile is a list of categories and each category has its indicators and attributes. By changing assessment classes, the designer can track the impact of the substitution on the profiles at different levels.

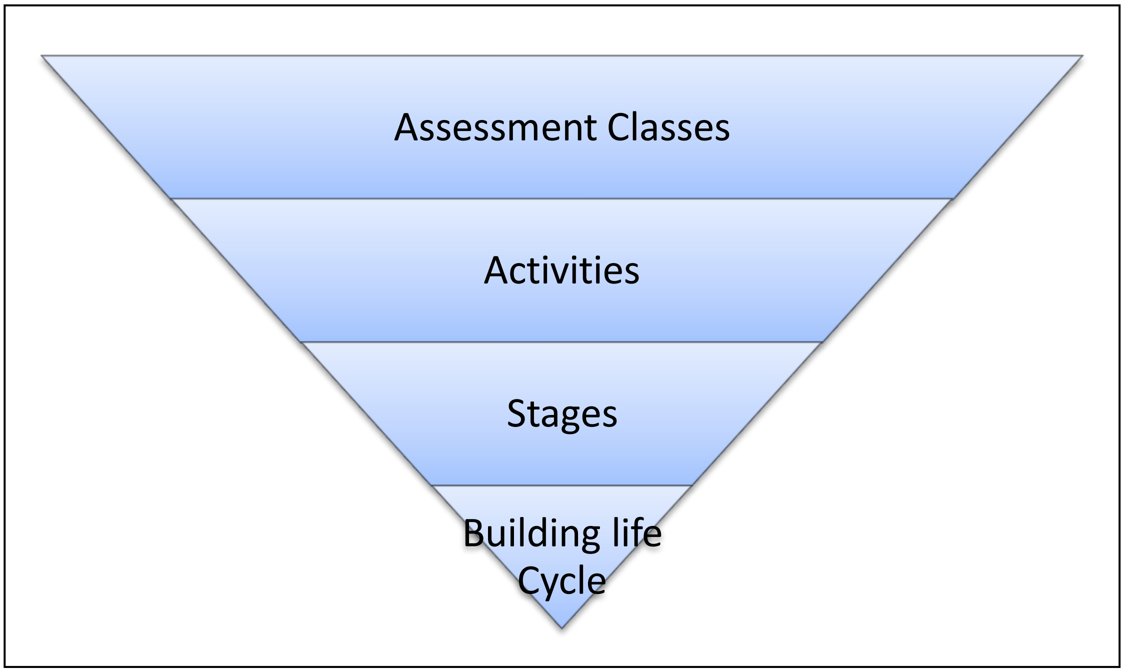

Figure 7: The synthesis step in the micro-assessment level of GREENOMETER-7

3.2.2.5 Ranking

The interpretation phase has two steps: ranking and weighting. The interpretation phase is similar for both the micro-assessment level and macro-assessment level of GREENOMETER-7. The ranking step is conducted using the 7-degree ranking scale of 0, 1, 2, 3, 4, 5, and 6. By using this scale for ranking, 0 means highly unsustainable, 3 means neutral (benchmark), and 6 means highly sustainable. It is a spectrum and any number between 0 and 6 can be selected, but it is recommended to use integer numbers. The output of this step at the micro-assessment level is a rank from 0 to 6 for each indicator. The indicator ranks are used in the valuation (weighting) step to generate a rank between 0 and 6 for each category. Also, the categories ranks are used in the valuation (weighting) step to generate a rank between 0 and 6 for the whole building, and it is called the building micro-score. Guidelines for ranking the indicators at the micro-level will be introduced in another section later.

3.2.2.6 Valuation (Weighting)

The next step in the interpretation phase is valuation (or weighting). In the valuation step the goal is to develop weighting factors at the category level and at the indicator level using one of the available weighting methods. Weighting factors at the indicator level are used to generate a category ranking score from integrating the ranks of its indicators. On the other hand, weighting factors at the category level are used to generate a single building score- at the micro-assessment level- from integrating the ranks of all categories. The analytic hierarchy process (AHP) is one of the methods that could be used to assign a weighting factor at the attribute level and at the category level for both macro-assessment and micro-assessment levels. The weighting factor for each indicator reflects its importance compared to other indicators within the same category. The weighting factor for each category reflects its importance compared to other categories within the same assessment level. A single score is obtained for each category by integrating the ranks of the indicators after multiplying each rank by the attribute weighting factor. The micro-score of the building is generated by multiplying the rank of each micro-category by its weighting factor and adding them together. The overall sustainability score of the building is obtained by multiplying the macro-score and micro-score by their weighting factors and adding them together. The output of the interpretation phase at the micro-assessment level is a single sustainability micro-score for the building over its life cycle. Weighting factors are intended to be adjusted by third parties to suit local conditions.

Although these scores are based on the subjective weighting step, it is much easier for the user to compare the effect of substituting design methods or building products. Every time a change is made, a new calculation is automatically performed and a new score is generated. Since it is a tool for use in the conceptual design phase, the profile and score of the building can be improved by making more sustainable selections. A single number representing a score for the building has advantage of being easy to understand. Reviewing the score is the fastest way at the conceptual design phase for measuring improvement toward sustainability, but it does not provide in-depth information.

3.2.3 Modeling and Optimization

Mass balance around the site (system) boundaries and multi-objective optimization model are the basis for selecting GREENOMETER-7 micro-assessment categories. The indicators of each category represent the optimization functions that need to be minimized or maximized in order to maximize sustainability.

Electricity Optimization Model

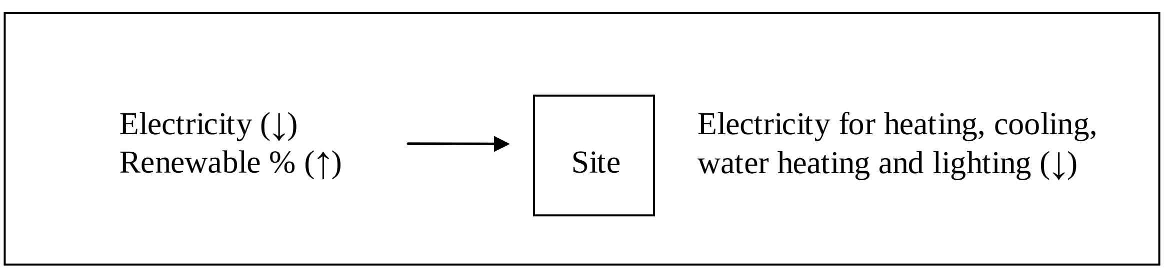

Figure 8: Electricity optimization model

The optimization model has been used for to identify the indicators of the electricity category. Sustainability requires minimizing electricity consumption by the building in general from all sources, nonrenewable and renewable sources.

Minimize (∑ non-renewable electricity + ∑ renewable electricity) …………………..(22)

Also sustainability requires minimizing the consumption of electricity from nonrenewable sources in comparison to renewable ones.

Minimize [(∑ non-renewable electricity)/ (∑ renewable electricity)] ……………….. (23)

Sustainability recommends minimizing the use of electricity for heating, cooling, water heating and lighting the building.

Minimize (electricity for space heating + electricity for cooling + electricity for water heating + electricity for lighting) ………………………………………………… (24)

Fossil Fuel Optimization

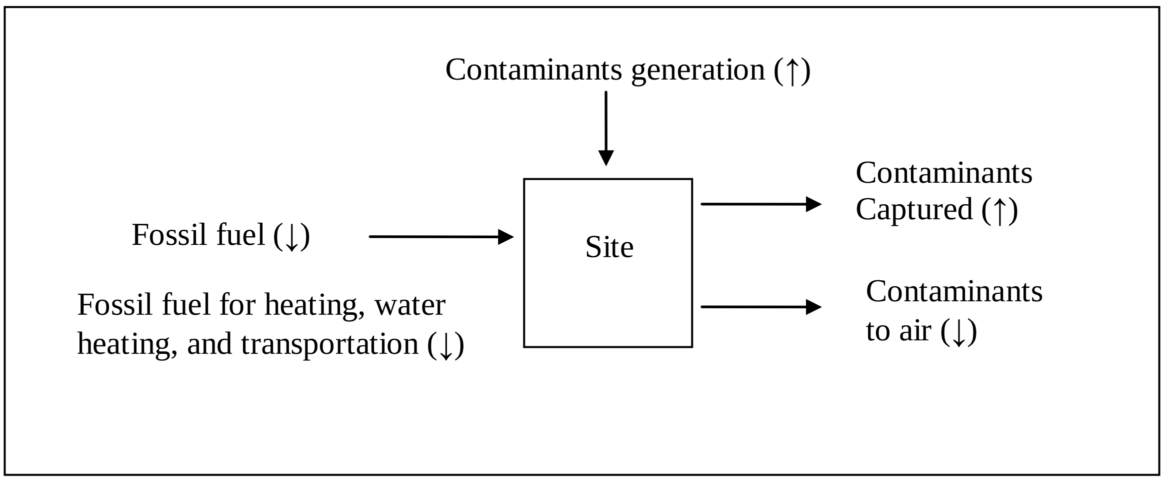

Figure 9: Fossil fuel optimization model

Sustainability requires minimizing combustion of fossil fuel in any of its forms.

Minimize (∑ Fossil fuel) ………………………………………………………….(25)

Also sustainability requires minimizing the release of combustion contaminants to the air.

Minimize (∑combustion contaminant to air) ……………………………………….(26)

Sustainability requires maximizing pollution prevention by capturing the air contaminants before they are released.

Maximize (∑ air contaminants captured) ………….……………………………..(27)

Sustainability requires minimizing the consumption of fossil fuel for space heating, water heating and transportation.

Minimize (fossil fuel for space heating +fossil fuel for water heating + fossil fuel for transportation) ………..…………………………………………………….....(28)

Water & Wastewater Optimization

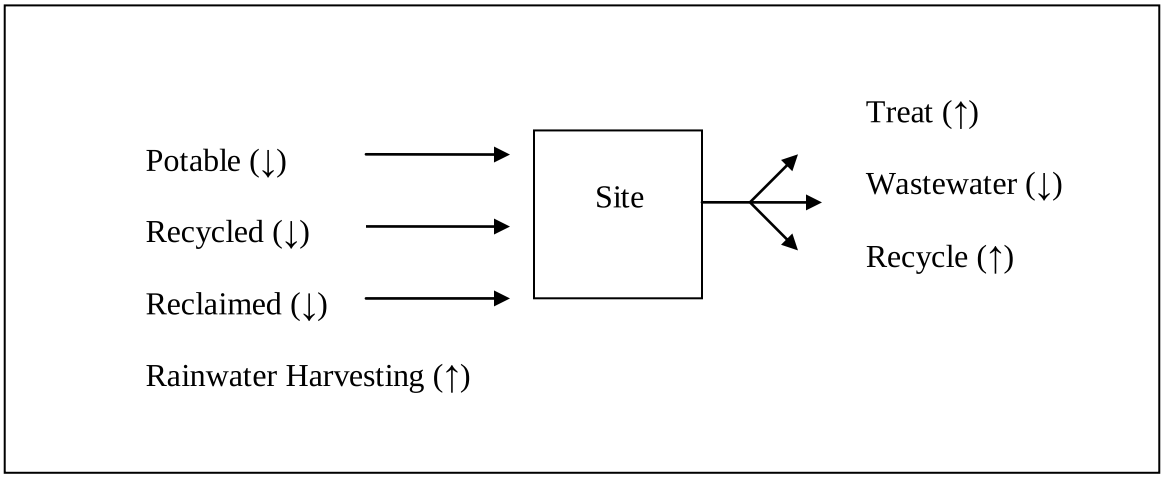

Figure 10: Water and wastewater optimization model

Sustainability requires water conservation by minimizing the use of water in all forms (potable, recycled, and reclaimed).

Minimize (Potable water + Recycled water + Reclaimed water) …………………..….(29)

Also sustainability requires minimizing the use of potable water, when applicable, compared to recycled and reclaimed water.

Minimize [(Potable Water)/ (Recycled Water + Reclaimed Water)] ……………….... (30)

Sustainability requires minimizing wastewater generation in addition to minimizing the portion of wastewater that leaves the site without recycling or treatment.

Minimize (Wastewater generation) ……………………………………………………(31)

Minimize [(Wastewater generation)/ (Recycled wastewater + Treated wastewater)] ...(32)

Resources optimization

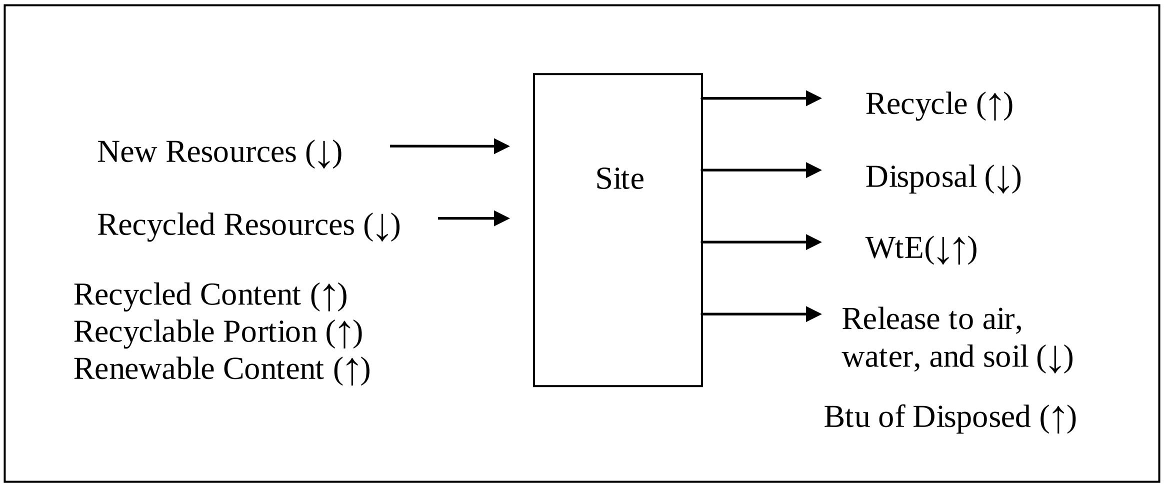

Figure 11: Resources optimization model

Sustainability requires conservation of resources by minimizing the consumption of all kinds of resources, especially non-renewable resources.

Minimize (∑Resource) …………………………………………………………...(33)

Sustainability also requires minimizing disposal compared to recycling and waste-to-energy at the end of service; however, recycling is favored over WtE.

Minimize [(∑ Disposal)/ (∑ Recycled+ ∑ WtE)] ……………………………..……(34)

Minimize [(∑ Recycled)/ (∑ WtE)] …………………………………………….…..(35)

Sustainability requires minimizing the release of solids, oil, and BOD to water to minimize the need to treat wastewater.

Minimize (Release of resources to water) ……………………………………….………(36)

Sustainability requires minimizing the use of new resources compared to recycled ones.

Minimize [(∑New resource)/(∑Recycled resource)] ……………………...........……(37)

Sustainability requires minimizing the use of resources that are not recyclable.

Minimize [(∑Non-recyclable resource)/ (∑Recyclable resource)] ………..…………..(38)

Sustainability requires minimizing the use of non-renewable resources compared to renewable ones:

Minimize [(∑non-renewable resources)/ (∑renewable resources)] ……………………..(39)

Contaminants Optimization

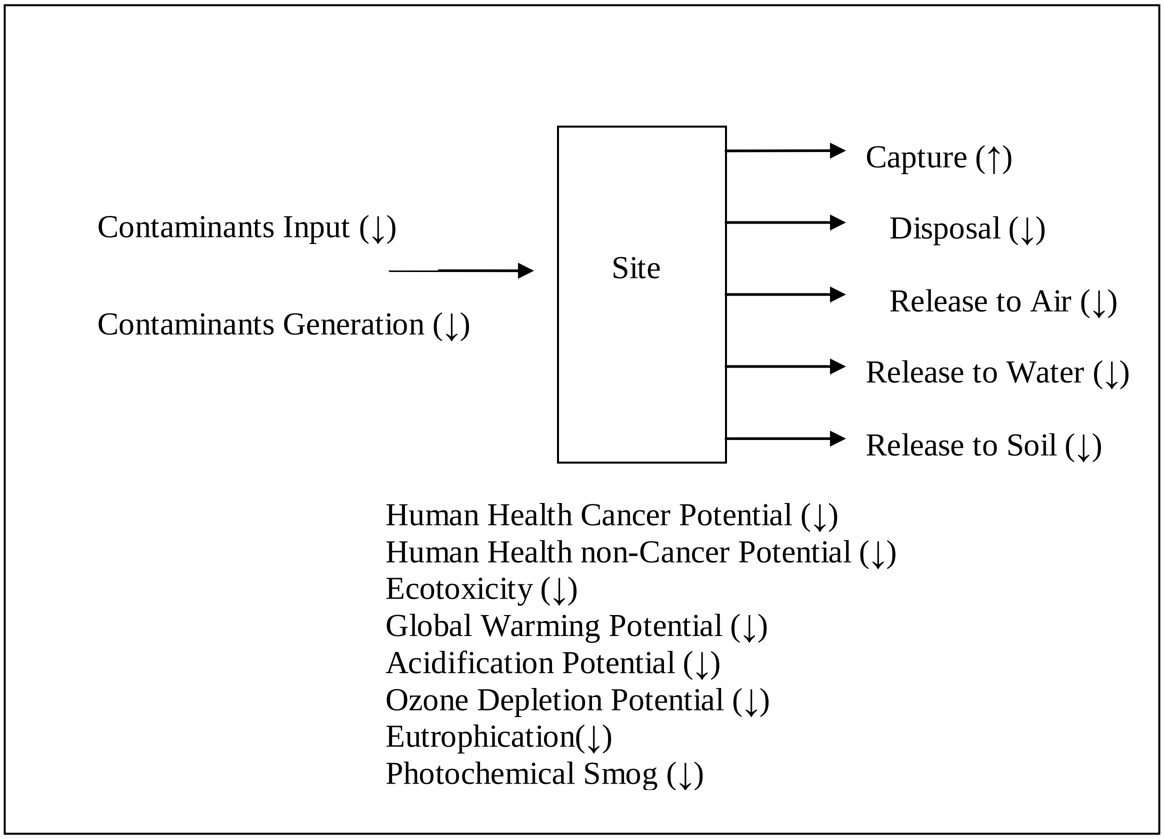

Figure 12: Contaminants Optimization Model

Sustainability requires minimizing the use and generation of contaminants that are harmful to human and the environment.

Minimize (∑Contaminant input) ………………………………...………………… (40)

Minimize (∑Contaminant generation) ……………………………………………...(41)

Sustainability recommends pollution prevention (PP) as a way to prevent the release of contaminants to the environment.

Maximize (PP 1 + PP 2 + PP 3 +) ……………….…………………………………….(42)

Sustainability requires minimizing disposal of contaminants.

Minimize (∑ Contaminant disposal 1) …………………….………………………. (43)

Sustainability requires minimizing the release of contaminants to air and indirectly minimizing human health impacts, ecotoxicity, acidification, ozone depletion, and photochemical smog.

Minimize (∑Release to air) …………………………………………..………….(44)

Sustainability requires minimizing impacts on human health through minimizing the release of toxic contaminants to the air

Minimize (∑Air toxic) ……………………………………..…………………(45)

Sustainability requires minimizing ecotoxicity through minimizing the release of toxic contaminants to the air.

Minimize (∑Air cco-toxic) ……………………………………………………….(46)

Sustainability requires minimizing global warming potential through minimizing the release of greenhouse gases to the air.

Minimize (∑Greenhouse gas) ……………………………………………………(47)

Sustainability requires minimizing stratospheric ozone depletion through minimizing the release of ozone depletion compounds to the air:

Minimize (∑OD compound) ……………………………………………………..(48)

Sustainability requires minimizing acidification potential through minimizing the release of acid rain forming chemicals to the air.

Minimize (∑Acid-rain chemical) ………………………………………………(49)

Sustainability requires minimizing photochemical smog through minimizing the release of smog forming or precursor chemicals to the air.

Minimize (∑Smog-forming chemical) ……………………………………………...(50)

Sustainability requires minimizing eutrophication through minimizing the release of eutrophication chemicals to water.

Minimize (∑Eutrohication chemical) ……………………………………………….(51)

Sustainability requires minimizing the release of contaminants to water and indirectly minimizing the human health impacts, ecotoxicity, eutrophication, and the need for treating wastewater.

Minimize (∑Release to water) ……………………………………………………...(52)

Sustainability requires minimizing impacts on human health through minimizing the release of toxic contaminants to the water

Minimize (∑Water Toxic) …………………………………………………………(53)

Sustainability requires minimizing ecotoxicity through minimizing the release of toxic contaminants to the water.

Minimize (∑Water Eco-toxic) ……………………………………………………...(54)

Sustainability requires minimizing eutrophication through minimizing the release of eutrophication chemicals to water.

Minimize (∑Eutrophication chemical) ……………………………………………...(55)

Sustainability also requires minimizing the release of contaminants to soil and the subsequent contamination of groundwater, ecotoxicity, and soil contamination.

Minimize (∑Release to soil) ……………………………………………......................(56)

Sustainability requires minimizing impacts on human health through minimizing the release of toxic contaminants to groundwater

Minimize (∑Groundwater Toxic) …………………………………………………………..(57)

Sustainability requires minimizing ecotoxicity through minimizing the release of toxic contaminants to the soil.

Minimize (∑Soil Eco-toxic) …………………………………………………………...(58)

Economics Optimization

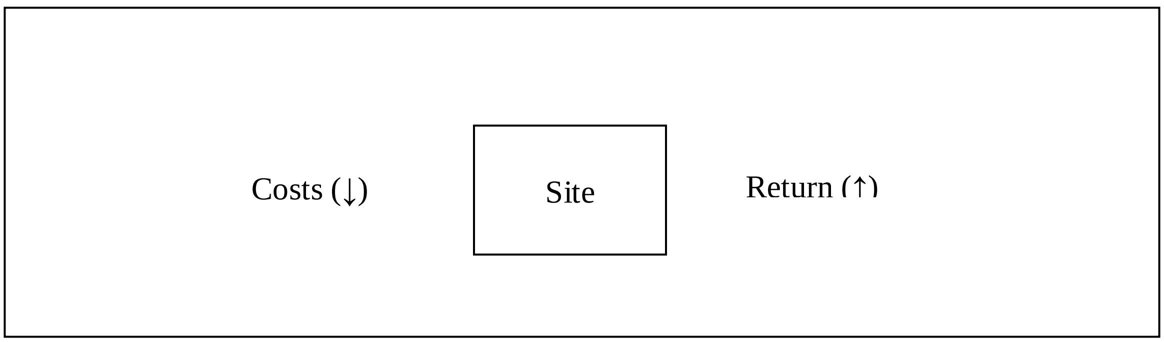

Figure 13: Economics Optimization Model

Sustainability requires minimizing the life cycle cost of the building through minimizing the cost of materials and labor cost.

Minimize (∑Cost) ……………………………………………………………………..(59)

Sustainability also encourages the use of products that have a return at their end life such as recycling returns.

Maximize (∑Return) …………………………………………………………………..(60)

3.2.4 Categories

At the micro-assessment level, actual assessment is only conducted for the assessment classes. In the profiling step, a functional unit is selected then the value of each attribute is determined. The assessment class profile is a quantitative assessment requires finding values for the attributes of each category. GREENOMETER-7 micro-level has 12 categories that fall into 5 fields: energy, water and wastewater, other resources, contaminants output, and economics. The energy field consists of two categories: electricity and fossil fuel. The other resources field consists of two categories: resources input and resources output. The contaminants output field has 6 categories: contaminants output-total, contaminants output-captured, contaminants output-disposal, contaminants output-air, contaminants output-water, and contaminants output-soil. The water and wastewater field has one category: water and wastewater. Finally, the economics field has one category: economics. Each category has its own indicators that are used in the ranking step. The value of the indicator is derived from the attributes values of that category. Each category will be discussed in details bellow.

3.2.4.1 Electricity

Objective

Electricity conservation is the main objective of the electricity category. This goal can be achieved by minimizing the use of electricity for heating, cooling, and lighting the building. According to this category the building is more sustainable if it uses less electricity. The form of electricity, renewable versus non-renewable, is evaluated at the macro-level.

Designer Responsibility

The designer can improve the building sustainability level based on this category by looking for ways to reduce the electricity consumption, these include passive heating and cooling design, passive lighting, high efficient equipment, efficient lighting, building insulation, etc.

Indicators

Electricity has five indicators:

- Total electricity consumption (needs to be minimized)
- Electricity for lighting (needs to be minimized)
- Electricity for space heating/ cooling (needs to be minimized)
- Electricity for Water Heating (needs to be minimized)
- Electricity for other equipment (needs to be minimized)

Attributes

The electricity consumption category has four attributes:

- Electricity for space heating/ cooling
- Electricity for lighting
- Electricity for water heating
- Electricity for other equipment

The total electricity consumption indicator is the sum of the four attributes and it is expressed in kwh. All attributes are expressed in kwh. Electricity heating/ cooling attribute is the electricity portion in kwh that is expected to be used for heating and cooling the building. Electricity for lighting is the electricity portion in kwh that is expected to be used for lighting the building. Electricity for water heating is the electricity portion in kwh that is expected to be used for heating water. Electricity for operating instruments is the electricity portion in kwh that is expected to be used to operate an instrument.

3.2.4.2 Fossil Fuel

Objective

The objective of this category is to minimize the consumption of fossil fuel during the whole life cycle of the building in addition to minimize the use of fossil fuel for heating. Buildings with lower fuel consumption profile are more sustainable.

Designer Responsibility

The designer can improve the building sustainability level based on this category by looking for ways to reduce the consumption of fossil fuel, especially during the operation phase. Similar to the electricity category, fossil fuel consumption can be reduced by adopting sustainable practices such as passive design, alternative fuels, and renewable energy.

Indicators

This category has four indicators:

- Total MMBtu (needs to be minimized)
- MMBtu for heating (needs to be minimized)
- MMBtu for water heating (needs to be minimized)
- MMBtu for transportation (needs to be minimized)
- MMBtu for other equipment (needs to be minimized)

Contaminants generated from burning fossil fuel (SOx, NOx, PM, CO, and VOCs) are represented in another category of the micro-assessment level.

Attributes

The fossil fuel category has three attributes:

- MMBtu for space heating
- MMBtu for water heating
- MMBtu for transportation
- MMBtu for other equipment

The total MMBtu indicator is the sum of the four attributes and it is expressed in MMBtu. All attributes are expressed in MMBtu of the fuel burned. Conversion factor will be provided for the most common units of measurement for each attribute. MMBtu for space heating is the portion of fossil fuel that is expected to be used for heating the building. MMBtu for water heating is the portion of fossil fuel that is expected to be used for heating water. MMBtu for transportation is the portion of fossil fuel used for transportation. MMBtu for cooking is the portion of fossil fuel that is expected to be used for cooking.

3.2.4.3 Water & Wastewater

Objective

The main objective of this category is to conserve water over the building whole life cycle. The second objective is to encourage the use of graywater, and reclaimed water. The third objective is to minimize the generation of wastewater and to encourage wastewater recycling and treatment onsite.

Designer Responsibility

The designer can improve the building sustainability level based on this category in various ways. These include installing ultra efficient fixtures, dual wastewater collection system, rain water harvesting, etc.

Indicators

This category has three indicators:

- Total water use (needs to be minimized)
- % recycled/ reclaimed water (needs to be maximized)
- Total wastewater generation (needs to be minimized)

Attributes

This category has three attributes:

- Potable water
- Recycled/ Reclaimed water
- Wastewater generation
- Water Evaporation

The total water use indicator is the sum of the potable water and recycled/ reclaimed water and is expressed in gallon. The total wastewater generation indicator equals the wastewater generation attribute and it is expressed in gallon. The percentage of recycled/ reclaimed water indicator is the portion of the used water that is expected to be from recycled or reclaimed water. All attributes are expressed in gallon.

3.2.4.4 Resources Input

Objective

The objective of this category is to minimize the use and consumption of resources, especially nonrenewable resources. Another objective is to encourage the use of products and equipment that have more recycled contents, more renewable resources, and more bio-based content. Moreover, this category encourages the use of products and equipment that has the potential to be recycled.

Designer Responsibility

The designer can improve the building sustainability level based on this category by selecting building materials, products, and equipment that satisfy the objectives listed above.

Indicators

This category has the following indicators:

- Total resources input (needs to be minimized)
- % of recycled content (needs to be maximized)
- % of bio-based content (needs to be maximized)
- % of chemicals content (needs to be minimized)

Attributes

The attributes of this category are:

- Recycled content
- Bio-based content
- Steel
- Aluminum
- Copper
- Other metals
- Rocks
- Rocks-Concrete
- Sand
- Sand-Glass
- Sand-Mortar

- Clay
- Clay-Brick
- Limestone
- Gypsum
- Portland Cement Clinker
- Ash
- Asphalt
- Polymer-Plastic
- Polymer-Rubber
- Wood
- Wood-Paper
- Wood-Cardboard
- Cotton/ wool/ Leather/ Jute
- Plants Products
- Oil
- Organic chemicals
- Inorganic chemicals
- Other

The total resources input indicator is the sum of all attributes and it is expressed in kilogram. The % of recycled content indicator represents the recycled portion. The % of renewable content indicator represents the renewable portion. The % of recyclable portion represents the portion that has the potential to be recycled at the end-life of the product or equipment. Attributes of this category are expressed in kilograms. The chemicals that are considered contaminants will be addressed in more details in the contaminants micro-categories.

3.2.4.5 Resources Output

Objective

The objective of this category is to encourage recycling/ reuse/ recovery (3R) of resources as an alternative to disposal. Waste-to-energy is a second alternative waste management after 3R.

Designer Responsibility

The designer can improve the building sustainability score based on this category by selecting materials, products, and equipment that have the potential to be recycled or reused.

Indicators

- Total resources output
- % expected to be recycled or reused (needs to be maximized)
- % expected to be wasted (needs to be minimized)
- MMBtu of wasted (needs to be maximized)

Resources that are expected to become contaminants are represented in other categories.

Attributes

Recovery/ recycling/ reuse is the desired waste management alternative. The attributes of this category are similar and almost identical to the resources input category. Each resource has two attributes one for recycled (R) and the other for wasted (W). Composting is considers recycling. Waste-to-energy is counted with disposal. These attributes are:

- MMBtu of wasted
- R-Steel
- R-Aluminum
- R-Copper
- R-Other metals
- R-Rocks
- R-Rocks-Concrete
- R-Sand
- R-Sand-Glass
- R-Sand-Mortar
- R-Clay
- R-Clay-Brick
- R-Limestone
- R-Gypsum
- R-Portland Cement Clinker

- R-Ash
- R-Asphalt
- R-Polymer-Plastic
- R-Polymer-Rubber
- R-Wood
- R-Wood-Paper
- R-Wood-Cardboard
- R-Cotton/ wool/ Leather/ Jute
- R-Plants Products
- R-Oil
- R-Other

- W-Steel
- W-Aluminum
- W-Copper
- W-Other metals
- W-Rocks
- W-Rocks-Concrete
- W-Sand
- W-Sand-Glass
- W-Sand-Mortar
- W-Clay
- W-Clay-Brick
- W-Limestone
- W-Gypsum
- W-Portland Cement Clinker

- W-Ash
- W-Asphalt
- W-Polymer-Plastic
- W-Polymer-Rubber
- W-Wood
- W-Wood-Paper
- W-Wood-Cardboard
- W-Cotton/ Wool/ Leather
- W-Plants Products
- W-Oil
- W-Other

The % of expected to be recycled indicator represents the portion of the resources that is not trashed. The % of expected to be trashed indicator represents the portion of the resources that is trashed. MMBtu of trashed is the estimated total MMBtu of all resources expected to be trashed. This indicator provides information about the energy value of the trashed waste and the feasibility of the waste-to-energy option. All attributes, except the MMBtu ones, are expressed in kilograms.

3.2.4.6 Contaminants Output- Total

Objective

The objective of this category is to minimize contaminants input and generation and the subsequent contaminant output in all its output routes including captured, release to air, release to water, release to soil, and disposal.

Designer Responsibility

The designer can improve the sustainability level of the building based on this category by selecting materials, products, and equipment that contain or generate no or minimum contaminants.

Indicators

This category has one indicator:

- Total contaminants output [from all contaminants output categories] (needs to be minimized)

3.2.4.7 Contaminants Output- Captured

Objective

The objective of this category is to encourage pollution prevention practices and not to allow contaminants to be released to the environment. Disposal of contaminants in an unaccountable way is an unsustainable practice that contaminates the air, water and/or soil and increases the risk of human, ecological, and environmental exposure.

Designer Responsibility

The designer can improve the sustainability level of the building based on this category by selecting materials, products, and equipment that does not allow the contaminants to be released to the environment or at least, allow for capturing the contaminants before they are released.

Indicators

This category has one indicator:

- % of contaminants output-captured (needs to be maximized)

Attributes

When it is possible it is recommended not to allow the contaminants to be released or to capture the contaminants to prevent their release to the environment. Examples of such contaminants include mercury in the thermometer, lead in the battery, and ozone depletion compounds on the air conditioner. The attributes of this category are:

- Hg
- Cr
- Cd
- Zn
- Pb
- Radon
- Asbestos
- CO
- CO2
- NO2
- SO2
- Particulates
- CFCs
- HCFCs
- Halons
- Formaldehyde
- Other inorganics
- Other Organics

The % of contaminants not released indicator represents the percent of contaminants not released compared to the total contaminants (input and generation from the previous category). The attributes are expressed in kilogram.

3.2.4.8 Contaminants output- Disposal

Objective

The objective of this category is to minimize the disposal of the contaminants and to encourage special handling of contaminant materials to minimize release to the environment.

Designer Responsibility

The designer can improve the building sustainability based on this category by selecting materials, products, and equipment that allow the contaminant content to be recycled or handled with care to prevent the release to the environment.

Indicators

This category has one indicator:

- Total contaminants output-disposal (needs to be minimized)

Attributes

This category mainly accounts for contaminants that are expected to be disposed of as a free material or as part of an equipment or product. An example of this category is mercury in the light bulb or thermometer if not captured before disposal. Another example is the refrigerant in the air condition. The chance for these contaminants to be release to the environment is very high if disposed to the trash. The attributes of this category are:

- Hg
- Cr
- Cd
- Zn
- Pb
- Asbestos
- CFCs
- HCFCs
- Halons
- Other inorganics
- Other Organics

The total contaminants output-disposal indicator represents the total quantity of contaminants disposed of. All the attributes of this category are expressed in kilograms.

3.2.4.9 Contaminants output- Air

Objective

The objective of this category is to minimize the release of contaminants to air. By minimizing the release of contaminants to air other negative impacts will be indirectly minimized such as human health impacts, ecotoxicity, global warming, acidification, ozone depletion, and smog.

Designer Responsibility

The designer can improve the building sustainability level based on this category by selecting material, products, equipment, and design practices that minimize the release of contaminants to air.

Indicators

This category has the following indicators and all of them need to be minimized:

- Total Contaminants output- air
- Global worming potential
- Acidification potential
- Ozone depletion potential
- Photochemical smog potential
- Eutrophication potential
- Ecotoxicity potential
- Human heath- Cancer
- Human health-non-cancer

- Human health - criteria

Attributes

Contaminants released to air have various impacts on human and the environment as emphasized on the indicators. Selected attributes in the tool will be listed these include:

- CO
- CO_2
- NO_2
- SO_2
- Particulates
- Asbestos
- Formaldehyde
- Other inorganics
- Other Organic

Different indicators in this category have different attributes. Some of the indicators such as ecotoxicity and human health cancer have numerous chemicals assigned to them and it is not practical to list all of them in the tool. In this case the indicator will be calculated externally and only the indicator value will provided. These indicators are calculated using TRACI method. The total release indicator is the sum of the attributes listed here and it is expressed in kilogram. The attributes are expressed in kilogram too.

3.2.4.10 Contaminants Output- Water

Objective

The objective of this category is to minimize the release of contaminants to the water. By minimizing the release of these contaminants other impacts on human and the environment will be minimized, these include human health impacts, ecotoxicity, eutrophication, and wastewater treatment cost.

Designer Responsibility

The designer can improve the building sustainability level by selecting materials, products, and equipment; in addition to adopting design practices that minimize the release of contaminants to water.

Indicators

The indicators of this category are the following and all of them need to be minimized:

- Total contaminants to water
- BOD (pre-calculated)
- Ecotoxicity (pre-calculated)
- Eutrophication Potential (pre-calculated)
- Human Health Cancer Potential (HHP-C) (pre-calculated)
- Human Health non Cancer Potential (HHP-NC) (pre-calculated)

Attributes

Contaminants released to water have different impacts on human and the environment as emphasized in the indicators. Selected attributes will be included in the tool these include:

- Hg
- Cr
- Cd
- Pb
- Zn
- Biodegradable
- Non-Biodegradable
- Nitrogen Compounds
- Phosphorous Compounds
- Other organics
- Other inorganics

Similar to air some of the indicators like ecotoxicity and human health cancer potential have numerous chemicals assigned to them. Since it is not practical to list all these chemicals as attributes in the tool, the indicators will be calculated externally and only the value of the indicator will be transferred to the tool. TRACI method will be used to calculate these indicators. The total contaminants to water indicator is the sum of all the attributes listed above and it is expressed in kilogram. The BOD indicator equals the BOD attribute and both are expressed in kilogram. BOD factors will be provided for common contaminants. All attributes are expressed in kilogram.

3.2.4.11 Contaminants output- Soil

Objective

The objective of this category is to minimize the release of contaminants to soil.

Designer Responsibility

The designer can improve the building sustainability based on this category by adopting design practices and selecting materials, products, and equipment that ensure minimum release of contaminants to the soil.

Indicators

This category has one indicator:

- Total Contaminants to Soil (needs to be minimized)

Attributes

The attributes of this category are:

- Hg
- Oil
- Fuel
- Other Organics
- Other inorganics

The total contaminants to soil indicator is the sum of all attributes and it is expressed in kilogram. All the attributes are expressed in kilogram.

3.2.4.12 Economics

Objective

The objective of this category is to minimize the total cost of the building overall its entire life cycle and to maximize the return.

Designer Responsibility

The designer can improve the building sustainability level based on this category by adopting design practices and selecting materials, products, and equipment that ensure minimum price and maximum return.

Indicators

This category has the following indicators:

- Costs (needs to be minimized)
- Return (needs to be maximized)
- % of return (needs to be maximized)

Attributes

In addition to the environmental aspects, the economic factors are important too. It is not practical to design a sustainable building that few people can afford it. The attributes of this category are:

- Materials cost
- Labor cost
- Maintenance cost
- Other costs

- Return

The costs indicator is the sum of material cost, labor cost and other cost and it is expressed in a currency unit. The return indicator is money received form practices such as recycling. All attributes are expressed in a currency unit.

3.2.5 Ranking Guidelines

At the ranking step of the micro-assessment level of GREENOMETER-7, each indicator is ranked separately using the 0 to 6 ranking system, where 6 means the highly sustainable, 0 means highly unsustainable or least sustainable, and 3 (benchmark) means neutral. Ranking is a relative and subjective process, for some attributes 6 could be assigned to the most practical value even if this value is not the ideal one. For example it is not practical to assign 6 to consuming 0 gallon of water because this will never happen. GREENOMETER-7 recognizes the differences between regions, and it also recognizes that it is not fair to expect the same requirements from buildings in completely different regions. Different regions have different climates, resources availability, water availability, etc. Some regions may require more energy requirements for heating and cooling than others. In one region wood is abundant, while rocks are abundant in another. Some regions may take advantage of the rivers while others could use the wind to generate renewable electricity. It is not expected to have one ranking standard for all similar buildings on all regions; at the same time it is not practical to have a ranking standard for each city. Guidance on ranking the indicators of the micro-assessment categories are provided bellow.

For ranking and weighting purposes some of the micro-assessment categories are combined. Electricity and fossil fuel categories are combined into energy category.

Resources input category and resources input category are combined into other resources category. The contaminants output categories are listed as

3.2.5.1 Electricity

In the electricity micro-assessment category the building needs to be ranked for the following indicators:

Total Electricity Consumption

The intent is to minimize electricity consumption. Electricity consumption per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. This indicator depends on the region; different regions have different standards because they have different electricity needs for heating and cooling (Table 2).

Table 2: Ranking guidelines for the total electricity consumption indicator (micro-assessment)

X (%)	Rank
$X \le 70$	6
$70 < X \le 80$	5
$80 < X \le 90$	4
$90 < X \le 100$	3
$100 < X \le 110$	2
$110 < X < 120$	1
$X \ge 120$	0
X is the total electricity consumption divided by a standard (expressed as percentage)	

Electricity for lighting

The intent is to minimize the use of electricity for lighting. This indicator encourages the use of passive lighting in addition to the use of sensors and electricity efficient light bulbs. Electricity used for lighting per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. The ranking guidelines in Table 2 can be used for ranking this indicator, except that X is electricity for lighting divided by a standard (expressed as percentage).

Electricity for Heating and Cooling

The intent is to minimize the use of electricity for heating and cooling purposes. This indicator encourages the use of passive heating, also it recommends better insulation. Electricity used for space heating and cooling per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. There may be a need to develop different standards to distinguish between buildings that use electricity for heating versus buildings that use fossil fuel. This indicator is region dependant because different climate regions have different heating requirements. For example, we can't use the same ranking standard to evaluate a building in Alaska compared to one on Texas. The ranking guidelines in Table 2 can be used for ranking this indicator, except that X is electricity for heating and cooling divided by a standard (expressed as percentage).

Electricity for Water Heating

The intent is to minimize electricity consumption for water heating. This indicator encourages the use of solar energy for heating water. Electricity used for water heating per the building area in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given for smaller values. The ranking guidelines in Table 2 can be used for ranking this indicator, except that X is electricity for water heating divided by a standard (expressed as percentage).

Electricity for other equipment

The intent is to minimize electricity consumption by appliances. This indicator encourages the use of highly efficient appliances. Electricity expected to be consumed by all appliances per the building area in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given for smaller values. The ranking guidelines in Table 2 can be used for ranking this indicator, except that X is electricity for other equipment divided by a standard (expressed as percentage).

3.2.5.2 Fossil Fuel

In the fossil fuel category the building needs to be ranked for the following indicators:

Total MMBtu

The intent is to minimize the consumption of fossil fuel. But per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given for smaller values. This indicator is region dependant because different regions have different fossil fuel needs for heating, in case that fossil fuel is used for heating. Moreover, some buildings use electricity for heating; as a result two sets of ranking standards are required for each region (Table 3)

Table 3: Ranking guidelines for the total MMBtu indicator

X (%)	Rank
$X \leq 70$	6
$70 < X \leq 80$	5
$80 < X \leq 90$	4
$90 < X \leq 100$	3
$100 < X \leq 115$	2
$115 < X < 130$	1
$X \geq 130$	0
X is the total MMBtu consumption divided by a standard (expressed as percentage)	

MMBtu for heating

The intent is to minimize the use of fossil fuel for heating. This indicator will encourage the use of passive heating. MMBtu used for space heating per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. There may be a need to develop different standards to distinguish between buildings that use electricity for heating versus buildings that use fossil fuel. This indicator is region dependant because different climate regions have different heating requirements. The ranking guidelines in Table 3 can be used for ranking this indicator, except that X is MMBtu for heating divided by a standard (expressed as percentage).

MMBtu for water heating

The intent is to minimize the use of fossil fuel for water heating. This indicator encourages the use of sun energy for heating water. MMBtu used for water heating per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given for smaller values. The ranking guidelines in

Table **3** can be used for ranking this indicator, except that X is MMBtu for water heating divided by a standard (expressed as percentage).

MMBtu for Transportation

The intent is to minimize the use of fossil fuel for transportation. This indicator encourages minimizing the consumption of fossil fuel for transportation through the use of public transportation and living close to work, school, and shopping area. MMBtu used for transportation per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given for small values. The ranking guidelines in Table 3 can be used for ranking this indicator, except that X is MMBtu for transportation divided by a standard (expressed as percentage).

MMBtu for other equipment

The intent is to minimize fossil fuel consumption by equipment like the range.. MMBtu consumed by all equipment per the building area in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given for smaller values. The ranking guidelines in Table 3 can be used for ranking this indicator, except that X is MMBtu for other equipment divided by a standard (expressed as percentage).

3.2.5.3 Water & Wastewater Indicators

In the water and wastewater category the building needs to be ranked for the following indicators:

Total water use

The intent is to minimize water use over the life cycle of the building. This indicator encourages the use of ultra efficient fixtures and the use of sensors in addition to any other opportunity to reduce water use. Water use (volume) per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values (Table 4).

Table 4: Ranking guidelines for the total water use indicator (micro-assessment)

X (%)	Rank
X ≤ 80	6
80 < X ≤ 90	5
90 < X ≤ 100	4
100 < X ≤ 110	3
110 < X ≤ 120	2
120 < X < 130	1
X ≥ 130	0
X is the total water consumption divided by a standard (expressed as percentage)	

% of Recycled or Reclaimed Water

The intent is to maximize the use of recycled and/ or reclaimed water. This indicator encourages graywater recycling and the use of reclaimed water in addition to harvesting rain water. The percentage of the recycled/ reclaimed water from the total water use is used in ranking the building for this indicator, and it needs to be maximized. A benchmark rang is selected and higher percentages take higher ranks (Table 5).

Table 5: Ranking guidelines for the percent of non-potable water use indicator

X (%)	Rank
X ≤ 1	0
1 < X ≤ 5	1
5 < X ≤ 10	2
10 < X ≤ 20	3
20< X ≤ 25	4
25 < X < 30	5
X ≥ 30	6
X is the percentage of non-potable water from the total water use.	

Total wastewater generation

The intent is to minimize wastewater generation over the life cycle of the building. This indicator similar to water use indicator encourages the use of highly efficient fixtures and the use of sensors in addition to any other opportunity to reduce water use. Wastewater generation (volume) per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. The ranking guidelines in Table 4 can be used for ranking this indicator, except that X is the total wastewater generation divided by a standard (expressed as percentage).

3.2.5.4 Ranking Resources-Input

In the resources input category the building needs to be ranked for the following indicators:

Total resources input

The intent is to generally minimize the use of resources in manufacturing building materials, products and equipment, especially if these resources are nonrenewable. Total resources weight per the unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Different standards are developed for different building types, i.e. concrete building has a different standard than wood building (Table 6).

Table 6: Ranking Guidelines for the total resources input indicator

X (%)	Rank
$X \leq 80$	6
$80 < X \leq 90$	5
$90 < X \leq 100$	4
$100 < X \leq 110$	3
$110 < X \leq 120$	2
$120 < X < 130$	1
$X \geq 130$	0
X is the total resources input divided by a standard (expressed as percentage)	

% of recycled content

The intent is to maximize the recycled content of the products. This indicator encourages the use of products with higher recycled content percentage. The percentage of the recycled content (over the life cycle of the building) is used in ranking the building for this indicator, and it needs to be maximized. A benchmark rang is selected and a higher percentage takes higher rank (Table 7).

Table 7: Ranking guidelines for the recycled content percentage indicator

X (%)	Rank
$X \leq 1$	0
$1 < X \leq 5$	1
$5 < X \leq 10$	2
$10 < X \leq 20$	3
$20 < X \leq 25$	4
$25 < X < 30$	5
$X \geq 30$	6
X is the percentage of recycled content from the total content.	

% of bio-based content

The intent is to maximize the bio-based content of the products. This indicator encourages the use of products with higher bio-based content. The percentage of the bio-based content (over the life cycle of the building) is used in ranking the building for this indicator, and it needs to be maximized. A benchmark rang is selected and a higher percentage takes higher rank (Table 8).

Table 8: Ranking guidelines for the bio-based content indicator

X (%)	Rank
X ≤ 2	0
2 < X ≤ 4	1
4 < X ≤ 6	2
6 < X ≤ 8	3
8< X ≤ 10	4
10 < X < 12	5
X ≥ 12	6
X is the percentage of bio-based content from the total content.	

% of chemicals content

The intent is to encourage the selection of products with less chemicals content. This indicator encourages the use of products with lower contaminant content. The chemicals content percentage (over the life cycle of the building) is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and a lower percentage takes higher rank (Table 9).

Table 9: Ranking guidelines for the chemicals content indicator

X (%)	Rank
X ≤ 0.5	6
1.0 < X ≤ 1.5	5
1.5 < X ≤ 2.0	4
2.0 < X ≤ 2.5	3
2.5< X ≤ 3.0	2
3.0< X < 3.5	1
X ≥ 3.5	0
X is the percentage of chemicals content from the total content.	

3.2.5.5 Resources-Output

In the resources output category the building needs to be ranked for the following indicators:

Total Resources Output

Does not need to be ranked, but it is used for ranking the next two indicators.

% of Expected to be Recycled of Reused

From a mass balance point of view, all the resources entered the site will leave at some point. If the product is not recyclable or recoverable it will be sent to the landfill or burned as a source of energy. Because recycling, recovery, and reuse (3R) conserve resources and reduce landfill size, it is recommended that the 3R practices to be maximize. The percentage of the total resources that are expected to be recycled, reused, or recovered (over the entire life cycle of the building) is used in ranking the building for this indicator, and it needs to be maximized. A benchmark rang is selected and a higher percentage takes higher rank (Table 10).

Table 10: Ranking guidelines for the percentage of resources out put expected to be recycled

X (%)	Rank
$X \leq 20$	0
$20 < X \leq 30$	1
$30 < X \leq 40$	2
$40 < X \leq 50$	3
$50 < X \leq 60$	4
$60 < X < 70$	5
$X \geq 70$	6
X is the percentage of output resources expected to be recycled or reused.	

% of resources expected to be wasted

This indicator is the opposite of the one before. The intent is to minimize disposal in comparison to the alternative recycling and reuse waste management practices. If the discarded products are sent to the landfill then the resources are wasted and the landfill is filled faster, for these reasons disposal of products needs to be minimized. The percentage of the total resources expected not to be recycled or recovered is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and a lower percentage takes higher rank (Table 11).

Table 11: Ranking guidelines for the resources output expected to be wasted indicator

X (%)	Rank
$X \leq 20$	6
$20 < X \leq 30$	5
$30 < X \leq 40$	4
$40 < X \leq 50$	3
$50 < X \leq 60$	2
$60 < X < 70$	1
$X \geq 70$	0
X is the percentage of output resources expected to be wasted.	

MMBtu of wasted

A second alternative to recycling and recovery is waste-to-energy (W-to-E). This indicator encourages the W-to-E option for what is left after recycling. In this case the energy content of what is left after recycling is important. The MMBtu per unit weight of the discarded waste (over the life cycle of the building) is used in ranking the building for this indicator, and it needs to be maximized (Table 12).

Table 12: Ranking guidelines for the MMBtu of the wasted resources output indicator

X (%)	Rank
$X \leq 80$	0
$80 < X \leq 90$	1
$90 < X \leq 100$	2
$100 < X \leq 110$	3
$110 < X \leq 120$	4
$120 < X < 130$	5
$X \geq 130$	6
X is the MMBtu of the wasted resources output divided by a standard (expressed as %)	

3.2.5.6 Contaminants Output- Total

In the contaminants output-total category the building needs to be ranked for the following indicator:

Total Contaminants output

This indicator is the total of all contaminants output categories: captured, wasted, air, water, and soil. The intent is to minimize contaminant output to any or to all of these routes. This indicator represents the contaminants that have the potential to be released to the environment. Total contaminants output per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values (Table 13).

Table 13: Ranking guidelines for the total contaminants output indicator

X (%)	Rank
$X \leq 60$	6
$60 < X \leq 80$	5
$80 < X \leq 100$	4
$100 < X \leq 110$	3
$110 < X \leq 120$	2
$120 < X < 130$	1
$X \geq 130$	0
X is the total contaminants output divided by a standard (expressed as percentage)	

3.2.5.7 Contaminants Output- Captured

In the contaminants output-Captured category the building needs to be ranked for the following indicator:

% of Contaminants output Captured

When it is not possible to prevent contaminants from being introduced to or generated on the site it is important to minimize their release to water, air and soil. This indicator encourages taking the necessary measures to maximize the not-released percentage. The percentage of contaminates captured is used in ranking the building for this category, and it needs to be maximized. A benchmark rang is selected and a higher rank is given to a higher percentage (Table 14).

Table 14: Ranking guidelines for the percentage of contaminants output-captured indicator

X (%)	Rank
X ≤ 10	0
10 < X ≤ 20	1
20 < X ≤ 30	2
30 < X ≤ 40	3
40< X ≤ 55	4
55 < X < 70	5
X ≥ 70	6
X is the percentage of the contaminants output captured from the total	

3.2.5.8 Contaminants Output-Disposal

In the contaminants output- disposal category the building needs to be ranked for the following indicators:

Total contaminants disposal

The intent is to minimize the disposal of contaminants because it increases the chance that these contaminants be released to air, water, or soil. This indicator encourages implementing necessary pollution prevention measures to minimize contaminants disposal. The weight of contaminants disposed per unit area of the building

Table 15: Ranking guidelines for the percentage of contaminants output-disposal indicator

X (%)	Rank
X ≤ 1	6
1 < X ≤ 5	5
5 < X ≤ 10	4
10 < X ≤ 15	3
15< X ≤ 20	2
20 < X < 25	1
X ≥ 25	0
X is the percentage of the contaminants output-disposal from the total	

in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values (Table 15).

3.2.5.9 Contaminants Output- Air

In the contaminants to air category the building needs to be ranked for the following indicators and all of them needs to be minimized:

Total contaminants to air

Release of contaminants to air needs to be minimized because of the many potential impacts on human and the environment. This indicator encourages minimizing the release of contaminants to air through implementing suitable measures including pollution prevention. The weight of contaminants released to air per unit area of the building in comparison to a standard is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values (Table 16).

Table 16: Ranking guidelines for the contaminants output-air indicator

X (%)	Rank
$X \leq 45$	6
$45 < X \leq 60$	5
$60 < X \leq 85$	4
$85 < X \leq 100$	3
$100 < X \leq 110$	2
$110 < X < 120$	1
$X \geq 120$	0
X is the quantity of contaminants output to air divided by a standard (expressed as %)	

Global Warming Potential

Because the release of greenhouse gases to air increases global warming potential, their release needs to be minimized. TRACI characterization factors are used to calculate the global warming potential (GWP). GWP per unit area of the building is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values (Table 17).

Table 17: Ranking guidelines for the global warming potential indicator

X (%)	Rank
X ≤ 40	6
40 < X ≤ 60	5
60 < X ≤ 80	4
80 < X ≤ 100	3
100 < X ≤ 110	2
110 < X < 120	1
X ≥ 120	0
X is the global warming potential divided by a standard (expressed as percentage)	

Acidification Potential

Because the release of acid rain precursors to air increases the acidification potential, their release to air needs to be minimized. TRAC characterization factors are used to calculate the acidification potential (AP). AP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 17 can be used for ranking this indicator, except that X is acidification potential divided by a standard (expressed as percentage).

Ozone Depletion Potential

Because the release of ozone depletion compounds increase ozone depletion potential, their release to air needs to be minimized. TRAC characterization factors are used to calculate the ozone depletion potential (ODP). ODP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 17 can be used for ranking this indicator, except that X is ozone depletion potential divided by a standard (expressed as percentage).

Photochemical Smog Potential

Because the release of photochemical smog precursors increases the photochemical smog potential, their release to air needs to be minimized. TRAC characterization factors are used to calculate the photochemical smog potential (SP). SP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 17can be used for ranking this indicator, except that X is photochemical smog potential divided by a standard (expressed as percentage).

Ecotoxicity Potential

Because the release of specific contaminants to air increases the ecotoxicity potential, their release to air needs to be minimized. TRAC characterization factors are used to calculate the ecotoxicicty potential (ETP). ETP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 17 can be used for ranking this indicator, except that X is ecotoxicity potential divided by a standard (expressed as percentage).

Human Health Cancer

Because the release of specific contaminants to air increases cancer potential, their release to air needs to be minimized. TRAC characterization factors are used to calculate human health cancer potential (HTP). HTP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 17 can be used for ranking this indicator, except that X is human cancer potential divided by a standard (expressed as percentage).

Human Health Non-Cancer

Because the release of specific contaminants to air increases the human health non-cancer potential, their release to air needs to be minimized. TRAC characterization factors are used to calculate the non-cancer toxicity potential (HTP). HTP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 17 can be used for ranking this indicator, except that X is human non-cancer potential divided by a standard (expressed as percentage).

Human Health Criteria

Because the release of criteria contaminants to air increases the human health criteria potential, their release to air needs to be minimized. TRAC characterization factors are used to calculate the human health criteria potential (HTP). HTP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 17 can be used for ranking this indicator, except that X is human health-criteria potential divided by a standard (expressed as percentage).

3.2.5.10 Contaminants Output- Water

In the contaminants output- to water category the building needs to be ranked for the following indicators and all of them need to be minimized:

Total contaminants output to water

Release of contaminants to water needs to be minimized because of the many potential impacts on human and the environment. This indicator encourages minimizing the release of contaminants to air through implementing suitable measures including pollution prevention. The weight of contaminants released to water per the building area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values (Table 18).

Table 18: Ranking guidelines for the total contaminants output to water indicator

X (%)	Rank
$X \leq 70$	6
$70 < X \leq 80$	5
$80 < X \leq 90$	4
$90 < X \leq 100$	3
$100 < X \leq 110$	2
$110 < X < 120$	1
$X \geq 120$	0
X is the total contaminants output to water divided by a standard (expressed as %)	

BOD

Because the release of biodegradable contaminants increases BOD, their release to water needs to be minimized. Theoretical BOD will be provided for common contaminants in kilogram. BOD per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 18 can be used for ranking this indicator, except that X is BOD divided by a standard (expressed as percentage).

Ecotoxicity Potential

Because the release of specific contaminants to water increases the ecotoxicity potential, their release to water needs to be minimized. TRAC characterization factors are used to calculate the ecotoxicicty potential (ETP). ETP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 18 can be used for ranking this indicator, except that X ecotoxicity potential divided by a standard (expressed as percentage).

Eutrophication Potential

Because the release of nitrogen and phosphorous compounds to water increases the eutrophication potential, their release to air needs to be minimized. TRAC characterization factors are used to calculate the eutrophication potential (EP). EP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 18 can be used for ranking this indicator, except that X is eutrophication potential divided by a standard (expressed as percentage).

Human Health Cancer

Because the release of specific contaminants to water increases cancer potential, their release to water needs to be minimized. TRAC characterization factors are used to calculate human health cancer potential (HTP). HTP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 18 can be used for ranking this indicator, except that X is human cancer potential divided by a standard (expressed as percentage).

Human Health Non-cancer

Because the release of specific contaminants to water increases human health non-cancer potential, their release to water needs to be minimized. TRAC characterization factors are used to calculate human health cancer potential (HTP). HTP per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values. Ranking guidelines in Table 18 can be used for ranking this indicator, except that X is human non-cancer potential divided by a standard (expressed as percentage).

3.2.5.11 Contaminants Output-Soil

In the contaminants to soil category the building needs to be ranked for the following indicator:

Total contaminants to soil

The intent is to minimize the release of contaminants to soil because of their potential to reach groundwater and the various potential impacts on human and the environment. This indicator encourages minimizing the release of contaminants to soil through implementing adequate measures including pollution prevention. The weight of contaminants released to soil per the building area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values (Table 19).

Table 19: Ranking guidelines for the contaminants output to soil

X (%)	Rank
X ≤ 40	6
40 < X ≤ 60	5
60 < X ≤ 80	4
80 < X ≤ 100	3
100 < X ≤ 110	2
110 < X < 120	1
X ≥ 120	0
X is the total contaminants output to soil divided by a standard (expressed as percentage)	

3.2.5.12 Economics

In the economics category the building needs to be ranked for the following indicators:

Costs

The intent is to minimize the cost of the building over its entire life cycle. The total cost per building unit area is used in ranking the building for this indicator, and it needs to be minimized. A benchmark rang is selected and higher ranks are given to smaller values (Table 20).

Table 20: Ranking guidelines for the costs indicator

X (%)	Rank
X ≤ 55	6
55 < X ≤ 70	5
70 < X ≤ 85	4
85 < X ≤ 100	3
100 < X ≤ 115	2
115 < X < 130	1
X ≥ 130	0
X is the total costs divided by a standard (expressed as percentage)	

Return

The intent is to maximize the return from recycling and similar options. The returns in $ per building unit area is used in ranking the building for this indicator, and it needs to be maximized. A benchmark rang is selected and higher ranks are given to higher values (Table 21).

Table 21: Ranking guidelines for the return indicator

X (%)	Rank
X ≤ 55	0
55 < X ≤ 70	1
70 < X ≤ 85	2
85 < X ≤ 100	3
100 < X ≤ 115	4
115 < X < 130	5
X ≥ 130	6
X is the total return divided by a standard (expressed as percentage)	

% of Return

The intent is to maximize the percent of return in comparison to the costs. This indicator encourages selecting materials, products and equipment that have the potential to be recycled. The percentage of return is used in ranking the building for this indicator, higher percentage takes higher rank.

3.2.6 Micro-Assessment Weighting Guidelines

Weighting factors need to be assigned to the categories at the micro-assessment level of GREENOMETER-7 as identified in Table 22.

Table 22: Generic category weighting factors for the micro-assessment level

Category	**Category Weighting Factor (%)**
1.1 Electricity	A
1.2 Fossil Fuel	B
2.1 Water and Wastewater	C
3.1 Resources Input	D
3.2 Resources Output	E
4.1 Contaminants Output-Total	F
4.2 Contaminants Output-Captured	G
4.3 Contaminants Output-Disposal	H
4.4 Contaminants Output-Air	I
4.5 Contaminants Output-Water	J
4.6 Contaminants Output- Soil	K
5.1 Economics	L

The total of all categories weighting factors must equal 100 as show in the following equation:

$$A+B+C+D+E+F+G+H+I+J+K+L=100 \qquad (61)$$

Similarly, weighting factors need to be assigned to the indicators of each category as shown in Table 23.

Table 23: Generic indicator weighting factors for the micro-assessment level

Category	Indicator	Weighting Factor (%)
1.1) Electricity	Total Electricity consumption	a1
	Electricity for lighting	a2
	Electricity for heating/ cooling	a3
	Electricity for water heating	a4
	Electricity for instruments	a5
1.2) Fossil Fuel	Total MMBtu	b1
	MMBtu for space heating	b2
	MMBtu for water heating	b3
	MMBtu for transportation	b4
	MMBtu for instruments	b5
2.1) Water and Wastewater	Total water use	c1
	% Recycled/ reclaimed water	c2
	Total wastewater generated	c3
3.1) Resources Input	Total Resources Input	d1
	% of recycled content	d2
	% of biobased content	d3
	% of chemicals content	d4
3.2) Resources Output	Total resources output	e1
	% expected to be recycled	e2
	% expected be wasted	e3
	MMBtu of wasted	e4
4.1) Contaminants-Total	Total Contaminants output	f1
4.2) Contaminants-Captured	% of Contaminants- captured	g1
4.3) Contaminants-Disposal	Total Contaminants- disposal	h1
4.4) Contaminants-Air	Total Contaminants output- air	i1
	Global warming potential	i2
	Acidification potential	i3
	Ozone depletion potential	i4
	Photochemical smog potential	i5
	Eutrophication potential	i6
	Ecotoxicity potential	i7
	Human health-cancer	i8
	Human health-non-cancer	i9
	Human health-criteria	i10
4.5) Contaminants-Water	Total contaminants output- water	j1
	BOD	j2
	Ecotoxicity	j3
	Eutrophication Potential	j4
	Human health- cancer	j5
	Human health- non-cancer	j6
4.6) Contaminants- Soil	Total Contaminants output- soil	k1
5.1) Economics	Total costs	l1

Category	Indicator	Weighting Factor (%)
	Total Return	l2
	% of return	l3

The total of indicator weighting factors for the same category must equal 100 as shown in the following equations:

- Electricity

a1+a2+a3+a4+a4+a5=100 ……………………………………………….…………..(62)

- Fossil fuel

b1+b2+b3+b4+b5=100 ……………………………….……………………………(63)

- Water and Wastewater

c1+c2+c3=100 ………………….……………………………………………………(64)

- Resources Input

d1+d2+d3+d4=10 ……………………………………………………………………(65)

- Resources Output

e1+e2+e3+e4=100 …………………………………………………………………..(66)

- Contaminants output-total

f1=100 ……………………………………………………………….…………..(67)

- Contaminants output-captured

g1=100 ..………………….………………………………………………………..(68)

- Contaminants output-disposal

h1=100 ……………………………………….…………………….…………(69)

- Contaminants output-air

i1+i2+i3+i4+i5+i6+i7+i8+i9+i10=100 …………………………………………..(70)

- Contaminants output-water

$$j1+j2+j3+j4+j5+j6=100 \quad (71)$$

- Contaminants output-soil

$$k1=100 \quad (72)$$

- Economics

$$l1+l2+l3=100 \quad (73)$$

3.3 Macro-Assessment

This chapter provides in-depth information about GREENOMETER-7 macro-assessment level: its structure, categories, and ranking. The macro-assessment level evaluates the building as a whole and it is based on the principles of criteria scoring systems. It does not provide in-depth assessment, but it is essential because it covers areas that are only applicable at the whole building level and they may not be applicable at the building assessment class level.

3.3.1 Structure

The macro-assessment level of GREENOMETER-7 has two phases: Inventory and interpretation (Figure 14). The inventory phase has two steps macro-survey, and macro-profile. The interpretation phase has two steps ranking and valuation, similar to the interpretation phase at the micro-assessment level of the tool.

3.3.1.1 Macro-Survey

Macro-survey is the first step in the macro-assessment phase. In this step the designer collects information about the location, land use, site, envelope, and the building as a whole that can be used to for the macro-assessment of the building. This information is the basis for developing the macro-profile in the next step, so each indicator in the macro-profile should be presented with one or more question in the macro-survey. The macro-survey is expected to provide enough details so that it can be easily transformed into macro-profile.

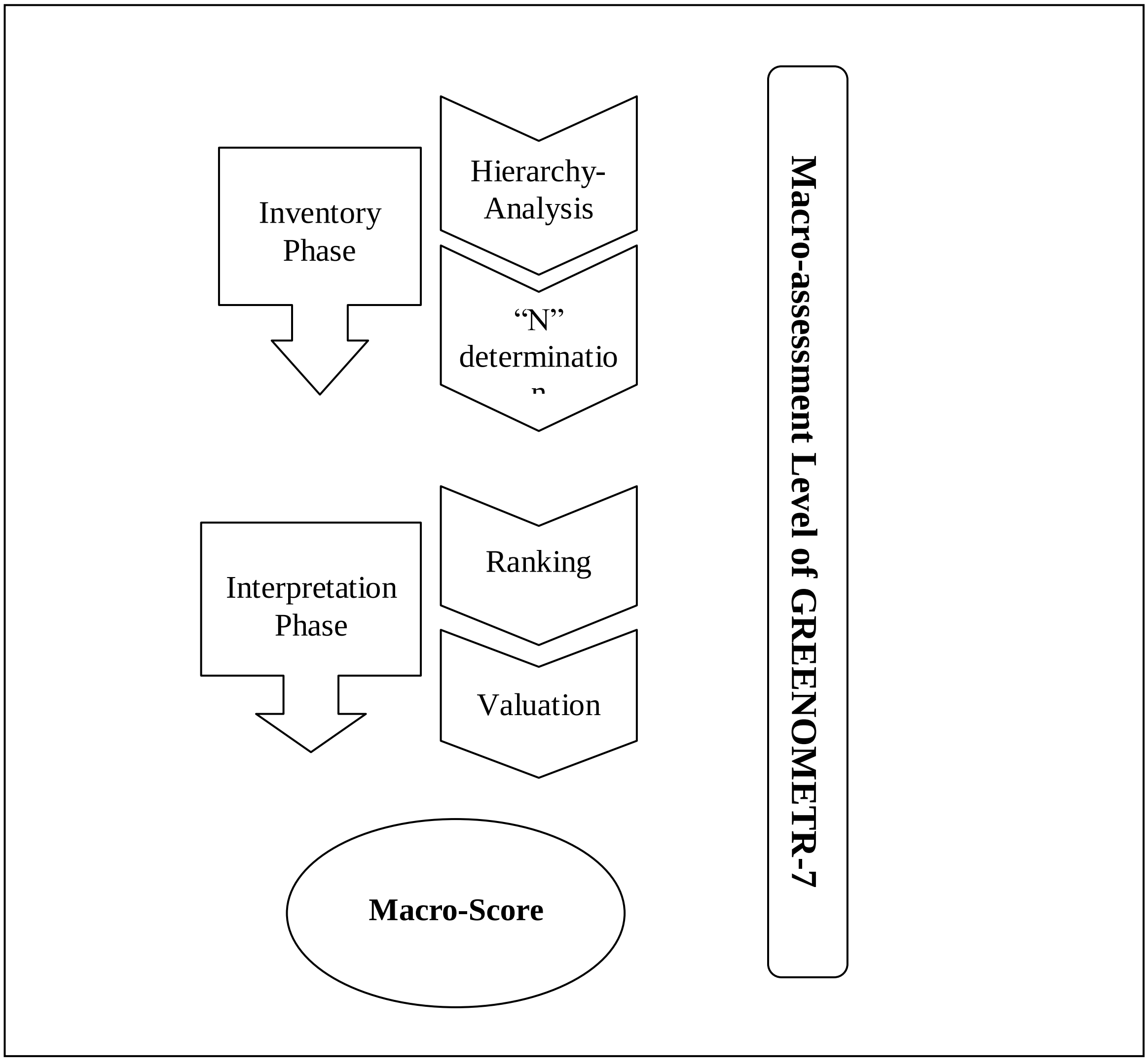

Figure 14: Flowchart of the macro-assessment level of GREENOMETER-7

3.3.1.2 Macro-Profile

Macro-profile is the next step in the macro-assessment phase. In this step the designer uses the information gathered in the macro-survey to develop the building profile at the macro-level. Information provided by the macro-survey should be adequate to give a value or qualitative description for each indicator. Information in the macro-profile will be ranked later in the ranking step, so that information should be consistent with the ranking standard. The micro-profile consists of eight macro-assessment categories: location, land use, energy, water & wastewater, resources, IEQ, Stormwater/ heat-island/ landscaping, and management. Each category has its own indicators. The categories and indicators will be discussed later in more details. The output of this step is the macro-profile that is ranked and weighted in the interpretation phase.

3.3.1.3 Ranking

The interpretation phase has two steps: ranking and weighting. The ranking step for the macro-assessment level is similar to that for the micro-assessment level. The ranking step is conducted using the 7-degree ranking scale of 0, 1, 2, 3, 4, 5, and 6. By using this scale for ranking, 0 means highly unsustainable, 3 means neutral (benchmark) and 6 means highly sustainable. It is a spectrum and any number between 0 and 6 can be selected, but it is recommended to use integer numbers. The output of this step at the macro-assessment level is a rank from 0 to 6 for each indicator. The indicator ranks are used in the valuation (weighting) step to generate a rank between 0 and 6 for each category. Also, the categories ranks are used in the valuation (weighting) step to generate a rank between 0 and 6 for the whole building and it is called the building macro-score. Guidelines for ranking each indicator at the macro-assessment level are provided in another section.

3.3.1.4 Valuation (Weighting)

The next step in the interpretation phase is valuation (or weighting). In the valuation step the goal is to develop weighting factors at the category level and at the indicator level using one of the available weighting methods in order to be able to integrate the array of ranking scores into one score. Weighting factors at the indicator level are used to generate a category ranking score from integrating the ranks of its indicators. On the other hand, weighting factors at the category level are used to generate a single building score, at the macro-assessment level, from integrating the ranks of all categories. The analytic hierarchy process (AHP) is one of the methods that could be used to assign a weighting factor at the attribute level and at the category level. The weighting factor for each attribute reflects its importance compared to other attributes within the same category. The weighting factor for each category reflects its importance compared to other categories within the same assessment level. The AHP can be used to assign weighting factors for the categories at the macro-level that reflect their importance compared to one another. A single score is obtained for each category by integrating the ranks of the indicators after multiplying each rank by the attribute weighting factor. The sustainability macro-score of the building is generated by multiply the rank of each macro-category by its weighting factor and adding them together. The overall sustainability score of the building is obtained by multiplying the macro-score and micro-score by their weighting factors and adding them together. The output of the interpretation phase at the macro-assessment level is a single sustainability micro-score for the building over its life cycle. Weighting factors are intended to be adjusted by third parties to suit local conditions.

3.3.2 Categories

The categories of the macro-assessment level of GREENOMETER-7 are: location; land use & land value; stormwater; heat-island and landscaping; water & wastewater; energy; resources; and IEQ. In this section the macro-assessment categories will be discussed in more details.

3.3.2.1 Location

Objective

The objective of this category is to ensure that the building is located in a sustainable location.

Designer Responsibility

The designer/ owner can improve the building sustainable level based on this category by selecting a sustainable location for the building.

Indicators

- Vulnerability of site to flooding
- Proximity to public transportation
- Proximity to existing infrastructure
- Public Transportation Quality
- Distance between site and centers of employment (or residential neighborhoods)
- Proximity to services
- Proximity to contaminants/ odor sources
- Proximity to noise sources
- Impact of adjacent building
- Availability of renewable energy
- Availability of potable water
- Impact of the building on the surroundings

3.3.2.2 Land Use & Land Value

Objective

The objective of this category is to reduce land use especially that when the land has agricultural or ecological value. In evaluating the sustainability of the building the type of the occupied land is considered in addition to its area.

Designer Responsibility

The designer can improved the building sustainability level based on this category by adopting sustainable practices related to land use and land selection.

Indicators

- Ecological sensitivity of the land
- Agricultural value of the land
- Contamination and development status of the land
- Relevance of the footprint of the building (right-sized building)
- Pavement density (pavement area divided by the footprint)
- Landscaping/ disruption density (landscape/ disrupted area divided by the footprint)
- Development density (footprint divided by land area)

3.3.2.3 Stormwater, heat-island & landscaping

Objective

The objective of this category is to minimize stormwater generation, reduce heat-island effect, and ensure sustainable landscaping.

Designer Responsibility

The designer can improve the building sustainability level based on this category by adopting design practices that ensure minimum stormwater generation, reduced heat-island and sustainable landscaping.

Indicators

- Stormwater run-off
- Erosion degree and run-off level of contamination
- Heat island effect
- Native planting
- Landscaping design strategy

3.3.2.4 Water & Wastewater

Objective

The objective of this category is to reserve water and to minimize wastewater generation.

Designer Responsibility

The designer can improve the building sustainability level based on this category by adopting practices that ensure water saving and reduce wastewater generation.

Indicators

- Landscaping water efficiency
- Non-potable water use for irrigation
- Non-potable water use for toilet
- Harvesting rainwater for reuse

- Installation of high efficiency fixtures
- Availability of dual wastewater system

3.3.2.5 Energy

Objective

The objective of this category is to save energy consumption by the building as a whole.

Designer Responsibility

The designer can improve the building sustainability level based on this category by adopting design strategies that ensure minimum energy consumption.

Indicators

- Use of renewable energy
- Computer modeling for energy optimization
- Exploring passive lighting, heating and ventilation
- Energy controls utilization
- Envelope insulation and air leakage
- Building orientation
- Lighting fixtures efficiency
- Heating and cooling system efficiency
- Appliances efficiency

3.3.2.6 Resources

Objective

The objective of this category is to ensure that the minimum quantity of resources is used by the building.

Designer Responsibility

The designer can improve the building sustainability level based on this category be adopting practices that ensure the use of minimum quantities of resources.

Indicators

- Collection of recyclable waste at the construction stage
- Collection of recyclable waste at the operation stage
- Collection of recyclable waste at the demolition stage
- Right-size building
- Design for disassembly (DfD)
- Durability of building materials and products
- Selection of products based on LCA
- Locally produced materials
- Use Ozone depletion refrigerants

3.3.2.7 IEQ

Objective

The objective of this category is to provide healthy and comfortable indoor environmental quality.

Designer Responsibility

The designer can improve the building sustainability level based on this category by adopting design practices that considers indoor environmental quality.

Indicators

- Ventilation effectiveness and CO2 concentration
- Temperature and relative humidity
- Air filtering and venting of combustion gases and odors
- Environmental Tobacco Smoke (ETS)
- Noise and vibration
- Exposure to Radon
- Lighting Quality
- Access to daylight and outside view

3.3.3 Ranking Guidelines

Similar to the micro-assessment level, ranking at the macro-assessment level of GREENOMETER-7 uses the 0 to 6 ranking system for ranking the indicators, where 6 means the highly sustainable, 0 means highly unsustainable or least sustainable, and 3 (benchmark) means neutral. Guidelines are provided below for ranking the indicators of each category at the micro-assessment level.

3.3.3.1 Location

- **Vulnerability of site to flooding**

The intent is to encourage the selection of land for building that is less vulnerable to flooding. The height of the minimum elevation of the site above the elevation of the

100-year flood plain has been selected for ranking the site for this indicator and it needs to be maximized (Table 24).

Table 24: Ranking guidelines for the vulnerability of site to flooding indicator

X (meter)	Rank
X ≤ 1	0
1 < X ≤ 2	1
2 < X ≤ 3	2
3 < X ≤ 4	3
4 < X ≤ 5	4
5 < X < 6	5
X ≥ 6	6
X is the height of the minimum elevation of the site above the elevation of the 100-year flood plain.	

- **Proximity to public transportation**

The intent is to select a site that is within a walking distance to a public transportation stop so that pollution from automobile use can be reduced. The distance between the site and the public transportation stop has been selected to rank the site and it needs to be minimized (Table 25).

- **Public transportation availability and quality**

The intent is to encourage selecting the site where a satisfactory public transportation service is available. The classification of the public transportation based on the availability, number of trips, and quality has been selected to rank the site for this indicator (Table 26).

Table 25: Ranking guidelines for the proximity to public transportation indicator

X (meter)	Rank
X ≤ 100	6
100 < X ≤ 200	5
200 < X ≤ 300	4
300 < X ≤ 400	3
400 < X ≤ 500	2
500 < X < 600	1
X ≥ 600	0
X is the distance of the site from a public transportation stop.	

Table 26: Ranking guidelines for the public transportation availability and quality indicator

X	Rank
Very Poor	0
Poor	1
Fair	2
Average	3
good	4
Very good	5
Excellent	6
X is the description of the public transportation service based on the availability, number of trips, quality.	

- **Proximity to existing infrastructure**

The intent is to encourage the selection of site that is served by or is near existing infrastructure (i.e. water line, sewer line, electricity, etc.). The distance between the site and the existing infrastructure connections has been selected to rank the site for this indicator and it needs to be minimized (Table 27).

- **Distance between site and centers of employment (or residential neighborhoods)**

The intent is to encourage the selection of sites that require reasonable daily commute. For residential sites, the distance to employment center (downtown) has been selected to rank the site for this indicator. On the other hand, for non-residential site, the average distance to major residential neighborhoods has been selected to rank the site fort this indicator. In both cases the distance needs to be minimized (Table 28).

Table 27: Ranking guidelines for the proximity to existing infrastructure

X (meter)	Rank
X ≤ 50	6
50 < X ≤ 100	5
100 < X ≤ 150	4
150 < X ≤ 200	3
200 < X ≤ 250	2
250 < X < 300	1
X ≥ 300	0
X is the average distance between the site and existing infrastructure connections.	

Table 28: Ranking guidelines for the daily commute indicator

X (km)	Rank
X ≤ 1	6
1 < X ≤ 2	5
2 < X ≤ 3	4
3 < X ≤ 5	3
5 < X ≤ 7	2
7 < X < 9	1
X ≥ 9	0
X is the distance between site and employment center (for residential buildings). X is distance between site and residence (for non-residential buildings)	

- **Proximity to services**

The intent is to encourage the selection of sites that are located in a reasonable distance from the shopping centers, social centers, schools, etc. The average distance to the most common services has been selected to rank the site for this indicator, and it needs to be minimized (Table 29).

Table 29: Ranking guidelines to the proximity to services indicator

X (km)	Rank
X ≤ 1	6
1 < X ≤ 2	5
2 < X ≤ 3	4
3 < X ≤ 4	3
4 < X ≤ 5	2
5 < X < 6	1
X ≥ 6	0
X is the average distance of the site from services (commercial, social, etc.).	

- **Proximity to contaminants/ odor sources**

The intent is to encourage selecting the sites in an adequate distance from industrial facilities, landfills, etc. The weighted average distance to the major surrounding contaminant sources have been selected to rank the site for this indicator, and it needs to be maximized (Table 30Table 30).

Table 30: Ranking guidelines to the proximity to the sources of contaminants indicator

X (meter)	Rank
X ≤ 200	0
200 < X ≤ 300	1
300 < X ≤ 400	2
400 < X ≤ 600	3
600 < X ≤ 800	4
800 < X < 1,000	5
X ≥ 1,000	6
X is the weighted average distance between the site and contaminant sources (landfills, industrial facilities, etc.).	

- **Proximity to major noise pollution sources**

The intent is to select the sites that are in an adequate distance form noise pollution sources such as major roads, highways, railroads, etc. The weighted average distance to the major surrounding noise pollution has been selected to rank the site for this indicator, and it needs to be maximized (Table 31).

Table 31: Ranking guidelines for the proximity to noise pollution sources indicator

X (meter)	Rank
X ≤ 200	0
200 < X ≤ 300	1
300 < X ≤ 400	2
400 < X ≤ 600	3
600 < X ≤ 800	4
800 < X < 1,000	5
X ≥ 1,000	6
X is the weighted average distance between the site and noise sources (roads, railroad, ..)	

- **Impact of adjacent buildings**

The intent is to select a site where the adjacent buildings have minimum impact on access to day lighting and view. The severity of the impact has been selected to rank the site for this indicator, it needs to be minimized (Table 32).

Table 32: Ranking guidelines to the impact of adjacent buildings indicator

X	Rank
Severely affected	0
Strongly affected	1
Somewhat affected	2
Minimum impact	3
Somewhat not affected	4
Not affected	5
Totally not affected	6
X is the impact of adjacent buildings now or in the future on the access to daylight and view.	

- **Availability of renewable energy**

The intent is to encourage the consideration and use of renewable energy sources. The combination of availability and affordability has been selected to rank the site for this indicator (Table 33).

Table 33: Ranking guidelines for the availability of renewable energy indicator

X	Rank
Not available	0
Limited availability and very expensive	1
Limited availability and expensive	2
Limited availability and somewhat reasonable price	3
Available and somewhat reasonable price	4
Available and reasonable price	5
Available and low price	6
X is the classification of renewable energy based on availability and affordability.	

- **Availability of potable water**

The intent is to ensure that the site is located in area where availability and quality of water are acceptable. The site has been ranked Different classifications have developed for ranking the site based on this indicator (Table 34).

Table 34: Ranking guidelines of the potable water availability and quality

X	Rank
Extremely not satisfied	0
Strongly not satisfied	1
Not satisfied	2
neutral	3
Satisfied	4
Strongly satisfied	5
Extremely satisfied	6
X is the classification of potable water based on its availability and quality.	

- **Impact of the building on the surroundings**

The intent is to ensure that the building has minimum impact on adjacent water bodies and at the same time does not block adjacent buildings access to daylight. The severity level of the impact has been used in raking the building for this indicator (Table 35).

Table 35: Ranking guidelines for the impact of the building on its surroundings indicator

X	Rank
Extremely affected	0
Strongly affected	1
Somewhat affected	2
Minimum impact	3
Somewhat not affected	4
Not affected	5
Totally not affected	6
X is the impact of the building on the surroundings (nearby water body, buildings, etc.)	

3.3.3.2 Land Use and Land Value

- **Ecological sensitivity of the land**

The intent is to avoid selecting ecologically sensitive land (habitat for endangered species, wetland, conservation, rainwater harvesting, etc.) for sitting the building. Different classes have been developed to rank the site for this indicator (Table 36).

Table 36: Ranking guidelines for the ecological sensitivity of the land indicator

X	Rank
Extremely sensitive and/ or supports endangered species	0
Strongly sensitive	1
Sensitive	2
Somewhat sensitive	3
Somewhat not sensitive	4
Not sensitive	5
Totally not sensitive	6
X is the classification of the land based on its ecological value or sensitivity.	

- **Agricultural value of the land**

The intent is to discourage sitting the building on land of high agricultural value. Different classification has been developed based on the agricultural value of the land to be used in ranking the site for this indicator (Table 37).

Table 37: Ranking guidelines for the land agricultural value indicator

X	Rank
Extremely high agricultural value	0
Strongly high agricultural value	1
High agricultural value	2
Some agricultural value	3
Low agricultural value	4
Very low agricultural value	5
No agricultural value	6
X is the classification of the land based on its agricultural value.	

- **Contamination and development status of the land**

The intent is to encourage placing the building on a previously developed land and to use existing infrastructure. The building receives extra credit for redeveloping damaged or contaminated sites because it reduces development pressure on undeveloped land (Table 38).

Table 38: Ranking guidelines for the contamination and development status of the land indicator

X	Rank
No subsurface contamination. Never used and it is currently used for agriculture	0
No subsurface contamination. Never developed but not currently used for agriculture	1
No subsurface contamination. The land was previously developed but it could be restored	2
No subsurface contamination and the land was previously developed	3
Subsurface is somewhat contaminated	4
Subsurface is contaminated	5
Subsurface is highly contaminated	6
X is the classification of the land based on its contamination status and development status.	

- **Relevance of the footprint of the building (right-footprint)**

The intent is to preserve land by ensuring that the building has the right footprint. A footprint more than what is needed wastes land, resources and money. The deviation from a footprint standard has been selected in ranking the building fro this indicator (Table 39).

Table 39: Ranking guidelines for ranking the relevance of the building footprint

X (%)	Rank
X ≤ 50	6
50 < X ≤ 70	5
70 < X ≤ 90	4
90 < X ≤ 100	3
100 < X ≤ 120	2
120 < X < 140	1
X ≥ 140	0
X is the building footprint divided by a footprint standard expressed as percentage.	

- **Relevance of the pavement density (pavement area divided by the footprint)**

The intent is to ensure that the building has minimum paved areas (parking, driveways, etc.) to reserve land and to reduce heat island effect. Site disturbance needs to be minimized beyond the footprint of the building. The deviation from a standard has been selected for ranking the building for this indicator (Table 40).

Table 40: Ranking guidelines for the relevance of pavement density indicator

X (%)	Rank
X ≤ 50	6
50 < X ≤ 70	5
70 < X ≤ 90	4
90 < X ≤ 100	3
100 < X ≤ 120	2
120 < X < 140	1
X ≥ 140	0
X is the pavement density divided by the standard expressed as a percentage.	

- **Landscaping/ disruption density (landscape/ disrupted area divided by the footprint)**

The intent is to encourage the efficient use of land, to restore damaged areas, and to conserve water. Site disturbance needs to be minimized beyond the building footprint. The deviation from a standard has been selected to rank the site for this indicator (Table 41).

Table 41: Ranking guidelines for the landscaping density indicator

X (%)	Rank
X ≤ 50	6
50 < X ≤ 70	5
70 < X ≤ 90	4
90 < X ≤ 100	3
100 < X ≤ 120	2
120 < X < 140	1
X ≥ 140	0
X is the landscape/ disturbance density divided by the standard, expressed as a percentage.	

- **Development density (footprint divided by land area)**

The intent is to encourage the efficient use of developed land and to reduce stress on undeveloped land (Table 42).

Table 42: Ranking guidelines for the development density indicator

X (%)	Rank
X ≤ 50	6
50 < X ≤ 70	5
7 < X ≤ 90	4
90 < X ≤ 100	3
100 < X ≤ 120	2
120 < X < 140	1
X ≥ 140	0
X is the development density divided by the standard, expressed as a percentage.	

3.3.3.3 Stormwater, heat island, and landscaping

- **Stormwater run-off**

The intent is to encourage the use of design features and stormwater management practices that ensure minimum stormwater run-off. These management practices include permeable pavements, stormwater reservoirs, greenroof, etc. The projected percentage of stormwater run-off has been selected in ranking the site for this indicator (Table 43).

Table 43: Ranking guidelines for the stormwater run-off indicator

X (%)	Rank
$X \leq 10$	6
$10 < X \leq 20$	5
$20 < X \leq 30$	4
$30 < X \leq 40$	3
$40 < X \leq 55$	2
$55 < X < 70$	1
$X \geq 70$	0
X is the percentage of stormwater run-off	

- **Erosion degree and run-off level of contamination**

The intent is to encourage the use of design features and control measures that ensure minimum soil erosion and run-off contamination (Table 44).

Table 44: Ranking guidelines for the erosion degree and run-off level of contamination

X	Rank
Extreme level of erosion and extreme run-off turbidity	0
Very high level of erosion and very high run-off turbidity	1
High level of erosion and high run-off turbidity	2
Some level of erosion with some run-off turbidity	3
Very low level of erosion and very low run-off turbidity	4
Almost no erosion and almost no run-off turbidity	5
No erosion and no run-off turbidity	6
X is the level of erosion and the consequent level of run-off contamination	

- **Heat-island effect**

The intent is to reduce the heat islands (thermal gradient difference between developed and undeveloped areas). Methods that can be used to reduce heat island effect include selecting light colored surfaces and roof, provide shading using native trees, etc. The average increase in temperature has been selected to rank the site for this indicator, and it needs to be decreased (Table 45).

Table 45: Ranking guidelines for the heat island effect indicator

X (C)	Rank
$X \leq 0.2$	6
$0.2 < X \leq 1$	5
$1 < X \leq 1.5$	4
$1.5 < X \leq 2$	3
$2 < X \leq 3.5$	2
$3.5 < X < 5$	1
$X \geq 5$	0
X is the increase in temperature compared to the undeveloped area.	

- **Native planting**

The intent is to encourage the use of native planting because native plants are adapted to the local climate and they reduce or eliminate irrigation requirements. The percentage of native trees and shrubs has been selected to rank the site for this indicator (Table 46).

Table 46: Ranking guidelines for the native planting indicator

X (%)	Rank
$X \leq 20$	0
$20 < X \leq 40$	1
$40 < X \leq 60$	2
$60 < X \leq 70$	3
$70< X \leq 80$	4
$80 < X < 90$	5
$X \geq 90$	6
X is the percentage of native plants.	

- **Landscaping design strategy**

The intent is to encourage the use of landscape design strategies that reduce irrigation requirements, minimize the need for synthetic chemicals, and maintain biodiversity. Different classifications have been selected in ranking the site for this indicator (Table 47).

Table 47: Ranking guidelines for the landscaping design strategy indicator

X	Rank
Very poor landscaping design	0
Poor landscaping design	1
Fair landscaping design	2
Average landscaping design	3
Good landscaping design	4
Very good landscaping design	5
Excellent landscaping design	6
X is the landscape design classification	

3.3.3.4 Water and Wastewater

- **Landscaping water efficiency**

The intent is to minimize the use of water for maintaining plants and lawn areas through water-efficient irrigation. The percent ratio of volume of irrigation divided by a standard has been selected to rank the site based on this indicator, and it needs to be minimized (Table 48).

- **Non-potable water use for irrigation**

The intent is to discourage the use of potable water for irrigation or to keep its use to minimal. Non-potable water sources include rainwater harvesting, recycled water, graywater, etc. The percentage of non-potable water demand for irrigation has been selected in ranking the site for this indicator, and it needs to be maximized (Table 49).

Table 48: Ranking guidelines for the landscaping water efficiency indicator

X (%)	Rank
X ≤ 50	6
50 < X ≤ 70	5
7 < X ≤ 90	4
90 < X ≤ 100	3
100 < X ≤ 120	2
120 < X < 140	1
X ≥ 140	0
X is the percentage of irrigation volume divided by a standard.	

Table 49: Ranking guidelines for the non-potable water use for irrigation indicator

X (%)	Rank
X ≤ 20	0
20 < X ≤ 40	1
40 < X ≤ 60	2
60 < X ≤ 70	3
70< X ≤ 80	4
80 < X < 90	5
X ≥ 90	6
X is the percentage of non-potable water from the total water demand for irrigation.	

- **Non-potable water use for toilet**

The intent is to discourage the use of potable water for toilet flushing or to keep it to minimum. The percentage of non-potable water use for toilet has been selected to rank the building for this indicator, and it needs to be maximized (Table 50).

- **Harvesting rainwater for reuse**

The intent is to encourage harvesting rainwater to be reused onsite. The capacity of the collection system has been selected in ranking the site for this indicator, and it needs to be increased (Table 51).

Table 50: Ranking guidelines for the non-potable water use for toilet indicator

X (%)	Rank
X ≤ 20	0
20 < X ≤ 40	1
40 < X ≤ 60	2
60 < X ≤ 70	3
70< X ≤ 80	4
80 < X < 90	5
X ≥ 90	6
X is the percentage of non-potable water from the total water demand for toilet.	

Table 51: Ranking guidelines for the rainwater harvesting and reuse indictor

X (%)	Rank
X ≤ 1	0
1 < X ≤ 5	1
5 < X ≤ 10	2
10 < X ≤ 20	3
20< X ≤ 30	4
30 < X < 40	5
X ≥ 40	6
X is the percentage of rainwater that can be collected and reused.	

- **Installation of high efficiency fixtures**

The intent is to encourage the use of very high efficient fixtures to minimize the demand for potable water. The weighted average flow of all fixtures has been used for ranking the site for this indicator, and it needs to be minimized (Table 52).

Table 52: Ranking Guidelines for the installation of high efficiency fixtures indicator

X (%)	Rank
X ≤ 70	6
70 < X ≤ 80	5
80 < X ≤ 90	4
90< X ≤ 100	3
100< X ≤ 120	2
120< X < 140	1
X ≥ 140	0
X is percentage ratio of the weighted average flow of all fixtures divided by a standard.	

- **Availability of dual wastewater system**

The intent is to encourage the installation of grey water system, so that the gray water can be reused for irrigation. The percentage of potential grey water that can be collected has been selected in ranking the building for this indicator, and it needs to be maximized (Table 53).

Table 53: Ranking guidelines for the availability of dual wastewater system indicator

X (%)	Rank
$X \leq 30$	0
$30 < X \leq 40$	1
$40 < X \leq 50$	2
$50 < X \leq 60$	3
$60 < X \leq 70$	4
$70 < X < 80$	5
$X \geq 80$	6
X is the percentage of potential gray water that can be collected	

3.3.3.5 Energy

- **Use of renewable energy**

The intent is to encourage the consideration and use of renewable energy sources in order to reduce environmental and economic impacts associated with fossil fuel energy use. The percentage of projected green energy consumption from total consumption has been selected to rank the building for this indicator, and it needs to be increased (Table 54).

Table 54: Ranking guidelines for the renewable energy use indicator

X (%)	Rank
X ≤ 5	0
5 < X ≤ 10	1
10 < X ≤ 20	2
20 < X ≤ 30	3
30 < X ≤ 40	4
40< X < 50	5
X ≥ 50	6
X is the percentage of renewable energy from total energy load.	

- **Computer modeling for energy optimization**

The intent is to encourage computer energy modeling using a number of runs for heating, cooling and lighting optimization. Different levels of utilization have been identified to rank the building for this indicator (Table 55).

Table 55: Ranking guidelines for the computer modeling for energy optimization indicator

X	Rank
No utilization	0
Low utilization	1
Fair utilization	2
Average utilization	3
High utilization	4
Very high utilization	5
Extensive utilization	6
X is level of model utilization	

- **Exploring passive lighting, heating and ventilation**

The intent is to ensure that all passive options lighting, heating, water heating, and venting the building has been explored first to reduce the demand on non-renewable energy sources. Different levels of exploring passive energy have been identified for ranking the building for this indicator (Table 56).

Table 56: Ranking guidelines for exploring the passive energy options indicator

X	Rank
No consideration	0
Low consideration	1
Fair consideration	2
Average consideration	3
High consideration	4
Very high consideration	5
Extensive consideration	6
X is level of exploring passive energy for lighting, heating, cooling, water heating and ventilation.	

- **Energy controls utilization**

The intent is to reduce energy use through monitoring and adjusting energy consumption continuously. Different levels of controls utilization have been identified to rank the building for this indicator (Table 57Table 57).

Table 57: Ranking guidelines for the utilization of energy controls indicator

X	Rank
No or very limited utilization	0
Low level of utilization	1
Fair level of utilization	2
Average level of utilization	3
High level of utilization	4
Very high level of utilization	5
Extensive level of utilization	6
X is level of energy controls utilization	

- **Envelope insulation and air leakage**

The intent is to ensure that the thermal resistance of the building envelope meets or exceeds the standards. The percentage ratio of the average building insulation value divided by the standard has been selected in raking the building for this indicator (Table 58).

Table 58: Ranking guidelines for the building insulation and air leakage indicator

X (%)	Rank
$X \leq 70$	0
$70 < X \leq 80$	1
$80 < X \leq 90$	2
$90 < X \leq 100$	3
$100 < X \leq 110$	4
$110 < X < 120$	5
$X \geq 120$	6
X is the percentage ratio of the building insulation divided by the standard.	

- **Building orientation**

The intent is to ensure that the building is oriented such that passive lighting and heating are maximized. Different orientation categories have been identified for ranking the building for this indicator (Table 59).

Table 59: Ranking guidelines for the building orientation indicator

X	Rank
Worst orientation	0
Almost worst orientation	1
Bad orientation	2
Average orientation	3
good orientation	4
Almost best orientation	5
Optimum orientation	6
X is description of the orientation from the passive energy perspective.	

- **Lighting fixtures efficiency**

The intent is to ensure that the most efficient lighting systems are installed. Energy consumption by the lighting system in comparison to a standard has been selected in ranking the building for this indicator, and it needs to be minimized (Table 60).

Table 60: Ranking guidelines for the lighting fixtures efficiency indicator

X (%)	Rank
$X \leq 70$	6
$70 < X \leq 80$	5
$80 < X \leq 90$	4
$90 < X \leq 100$	3
$100 < X \leq 110$	2
$110 < X < 120$	1
$X \geq 120$	0
X is the percentage of the energy consumption by the lights in comparison to a standard.	

- **Heating and cooling system efficiency and size**

The intent is to ensure that right-sized and energy efficient heating and cooling systems are installed. Energy consumption by the heating and cooling system in comparison to a standard has been selected in ranking the building for this indicator, and it needs to be minimized (Table 61).

Table 61: Ranking guidelines for the heating and cooling system efficiency indicator

X (%)	Rank
$X \leq 70$	6
$70 < X \leq 80$	5
$80 < X \leq 90$	4
$90 < X \leq 100$	3
$100 < X \leq 110$	2
$110 < X < 120$	1
$X \geq 120$	0
X is the percentage of the energy consumption by the heating and cooling system in comparison to a standard.	

- **Appliances efficiency**

The intent is to insure that the most energy efficient appliances are installed. Average energy consumption by the appliances in comparison to a standard has been selected in ranking the building for this indicator, and it needs to be minimized (Table 62).

Table 62: Ranking guidelines for the appliances efficiency indicator

X (%)	Rank
X ≤ 70	6
70 < X ≤ 80	5
80 < X ≤ 90	4
90 < X ≤ 100	3
100 < X ≤ 110	2
110< X < 120	1
X ≥ 120	0
X is the average percentage of the energy consumption by the appliances in comparison to a standard.	

3.3.3.6 Resources

- **Collection of recyclable waste at the construction stage**

The intent is to divert construction and land-clearing debris from disposal in landfills and incinerators and redirect the recyclable portion back to the manufacturing process. The portion expected to be diverted from total recyclable waste has been used to rank the site for this indicator, and it needs to be maximized (Table 63).

Table 63: Ranking guidelines for the collection of recyclable waste at the construction stage indicator

X (%)	Rank
X ≤ 20	0
20 < X ≤ 30	1
30 < X ≤ 40	2
40 < X ≤ 50	3
50 < X ≤ 60	4
60 < X < 70	5
X ≥ 70	6
X is the percentage of the portion expected to be recycled from total recyclables at the construction stage.	

- **Collection of recyclable waste at the operation stage**

The intent is to ensure that recyclable organic and inorganic wastes are collected and recycled at the operation stage. The portion expected to be recycled from the total recyclables has been selected to rank the building for this indicator, and it needs to be maximized (Table 64).

Table 64: Ranking guidelines for the collection of recyclable waste at the operation stage

X (%)	**Rank**
$X \leq 20$	0
$20 < X \leq 30$	1
$30 < X \leq 40$	2
$40 < X \leq 50$	3
$50 < X \leq 60$	4
$60 < X < 70$	5
$X \geq 70$	6
X is the percentage of the portion expected to be recycled from total recyclables at the operation stage.	

- **Collection of recyclables at the demolition stage**

The intent is to divert demolition waste from disposal in landfills and incinerators. The portion expected to be recycled from the total recyclables has been selected to rank the building for this indicator, and it needs to be maximized (Table 65).

Table 65: Ranking guidelines for the collection of recyclable waste at the demolition stage

X (%)	**Rank**
$X \leq 20$	0
$20 < X \leq 30$	1
$30 < X \leq 40$	2
$40 < X \leq 50$	3
$50 < X \leq 60$	4
$60 < X < 70$	5
$X \geq 70$	6
X is the percentage of the portion expected to be recycled from total recyclables at the demolition stage.	

- **Right-size building**

The intent is to ensure that the building has the right size and resources are reserved. A comparison with a slandered has been selected for ranking the building for this indicator (Table 66).

Table 66: Ranking guidelines for the right-size building indicator

X (%)	Rank
X ≤ 70	6
70 < X ≤ 80	5
80 < X ≤ 90	4
90 < X ≤ 100	3
110 < X ≤ 120	2
120 < X < 130	1
X ≥ 130	0
X is the percentage ratio of the building size divided by a standard.	

- **Design for disassembly (DfD)**

The intent is to encourage a building design that will facilitate the easy disassembly of components so that they can be re-used or recycled and less waste is generated. Different classifications have been identified for ranking the building for this indicator (Table 67).

Table 67: Ranking guidelines for the design for disassembly (DfD) indicator

X	Rank
No or very limited measures have been taken to facilitate future disassembly	0
Few measures have been taken to facilitate future disassembly	1
Fair measures have been taken to facilitate future disassembly	2
Average measures have been taken to facilitate future disassembly	3
High measures have been taken to facilitate future disassembly	4
Very high measures have been taken to facilitate future disassembly	5
Extensive measures have been taken to facilitate future disassembly	6
X is the level of exploring DfD	

- **Durability of building materials and products**

The intent is to extend the life of the building materials and products, and conserve resources by minimizing the need to replace materials and products. Different durability levels have been indentified for ranking the building for this indicator (Table 68).

Table 68: Ranking guidelines for the durability of the building materials and product indicator

X	Rank
No or very limited considerations	0
Poor considerations	1
Fair consideration	2
Average considerations	3
High considerations	4
Very high considerations	5
Extensive considerations	6
X is the level of exploring durability	

- **Selection of products based on LCA**

The intent is to encourage selection of environmentally preferable products and materials with the lowest life cycle environmental impacts. Another objective is to increase demand for building products and materials that incorporate recycled and bio-based contents. The level of LCA utilization has been selected to rank the building for this indicator (Table 69).

Table 69: Ranking guidelines for the utilization of LCA indicator

X	Rank
No or limited utilization	0
Poor utilization	1
Fair utilization	2
Average utilization	3
High utilization	4
Very high utilization	5
Extensive utilization	6
X is the level of LCA utilization in selecting building products and materials.	

- **Locally produced materials**

The intent is to increase the demand for building materials and products that are extracted and manufactured locally or regionally, thereby reducing the environmental impacts resulting from transportation. The percentage, by weight, of the materials and products produced regionally has been used for ranking the building for this indicator, and it needs to be increased (Table 70).

Table 70: Ranking guidelines for the locally produced materials indicator

X (%)	Rank
X ≤ 20	0
20 < X ≤ 30	1
30 < X ≤ 40	2
40 < X ≤ 50	3
50 < X ≤ 60	4
60 < X < 70	5
X ≥ 70	6
X is the percentage of the locally produced materials and products from total.	

- **Use of ozone depletion refrigerants**

The intent is to avoid ozone depletion refrigerants. The percentage of ozone depletion refrigerants from total refrigerants has been selected for ranking the building for this indicator, and it needs to be minimized (Table 71).

Table 71: Ranking guidelines for the use of ozone depletion refrigerants indicator

X (%)	Rank
X ≤ 5	6
5 < X ≤ 10	5
10 < X ≤ 20	4
20 < X ≤ 30	3
30 < X ≤ 40	2
40 < X < 50	1
X ≥ 50	0
X is the percentage of ozone depletion refrigerants from the total.	

3.3.3.7 IEQ

- **Ventilation effectiveness and CO2 concentration**

The intent is to ensure that veneration is adequate to provide a satisfactory level of air quality. An air quality indicator, such as CO2 concentration, has been selected for ranking the building for this indicator (Table 72).

Table 72: Ranking guidelines for the ventilation effectiveness indicator

X (%)	Rank
X ≤ 70	6
70 < X ≤ 80	5
80 < X ≤ 90	4
90 < X ≤ 100	3
110 < X ≤ 120	2
120 < X < 130	1
X ≥ 130	0
X is the ratio (as percentage) of CO2 concentration divided by a standard.	

- **Temperature and relative humidity**

The intent is to provide a thermally comfortable environment and an acceptable humidity level. The expected occupants' satisfaction degree has been selected to rank the building for this indicator (Table 73).

Table 73: Ranking guidelines for the temperature and relative humidity indicator

X	Rank
Extremely not satisfied	0
Highly not satisfied	1
Not satisfied	2
Acceptable	3
Satisfied	4
Very satisfied	5
Extremely satisfied	6
X is the level of expected occupants thermal comfort satisfaction	

- **Air filtering and venting of combustion gases and odors**

The intent is to minimize exposure of building occupants to particulates, combustion gases, and other pollutants. The efficiency of the filtering and venting system has been selected for ranking the building for this indicator (Table 74).

Table 74: Ranking guidelines for the air filtering and pollutants venting indicator.

X	Rank
Worst efficiency or not installed	0
Bad efficiency	1
Fair efficiency	2
Average efficiency	3
Good efficiency	4
Almost the best efficiency	5
Optimum efficiency	6
X is the filtration and venting efficiency.	

- **Environmental Tobacco Smoke (ETS)**

The intent is to minimize exposure of building occupants to environmental tobacco smoke (ETS). The smoking policy has been selected to rank the building for this indicator (Table 75).

Table 75: Ranking guidelines for the environmental tobacco smoke (ETS) indicator

X	Rank
Smoking is allowed in all the building	0
Smoking is allowed in most of the building	1
Smoking is allowed in designated areas	2
Smoking is prohibited in all building areas	3
X is the restriction level of smoking inside the building	

- **Noise and vibration**

The intent is to avoid noise and vibration at harmful or distraction levels to occupants. The expected occupants' satisfaction level has been selected for ranking the site for this indicator (Table 76).

Table 76: Ranking guidelines for the noise and vibration indicator

X	Rank
Extremely unsatisfied	0
Very unsatisfied	1
Unsatisfied	2
Acceptable	3
Satisfied	4
Highly satisfied	5
Extremely satisfied	6
X is the occupants' satisfaction concerning the noise and vibration levels.	

- **Exposure to Radon**

The intent is to avoid occupants' exposure to Radon. The level of exposure to radon has been selected for ranking the site for this indicator (Table 77).

Table 77: Ranking guidelines for the exposure to Radon indicator

X	Rank
Exposure to extreme levels	0
Exposure to very high levels	1
Exposure to high levels	2
Exposure to low levels	3
Exposure to very low levels	4
Almost no exposure	5
No exposure	6
X is the occupants' level of exposure to Radon.	

- **Lighting Quality**

The intent is to ensure that lighting systems provides adequate quality levels, where electric lighting should be designed to supplement passive lighting as the primary source of lighting. The occupants' level of satisfaction concerning the lighting quality to has been selected for ranking the site for this indicator (Table 78 78).

Table 78: Ranking guidelines for lighting quality indicator

X	Rank
Extremely not satisfied	0
Highly not satisfied	1
Not Satisfied	2
Acceptable	3
Satisfied	4
Highly satisfied	5
Extremely satisfied	6
X is the occupants' satisfaction level about the lighting quality.	

- **Access to daylight and outside view**

The intent is to enhance occupant well-being by providing natural light outside view. The percent of the building areas that have access to daylight and outside view has been selected for ranking the building for this indicator (Table 79).

Table 79: Ranking guidelines for access to daylight and outside view indicator

X (%)	Rank
$X \leq 40$	0
$40 < X \leq 50$	1
$50 < X \leq 60$	2
$60 < X \leq 70$	3
$70 < X \leq 80$	4
$80 < X < 90$	5
$X \geq 90$	6
X is the percentage of the building areas that has access to daylighting.	

3.3.4 Weighting Guidelines

Using one of the available methods, weighting factors need to be assigned to the categories at the macro-assessment level of GREENOMETER-7 as identified in Table 80.

Table 80: Generic Weighting Factors for the macro-assessment level

Category	**Category Weighting Factor (%)**
1. Location	A
2. Land Use & Value	B
3. Stormwater, Heat-island & Landscaping	C
4. Landscaping	D
5. Energy	E
6. Resources	F
7. IEQ	G

The total of all category weighting factors must equal 100, as shown in the following equation:

$$A+B+C+D+E+F+G=100 \quad \text{(74)}$$

Similarly, weighting factors need to be assigned to the indicators of each category at the micro-assessment level of GREENOMETER-7 as identified in Table 81.

Table 81: Generic Weighting Factors for the macro-assessment level

Category	Indicator	Indicator Weighting Factor (%)
Category 1 Location	Vulnerability of site to flooding	a1
	Proximity to public transportation	a2
	Public Transportation Quality	a3
	Proximity to existing infrastructure	a4
	Distance between site and centers of employment	a5
	Proximity to services	a6
	Proximity to contaminants/ odor sources	a7
	Proximity to noise sources	a8
	Impact of adjacent building	a9
	Availability of renewable energy	a10
	Availability of potable water	a11
	Impact of the building on the surroundings	a12
Category 2 Land Use &Value	Ecological sensitivity of the land	b1
	Agricultural value of the land	b2
	Contamination and development status of the land	b3
	Relevance of the footprint of the building	b4
	Pavement density	b5
	Landscaping/ disruption density	b6
	Development density	b7
Category 3 Stormwater, Heat-Island & Landscaping	Stormwater run-off	c1
	Erosion degree and run-off level of contamination	c2
	Heat island effect	c3
	Native planting	c4
	Landscaping design strategy	c5
Category 4 Water & Wastewater	Landscaping water efficiency	d1
	Non-potable water use for irrigation	d2
	Non-potable water use for toilet	d3
	Harvesting rainwater for reuse	d4
	Installation of high efficiency fixtures	d5
	Availability of dual wastewater system	d6
Category 5 Energy	Use of renewable energy	e1
	Computer modeling for energy optimization	e2
	Exploring passive lighting, heating and ventilation	e3
	Energy controls utilization	e4
	Envelope insulation and air leakage	e5
	Building orientation	e6
	Lighting fixtures efficiency	e7

Category	Indicator	Indicator Weighting Factor (%)
	Heating and cooling system efficiency	e8
	Appliances efficiency	e9
Category 6 Resources	Collection of recyclable waste at the construction stage	f1
	Collection of recyclable waste at the operation stage	f2
	Collection of recyclable waste at the demolition stage	f3
	Right-size building	f4
	Design for disassembly (DfD)	f5
	Durability of building materials and products	f6
	Selection of products based on LCA	f7
	Locally produced materials	f8
	Use Ozone depletion refrigerants	f9
Category 7 IEQ	Ventilation effectiveness and CO2 concentration	g1
	Temperature and relative humidity	g2
	Air filtering and venting of combustion gases and odors	g3
	Environmental Tobacco Smoke (ETS)	g4
	Noise and vibration	g5
	Exposure to Radon	g6
	Lighting Quality	g7
	Access to daylight and outside view	g8

The total of the indicator weighting factor for each category must equal 100, as shown in the following equations:

- Location

a1+a2+a3+a4+a4+a5+a6+a7+a8+a9+a10+a11+a12=100 ……………………………….(75)

- Land use & land value

b1+b2+b3+b4+b5+b6+b7=100 ………………………………………………….… (76)

- Stormwater, heat-island & landscaping

c1+c2+c3+c4+c5=100 ………………………………………………………..(77)

- Water &Wastewater

d1+d2+d3+d4+d5+d6=100 ……………………………………………………....(78)

- Energy

e1+e2+e3+e4+e5+e6+e7+e8+e9=100 …..…..……………………………………..…(79)

- Resources

f1+f2+f3+f4+f5+f6+f7+f8+f9=100 ……..……………………………………………(80)

- IEQ

g1+g2+g3+g4+g5+g6+g7=100 …..…………………………………………………….(81)

3.4 GREENOMETER-7 into LEED

The LEED scoring system has emerged in recent years with a high level of visibility and it is the predominant green building rating system in the United States. USGBC is in the process of incorporating life cycle assessment (LCA) into LEED. Working groups have been established to provide USGBC with recommendations on how to best implement the integration. Reports of initial recommendations have been released at the end of 2006 and it was recommended to award LEED credits for selecting products based on LCA and fro making decisions based on the use of an LCA tool by the design team.

GREENOMETER-7 is a LCA assessment tool and by utilizing it assures incorporating LCA into LEED. One approach of incorporating LCA in to LEED is by using GREENOMETER-7 to justify LEED credits, where each LEED credit is matched with applicable GREENOMETR-7 indicators at the micro- and macro-assessment level. For the credit to be awarded of the credit's indicators must meet a threshold. For example, the building satisfies LEED credit X and receives 1 point if the score of indicator Y of GREENOMETER-7 is 5 or more. A correlation between LEED credits and GREENOMETER-7 indicators needs to be established. One or more indicators may be required to justify each LEED credit. For each indicator it needs to be determined at what score to award LEED points. The points of the credits that meet the criteria are added to determine the LEED certification level of the projected building. A unique advantage is that by using GREENOMETER-7, the LEED certification level is forecasted in the conceptual design stage so that modifications in the design are possible if a better certification level is desired. The LEED certification system receives more credibility by incorporating LCA into LEED through GREENOMETER-7.

For some LEED credits there may be no matching GREENOMETER-7 indicators, in this case LEED criteria is used in awarding the points. On the other hand, some of GREENOMETER-7 indicators may not be covered by any of the LEED credits. This may require expanding the research in the future to ensure that all major areas are covered by one way or another in both systems.

In the following tables the credits of each LEED categories and their matching GREENOMETER-7 indicators are listed. Also it identifies the number of LEED points that are received be meeting or exceeding the indicator threshold score. LEED categories are sustainable site (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), and indoor environmental quality (EIQ).

Table 82Table 82 shows GREENOMETER-7 indicators applicable for the credits of LEED sustainable site (SS) category. It also shows for each indicator the number of LEED points that can be awarded if the identified threshold is met.

Table 82: Credits of the sustainable site (SS) category of LEED

LEED Credit	Matching GREENOMETER-7 Indicators	Required Score	LEED Points
SS-1 Site Selection	Macro-2.1 Ecological Sensitivity of the Land	≥ 4	1
	Macro-2.2 Agricultural value of the land	≥ 4	1
SS-2 Preferred Location	Macro-2.3 Contamination and development status of the land	4 or 5	1
		6	2
SS-3 Infrastructure	Macro-1.4 Proximity to existing infrastructure	≥ 4	1
SS-4 Alternative transportation	Macro-1.2 Proximity to public transportation	≥ 4	1
	Macro-1.3 Public transportation quality	≥ 4	1
	Macro-1.6 Proximity to services	4 or 5	1
		6	2
SS-5 Site Development	Macro-2.5 Pavement density	≥ 4	1
	Macro-2.6 Disruption density	≥ 4	1
	Macro-2.7 Development density	≥ 4	1
SS-6 Stormwater Design	Macro-3.1 Stormwater run-off	4	1
		5	2
	Macro-3.2 Erosion degree and level of contamination	6	3
SS-7 Heat-island effect	Macro-3.3 Heat-island effect	≥ 4	1
SS-8 Landscaping	Macro-3.4 Native planting	≥ 4	1
	Macro-3.5 Landscaping design strategy	≥ 4	1
SS-9 Light pollution reduction	Only light areas as required for safety and comfort	NA	1
Total possible points in the sustainable site category			**19**

Table 83 shows GREENOMETER-7 indicators applicable for the credits of LEED water efficiency (WE) category. It also shows for each indicator the number of LEED points that can be awarded if the identified threshold is met.

Table 83: Credits of the water efficiency category (WE) of LEED

LEED Credit	Matching GREENOMETER-7 Indicators	Required Score	LEED Points
WE-1 Irrigation System	Macro-4.1 Landscaping water efficiency	≥ 4	1
	Macro-4.2 Non-potable water for irrigation	≥ 4	1
WE-2 Water reuse	Micro-2.1.2 % or recycled/ reclaimed water	4 or 5	1
		6	2
	Macro-4.4 Harvesting rainwater for reuse	≥ 4	1
	Macro-4.3 Non-potable water use for toilet	≥ 4	1
	Macro-4.6 Availability of dual wastewater system	≥ 4	1
WE-3 Water use	Micro-2.1.1 Total water use	4 or 5	1
		6	2
	Macro-4.5 Installation of high efficiency fixtures	4 or 5	1
		6	2
WE-4 Innovative wastewater technologies	Treat at least50% of wastewater on-site to tertiary standards	NA	1
Total possible points for the water efficiency category			**12**

Table 84 shows GREENOMETER-7 indicators applicable for the credits of LEED energy and atmosphere (EA) category. It also shows for each indicator the number of LEED points that can be awarded if the identified threshold is met.

Table 84: Credits of the energy and atmosphere (EA) category of LEED

LEED Credit	Matching GREENOMETER-7 Indicators	Required Score	LEED Credit
EA-1 Optimize Energy performance	Micro-1.1.1 and 1.2.1 Total energy consumption	3	2
		4	4
		5	6
		6	8
	Macro-5.2 Computer modeling for energy optimization	≥ 4	1
	Macro-5.3 Exploring passive lighting, heating and ventilation	≥ 4	1
	Macro-5.4 Energy controls utilization	≥ 4	1
CA-2 Insulation	Macro-5.5 Envelop insulation and air leakage	≥ 4	1
CA-3 Space Heating and Cooling	Micro-1.1.3 or 1.2.3 Energy for heating and cooling	≥ 4	1
	Macro-5.8 Heating and cooling system efficiency	≥ 4	1
EA-4 Lighting	Micro-1.1.2 Electricity for lighting	≥ 4	1
	Macro-5.7 Lighting fixtures efficiency	≥ 4	1
EA-5 Appliances	Micro-1.1.5 and 2.2.5 Energy for equipment	≥ 4	1
	Macro-5.9 Appliances efficiency	≥ 4	1
EA-6 Renewable Energy	Macro-5.1 Use of renewable energy	≥ 4	1
EA-7 Refrigerants Management	Macro-6.9 Use of Ozone depletion refrigerants	≥ 4	1
	Micro4.4.4 Ozone depletion potential	≥ 4	1
Total possible points for the energy & atmosphere category			**21**

Table 85 shows GREENOMETER-7 indicators applicable for the credits of LEED materials and resources (MR) category. It also shows for each indicator the number of LEED points that can be awarded if the identified threshold is met.

Table 85: Credits of the materials and resources (MR) category of LEED

LEED Credit	**Matching GREENOMETER-7 Indicators**	**Required Score**	**LEED Credit**
MR-1 Waste management	Micro-3.2.2 % of resources output expected to be recycled	4	1
		5	2
		6	3
	Macro-6.1 Collection of recyclable waste at the construction stage	≥ 4	1
	Macro-6.2 Collection of recyclable waste at the operation stage	≥ 4	1
	Macro-6.3 Collection of recyclable waste at the demolition stage	≥ 4	1
MR-2 Recycling content	Micro-3.1.2 % of recycled content	4 or 5	1
		6	2
MR-3 Environmentally preferred products	Macro-6.7 Selection based on LCA	4 or 5	1
		6	2
MR-4 Regional Materials	Macro-6.8 Locally produced materials	4 or 5	1
		6	2
Total possible points for the materials and resources category			**12**

Table 86 shows GREENOMETER-7 indicators applicable for the credits of LEED indoor environmental quality (IEQ) category. It also shows for each indicator the number of LEED points that can be awarded if the identified threshold is met.

Table 86: Credits for the indoor environmental quality (EQ) category of LEED

LEED Credit	Matching GREENOMETER-7 Indicators	Required Score	LEED Credit
EQ-1 Outdoor Air Delivery Monitoring	Macro-7.1 Ventilation effectiveness and CO2 concentration	4 or 5	1
		6	2
EQ-2 Moisture Control and thermal control	Macro-7.2 Temperature and relative humidity	4 or 5	1
		6	2
EQ-3 Construction IAQ management plan	Develop and implement an IAQ management plan for the construction stage	NA	1
EQ-4 Low-emitting materials	Micro-3.1.4 % of chemical content	≥ 4	1
	Micro-4.4.1 Total contaminants output to air	≥ 4	1
EQ-5 Indoor chemical & pollution source control	Macro-7.6 Exposure to Radon	≥ 4	1
	Macro-7.3 Air filtering and venting of combustion gases	≥ 4	1
EQ-6 Lighting comfort	Macro-7.7 lighting quality	≥ 4	1
EQ-7 Daylight and view	Macro-7.8 Access to daylight and outside view	≥ 4	1
Total possible points for the indoor environmental quality category			**11**

Table 87 summarizes the maximum possible points for each LEED category and the total possible points from adding all categories together.

Table 87: Possible points for each LEED category and total possible points

LEED Category	Possible Points
Sustainable Site (SS)	19
Water Efficiency (WE)	12
Energy and Atmosphere (EA)	21
Materials and Resources (MR)	12
Indoor Environmental Quality (EQ)	11
Innovation and Design Process (ID)	NA
Total Possible LEED Points: 75	

Table 88 shows the range of points required to achieve each LEED certification levels.

Table 88: LEED points requirements for each certification level

LEED Certification	LEED Points
Certified	26-32
Silver	33-38
Gold	39-51
Platinum	≥ 52

3.5 Procedures for Conducting GREENOMETER-7

GREENOMETER-7 is a tool for use at the conceptual design stage. The designer has the option to conduct only the micro-assessment level or both the micro- and macro-assessment levels of GREENOMETER-7. It is usually recommended to start with the macro-assessment since it requires less effort and resources. Figure 15 shows the procedures for conducting the macro-assessment. Figure 16 shows the procedures for conducting the micro-assessment.

In addition to conducting either the macro-assessment or both the macro-assessment and the micro-assessment, the designer has the option to forecast the LEED points expected to be received by the building an subsequently forecasting he LEED certification level for the projected building. The advantage of forecasting the LEED certification at the conceptual design stage is that improvement can be made if a better certification level is desired. LEED points can be forecasted after conducting the macro-assessment. In this case LEED credits are justified using macro-assessment indicators only. Figure 17 shows the procedures for forecasting the LEED points after the macro-assessment while figure 18 shows the procedures for forecasting the LEED points after conducting both the macro-and micro-assessment.

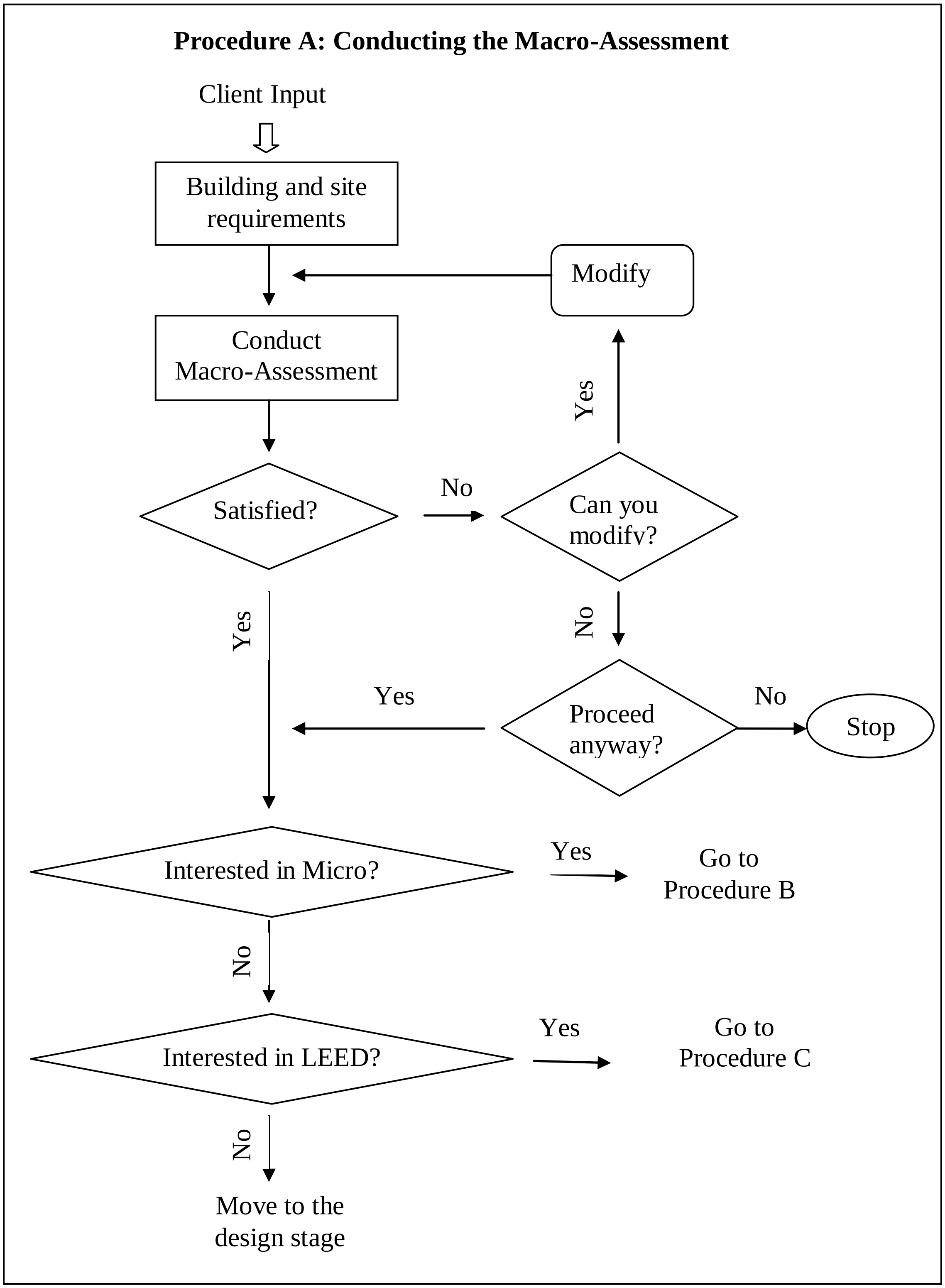

Figure 15: Procedures for conducting the micro-assessment level of GREENOMETR-7

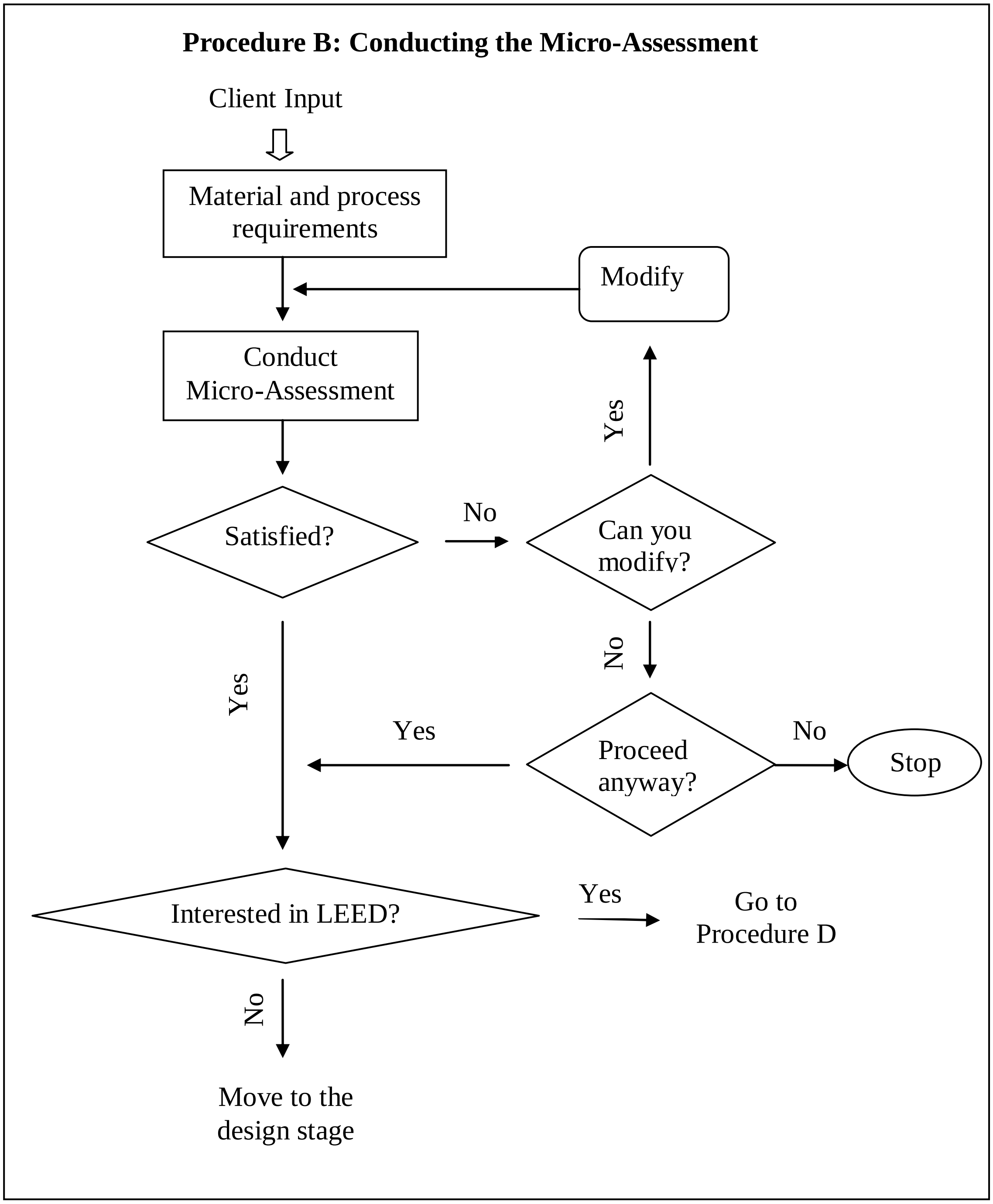

Figure 16: Procedures for conducting the micro-assessment level of GREENOMETER-7

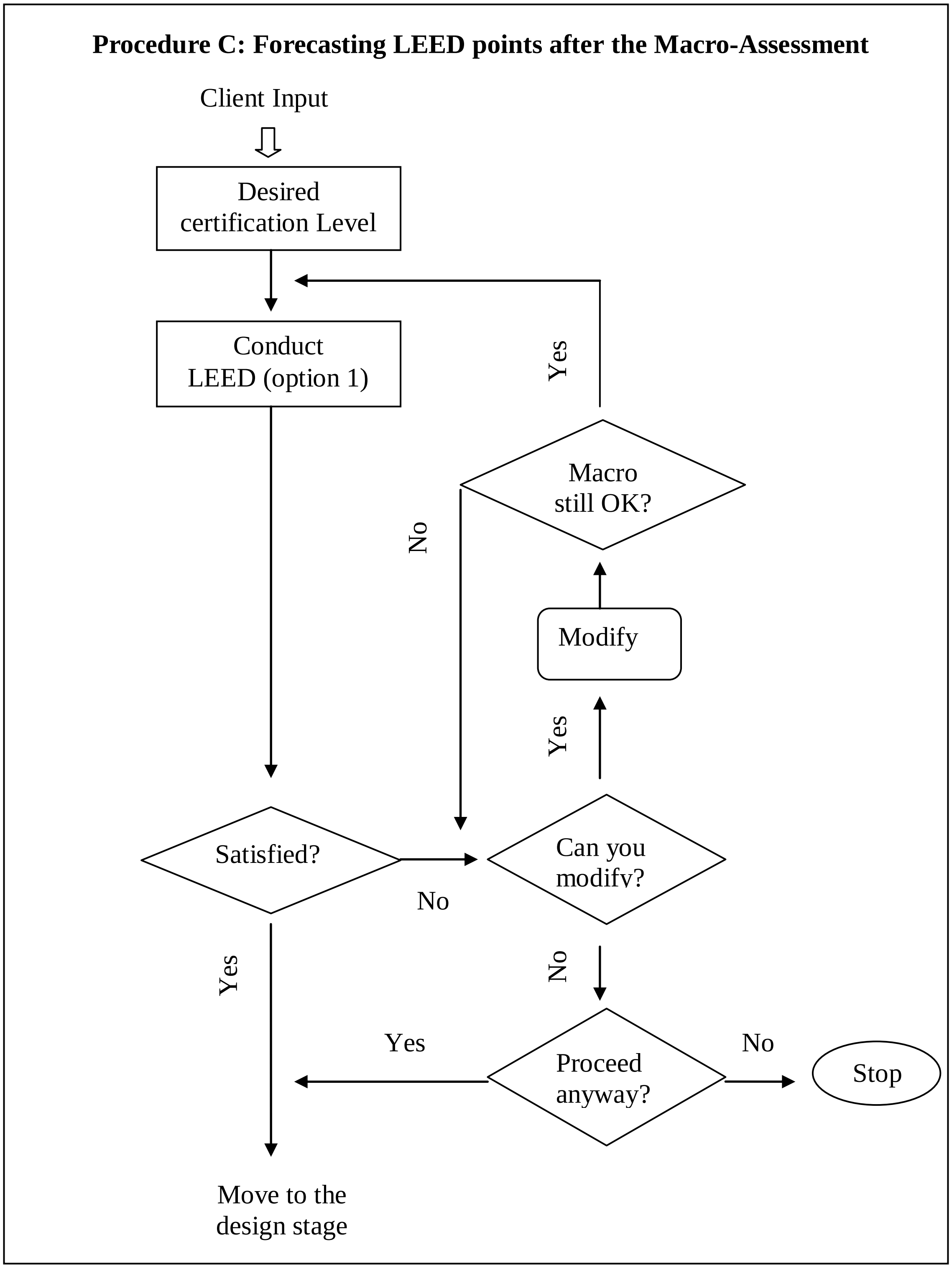

Figure 17: Procedures for forecasting LEED points after the macro-assessment

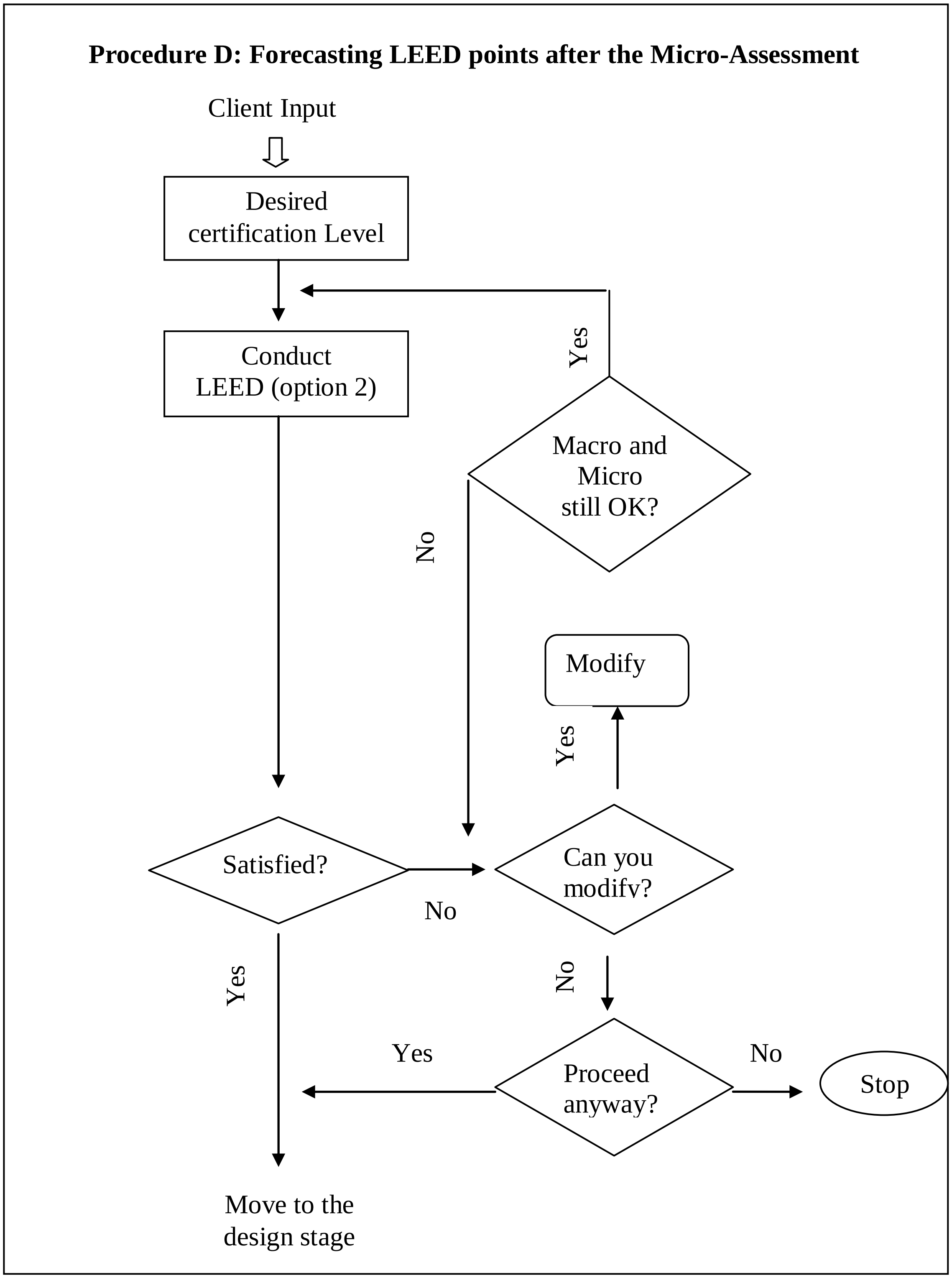

Figure 18: Procedures for forecasting LEED points after the micro-assessment level

CHAPTER IV

ANALYSIS AND RESULTS

4.1 Profiling of Selected Assessment Classes

In this Chapter profiles have been developed for various assessment classes. This assessment classes are related to products entering or leaving the site, equipment entering, leaving or being used in the site. The goal was to develop profiles fort eh assessment classes related to products and equipment from different building and construction fields. Such an effort can be extended to develop a database of commonly used assessment classes to be used by the designers.

4.1.1 Concrete 21 MPa

Concrete is a mixture of portland cement, water, fine aggregate, such as sand or finely crushed rock, and coarse aggregate such as gravel or crushed rock. Granulated furnace slag, fly ash, silica fume, or limestone may be substituted for a portion of the Portland cement in the concrete mix. Concrete common strengths are 21 MPa (3,000 lb/in2), 28 MPa (4,000 lb/in2), and 34 MPa (5,000 lb/in2). Concrete with 21 MPa strength is used in applications such as residential slabs and basement walls, while strengths of 28 MPa and 34 MPa are used in structural applications such as beams and columns (Lippiatt, 2007a). Each concrete type has both E and L assessment classes. Only Concrete 21 MPa will be discussed in details.

4.1.1.1 E-Concrete 21 MPa

Concrete with 21 MPa strength has two assessment classes: E-Concrete 21 MPa and L-Concrete 21MPa. The E assessment class evaluates the impacts of the product when it enters the site, while the L assessment class evaluates the impacts of the product when it leaves the site at its end of life. In developing the E profile for Concrete 21 MPa only applicable categories are evaluated. It is gate-to-gate assessment, which means that only impacts inside the boundaries of the site are considered. A functional unit of 1-cubic meter (m3) has been selected for this assessment class, so all applicable attributes are evaluated based on 1 m3 of Concrete 21 MPa entering the site.

- **Electricity**

This category is not applicable when the concrete enters the site. Consumption of electricity by equipment while installing the concrete is considered in the U assessment classes of the equipment in question.

- **Fossil Fuel**

This category is not applicable when the concrete enters the site. Consumption of fossil fuel by equipment while installing the concrete is considered in the U assessment class of the equipment. Consumption of fossil fuel for transporting the concrete to the site is not considered because it is outside the boundaries of the site.

- **Water and Wastewater**

Both water content and water added to the concrete later to increase strength are considered in this category. Since the excess water is evaporated, wastewater generation attribute is ignored. Each 1 m3 of concrete mixture contains 141 L water. Water added later is estimated about 850 L. The value assigned to the potable water use attribute is 241 L. Assume that 100 L will evaporate, so assign 759 L to water evaporation. The remaining water becomes chemically bounded to the cement.

- **Resources Input**

The constituents of 1 m3 Concrete 21 MPa include the following: 223 kg Portland cement, 1,127 kg coarse aggregate, 831 kg fine aggregate, and 141 kg water. Water was counted for in the water and wastewater category. The 1,127 kg coarse aggregate is assigned to the rocks attribute and the 831 kg fine aggregate are assigned to the sand attribute. Portland Cement is a fine powder produced by grinding Portland cement clinker (more than 90%), a limited amount of gypsum (about 3% by mass fraction) which control the set time, and up to 5% minor constituents as allowed by various standards (Wikipedia, 2007). The 223 kg cement is assigned to the following attributes: 205.16 kg Portland cement clinker, 6.69 kg gypsum, and 11.15 kg others. Assume no recycled content so that the recycled content attribute is 0 kg. No biobased content.

- **Resources Output**

Since it is an E assessment class only the resources leaving the site at this point are considered. It is important to determine if they are taking the recycling or the disposal route. It is assumed that no concrete is wasted and all attributes are assigned 0 kg. Some plywood may be wasted but it is recommended to consider it in a separate E assessment class because not all concrete applications require the same quantity of plywood.

- **Contaminants Input and Generation**

For concrete received from ready-mix plants, no particulate contaminants are expected to be generated at the site. All attributes of this category are assigned 0 kg values.

- **Contaminants Output**

No contaminants output is expected from concrete received from ready-mix plants, none of the five contaminants output categories are applicable and all of their attributes are assigned 0 values.

- **Economics**

The materials costs attribute is a ssigned $90 dollars , which is the cost of 1 m3 Concrete 21 MPa. The laber cost attribute is a ssigned $70 dollars. The costs may vary from place to place so the user can update accordingly.

4.1.1.2 L-Concrete 21 MPa

Assessment class L for Concrete 21 MPa considers the impacts when concrete leaves the site at its end of life; this may happen many years after the E assessment component of the same concrete is applicable. There is always a relationship between the E assessment class and the L assessment class for the same product. In developing the profile for L-Concrete 21 MPa only attributes in applicable micro-assessments categories are evaluated. It is gate-to-gate assessment, which means that only impacts inside the boundaries of the site are considered. A functional unit of 1-cubic meter (m3) has been selected for this assessment class; as a result all attributes are evaluated based on 1 m3 of Concrete 21 MPa leaving the site.

- **Electricity**

Not applicable, any electricity consumption by the equipment is considered in the equipment U assessment classes.

- **Fossil Fuel**

Not applicable, any fossil fuel consumption by the equipment is considered in the equipment U assessment classes.

- **Water and Wastewater**

Not applicable. No water is used in demolition nor wastewater is generated.

- **Resources Input**

Not applicable.

- **Resources Output**

For resources output there are two routes available: recycling (R) and to disposal (D). It is assumed that 100% of the product will be recycled so the resources output will be assigned to the recycling route. The user can change it to the disposal route if recycling is not the most probable. The mass of 1 m3 Concrete 21 MPa at the end of life is 1300 kg. Since the product is recycled mainly as a filler, all constituents will be assigned to the rocks-concrete attribute. Assume that 0.5 kg of particulates is generated during demolition, so 1299.5 kg is assigned to the R-rocks-concrete attribute.

- **Contaminants Output**

The weight of 1 m3 of Concrete 21MPa is expected to be around 2300 kg, it is assumed that in average 0.5 kg of particulates is generated per each 1 m3 concrete demolished. The particulates generated from the demolition process needs to be assigned to one or more of the output routs. It is assumed that 80% of the 0.5 kg particuletes will be collected and the remaining 20% will be released to the air. The particulates attribute in the captured category will be assigned 0.4 kg, while the particulates attribute in the release to air category will be assigned 0.1 kg.

- **Economics**

The costs associated with the demolition are mainly labor costs, it is important not to double count the labor cost when developing the equipment U profiles. The labor cost per functional unit is estimated at $40.

4.1.2 Oriented Strand Board (OSB) Sheathing

Engineered wood includes a range of derivative wood products which are manufactured by binding the strands, particles, fibers, or veneers of wood together with adhesives to form composite materials. Oriented stand board (OSB) is an example of flakes-based products, plywood is an example of veneer –based products, and medium density fiberboard (MDF) is an example of particle-based products. MDF is heavily used in the furniture industry. The E and L assessment class for both oriented strand board (OSB) sheathing and plywood sheathing will be discussed in details

4.1.2.1 E-OSB Sheathing (1.1cm)

Oriented Strand Board (OSB) is an engineered wood product formed by layering strands (flakes) of wood in specific orientation. It is manufactured from cross-oriented types of thin, rectangular wood or strips compressed and bonded together with wax resin adhesives. Phenol-formaldehyde (PF resin) and methylene-diphenyl-isocyanate (MDI resin) are used as binder materials to hold the strands together. OSB sheathing is a structural building material used for residential and commercial construction. The most common sheathing thickness for OSB is 1.1 cm (7/16 in). A functional unit of 1-square meter has been selected. Only the applicable categories to the E assessment class will be discussed and these include:

- **Resources Input**

The constituents of 1 m2 of 1.1 cm thick OSB sheathing are 6.76 kg wood, 0.237 PF resin, 0.043 kg MDI resin, and 0.108 kg wax (7.148 kg total), (Lippiatt, 2007a). The 6.76 kg wood is assigned to the wood attribute and the other constituents (0.388 kg) are assigned to the organic chemicals contribution. Assume no recycled content. Wood mass is assigned to the biobased attribute.

- **Resources Output**

It is estimated that 1.5% of the mass of the product to be lost as waste during installation and it is expected to be sent to the landfill. The amount of 0.1014 kg is assigned to the W-Wood attribute.

- **Contaminants Output**

Since 1.5% of the mass of the product is lost as waste during installation and it is expected to be disposed of then 0.00582 kg is assigned to the Organic Chemicals in the contaminants output- disposal category. The remaining organic contaminants mass is 0.38218 kg. Assume that 1% of the remaining contaminants mass is released to the air as formaldehyde (0.00382 kg) and 1% as phenol (0.00382kg) after installation.

Formaldehyde is one of the human health cancer factors in the release to air category and its factor (from TRACI) is 0.00030022. Phenol is a human health non-cancer factor in the release to air category and its factor is 0.057121075. Phenol is also an ecotoxicity factor in the release to air category and its factor is 0.038.

4.1.2.2 L-OSB Sheathing (1.1 cm)

The L assessment class evaluates the impacts of the OSB when it leaves the site at the end of its life. A functional unit of 1-square meter of the 1.1 cm thick OSB has been selected. Only the applicable categories to the L assessment class will be discussed and these include:

- **Resources Output**

In this category consider only what is leaving the site at the end of the product life is considered. The quantity that left the site at the time of installation is subtracted. Assuming that 10% of the resin is evaporated after installation, the constituents of 1 m2 of 1.1 cm thick OSB sheathing at its end life are 6.76 kg wood, 0.2346 kg PF resin, 0.0425 kg MDI resin, and 0.108 kg wax (7.1451 kg total). It is assume that 100% of the product will be disposed of then the 6.76 kg wood is assigned to the W-Wood attribute and the other constituents (0.3851 kg) are assigned to the Organic Chemicals attribute in the contaminants output-disposal category. Ignore the particulate emission to air.

- **Economics**

The removal of each 1 m2 of the product will cost $2.0 as labor cost.

4.1.3 Plywood Sheathing

Plywood is an engineered wood made from 3 or more thin sheets of wood veneer. These layers are glued together under heat and pressure with strong adhesive, usually formaldehyde. Plywood sheathing is a structural building material used for residential and commercial construction, it is made from lower density softwoods. The most common plywood sheathing thickness is 1.2 cm (15/32 in). A functional unit of 1-m2 of the 1.2 cm thickness plywood sheathing has been selected for both the E and L assessment classes.

4.1.3.1 E-Plywood Sheathing

The E considers the impacts when the product enters the site including installation. Only applicable micro-assessment categories will be considered and these include:

- **Resources Input**

The constituents of 1 m2 of 1.2 cm thick plywood in terms of their final product percentages: 5.96 kg wood, 0.108 kg PE resin, 0.965 kg extender, and 0.014 kg catalyst (NaOH) (6.147 kg total) (Lippiatt, 2007a). Wood mass is assigned to the wood attribute, the total mass of PE resin and extender is assigned to organic chemicals, and the catalyst mass is assigned to inorganic chemicals. It is assumed that the recycled content is 0 percent. Wood mass is assigned to the biobased content attribute.

- **Resources Output**

It is estimated that 1.5% of the product is wasted during installation and it is assumed to be sent to landfill. The wood mass (0.0894 kg) of the 1.5% is assigned to the W-Wood attribute of the resource output category, while the other constituents are assigned to the contaminants output-disposal category.

- **Contaminants Output**

The chemical contents associated with the wasted 1.5 % are assigned to the appropriate attribute in the contaminants output- disposal category, i.e. 0.002595 kg is assigned to the other organics attribute and 0.00021 kg to other inorganic attribute. 1% of the PF resin mass is assumed to be released to the air as formaldehyde, as a result 0.00108 kg is assigned to formaldehyde attribute in the contaminant output- to air category.

4.1.3.2 L-Plywood Sheathing

The L assessment class considers the impacts of the product at its end of life, including the removal activity. Only applicable categories will discussed in details and these include:

- **Resources Output**

Except for 1% of the PF resin mass that assumed to be released to the air in the E assessment class, everything else is assigned to the resources output or contaminant output categories. Assuming that the product is wasted at the end of life wood mass (5.96 kg) is assigned to the W-Wood attribute.

- **Contaminants Output**

The chemical contents are assigned to the appropriate attributes in the contaminants output- disposal category. The remaining 99% PF resin (0.10692 kg) in addition to the extender mass (.065 kg) are assigned to the other organics attribute. The catalyst mass (0.014 kg) is assigned to the other inorganic attribute. It is assume that no contaminants are release to the environment.

- **Economics**

The removal of each 1 m2 of the product will cost $2.0 as labor cost.

4.1.4 Brick

Brick is a masonry unit of clay molded into a rectangular shape and then burned or fired in a kiln until hard. Facing brick is used on exterior walls. Mortar is used to bond the bricks into a single unit. Both the E and L assessment classes will be developed for brick products. The common dimensions of a brick 9.2 cm x 19.4 cm x 19.4 cm (3.6 in x 2.2 in x 7.62 in). A functional unit of 1-m2 has been selected. A brick wall is assumed to be 80% brick and 20% mortar by surface area.

4.1.4.1 E-Brick

The E assessment class evaluates the impacts of brick when it enters the site including installation. Only applicable categories will be discussed and these include:

- **Resources Input**

The dimensions of each brick unit are 9.2 cm x 5.7 cm x 19.4 cm, so the surface area is 0.11 m2. The weight of one unit is 1.86 kg so the weight of 1 m2 of surface area is 169.00 kg of brick. The mass fraction of brick is 99.2% (167.648 kg) clay and 0.8% (1.352 kg) bottom ash (Lippiatt, 2007a). The clay content is assigned to the clay attribute and the bottom ash mass is assigned to others. It is assumed that the recycled content is 0%. No bio-based content.

4.1.4.2 L-Brick

The L assessment class evaluates the impacts of brick removal at its end of life. Only applicable categories will be considered and these include:

- **Resources Output**

75% of the brick weight is expected to be recycled. The weight of brick functional unit (1-m2) is 169 kg. The amount of 0.5 kg of particulates is expected to be generated during demolition. The remaining 168.5 kg per functional unit will be assigned to the attributes of the resources output category. The constituents will be assigned to the attributes as the following: 126.375 kg R-Clay-Brick and 42.125 kg W-Clay-Brick.

- **Contaminants Output**

A 0.5 kg of particulates is estimated to be generated per demolition of each functional unit. It is assumed that 0.1 kg is released to air and 0.4 kg is captured. The particulates attribute in the contaminants output-captured category is assigned 0.4 kg, while the particulates attribute in the contaminants output-to air category is assigned 0.1 kg.

- **Economics**

The removal of each 1 m2 of the product will cost $2.0 as labor cost.

4.1.5 Mortar-Type N

Mortar is a material used in masonry to bind construction blocks together and fill the gaps between them. The blocks may be stone, brick, concrete block etc. Mortar is a mixture of sand, a binder such as Portland cement, and water.

4.1.5.1 E-Mortar-Type N

The E assessment class considers the impact of the mortar when it enters the site and it is installed. A functional unit of 1-m3 has been selected. Only applicable categories will be considered and these include:

- **Water and Wastewater**

Portland cement mortar is created by mixing Portland cement with sand and water. Some water in mortar is chemically bound, so there is some net consumption of water, based on 25% by weight for hydration, approximately 230 kg/m3 of water is used. Assume that 1000 L water is added per functional unit and 770 L of it evaporates. Assign 1000 L to the portable water attribute and 770 L to the water evaporation attribute.

- **Resources Input**

Type N mortar consists of 1 part masonry cement (by volume fraction), 3 parts sand, and 6.3 L (1.7 gal) of water. The constituents of the masonry cement by mass fraction are 50% Portland cement clinker, 47.5% limestone, and 2.5% gypsum (Lippiatt, 2007a). The density of Portland cement is 1500 kg/ m3, and for dry sand is 1600 kg/m3. The functional unit for mortar is 1-m3. The constituents of wet mortar per functional unit are 500 kg masonry cement, 1000 kg sand, and 1000 kg water. The 500 kg masonry cement consists of 250 kg Portland cement clinker, 237.5 kg limestone, and 12.5 kg gypsum. Assume that no recycled content and 100% of the mortar is sent to landfill at the end of life.

4.1.5.2 L-Mortar-Type N

The L assessment class evaluates the impacts when the mortar is removed at the end of life. Only applicable categories are discussed and these include:

- **Resources Output**

The functional unit is 1-m3. The density of mortar at the end of life is about 1750 kg/m3. Assume that 0.01% of the dry mortar is converted to particulate during demolition. Assume that 100% of the remaining mortar is sent to landfill. Since mortar is trashed as product, assign 1748.25 kg to the W-sand-mortar attribute.

- **Contaminants Output**

A 0.01% of the mortar is assumed to be converted to particulates and released to air. Assign 1.75 kg to the particulate attribute in the release to air category.

- **Economics**

The cost of demolition will be considered with the demolition of the blocks.

4.1.6 Portland Cement Stucco

Modern stucco is cement plaster made of Portland cement, lime and water that is applied wet and harden while it dries. It is used as a coating for walls and ceilings and for decoration. Lime is often added to decrease permeability and increase the workability of stucco. It is usually applied in 2 to 3 layers over an extended metal lath that is fastened to the wall sheathing with staples. The density of the base coat is about 1830 kg/ m3, while it is 1971 kg/m3 for the finish coat. The volume fractions of the base coat are 1 part and Portland cement, 1 part lime, and 3.25 parts. The volume fractions for the finish coat are 1 part Portland cement, 1.125 lime, and 3 parts sand. The functional unit is 1 m2 of stucco in 3-coat covering totaling 2.22 cm in thickness. Coat 1 and 2 are each 0.95 cm thick and the finish coat is 0.32 cm thick.

4.1.6.1 E-Portland Cement Stucco

- **Water and Wastewater**

Assume that 100 L water is consumed per functional unit and 77 L of it evaporated.

- **Resources Input**

The constituents per functional unit are 33 kg sand, 13 kg Portland cement, and 5 kg lime. Portland cement constituents as mass fraction are 92% (11.96 kg) Portland cement clinker, 3% (0.39 kg) gypsum, and 5% (0.65 kg) other minor constituents. The resources input attributes are assigned values as the following: 33 kg sand, 5 kg limestone, 11.7 kg Portland cement clinker, 0.39 kg gypsum, and 0.65 kg others. No biobased content and no recycled content.

4.1.6.2 L-Portland Cement Stucco

- **Resources output**

Assume that 100% of the stucco will be recycled at its end of life. The same functional unit (1-m2 of stucco) will be used for the L assessment class. The mass per functional unit at the end of life is around 50 kg. The whole quantity (50 kg) will be assigned to the R-Sand-mortar since the constituents act as a product. The particulates generated are assumed negligible.

4.1.7 Aluminum Siding

Aluminum siding is a commonly used wall siding that is known for its light weight and durability. A functional unit of 1 m2 of a board 0.061 cm thick will be selected with a weight of 1.631 kg.

4.1.7.1 E-Aluminum Siding

- **Resources Input**

If the aluminum siding is not coated the only resource input is aluminum. The weight is 1.631 kg/m2 so assign 1.631 kg to the aluminum attribute. It is assume that 100% of the product is from recycled aluminum.

- **Resources Output**

Installation waste with a mass fraction of 5% is assumed, and all waste is assumed to be recycled. Assign 0.08155 kg to the R-aluminum attribute.

4.1.7.2 L-Aluminum Siding

- **Resources Output**

Aluminum scrap has a significant economic value. There is therefore a financial incentive to recover aluminum siding from a building at the end of life. Assign 1.631 kg to the R-aluminum attribute.

4.1.8 Cedar Siding

Cedar wood is used for exterior siding because it is a lightweight, low-density, aesthetically-pleasing material that provides adequate weatherproofing. Though installation and repair is relatively easy, wood siding requires more maintenance than other popular solutions. It requires treatment every four to nine years. Wood is a moderately renewable resource and is biodegradable. However, most paints and stains used to treat wood are not environmentally friendly and may be toxic. A functional unit of 1-m2 of 1.3 cm thick cedar siding at a weight of 6.627 kg has been selected (density of 509.77 kg/m3)

4.1.8.1 E-Cedar Siding

- **Resources Input**

The weight of the functional unit is 6.627 kg. Since the cedar siding is made from wood, 6.627 kg has been assigned to the wood attribute. Assume 100% of the product will be disposed of at end of life.

- **Resources Output**

Installation waste with a mass fraction of 5% is assumed, and all waste is assumed to go to landfill. Assign 0.33135 kg to the W-wood attribute.

4.1.8.2 L-Cedar Siding

- **Resources Output**

All the cedar siding is assumed to be disposed of in landfill at end of life. Assign 6.627 kg to the W-wood attribute.

4.1.9 Vinyl Siding

Unlike wood, vinyl siding will not rot or flake, but it does not provide additional insulation for the building. Vinyl siding has grown in popularity due to the generally low maintenance and low cost. The product is manufactured in a wide variety of profiles, colors, and thicknesses to meet different market applications. The weight of vinyl siding is about 2.6 kg per 1 m2, for a typical 0.107 cm thickness. A functional unit of 1-m2 of the 0.107 cm thick vinyl unit will be selected.

4.1.9.1 E-Vinyl Siding

- **Resources Input**

Polyvinyl chloride (PVC) is the main component in the manufacture of vinyl siding. A typical percentage of the final product is 15% recycled post-industrial material. Calcium carbonate is used as a filler material in vinyl siding. Titanium dioxide (TiO_2) is a chemical additive that is used in the siding as a pigment and stabilizer. The constituents of vinyl siding as mass fraction are PVC 82.5%, Filler (typically calcium carbonate) 8.5%, Titanium dioxide 2.5%, and other organic chemicals (stabilizer and lubricant) 6.5%. The weight per functional unit is 2.6 kg so assign values to the attributes as the following: 2.145 kg polymer-plastic, 0.221 kg limestone, 0.065 kg inorganic chemicals, 0.169 kg organic chemicals. 15% of PVC is recycled post-industrial material so assign

0.32175 to the recycled content. Assume 95% of the product is recyclable at end of life, so assign 2.47 kg to recyclable portion.

- **Resources Output**

Installation waste with a mass fraction of 5% is assumed, and this waste is assumed to go to a landfill. Assign values to the attributes as the following: 0.10725 kg W-polymer-plastic, and 0.01105 kg W-limestone.

- **Contaminants Output-disposal**

Assign values to the attributes as the following: 0.00325 kg inorganic chemicals, 0.00845 kg organic chemicals.

4.1.9.2 L-Vinyl Siding

- **Resources Output**

Assume 100 of the product is recyclable at end of life. Assign values to the attributes as the following: 2.145 kg R-polymer-plastic, and 0.221 kg R-limestone.

- **Contaminants Output-disposal**

Assign values to the attributes as the following: 0.065 kg inorganic chemicals, and 0.169 kg organic chemicals.

4.1.10 Fiberglass Insulation

There are a number of different materials from which insulation can be made; these include cellulose, fiberglass, mineral wool, and polyurethane. Fiberglass is one of the most common insulation materials and is available in batts and rolls. Fiberglass batt insulation is made by forming spun-glass fibers into batts. The raw materials are melted in a furnace at very high temperatures. The resulting melt are either spun into fibers after falling onto rapidly rotating flywheels or drawn through tiny holes in rapidly rotating spinners. The structure and density of the product is controlled by the conveyer speed and height as it passes through a curing oven. Blown fiberglass insulation is made by forming spun-glass fibers but leaving the insulation loose and unbounded. Fiberglass Batt provides an R-value of approximately R-1.7 per centimeter of thickness in wall applications. Fiberglass batt for wall application is available in R-13, R-15, R-19. R-13 has a thickness of 8.9 cm (3.5 in.) and a density of 12.1 kg/ m3; R-15 has a thickness of 8.9 cm (3.5 in.) and a density of 22.6 kg/m3; and R-19 has a thickness of 15.9 cm (6.25 in.) and a density of 7.7 kg/m3 (Lippiatt, 2007a). Fiberglass batt for ceiling application is available at R-38 with a thickness of 30.5 (12.0 in.) and a density of 7.7 kg/ m3. R-13 and R-19 for wall in addition to R-38 for ceiling will be discussed in more details; a functional unit of 1-m2 has been selected. The mass per functional unit (1-m2) is 1.07 kg for R-13 (wall), 1.11 kg for R-19 (wall), and 2.35 kg for R-38 (ceiling).

4.1.10.1 E-Fiberglass Insulation (R-13/8.9 cm)

- **Resources Input**

The constituents of fiberglass batt insulation in mass fraction are 9% soda ash, 12% borax, 6% glass coatings, 35% glass cullet, 9% limestone, and 29% sand (Lippiatt, 2007a). The mass per 1 m2 functional unit is 1.07 kg. Borax, soda ash and glass coating will be assigned to the inorganic chemicals attribute. Glass cullet will be assigned to the sand-glass attribute. The attributes values are: 0.2889 kg inorganic chemicals, 0.3745 kg sand-glass, 0.0963 kg limestone, and 0.3103 kg sand. The glass cullet is recycled so assign 0.3745 to recycled content. No biobased content.

4.1.10.2 L-Fiberglass Insulation (R-13/8.9 cm)

- **Resources Output**

Assume that 100% of the product will be send to the landfill at the end of life. Assign 0.3745 kg to W-Sand-Glass attribute, 0.0963 kg to W-Limestone attribute, 0.3103 kg to W-sand attribute, and 0.2889 kg to W-Others.

4.1.10.3 E-Fiberglass Insulation (R-19/15.9 cm)

- **Resources Input**

The constituents of fiberglass batt insulation in mass fraction are 9% soda ash, 12% borax, 6% glass coatings, 35% glass cullet, 9% limestone, and 29% sand (Lippiatt, 2007a). The mass per 1 m2 functional unit is 1.11 kg. Borax, soda ash and glass coating will be assigned to the inorganic chemicals attribute. Glass cullet will be assigned to the sand-glass attribute. The attributes values are: 0.2997 kg inorganic chemicals, 0.3885 kg sand-glass, 0.0999 kg limestone, and 0.3219 kg sand. The glass cullet is recycled so assign 0.3885 to recycled content. No biobased content.

4.1.10.4 L-Fiberglass Insulation (R-19/15.9 cm)

- **Resources Output**

Assume that 100% of the product will be send to the landfill at the end of life. Assign 0.3885 kg to W-Sand-Glass attribute, 0.0999 kg to W-Limestone attribute, 0.3219 kg to W-sand attribute, and 0.2997 kg to W-Others.

4.1.10.5 E-Fiberglass Insulation (R-38/30.5 cm)

- **Resources Input**

The constituents of fiberglass batt insulation in mass fraction are 9% soda ash, 12% borax, 6% glass coatings, 35% glass cullet, 9% limestone, and 29% sand (Lippiatt, 2007a). The mass per 1 m2 functional unit is 2.35 kg. Borax, soda ash and glass coating will be assigned to the inorganic chemicals attribute. Glass cullet will be assigned to the sand-glass attribute. The attributes values are: 0.6345 kg inorganic chemicals, 0.8225 kg sand-glass, 0.2115kg limestone, and 0.6815 kg sand. The glass cullet is recycled so assign 0.8225 to recycled content. No biobased content.

4.1.10.6 L-Fiberglass Insulation (R-38/30.5 cm)

- **Resources Output**

Assume that 100% of the product will be send to the landfill at the end of life. Assign 0.8225 kg to W-Sand-Glass attribute, 0.2115 kg to W-Limestone attribute, 0.6815 kg to W-sand attribute, and 0.6345 kg to W-Others.

4.1.11 Steel Framing

Steel is an important construction framing material. Cold-formed steel studs (structural members) for framing are manufactured from blanks sheared from sheets cut from coils or plates, or by roll-forming coils or sheets. Framing studs are usually produced in a thickness of 12 to 25 gauge. The selected functional unit is 1 m of specific stud. A C-shape stud of 18 mil thickness, 0.125" flang, and 3.5" web has a weight of 0.5803 kg per functional unit. A C-shape stud of 68 mil thickness, 0.125" flang, and 3.5" web has a weight of 2.113 kg per functional unit. A c-shape stud of 18 mil thickness, 0.125" flang, and 5.5" web has a weight of 3.978 kg per functional unit. A C-shape stud of 68 mil thickness, 0.125"flang, and 5.5" web has a weight of 14.61 kg per functional unit (SCAFCO, 2007).

4.1.11.1 E-Steel Framing 18mil/5.5”

- **Resources Input**

The only resource input is steel, assign 3.978 kg to the steel attribute. **Resources Output**

During installation of the steel stud framing, 1% of the installation materials are assumed to be lost as waste but it is recycled. Assign 0.03978 kg to the R-steel attribute.

4.1.11.2 L-Steel Framing 18 mil/5.5”

- **Resources Output**

Assume that 100% of the product is recyclable at the end of life. All the steel framing is assumed to be recycled at end of life. Assign 3.978 kg to the R-steel attribute.

4.1.12 Wood Framing

Wood frame structures are built with light wood studs and joists. The walls are typically constructed 2 x 4 or 2 x 6 in studs spaced 16” to 24” apart. These walls sit on top of the foundation and support the roof. Gypsum wallboard (Plywood) is attached to the studs to form the interior finish. The exterior finish may be wood, vinyl or metal siding. The roof is constructed with 2x4 or 2x8 rafters spaced 16” or 24” apart. Roof sheathing is nailed to the top of the rafters, and the roofing material (shingles) is applied to the top of the sheathing. The floors are usually constructed with 2x10 joists spaced 16” apart. The floor sheathing is nailed to the top of the joists. Actual dimensions of a 2x4 are 1.5x3.5 in, of a 2x6 are 1.5x5.5 in, of a 2x8 are 1.5x7.25 in, of a 2x10 are 1.5x9.25, and of a 2x12 are 1.5x11.25 in. Framing lumber is processed in a sawmill, where harvested wood is sawn into specific dimensions. It may be treated with preservatives in order to guard against insect attack or fungal decay. A functional unit of 1-m has been selected from each framing type. The density of 560 kg/m3 (35 lbs/ft3) is used to calculate the weight per functional unit for each framing type, based on actual volume.

4.1.12.1 E-Wood Framing 2x4

- **Resources Input**

The weight of the functional unit of 1-m is 1.91 kg. The only resource input is wood; 1.91 kg is assigned to the Wood attribute.

Resources Output

Assume 5% of the product is lost to waste, and all this waste is disposed of in a landfill. Assign 0.0955 kg to the W-Wood attribute.

4.1.12.2 L-Wood Framing 2x4

- **Resources Output**

All the wood framing is assumed to be disposed of in landfill at the end of life. Assign 1.91 kg to the W-Wood attribute.

4.1.12.3 E-Wood Framing 2x6

- **Resources Input**

The weight of the functional unit of 1-m is 2.98 kg. The only resource input is wood; 2.98 kg is assigned to the Wood attribute.

Resources Output

Assume 5% of the product is lost to waste, and all this waste is disposed of in a landfill. Assign 0.1149 kg to the W-Wood attribute.

4.1.12.4 L-Wood Framing 2x6

- **Resources Output**

All the wood framing is assumed to be disposed of in landfill at the end of life. Assign 2.98 kg to the W-Wood attribute.

4.1.12.5 E-Wood Framing 2x8

- **Resources Input**

The weight of the functional unit of 1-m is 3.93 kg. The only resource input is wood; 3.93 kg is assigned to the Wood attribute.

Resources Output

Assume 5% of the product is lost to waste, and all this waste is disposed of in a landfill. Assign 0.1965 kg to the W-Wood attribute.

4.1.12.6 L-Wood Framing 2x8

- **Resources Output**

All the wood framing is assumed to be disposed of in landfill at the end of life. Assign 3.93 kg to the W-Wood attribute.

4.1.12.7 E-Wood Framing 2x10

- **Resources Input**

The weight of the functional unit of 1-m is 5.0 kg. The only resource input is wood; 5.01 kg is assigned to the Wood attribute.

Resources Output

Assume 5% of the product is lost to waste, and all this waste is disposed of in a landfill. Assign 0.25 kg to the W-Wood attribute.

4.1.12.8 L-Wood Framing 2x10

- **Resources Output**

All the wood framing is assumed to be disposed of in landfill at the end of life. Assign 5.01kg to the W-Wood attribute.

4.1.12.9 E-Wood Framing 2x12

- **Resources Input**

The weight of the functional unit of 1-m is 6.1 kg. The only resource input is wood; 6.1 kg is assigned to the Wood attribute.

Resources Output

Assume 5% of the product is lost to waste, and all this waste is disposed of in a landfill. Assign 0.305 kg to the W-Wood attribute.

4.1.12.10 L-Wood Framing 2x12

- **Resources Output**

All the wood framing is assumed to be disposed of in landfill at the end of life. Assign 6.1 kg to the W-Wood attribute.

4.1.13 Asphalt Shingles

Asphalt shingles are one of the most widely used roofing covers because they are relatively inexpensive and fairly simple to install. Asphalt shingles are commonly made from fiberglass mates impregnated and coated with a mixture of asphalt and mineral filler for both a decorative finish and a wearing layer. A typical wood roof frame is constructed with 2x6 or 2x8 rafters spaced 16" to 24" apart. Roof sheathing, typically oriented strand board, is nailed to the top of the rafters. The shingles are nailed over roofing underlayment installed over the sheathing. Laminated asphalt shingles typically are available in dimensions of 30 cm by 91 cm (21 in by 36 in). A functional unit of 1 m2 asphalt shingle will be selected with a weight of 14 kg/ m2.

4.1.13.1 E-Asphalt Shingles 30x91

- **Resources Input**

The constituents of asphalt shingles as mass fraction are 20% asphalt, 43% filler, 5% fiberglass matt, 25% granules, and 7% Back surfacing (sand and talc) (Lippiatt, 2007a). The mass per m2 of asphalt shingles is 14 kg. The constituents will be assigned to the attributes as the following: 2.8 kg asphalt, 6.02 kg rocks, 0.7 kg sand-glass, 3.5 kg others, and 0.98 kg sand. Assume that 90% of the product is recyclable.

- **Resources Output**

Installation waste from scrap is estimated at approximately 10% of the installed weight. Installation scrap is generally land-filled. Assign 0.028 kg to W-asphalt, 0.0602 kg to W-rocks, 0.0007 kg to sand-glass, 0.035 kg to others, and 0.00098 kg to sand.

4.1.13.2 L-Asphalt Shingles 30x91

- **Resources Output**

When the shingles are removed all materials are assumed to be recycled into pavement products. Assign 2.8 kg to R-asphalt, 6.02 kg to R-rocks, 0.7 kg to R-sand-glass, 3.5 kg to R-others, and .098 kg to R-sand.

4.1.14 Underlayment

The type of underlayment used has typically been asphalt-impregnated organic felt. For roof pitches from 3:12 to 4:12, two layers of type-15 felt underlayment are used. Roof pitches greater than 4:12 require only one layer of Type-15 felt. A functional unit of 1 m2 of type 15 felt underlayment will be selected with a weight of 0.6 kg/ m2.

4.1.14.1 E-Underlayment Type-15

- **Resources Input**

Type 15 felt underlayment constituents are 45% asphalt, 40% organic felt, 10% limestone, and 5% sand (Lippiatt, 2007a). The weight per 1 m2 of type-15 underlayment is 0.6 kg. The organic felt is assumed to be consisted of 50% recycled cardboard and 50% w00d chips. Assign values to the attributes as the following: 0.27 kg asphalt, 0.12 kg wood-cardboard, 0.12 kg wood, 0.06 kg limestone, and 0.03 kg sand. Assume 100% of the product is recyclable. Assign the organic felt mass to the biobased content attribute.

4.1.14.2 L-Underlayment Type-15

- **Resources Output**

When the underlayment is removed all materials are assumed to be recycled into pavement products. Assign 0.27 kg to R-asphalt, 0.12 kg to R-wood-cardboard, 012 kg to R-wood, 0.06 kg to R-limestone, and 0.03 kg to R-sand.

4.1.15 Clay Tile

Clay tile is manufactured from clay, shale, or similar-occurring earth substances and subject to heat treatment at elevated temperatures. The most commonly used clay tile for roofing are the “S” shape tile. Red-colored tiles are still quite popular, although there is now a wide range of colors available. Clay tiles are installed over a deck of wood sheathing, typically OSB, covered with underlayment. A functional unit of 1 m2 will be used with a weight of 66.5 kg/m2.

4.1.15.1 E-Clay Roof Tile

- **Resources Input**

The weight of clay roof tile is 66.5/m2 and it consists of 100% clay. Assign 66.5 kg to the clay attribute. Assume 90% of the product is recyclable.

- **Resources Output**

Installation waste from scrap is estimated at 2% of the installed weight and it is assumed to be landfilled. Assign 1.33 kg to the W-clay attribute.

4.1.15.2 L-Clay Roof Tile

- **Resources Output**

At end of life, clay tiles are recovered and reused. Assume 95% recovery. Assign 63.175 kg to the R-clay attribute and 13.3 kg to the W-clay attribute.

4.1.16 Fiber Cement Shingles

Fiber cement is a composite material made of sand, cement and cellulose fiber. Fiber cement shingles are considered a synthetic equivalent to wood shingles and they can last longer than wood or asphalt products. A functional unit of 1 m2 will be used with a weight of 16 kg.

4.1.16.1 E-Fiber Cement Shingles

- **Resources Input**

The constituents of fiber cement shingles as mass fraction are 40% Portland cement, 33% fly ash, 8% silica fume, 10% sand, 8% organic fiber (wood chips and recycled newsprint), and 1% pigments (Lippiatt, 2007a). Portland cement constituents are 92% Portland cement clinker, 3% gypsum, and 5% minor constituents. The weight per 1 m2 of fiber cement shingles is 16 kg. Assign values to the attributes as the following:

5.888 kg Portland cement clinker, 0.192 kg gypsum, 0.32 kg inorganic chemicals, 6.56 kg others (fly as and silica fume), 1.6 kg sand, 0.64 kg wood, 0.64 kg wood-cardboard, and 0.16 kg organic chemicals. The mass of the wood-cardboard is assigned to the recycled content. The mass of both wood and wood-cardboard is assigned to biobased content.

- **Resources Output**

Installation scrap is estimated at 5% of the installed weight and it is assumed to be landfilled. Assign values to the attributes as the following: 0.2944 kg W-Portland cement clinker, 0.0096 kg W-gypsum, 0.328 kg W-others, 0.08 kg W-sand, 0.032 kg W-wood, and 0.032 kg W-wood-cardboard.

- **Contaminants Output- disposal**

Assign 0.016 kg to inorganic chemicals and 0.008 kg to organic chemicals

4.1.16.2 L-Fiber Cement Shingles

- **Resources Output**

When the shingles are removed at the end of life, all materials are assumed to be disposed of in a landfill and are modeled as such. Assign values to the attributes as the following: 5.888 kg W-Portland cement clinker, 0.192 kg W-gypsum, 6.56 kg W-others (fly as and silica fume), 1.6 kg W-sand, 0.64 kg W-wood, and 0.64 kg W-wood-cardboard.

- **Contaminants Output- disposal**

Assign 0.32 kg to the inorganic chemicals attribute.

4.1.17 Drywall (Gypsum Board)

Drywall is used globally for the finish construction of interior walls and ceilings. A drywall panel consists of paper covering wrapped around a core of gypsum, the semihydrous form of calcium sulphate ($CaSO_4.1/2\ H_2O$). Several varieties of gypsum board products are available; these include regular gypsum wallboard, moisture resistant gypsum board, and type-X fire-resistant gypsum board. The most commonly used drywall is one-half inch thick. The bulk density of wallboard is assumed to be 770 kg/m3. A functional unit of 1-m2 of the ½ inch thick board will be selected as the functional unit. The weight of the functional unit is 9.779 kg.

4.1.17.1 E-Drywall

- **Resources Input**

The constituents of 1 m2 drywall as mass fraction are 85% gypsum, 10% paper, 3% additives, and 2% starch. Assign values to the attributes as the following: 8.312 kg gypsum, 0.9779 kg wood-paper, 0.1956 kg plant products, and 0.2934 kg others. Assume that 88% of the product is recyclable at the end of life, so assign 8.606 kg to recyclable portion. Paper and starch are biobased components, so assign 1.1735 kg to biobased products.

- **Resources Output**

About 12% of the installation materials are assumed to go to waste, all of which is disposed of in landfill. Assign values to the attributes as the following: 0.997 kg W-gypsum, 0.1173 kg W-wood-paper, 0.023 kg W-plant products, 0.0352 W-others.

4.1.17.2 L-Drywall

- **Resources Output**

Assume that 100% of the product is recycled at end of life. Assign the following values to the attributes: .312 kg R-gypsum, 0.9779 kg R-wood-paper, 0.1956 kg R-plant products, and 0.2934 kg R-others

4.1.18 Latex Paint

Paint is a mixture of four basic ingredients: pigments, resins, solvents, and additives. Pigment is a coloring material that gives the color to the paint. Resin (binder) in paint is the binding agent that encapsulates the pigment and binds the pigment to the surface being painted. The main purpose of the solvent (vehicle or carrier) is to adjust the viscosity of the paint. Solvent is volatile and it does not become part of the paint film. Paints are generally classified into two types based on the solvent category: water based paint (also called latex paint), and oil (solvent) based paint. The solvent in water based paints is water. The solvent in oil based paints consists of volatile organic compounds (VOC). Because they do not use solvents as the primary carrier, latex paints emit fewer volatile organic compounds upon application. The coalescing agent is typically glycol or glycol ether. The resin is synthetic latex made from polyvinyl acetate and/or acrylic polymers and copolymers. Titanium dioxide is the primary pigment used in white and light-colored paints. Other additives include surfactants, defoamers, preservatives, and fungicides. A functional unit of 1 kg will be selected.

4.1.18.1 E-Latex Paint

- **Resources Input**

The major constituents of latex paint are resins (binder), titanium dioxide (pigment), limestone (extender), and water (solvent), which are mixed together until they form an emulsion. The average composition of latex paint as mass fraction is: 25% resin, 7.5% titanium dioxide, 7.5% limestone (extender), and 60% water (Lippiatt, 2007a). The resins used for interior latex paint include vinyl acrylic, polyvinyl acrylic, and styrene acrylic (Lippiatt, 2007a). Based on 1 kg functional unit assign values to the attributes as the following: 0.25 kg organic compounds, 0.075 inorganic compounds, and 0.075 limestone. Assign 0.6 kg water to the potable water attribute in the water and wastewater category. Assign 0.6 kg water to the water evaporation attribute.

4.1.18.2 U-Latex Paint

- **Contaminants Output to Air**

Assume that 10% of the organic content to be released to the air over the paint life period. Assign 0.025 kg to the other organic attribute and find the value for applicable indicators based on the chemicals released.

4.1.18.3 L-Latex Paint

- **Resources Output**

At end of life, assume that all the paint goes into landfill. Assign values to the attributes as the following: 0.075 kg W-limestone.

- **Contaminants Output- disposal**

Assign values to the attributes as the following: 0.25 kg organic compounds and 0.075 kg inorganic compounds.

4.1.19 Ceramic Tile

Ceramic tile includes a wide variety of clay products fired into thin units which are installed using a abed of mortar or mastic. Ceramic tile flooring may consist of clay, or a mixture of clay and other ceramic materials, which is baked in a kin to a permanent hardness. Recycle glass can be added to improve environmental performance. A ceramic tile with 75% recycled windshield glass content has been selected. The functional unit is 1 m2 and its weight is 27.2 kg.

4.1.19.1 E-Ceramic Tile

- **Resources Input**

The constituents of ceramic tile that contains 75% recycled glass are 25% clay and 75% glass as mass fraction. Assign 6.8 kg to the clay attribute and 20.4 kg to the sand-glass attribute. Assign the glass content to the recyclable portion attribute. Assume that all of the ceramic tile will be disposed of in landfill at end of life.

- **Resources Output**

About 5% of the installation materials are assumed to go to waste, all of which is disposed of in a landfill. Assign 0.34 kg to the W-clay attribute and 1.02 kg to the sand-glass attribute.

4.1.19.2 L-Ceramic Tile

- **Resources Output**

All of the ceramic tiles are assumed to be disposed of in a landfill at end of life. Assign 6.8 kg to the W-clay attribute and 20.4 kg to the W-sand-glass attribute.

4.1.20 Vinyl Composition Tile (VCT)

Vinyl composition tile (VCT) is a mix of thermoplastic binder, filler, and pigments. It is a resilient floor covering, it contains a high proportion of inorganic filler relative to the other types of vinyl flooring. A functional unit of 1 m2 of 30 cm x 30 cm x 0.3 cm tile has been selected and its weight is 6.6 kg.

4.1.20.1 E-Vinyl Composition Tile

- **Resources Input**

The average constituents of vinyl composition tile (VCT) are 84% limestone, 4% plasticizer, and 12% vinyl resin (Lippiatt, 2007a). The plasticizer consists of 60% butyl benzyl phthalate and 40% diisononyl phthalate. Vinyl resin is a copolymer of 5% vinyl acetate and 95% vinyl chloride. Assign values to the attributes as the following: 5.54 kg to the limestone attribute and 1.056 kg to the organic chemicals attribute.

- **Resources Output**

It is estimated that, on average, installation scrap is 2%. Scrap is sent to landfill. Assign 0.11 kg to the W-limestone attribute.

- **Contaminants output- disposal**

Assign 0.021 kg to the organic chemicals attribute

4.1.20.2 L-Vinyl Composition Tile

- **Resources Output**

At the end of service, the VCT and adhesive are assumed to be disposed in a landfill. Assign 5.54 kg to W-limestone.

- **Contaminants Output- disposal**

At end of life, the VCT and adhesive are assumed to be disposed in a landfill. Assign 1.056 kg to the organic chemicals attribute.

4.1.21 Nylon Carpet

Carpet can be made from many single or blended natural and synthetic fibers. Fibers are chosen for durability, appearance, ease of manufacture, and cost. The most common fibers are nylon, polypropylene (olefin), acrylic, polyester, wool, and cotton. Each of the fiber systems used in the manufacture of carpet can be divided into two classifications: staples and bulked continuous filament (BCF). Nylon is the most popular synthetic fiber used in carpet production and it is produced in both staple and BCF yarn. Although nylon carpet is not as cheap as olefin, it is much cheaper than wool carpet.

Nylon is dyed after the fiber is manufactured. A functional unit of 1 m2 has been selected.

4.1.21.1 E-Nylon Carpet

- **Resources Input**

The selected nylon carpet has the following constituents per 1 m2 functional unit: 1.029 kg nylon 6, 6 (face fiber), 0.227 kg polypropylene, 0.263 kg styrene butadiene latex, 0.909 kg limestone filler, 0.24 kg stain blocker, and 0.2 kg other additives. Assign values to the attributes as the following: 1.256 kg polymer-plastic, 0.263 kg organic chemicals, and 0.44 kg others. Assume no recycled content and 100% of the product will be disposed of at end of life.

- **Resources Output**

During installation 5% of the carpet is assumed to be lost as landfill waste. Assign values to the attributes as the following: 0.0628 kg W-polymer-plastic, 0.022 kg W-other attribute

- **Contaminants Output- disposal**

During installation 5% of the carpet is assumed to be lost as landfill waste. Assign 0.0135 kg to W-organic chemicals.

4.1.21.2 L-Nylon Carpet

- **Resources Output**

At end of life 0% of carpet is assumed to be recycled. Assign values to the attributes as the following: 1.256 kg W-polymer-plastic and 0.44 kg W-others.

- **Contaminants Output- disposal**

At end of life 0% of carpet is assumed to be recycled. Assign values to the attributes as the following: 0.263 kg W-organic chemicals.

4.1.22 Appliances

4.1.22.1 U-Refrigerator

The refrigerator has four assessment classes: E, U, L, and M. Only assessment class U has been discussed here. General Eclectic refrigerator model DTH18ZBS has a capacity of 18 cu. ft. and its electricity consumption is 410 kwh/ year. The refrigerator may require maintenance, where refrigerant needs to be added. This activity is considered in the M assessment class because it is a maintenance activity.

- **Electricity**

One year has been selected as the functional unit for the refrigerator's U assessment class. Electricity for instrument is the only applicable attribute under the electricity category and its value is 410 kwh (Energy Star, 2008).

4.1.22.2 U-Dishwasher

The dishwasher has three assessment classes: E, U, and L. Only assessment class U has been considered here. General Electric dishwasher model PDW9980NSS has been selected, it has a standard capacity and with 327 kwh/ year estimated electricity use based on four wash loads a week assumption. One load has been selected as the functional unit.

- **Electricity**

Electricity for instrument is the only applicable attribute under the electricity category and its value is 1.57 kwh/load (General Electic, 2008).

- **Water and Wastewater**

A value of 57 litters has been assigned to both the water and the wastewater attributes, assuming 15 gallon per load.

- **Resources Input**

A value of 0.05 kg has been assigned to the organic chemicals attribute representing the dishwasher detergent.

- **Contaminants Output-Water**

All the detergent added to the water remains in the wastewater, a value of 0.05 kg is assigned to the other organics attribute. Food is added to the wastewater; as a result 0.5 kg is assigned to the biodegradable attribute.

4.1.22.3 U-Washer

The washer has three assessment classes E, U, and L. Only assessment class U has been discussed here. General Electric model WBVH5100H washer has been selected. It has a capacity of 3.6 cu. ft., 120 kwh/year, and water factor (gallons per cycle per cubic foot) of 4.31. One load has been selected as the functional unit.

- **Electricity**

Electricity for instrument is the only applicable attribute under the electricity category and its value is 0.288 kwh/load (General Electic, 2008).

- **Water and Wastewater**

A value of 190 litters has been assigned to both the water and the wastewater attributes, assuming 50 gallon per load.

- **Resources**

A value of 0.05 kg has been assigned to the organic chemicals attribute representing the dishwasher detergent.

- **Contaminants output-Water**

All the detergent added to the water remains in the wastewater, a value of 0.05 kg is assigned to the other organics attribute.

4.1.22.4 U-Dryer

The dryer has three assessment classes E, U, and L. Only assessment class L has been discussed here. General Electric model DWSR463EGWW dryer has been selected. It has 7 cu. ft. capacity and its power rating is 5.6 kwh. One cycle has been selected as the functional unit.

- **Electricity**

Electricity for instrument is the only applicable attribute under the electricity category and its value is 5.6 kwh/load.

4.1.22.5 U-Range (Electric)

The range has three assessment classes E, U, and L. Only assessment class U has been considered here. General Electric model JBS55WKWW range has been selected. It has four heating elements, two of them are rated at 2 kwh and the other two at 1.5 kwh. The oven capacity is 5.3 cu. ft. A functional unit of 1-hour has been selected for this assessment class.

- **Electricity**

Electricity for instrument is the only applicable attribute under the electricity category, and its value is 2.0 kwh/hour.

4.1.22.6 U-Water Heater (50 Gal, 4500W)

The water heater has three assessment classes E, U, and L. Only assessment class U has been considered here. Whirlpool 50 gallon electric water heater model E1F50RD045V has been selected. A functional unit of 1-hour has been selected for this assessment class.

- **Electricity**

Electricity for water heating is the only applicable attribute under the electricity category, and its value is 4.5 kwh/hour.

4.1.23 Lighting

4.1.23.1 U-CFL Bulb (13W)

Compact Fluorescent Light (CFL) bulb has three assessment classes E, U, and L. Only assessment class E has been considered here. A functional unit of 1-hour has been selected.

- **Electricity**

Electricity for lighting is the only applicable attribute under the electricity category, and its value is 0.013 kwh/hour.

4.1.23.2 U-Fluorescent (20W, 24", T12)

Straight fluorescent bulb has three assessment classes E, U, and L. Only assessment class U has been considered here. A functional unit of 1-hour has been selected.

- **Electricity**

Electricity for lighting is the only applicable attribute under the electricity category, and its value is 0.02 kwh/hour.

4.1.24 Heating/ Cooling

4.1.24.1 U-Heating System

The heating system has three assessment classes E, U, and L. Only assessment class U has been considered here. A functional unit of 1-year has been selected for the U assessment unit.

- **Electricity**

Electricity for heating/ cooling is the only applicable attribute under the electricity category, and its value is 3500 kwh/year.

4.1.24.2 U-Cooling System

The cooling system has three assessment classes E, U, and L. Only assessment class U has been considered here. A functional unit of 1-year has been selected for the U assessment unit.

- **Electricity**

Electricity for heating/ cooling is the only applicable attribute under the electricity category, and its value is 2800 kwh/year.

4.1.25 Fixtures

4.1.25.1 U- Shower Head

The most important assessment class in the shower head is the U assessment class. One hour has been selected as the functional unit.

- **Water and Wastewater**

Low flow shower head is typically rated 2.5 gpm or less. Using 2.5 gpm, the potable water and wastewater generation attributes are assigned 568 litters each.

4.1.25.2 U- Faucet (Shower)

One hour of use has been selected as the functional unit for shower faucet.

- **Water and Wastewater**

Low flow faucet is typically rated 2.5 gpm or less. Using 2.5 gpm, the potable water and wastewater generation attributes are assigned 568 litters each.

4.1.25.3 U- Faucet (Kitchen)

One hour of use has been selected as the functional unit for the kitchen faucet.

- **Water and Wastewater**

Low flow faucet is typically rated 2.5 gpm or less. Using 2.5 gpm, the potable water and wastewater generation attributes are assigned 568 litters each.

4.1.25.4 U- Faucet (Lavatory)

One hour of use has been selected as the functional unit for the lavatory faucet.

- **Water and Wastewater**

Low flow faucet is typically rated 2.5 gpm or less. Using 2.5 gpm, the potable water and wastewater generation attributes are assigned 568 litters each.

4.1.25.5 U-Toilet

A functional unit of 1-flush has been selected for the U assessment element of the toilet.

- **Water and Wastewater**

Low flow toilet uses a maximum of 1.6 gallon per flush. Using 1.6 gpf, the potable water and wastewater generation attributes are assigned 6 litters each.

4.1.26 Wrap

Home wrap has two assessment classes E and L. A functional unit of 1-m2 will be used for both assessment classes. The weight per functional unit (1-m2) is 0.059 kg. The constituents of Tyvek home wrap are 50% butyl compound, 21% polyethelene, 9% carbon black, 10% calcium carbonate, 4% styrene isoprene adhesive, 1 % polyurethane adhesive, and 5% elastomeric fiber (DuPont, 2008).

4.1.26.1 E-Wrap

- **Resources Input**

Assume no recycled or biobased content. The calcium carbonate content (0.0059 kg) will be assigned to the limestone attribute. The styrene adhesive and polyurethane adhesive (0.00295 kg) will be assigned to the organic chemicals, carbon black (0.0053 kg) to the inorganic chemicals attribute, and everything else (0.0448 kg) to the polymer-plastic attribute.

4.1.26.2 L-Wrap

- **Resources Output**

It is assumed that the entire wrap is wasted at its end of life. The attributes will be assigned values as the following: W-limestone .0059 kg and W-polymer-plastic 0.0448 kg.

- **Contaminants output-disposal**

The attributes in this category will be assigned values as the following: other organic 0.00295 kg, and other inorganic 0.0053 kg.

4.1.27 Vehicle

The vehicle has four assessment classes E, U, M, and L. Only assessment class U will be discussed here.

4.1.27.1 U-Vehicle

A functional unit of 1 mile will be selected for the U assessment class. It is assumed that the car consumes 1 gallon of gasoline every 25 miles.

- **Fossil Fuel**

The only applicable attribute in this category is MMBtu for transportation. One gallon of gasoline is equivalent to 25,000 Btu. A value of 0.1MMBtu is assigned to the MMBtu for transportation attribute based on 0.04 gallon of gasoline consumption per mile.

- **Resources Input**

It is assumed that oil is changed every 3,000 miles and every oil change needs 4 kg oil. A value of 0.00133 kg is assigned to the oil attribute.

CHAPTER V

CASE STUDY

5.1 Case Study Description

5.1.1 The Site

A case study has been carried out to illustrate the use of the tool. The property that was selected for this case study is located in Franklin County. The property is located at 5191 Wilcox Road in Dublin, Ohio. The Parcel number is 485-268864-00 and it is located at the corner of Wilcox Road and Noor Road (Franklin County Auditor, 2008). The diminutions of the land are 100 ft on Wilox Road by 395.6 ft on Noor Road, and its area is 39,560 sq. ft. (0.908 acres). The land is located in a low to moderate risk flood area; buildings in these zones could be flooded by severe, concentrated rainfall coupled with inadequate local drainage systems (FEMA, 2008). It is 3 miles away from the centers of both Dublin and Hilliard, while it is 15 miles away from the center of Columbus city. The closest highway is I-270 and it is around 1 mile away.

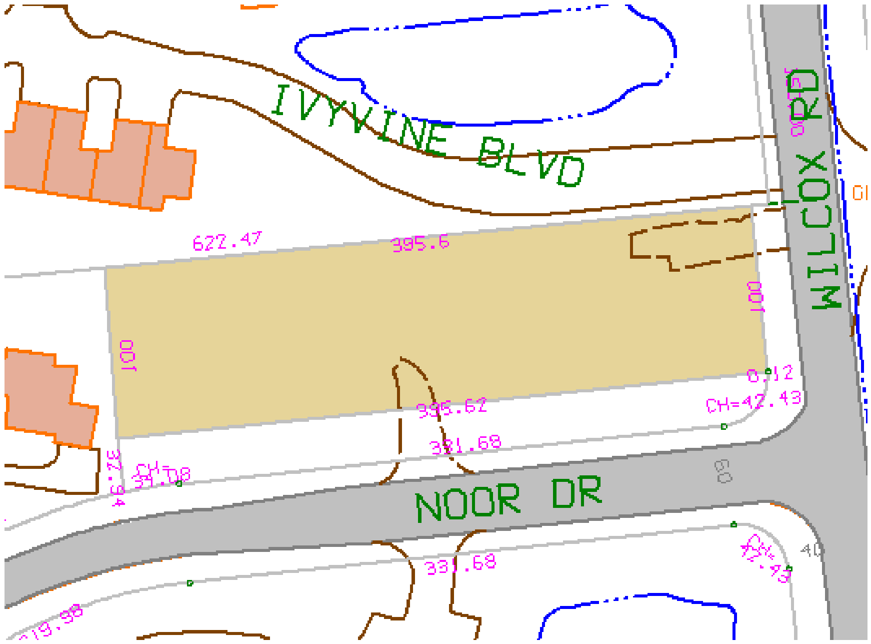

Figure 19: The location of the case study site and the area of the land.

Figure 20: A map showing the location of the case study site.

5.1.2 The Building

The building that was selected for this case study is a one-story residential house. Sutherlands Lumber Company provides the blueprint and the material package for several house styles. The “Grand House” style has been selected for this case study. The Grand House is approximately 2,284 sq. ft. (212 m2) including the garage. As shown in the floor plan, it consists of 3 bedrooms, kitchen, living room, laundry room, two baths, and 2-car garage.

Figure 21: A picture of the “Grand House” style that was selected for the case study

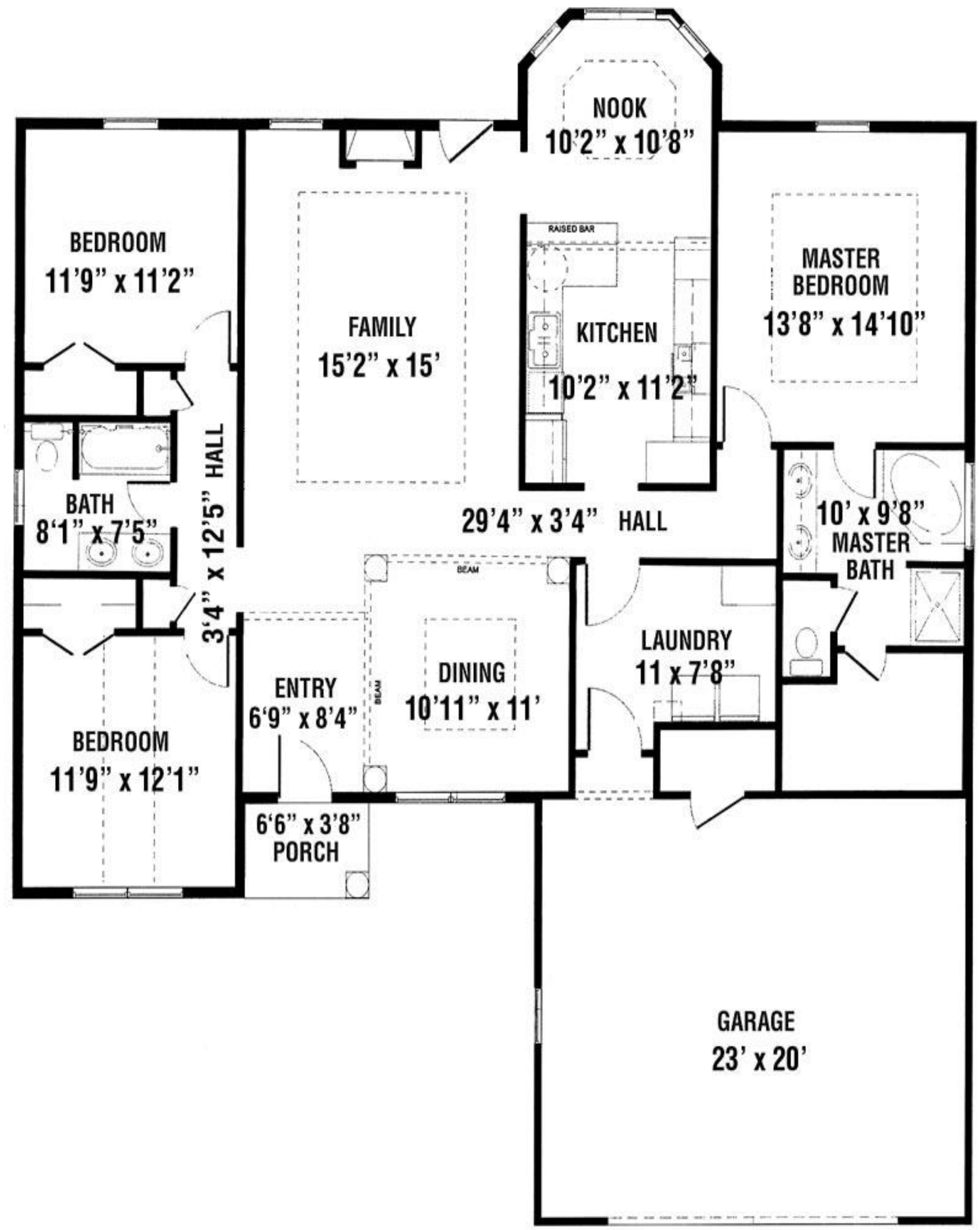

Figure 22: The floor plan for the building (Grand House) that was selected for the case study.

5.1.3 Building Method

The wood platform frame is the proposed construction method for the Grand House. Platform frame buildings are easily constructed, but if ignited, it burns rapidly. This construction method is popular because it is an extremely flexible and economical way of constructing small buildings. The platform frame is made entirely of nominal 2-inch members, which are actually 1 ½ inches in thickness. The building process starts with building the floor platform on top of the foundation, then walls are assembled horizontally on the platform and tilted up into place, finally the roof is built on top of the walls. Anchor bolts hold the frame to the foundation. The sill is bolted to the foundation as a base for wood framing. A compressible sill sealer is inserted between the sill and foundation to reduce air infiltration through the gap. All constructions are made with nails, using face nailing, end nailing, or toe nailing. Nails are driven by hammer or nail gun.

Each plane of the platform frame is made by aligning a number of pieces of framing lumber parallel to one another at specified intervals nailed to crosspieces at either end to maintain their spacing, then covering the plane of framing with sheathing. The standard spacing is 16 or 24 inches o.c. (on center). In the floor structure, the parallel pieces are called joists and the crosspieces at the ends of the joists are called headers. Wood composite I-joists are used more commonly than solid wood joists. The I-joists has laminated veneer lumber (LVL) flanges and a plywood web. In the wall structure, the parallel vertical pieces are called studs, and the horizontal crosspieces at the bottom and top of the wall are called plates. The 2 x 6 studs could be used for the outside walls to allow for more thermal insulation than can be inserted in the cavities of a wall framed with 2 x 4 studs. In a sloping roof structure, the parallel pieces are called rafters. The rafters are headed off by the top plates at the lower edge of the roof, and by the ridge board at the peak. I-joists may be used as rafter material instead of solid lumber. Each surface is sheathed with wood panels, mainly oriented strand board (OSB). The sheathing on the floor is called the subfloor.

Openings are required in walls, floors, and roofs. Openings in floors are framed with headers and trimmers, which must be doubled to support the higher loads placed on them by the presence of opening. Openings in walls are framed with strong headers across the tops and sills that head off the bottoms of the openings.

As the platform frame building nears competition, a sequence of exterior finishing operations begins. First the eaves (horizontal roof edges) and rakes (sloping roof edges) of the roof are finished, and then the roof is shingled. When the roof has been completed the windows and doors are installed. Then the siding is applied. At this point the interior finishing work can take place.

The eaves must be ventilated to allow free circulation of air beneath the roof sheathing. Gutters and downspouts (leaders) are installed on the eaves to remove rainwater and snowmelt. Asphalt shingles are the most common roof shingles because they are less expensive than other type of roofing and because they are highly resistant to fire. Before the windows and doors are installed the wall sheathing is covered with house wrap, a vapor-permeable layer of thin sheet material that acts as an air barrier. Many different types of materials are used as siding, vinyl siding has been used for the case study.

Thermal insulation helps keep a building cooler in summer and warmer in winter by retarding the passage of heat through the exterior surfaces of the building. Glass fiber batts are the most popular type of insulation for wall cavities in new construction. Other types of insulation are materials are redid board, loose-fill and sprayed-on foam insulation. A 2 x 6 exterior wall studs and insulating sheathing materials are recommended for a better insulation. Radiant barriers are increasingly used in roofs and walls to reduce the flow of solar heat into the building; they are installed beneath the sheathing. They are thin sheets faced with a bright metal foil that reflects infrared radiation. Gypsum-based plaster and drywall are the most popular for walls and ceilings finish, where all wall and ceiling surfaces are covered with plaster or gypsum board. Finally, finish flooring is installed.

5.1.4 List of Major Materials/ Products

The following table shows the major building materials, as listed in the package offered from Netherland Lumber Company. The materials have been categorized according to their use into floor, wall, ceiling, roof, plumbing, and electric materials or products. Minor materials and products have not been included in the list.

Table 89: List of the major materials and products for the building in the case study

Description	Unit	Quantity
Floor materials/ products		
½” x 12” anchor bolts	pc.	50
2” x 12” sill (treated)	16’ pc.	13
2” x 10” joist (16”oc)	18’ pc.	49
2” x 10” joist	16’ pc.	32
2” x 10” joist	14’ pc.	10
2” x 10” joist	12’ pc.	3
4’ x 8’ sheathing	Pc.	62
2” x 12” headers	16’ pc.	17
2” x 10” beams (triple)	16’ pc.	36
6 ¼” x 15” R-19 insulation	39’ roll	33
12” x 12” Ceramic tile	pc.	594
Mortar thin set	50 lb	19
4’ x 4’ fiber-roc under lay	¼” pc.	36
carpet	Sq. ft.	1200
Carpet pad ½” 6#	Sq. ft.	1200
Wall materials/ Products		
2” x 6” studs (exterior)	8’ pc.	200
2” x 6” plates (exterior)	16’ pc.	38
2” x 4” studs (interior)	8’ pc.	200
2” x 4” plates (interior)	16’ pc.	38
2” x 4” studs (garage)	10’ pc.	52
2” x 4” plates (garage)	16’ pc.	4
2” x 4” treated plates (garage)	16’ pc.	7
4’ x 8’ OSB sheathing	7/16” pc.	78
36” x 36” vinyl window	pc.	1
50” x 50” vinyl window	pc.	1
32” x 60” vinyl window	pc.	1
24” x 60” vinyl window	pc.	1
36” x 60” vinyl window	pc.	8
48” x 60” fixed picture wind.	pc.	1
9’ x 100’ roll House wrap	pc.	3
Vinyl siding	Square (100 sq. ft.)	25
10’ o/s corner siding	pc.	14
10’ i/s corner siding	pc.	6
12 ½’ freeze runner	pc.	26
12 ½’ J channel	pc.	31
12 ½’ finish trim	pc.	20
12 ½’ starter	pc.	18
12’ ctr/ vent soffit	pc.	23
4’ x 12’ plaster board	½” pc.	176 (including ceiling)
4” x 8’ plaster board	½” pc.	3
6 ¼” x 15” R-19 insulation	39’ roll	38

3 ½" x 15" R-13 insulation (garage walls)	39' roll	13
Wall primer	5 gal	6
Wall paint	5 gal	4
Ceiling materials/ Products		
2" x 6" joists	10' pc.	32
2" x 6" joists	12' pc.	55
2" x 6" joists	14' pc.	30
2" x 6" joists	16' pc.	46
2" x 6" metal hanger	pc.	36
2" x 6" truss girder	12' pc.	2
2" x 6" truss girder	14' pc.	2
2" x 6" truss girder	20' pc.	2
4' x 6' 7/16" OSB sheet	pc.	3
R-38 cellulose insulation	22.55 lbs. bag	38
R-24 cellulose insulation (garage ceiling)	22.55 lbs. bag	16
Roof materials/ products		
2" x 6" rafters	8' pc.	10
2" x 6" rafters	14' pc.	4
2" x 6" rafters	16' pc.	34
2" x 6" rafters	20' pc.	95
2" x 6" rafters	22' pc.	21
2" x 8" ridge	16' pc.	11
2" x 4" stiff back	16' pc.	32
2" x 4" vertical brace	8' pc.	10
2" x 4" collar tie	16' pc.	12
2" x 6" facia	16' pc.	13
4' x 8' OSB sheathing	7/16" pc.	104
10' "D" painted roof edging	pc.	25
5" x 7" metal shingles	pc.	35
14" x 10' aluminum flashing	pc.	1
Felt # 15 roll	pc.	8
Shingles	Square (100 sq. ft.)	36
Roof vents	pc.	12
Plumbing materials/ products		
3" x 10' PVC pipe	pc.	7
2" x 10' PVC pipe	pc.	12
¾" x 10' PVC pipe	pc.	10
½" x 10' PVC pipe	pc.	10
toilet	pc.	2
Lavatory faucet	pc.	4
Vanity	pc.	1
Shower faucet	pc.	1
Shower head	pc.	1

33” x 22” white cast iron sink	pc.	1
Electric materials/ products		
Water heater (50-gal)	pc.	1
Electric range	pc.	1
dishwasher	pc.	1
microwave	pc.	1
24” fluorescent light	pc.	4
Exhaust fan	pc.	2
Can light	pc.	33
Chandelier light (dining)	pc.	1
External light	pc.	3
Mount light for bath	pc.	3
Pendant light (nook)	pc.	1
Ceiling fan 4- blades	pc.	1

5.2 Results

5.2.1 Micro-Assessment

The first part of the case study is to conduct the micro-assessment level of GREENOMETER-7. It consists of the following phases: inventory (hierarchy-analysis and “N” determination), assessment (profiling and synthesis), and interpretation (ranking and weighting). Each step will be discussed in more details next.

5.2.1.1 Hierarchy-Analysis

Hierarchy-analysis is the first step in the micro-assessment level of GREENOMETER-7. The objective of this step is to identify the assessment classes of each stage of the building life cycle. Each stage can be divided into activities and the assessment classes of each stage can be sub-listed under applicable activities. In this case study, some of the activities are eliminated.

Table 90 shows the results of the hierarchy-analysis step of the micro-assessment level of GREENOMETER-7 at the construction stage. It shows the major activities and their assessment classes.

Table 91 shows the results of the hierarchy-analysis step of the micro-assessment level of GREENOMETER-7 at the operation stage. It identifies the major activities at the operation stage and their assessment classes.

Table 92 shows the results of the hierarchy-analysis step of the micro-assessment level of GREENOMETER-7 at the demolition stage. It identifies the major activities at the demolition stage and their assessment classes.

Table 90: The results of the hierarchy-analysis at the construction stage

Activity	Assessment Classes
Light Wood Framing	E-Lumber (2”x4”)
	E-Lumber (2”x6”)
	E-Lumber (2”x8”)
	E-Lumber (2”x10”)
	E-Lumber (2”x12”)
	E-OSB Sheathing (7/16” thick)
Insulation	E-Insulation (R-16, 6 1/4”)
	E-Insulation (R-38,Roof)
Siding Installation	E-Wrap
	E-Siding (Vinyl)
Walls/ Ceiling Finishing	E-Drywall (1/2”)
	E-Paint
Floor Finishing	E-Carpet
	E-Tile (Ceramic)
	E-Mortar
Roof Finishing	E-Underlayment
	E-Shingles (Asphalt)

Table 91: The results of the hierarchy-analysis step at the operation stage

Activity	Assessment Classes
Lighting	E-CFL Bulb (13W)
	U-CFL Bulb (13W)
	L-CFC Bulb (13W)
	E-Fluorescent (24”, 20W)
	U-Fluorescent (24”, 20W)
	L-Fluorescent (48”, 20W)
Heating/ Cooling	U-Heating System
	U-Cooling System
Water Heating	E-Water Heater
	U-Water Heater
	L-Water Heater
Carpet Replacement	E-Carpet
	L-Carpet
Re-painting	E-Paint
Shingles Replacement	E-Shingles
	L-Shingles
Washing/ Drying	E-Washer
	U-Washer
	L-Washer
	E-Dryer
	U-Dryer
	L-Dryer

Activity	Assessment Classes
Kitchen Activities	E-Range
	U-Range
	L-Range
	E-Microwave
	U-Microwave
	L-Microwave
	E-Refrigerator
	U-Refrigerator
	L-Refrigerator
	E-Dishwasher
	U-Dishwasher
	L-Dishwasher
	U-Ceiling Fan
	U-Exhaust Fan
	U-Faucet-Kitchen
Office Activities	E-Computer
	U-Computer
	L-Computer
	E-Printer
	U-Printer
	L-Printer
Bathroom Activities	U-Faucet-Shower
	U-Faucet-Lavatory
	U-Toilet
Driving	U-Vehicle

Table 92: The results of the hierarchy-analysis step at the demolition stage

Activity	**Assessment Classes**
Carpet/ Tile Removal	L-Carpet
	L-Tile
	L-Mortar
Wall/ Ceiling Disassembling	L-Drywall (1/2" thick)
	L-Paint
	L-Insulation (R-19, 6 1/4")
	L-Insulation (R-38, Ceiling)
Siding Removal	L-Siding (Vinyl)
	L-Wrap
Shingles Removal	L-Shingles
	L-Underlayment
Frame Disassembling	L-Lumber (2"x4")
	L-Lumber (2"x6")
	L-Lumber (2"x8")
	L-Lumber (2"x10")
	L-Lumber (2"x12")
	L-OSB Sheathing (7/16" thick)

Table 93: The results of the "N" Determination step at the construction stage

Activity	**Assessment Class**	**Functional Unit**	**"N"**
Framing	E-Lumber (2"x4")	1-meter	1047
	E-Lumber (2"x6")	1-meter	2251
	E-Lumber (2"x8")	1-meter	54
	E-Lumber (2"x10")	1-meter	479
	E-Lumber (2"x12")	1-meter	63
	E-OSB Sheathing (7/16" thick)	1-meter sq.	725
Insulating	E-Insulation (R-19, 6 ¼")	1-meter sq.	380
	E-Insulation (R-38,)	1-meter sq.	212
Siding	E-Wrap	1-meter sq.	251
	E-Siding (Vinyl)	1-meter sq.	232
Wall/ Ceiling Finishing	E-Drywall (1/2" thick)	1-meter sq.	798
	E-Paint	1-kg	176
Floor Finishing	E-Carpet	1-meter sq.	111
	E-Tile (Ceramic)	1-meter sq.	55
	E-Mortar	1-kg	431
Roof Finishing	E-Shingles (Asphalt)	1-meter sq.	334
	E-Underlayment	1-meter sq.	334

5.2.1.2 "N" Determination

"N" determination is the next step in the inventory phase of the micro-assessment level of GREENOMETER-7. The objective of this step is to determine the number of functional units "N" for each assessment class identified in the hierarchy-analysis step.

Table 93 provides the N value for the assessment classes applicable at the construction stage. Table 94 provides the N value for the assessment classes applicable at the operation stage. Table 95 provides the N value for the assessment classes applicable at the demolition stage.

Justification of the "N" values

The quantities received from Southerland Lumber Company for the "Grand House" package has been used in determining the N value for each assessment class at the construction, operation, and demolition stages. The units have been converted to the match the functional unit. For example, if the quantity is given in feet and the functional unit is 1-meter, then the quantity is converted to meter. For some N values the number is not direct and assumptions have to be made. Whenever the duration of the building life cycle is needed for the calculating N, it has been assumed that the house has a 50-years life cycle. It is assumed that the number of the house occupants is 5. The following are justifications on how the N values were determined for the assessment classes:

- **Framing**: The N values were determined directly from the quantities received from Sutherland Lumber Company.

- **Insulation**: The N values were determined directly using the numbers received from Sutherland Lumber Company.

- **Siding**: The N values were determined directly from the quantities received from Sutherland Lumber Company.

- **Drywall**: The N values were determined directly from the quantities received from Sutherland Lumber Company.

- **Carpet**: In determining N values associated with carpet, it was assumed that the house is carpeted 6 times over its 50-year life cycle, one time in the construction phase and 5 times in the operation phase. For simplicity, it is assumed the same type of carpet will be used.

- **Paint**: In determining N values associated with paint it was assumed that over the house life cycle, it is painted 6 times, one time in the construction phase and 5 times in the operation phase. It is assumed that the same type of paint is used at all times. Assume 60% water content.

- **Roofing**: In determining the N values associated with roofing, it was assumed that over the house life cycle, asphalt shingles will be installed 3 times, one time in the construction phase and 2 times in the operation phase. It is assumed that the same type of shingles will be used at all times.

- **Light Bulb**: In determining the N values associated with the light bulb, it was assumed that over the house life cycle, it is assumed that the total number of CFL bulbs at any time is 30 and they will be replaced 10 times (300 over the life cycle), while the fluorescent tubes will be replaced 20 times and there are 4 of them in the house (80 over the life cycle). For estimating the N value in 1-hour for

U-CFL, it was assumed that the CFL light bulbs are distributed as the following: 2 in each bedroom (6 total) and they are turned on for 2 hours daily each, 3 in each bathroom (6 total)and they are turned on for 2 hours daily each, 3 in dining and they are turned on for 1 hour daily each, 1 in the kitchen and it is turned on for 4 hours daily, 1 in the garage and it is turned on for 1 hour daily, 1 in the porch and it is turned on 6 hours daily, 3 in hallways and each is turned on for 2 hours daily, and 4 other and each is turned on for 1 hour daily. Total hours per day is around 48 (876,000 over the life cycle). On the other hand, the fluorescent tubes are 2 in the living room and 2 in the kitchen. Each is turned on for 6 hours daily (total of 24 hour per day which is equivalent to 438,000 hours over the life cycle of the building).

- **Water Heater**: In determining the N value for the U-water Hater it was assumed that it runs for 2 hours daily over the 50-years life cycle of the building.
- **Washer/ Dryer**: In determining the N value for the washer and dryer it was estimated that both are operated twice a week (52 weeks per year, 50-year life cycle of the building).
- **Range**: In determining the N value for U-Range it was assumed that the range is operated for 4 hours daily over the 50-year life cycle of the building.
- **Oven**: In determining the N value for U-Oven it was estimated that oven is operated for 5 hours per week over the 50-years life cycle of the building (52 weeks per year).

- **Microwave:** In determining the N value for the N-Microwave it was assumed that the microwave is operated for 0.5 hours daily over the 50-years life cycle of the building.

- **Dishwasher**: In determining the N value for the U-Dishwasher it was assumed that the microwave is operated once daily for the 50-year life cycle of the building.

- **Faucets**: In determining the N values for faucets it was assumed that they run at the maximum rate. The number of occupants is 5. Estimated shower is 15 min per person. Estimated faucet use is 20 minute per person per day. Estimated kitchen faucet use is 1 hour per day.

- **Toilet**: In determining the N value for U-Toilet it was assumed that 5 people live in the house and in average the toilet is flushed 5 times per day by each occupant.

- **Vehicle**: In determining the N value for U-Vehicle it was assumed that the total miles is 17,000 miles per year.

- **Computer**: In determining the N value for U-Computer it is assumed that the computer is operated for 8 hours per day during the life cycle of the building of 50-years.

5.2.1.3 Profiling

Profiling is the first step in the assessment phase of the micro-assessment level of GREENOMETER-7. The objective of this step is to develop a profile for each assessment class identified in the hierarchy-analysis step. The profiles for all the assessment classes of the case study are available in Chapter IV. Tables 96, 97, and 98 provide reference to the page number for each assessment class.

5.2.1.4 Synthesis

The synthesis step is the second step in the assessment phase of the micro-assessment level of GREENOMETER-7. It is used to generate profiles for the activities, stages and the building life cycle from the profiles of the applicable assessment classes in each case. The profile of each activity is generated by combining the profiles of its assessment classes after multiplying them with their "N" values. The profile of each life cycle stage is generated by combining all the profiles of that stage. The building micro-profile is the profile of the entire life cycle of the buildings. It is obtained by combining the profiles of the three life cycle stages: construction, operation, and demolition. Table 99 represents the micro-profile of the building. This is the only profile that will be used in the next ranking and valuation steps.

Table 94: The results of the "N" Determination step at the operation stage

Activity	Assessment Class	Functional Unit	"N"
Lighting	E-CFL Bulb (13W)	1-pc.	300
	L-CFL Bulb (13W)	1-pc.	300
	U-CFL bulb (13W)	1-hour	876,000
	E-Fluorescent (24", 20 W)	1-pc.	80
	L-Fluorescent (24", 20 W)	1-pc.	80
	U-Fluorescent (24", 20 W)	1-hour	438,000
Heating/ Cooling	U-Heating System	1-year	50
	U-Cooling System	1-year	50
Water Heating	U-Water Heater	1-hour	36,500
Carpet Replacement	E-Carpet	1-meter sq.	557
	L-Carpet	1-meter sq.	557
Re-painting	E-Paint	1-kg	454
Shingles Replacement	E-Shingles (Asphalt)	1-meter sq.	669
	L-Shingles (Asphalt)	1-meter sq.	669
Washing and Drying	U-Washer	1-cycle	5,200
	U-Dryer	1-cycle	5,200
Kitchen Activities	U-Refrigerator	1-year	50
	U-Range (electric)	1-hour	73,000
	U-Oven (electric)	1-hour	13,000
	U-Microwave	1-hour	9,125
	U-Dishwasher	1-cycle	1,8250
	U-Faucet-Kitchen	1-hour	18,250
	U-Exhaust Fan	1-hour	36,500
	U-Ceiling Fan	1-hour	54,750
Office Activities	U-Computer	1-hour	146,000
	U-Printer	1-hour	1,300
Bathroom Activities	U-Faucet-Shower	1-hour	22,500
	U-Faucet-Lavatory	1-hour	30,417
	U-Toilet	1-flush	456,250
Driving	U-Vehicle	1-mile	850,000

Table 95: The results of the "N" Determination step at the demolition stage

Activity	Assessment Class	Functional Unit	"N"
Carpet/ Tile Removal	L-Carpet	1-meter sq.	111
	L-Tile (Ceramic)	1-meter sq.	55
	L-Mortar	1-kg	431
Wall/ Ceiling Disassemble	L-Drywall (1/2" thick)	1-meter sq.	798
	L-Paint	1-kg	252
	L-Insulation (R-19, 6 ¼" thick)	1-meter sq.	380
	L-Insulation (R-38,)	1-meter sq.	212
Siding Removal	L-Siding (Vinyl)	1-meter sq.	232
	L-Wrap	1-meter sq.	251
Shingles Removal	L-Shingles (Asphalt)	1-meter sq.	334
	L-Underlayment	1-meter sq.	334
Frame Disassemble	L-Lumber (2"x4")	1-meter	1048
	L-Lumber (2"x6")	1-meter	2251
	L-Lumber (2"x8")	1-meter	54
	L-Lumber (2"x10")	1-meter	479
	L-Lumber (2"x12")	1-meter	63
	L-OSB Sheathing (7/16"	1-meter sq.	725

Table 96: Reference to the profiles of the assessment classes applicable at the construction stage

Assessment Class/ Construction	Profile Page Number
E-Lumber (2"x4")	218
E-Lumber (2"x6")	218
E-Lumber (2"x8")	219
E-Lumber (2"x10")	219
E-Lumber (2"x12")	220
E-OSB Sheathing (7/16" thick)	201
E-Insulation (R-16, 15.9 cm)	215
E-Insulation (R-38,30.5 cm)	215
E-Wrap	237
E-Siding (Vinyl)	212
E-Drywall (1/2")	225
E-Paint	226
E-Carpet	230
E-Tile (Ceramic)	228
E-Mortar	207
E-Underlayment	222
E-Shingles (Asphalt)	221

Table 97: Reference to the profiles of the assessment classes applicable at the operation stage

Assessment Class/ Operation	Profile Page Number
E-CFL Bulb (13W)	234
U-CFL Bulb (13W)	234
U-Fluorescent (24", 20W)	234
U-Heating System	235
U-Cooling System	235
U-Water Heater	234
E-Carpet	230
L-Carpet	230
E-Paint	226
E-Shingles	221
L-Shingles	221
U-Washer	232
U-Dryer	233
U-Range	233
U-Refrigerator	231
U-Dishwasher	231
U-Faucet-Kitchen	236
U-Faucet-Shower	236
U-Faucet-Lavatory	236
U-Toilet	236
U-Vehicle	238

Table 98: Reference to the profiles of the assessment classes applicable at the demolition stage

Assessment Class/ Demolition	Profile Page Number
L-Carpet	230
L-Tile	228
L-Mortar	208
L-Drywall (1/2" thick)	225
L-Paint	227
L-Insulation (R-19, 6 1/4")	215
L-Insulation (R-38, Ceiling)	216
L-Siding (Vinyl)	213
L-Wrap	237
L-Shingles	221
L-Underlayment	221
L-Lumber (2"x4")	218
L-Lumber (2"x6")	219
L-Lumber (2"x8")	219
L-Lumber (2"x10")	220
L-Lumber (2"x12")	220
L-OSB Sheathing (7/16" thick)	203

Table 99: The profile of entire life cycle of the building (micro-profile)

Category	Indicator	Unit	Life-cycle Value
1.1) Electricity	Total Electricity consumption	kwh	825,904
	Electricity for lighting	kwh	20,340
	Electricity for heating/ cooling	kwh	315,000
	Electricity for water heating	kwh	285,750
	Electricity for other equipment	kwh	204,814
1.2) Fossil Fuel	Total MMBtu	MMBtu	85,000
	MMBtu for space heating	MMBtu	0
	MMBtu for water heating	MMBtu	0
	MMBtu for transportation	MMBtu	85,000
	MMBtu for other equipment	MMBtu	0
2) Water and Wastewater	Total water use	m3	45,617
	% Recycled/ reclaimed water	%	0
	Total wastewater generated	m3	45,187
3.1) Resources Input	Total Resources Input	Kg	692,214
	% of recycled content	%	0.22
	% of biobased content	%	2.54
	% of chemicals content	%	0.30
3.2) Resources Output	Total resources output	Kg	798,613
	% expected to be recycled	%	2.76
	% expected be wasted	%	97.24
	MMBtu of wasted	MMBtu	NA
4.1) Contaminants Output-Total	Total Contaminants output	Kg	11,612
4.2) Contaminants Output-Captured	% of Contaminants- captured	%	0
4.3) Contaminants Output-Disposal	Total Contaminants output-disposal	Kg	555
4.4) Contaminants Output-Air	Total Contaminants output- air	Kg	760
	Global warming potential	Kg CO2 eq	NA
	Acidification potential	Moles of H+ eq	NA
	Ozone depletion potential	Kg CFC-11 eq	NA
	Photochemical smog potential	Kg NOx eq	NA
	Eutrophication potential	Kg N eq	NA
	Ecotoxicity potential	Kg 2,4-D eq	NA
	Human health-cancer	Kg benzene eq	NA
	Human health-non-cancer	kg toluene eq	NA
	Human health-criteria	kg PM2.5 eq	NA
4.5) Contaminants Output-Water	Total contaminants output- water	kg	10,297
	Biological Oxygen Demand (BOD)	kg	NA
	Ecotoxicity	Kg 2,4-D eq	NA
	Eutrophication Potential	Kg N eq	NA

Category	Indicator	Unit	Life-cycle Value
	Human health- cancer	Kg benzene eq	NA
	Human health- non-cancer	kg toluene eq	NA
4.6) Contaminants Output- Soil	Total Contaminants output- soil	Kg	0
5) Economics	Total costs	$	NA
	Total Return	$	NA
	% of return	%	NA

5.2.1.5 Ranking

The ranking step is the first step in the interpretation phase of the micro-assessment level of GREENOMETER-7. It is used to provide a score from 0 to 6 for all indicators. Table 100 shows the score for each indicator.

Justification of the Scores

The ranking guidelines provided in section 3.2.5 in Chapter III have been used to rank each indicator. Where comparison to a standard was required, assumptions have been made. For each indicator a standard (baseline) needs to be developed. These standards are different for different building types and sometimes for different regions. After the baseline has been identified ranges (in percentage of the baseline) are assigned for the scores of 0, 1, 2… 6. For example, the 835,904 kwh value of total electricity consumption indicator was assumed to be 95% of the baseline. By looking at the ranking guideline table for this indicator it shows that a value of 95% of the baseline receives a score of 3. Identifying a baseline for each indicator as a basis for scoring the indicator using the 0 to 6 scale is a recommendation for future work. These baselines are determined once for each building type by a third party and the user will not be allowed to change them for consistency.

5.2.1.6 Valuation (Weighting)

Valuation is the second step in the interpretation phase of the micro-assessment level of GREENOMETER-7. The valuation (weighting) step is used to generate a score from 0 to 6 for each category and a micro-score from 0 to 6 for the whole life cycle of the building. The indicators scores- from the ranking step- and the indicators weighting factors are used to generate a score for each category. The weighting factors total must equal 100% for the indicators of the same category as shown in Table 101. Different methods can be used to determine the weighting factors. The weighting factor for each indicator reflects its importance in comparison to other indicators in the same category. Weighting factors have been assigned hypothetically to show how the tool works. In practice, different weighting factors are assigned for different regions to consider the regional variations. Table 103 shows the category scores that were generated by multiplying the indicators scores by the indicators weighting factors then adding them together for each category.

The scores of the categories and their weighting factors are used to generate the building micro-score at the micro-assessment level. The weighting factors total for all categories must equal 100% as shown in Table 102. The weighting factor for each category reflects its importance in comparison to other categories. Weighting factors for the categories have been assigned hypothetically to show how the tool works. In practice, different weighting factors are assigned for different regions to consider the regional variations. Table 103 and Figure 23 show the micro-score of the building and the score of each category at the micro-assessment level of GREENOMETER-7. The micro-score is generated by adding the scores of the categories after multiplying them by the categories weighting factors.

Justification of the Weighting Factors

The weighting factors for the indicators and categories that were used for this case study were selected by the researcher. The selections are based on the researcher personal judgment and readings on the importance of one indicator compared to another or one category compared to another. The total of the weighting factors of the same category must equal 100 and the sum of the weighting factors of all categories must equal 100. For example, in the electricity category the electricity for lighting indicator was assigned an importance factor of 20 while the electricity for water heating was assigned an importance factor of 10 which means that the researcher sees the first indicator has double the importance of the second indicator. Similarly, an importance factor of 15 was assigned to the contaminants released to air category and an importance factor of 3 was assigned to the contaminants released to water category. It means the researcher sees the first category three times more important than the second category.

Similar to the indicator baseline in the ranking step, weighting (importance) factors must be assigned by a third party and the user will not be allowed to change them to keep consistency. Weighting factors may vary for different regions because what is the most important in region A may be second important in region B. The third part can use Expert Choice, a software based on the AHP method, to assist in assigning weighting factors for the indicators and categories.

Table 100: The scores of the indicators at the micro-assessment level

Category	Indicator	Ranking Value	Score
1.1 Electricity	Total Electricity consumption	95%	3
	Electricity for lighting	85%	4
	Electricity for heating/ cooling	110%	2
	Electricity for water heating	82%	2
	Energy for Other Equipment	85%	4
1.2 Fossil Fuel	Total MMBtu consumption	90%	3
	MMBtu for space heating	0%	6
	MMBtu for water heating	0%	6
	MMBtu for transportation	130%	0
	MMBtu for other equipment	0%	6
2.1 Water and Wastewater	Total water use	110%	2
	% Recycled/ reclaimed water	0%	0
	Total wastewater generated	100%	3
3.1 Resources Input	Total Resources Input	125%	1
	% of recycled content	20%	0
	% of biobased content	2.5%	2
	% of chemicals content	0.3%	6
3.2 Resources Output	% expected to be recycled	2.8%	0
	MMBtu of wasted	97%	0
4.1 Contaminants Output-Total	Total Contaminants output	95%	4
4.2 Contaminants Output-Captured	% of Contaminants- captured	0%	0
4.3 Contaminants Output-Disposal	Total Contaminants output- disposal	12%	3
4.4 Contaminants Output-Air	Total Contaminants output- air	113%	1
	Global warming potential	NA	3
	Acidification potential	NA	3
	Ozone depletion potential	NA	3
	Photochemical smog potential	NA	3
	Eutrophication potential	NA	3
	Ecotoxicity potential	NA	3
	Human health-cancer	NA	3
	Human health-non-cancer	NA	3
	Human health-criteria	NA	3
4.5 Contaminants Output-Water	Total contaminants output- water	95%	3
	BOD	NA	3
	Ecotoxicity	NA	3
	Eutrophication Potential	NA	3
	Human health- cancer	NA	3
	Human health- non-cancer	NA	3
4.6 Contaminants- Soil	Total Contaminants output- soil	45%	5
5.1 Economics	Total costs	NA	3
	Total Return	NA	3

Table 101: The weighting factors of the indicator at the micro-assessment level of the case study

Category	Indicator	W. Factor
1.1 Electricity	Total Electricity consumption	40
	Electricity for lighting	20
	Electricity for heating/ cooling	20
	Electricity for water heating	10
	Electricity for instruments	10
1.2 Fossil Fuel	Total MMBtu consumption	40
	MMBtu for space heating	20
	MMBtu for water heating	10
	MMBtu for transportation	20
	MMBtu for other equipment	10
2.1 Water and Wastewater	Total water use	40
	% Recycled/ reclaimed water	30
	Total wastewater generated	30
3.1 Resources Input	Total Resources Input	30
	% of recycled content	20
	% of biobased content	20
	% of chemicals content	30
3.2 Resources Output	Total resources output	0
	% expected to be recycled	80
	% expected be wasted	20
	MMBtu of wasted	0
4.1 Contaminants Output-Total	Total Contaminants output	100
4.2 Contaminants -Captured	% of Contaminants- captured	100
4.3 Contaminants-Disposal	Total Contaminants- disposal	100
4.4 Contaminants Output-Air	Total Contaminants output- air	30
	Global warming potential	30
	Acidification potential	4
	Ozone depletion potential	6
	Photochemical smog potential	3
	Eutrophication potential	3
	Ecotoxicity potential	4
	Human health-cancer	10
	Human health-non-cancer	5
	Human health-criteria	5
4.5 Contaminants Output-Water	Total contaminants output- water	20
	BOD	10
	Ecotoxicity	15
	Eutrophication Potential	20
	Human health- cancer	20
	Human health- non-cancer	15
4.6 Contaminants Output- Soil	Total Contaminants output- soil	100
5.1 Economics	Total costs	60
	Total Return	20

Table 102: The weighting factors for the categories at the micro-assessment level

Category	**Category Weighting Factor (%)**
1.1 Electricity	20
1.2 Fossil Fuel	10
2.1 Water and Wastewater	10
3.1 Resources Input	5
3.2 Resources Output	5
4.1 Contaminants Output-Total	10
4.2 Contaminants Output-Captured	5
4.3 Contaminants Output-Disposal	3
4.4 Contaminants Output-Air	15
4.5 Contaminants Output-Water	5
4.6 Contaminants Output- Soil	2
5.1 Economics	10

Table 103: The scores of the categories at the micro-assessment level

Category	**Category Score (0-6)**
1.1 Electricity	3.0
1.2 Fossil Fuel	3.6
2.1 Water and Wastewater	1.7
3.1 Resources Input	2.5
3.2 Resources Output	0.0
4.1 Contaminants Output-Total	4.0
4.2 Contaminants Output-Captured	0.0
4.3 Contaminants Output-Disposal	3.0
4.4 Contaminants Output-Air	2.4
4.5 Contaminants Output-Water	3.0
4.6 Contaminants Output- Soil	5.0
5.1 Economics	3.0
Building micro-score: 2.655	

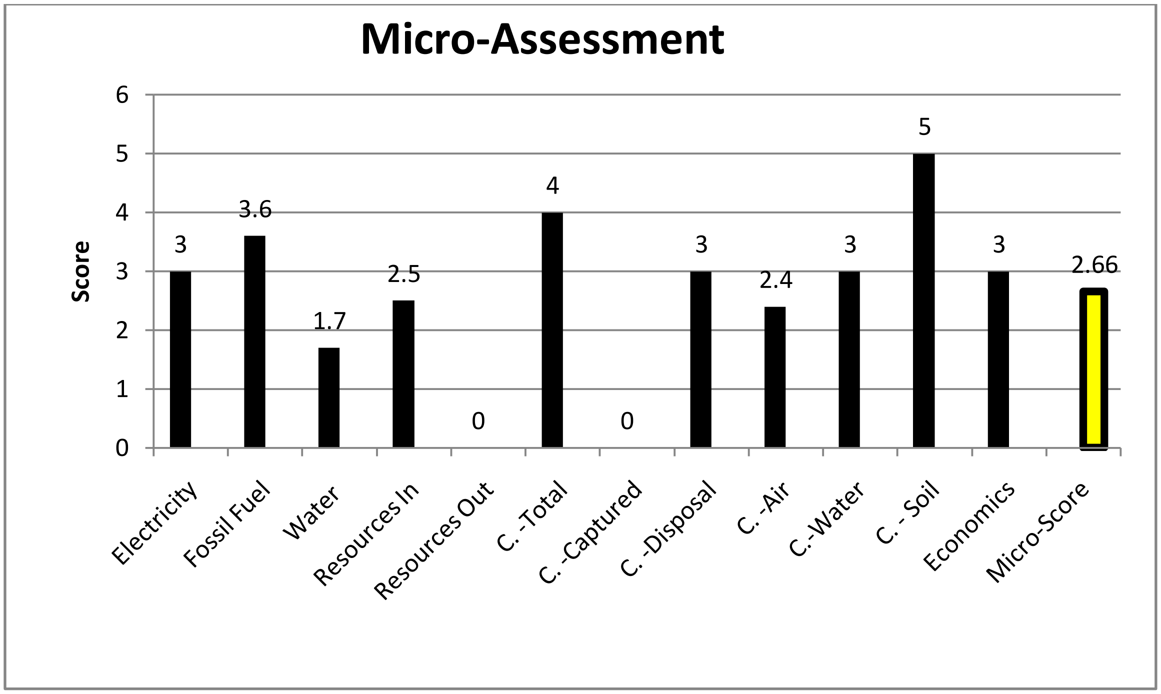

Figure 23: Scores of the categories of the micro-assessment level

5.2.2 Macro-Assessment

Conducting the macro-assessment level of GREENOMETER-7 is the second part of the case study. The macro-assessment level consists of two phases: inventory (the macro-survey and macro-profile steps) and interpretation (the ranking and weighting steps). Each step will be discussed in more details next.

5.2.2.1 Macro-Survey

The macro-survey is the first step in the inventory phase of the macro-level of GREENOMETR-7. The objective of this step is to gather the information for the designer to help in developing the macro-profile. The macro-profile of the case study is shown in Table 104.

5.2.2.2 Macro-Profile

The macro-profile is the second step in the macro-assessment phase of GREENOMETER-7. In this step the designer translate the information gathered in the macro-survey into a quantitative or qualitative statement for each indicator. These statements are the bases of the next ranking step. Table 105 represents the macro-profile for the case study.

Table 104: The macro-survey step for the case study

Indicator	Information
Category 1. Location	
Vulnerability of site to flooding	The site is located in low to moderate risk flooding area. The height id 5 meter above the elevation of the 100-year flood plan.
Proximity to public transportation	The closet bus stop is 0.5 km.
Public Transportation Quality	Only one trip in the morning and one trip in the evening to downtown Columbus.
Proximity to existing infrastructure	Water and sewer lines are located on Wilcox Rd., about10 meter from the site.
Distance between site and centers of employment	The site is about 3 km from the downtowns of Dublin and Hilliard, while about 12 km from Columbus downtown.
Proximity to services	The closest shopping center is about 4 miles away. Most of the services located within 5 km.
Proximity to contaminants/ odor sources	No landfills or industrial factories are close to the site.
Proximity to noise sources	Wilcox Rd. is not a heavy traffic road, but it could cause some noise. The highway is 0.9 km away.
Impact of adjacent building	No impact now, but in the future other buildings are expected to be built on both the north and west sides of the site.
Availability of renewable energy	No renewable energy is available in the area
Availability of potable water	Availability and quality of the water are not an issue.
Impact of the building on the surroundings	The building may block the daylight partially from the future buildings on both the north and west side of the site.
Category 2. Land Use &Value	
Ecological sensitivity of the land	The site was previously developed, no ecological sensitivity.
Agricultural value of the land	The site was not used for farming, but the land in the area has some agricultural value.
Contamination and development status of the land	The site was previously developed but it was not previously contaminated.
Relevance of the footprint of the building	The house footprint is about 2,300 sq. ft, including 450 sq. ft garage. It is expected to be occupied by 5 people.
Pavement density	The total area of the pavement is 600 sq. ft.
Landscaping/ disruption density	Total landscaping area is about 1200 sq ft
Development density (footprint divided by land area)	The area of the building 1,300 sq. ft. The land area of the site (footprint, landscaping, and pavement) is 5,500 sq. ft.

Indicator	Information
Category 3. Stormwater, Heat-Island & Landscaping	
Stormwater run-off	No green roof or reservoirs are intended in the design.
Erosion degree and run-off level of contamination	Enough erosion measures are considered in the design.
Heat-island effect	No green roof. No light colored surfaces. Native trees will be planted in the south side.
Native planting	The goal is to ensure that at least 80% of the plants are native.
Landscaping design strategy	Landscaping design is based on using minimum water for irrigation.
Category 4. Water & Wastewater	
Landscaping water efficiency	5,000 gallon is expected to be used annually to irrigate the 1,200 sq. ft land for landscaping.
Non-potable water use for irrigation	Potable water is the only source of water available.
Non-potable water use for toilet	Potable water is the only source of water available. No graywater recycling.
Harvesting rainwater for reuse	No harvesting of rainwater
Installation of high efficiency fixtures	Three faucets at 2.5 gallon per minute. Shower at 2.5 gallon per minute, and two toilets at 6 liter per flush.
Availability of dual wastewater system	No dual wastewater system.
Category 5. Energy	
Use of renewable energy	No portion of the electricity use is expected to be from a renewable source.
Computer modeling for energy optimization	No modeling is expected to be carried out
Exploring passive lighting, heating and ventilation	Passive lighting and heating are not considered.
Energy controls utilization	No controls will be installed for lighting. Controls will be provided for heating and cooling.
Envelope insulation and air leakage	R-19 for walls and R-36 for ceiling
Building orientation	Front to the east on Wilcox Rd. Two windows open to the east, three to the west, bathroom window to the south, and small bathroom window to the north.
Lighting fixtures efficiency	Mostly CFL at 13W, in addition to 2 straight fluorescent lights at 20W.

Indicator	Information
Heating and cooling system efficiency	Electricity consumption for heating is about 3,500 kwh per year. Electricity consumption for cooling is about 2,800 kwh per year.
Appliances efficiency	Electricity consumption by the refrigerator is about 410 kwh per year, dishwasher 1.57 kwh per cycle, dryer 1.57 kwh per load, waher 0.288 kwh per load, rang 2 kwh per hour of use, water heater 4.5 kwh per hour of use.
Category 6. Resources	
Collection of recyclable waste at the construction stage	60% of the recyclable materials are expected to be recycled
Collection of recyclable waste at the operation stage	20% of the recyclable materials are expected to be recycled
Collection of recyclable waste at the demolition stage	50% of the recyclable materials are expected to be recycled
Right-size building	Area of the building 2,300 sq. ft and expected occupants 5 people.
Design for disassembly (DfD)	Extensive consideration
Durability of building materials and products	Considered when price is competitive
Selection of products based on LCA	No utilization
Locally produced materials	About 30% of the major materials are produced locally
Use Ozone depletion refrigerants	Only none ozone depletion refrigerants are selected
Category 7. IEQ	
Ventilation effectiveness and CO2 concentration	Ventilation rate and CO2 concentration to meet the standard.
Temperature and relative humidity	Thermal comfort and humidity to meet the standard
Air filtering and venting of combustion gases and odors	Vacuum fans are installed as needed.
Environmental Tobacco Smoke (ETS)	Smoking is not allowed inside
Noise and vibration	Minimum noise and vibration from the building systems
Exposure to Radon	Design and take measures to ensure no exposure
Lighting Quality	Meets the standard
Access to daylight and outside view	5 windows

Table 105: The macro-profile step for the case study

Indicator	Quantitative/ Qualitative Statement
Category 1. Location	
Vulnerability of site to flooding	Height above the 100-year flood plain is 5 meter
Proximity to public transportation	The distance from a public transportation stop is 550 meter
Public Transportation Quality	Poor
Proximity to existing infrastructure	20 meter
Distance between site and centers of employment	12 km
Proximity to services	5 km
Proximity to contaminants/ odor sources	More than 2 km
Proximity to noise sources	0.9 km
Impact of adjacent building	Somewhat affected
Availability of renewable energy	Not available
Availability of potable water	Strongly satisfied
Impact of the building on the surroundings	Somewhat affected
Category 2. Land Use &Value	
Ecological sensitivity of the land	Not sensitive
Agricultural value of the land	Some agricultural value
Contamination and development status of the land	Subsurface is not contaminated. The site was previously developed
Relevance of the footprint of the building	117% of the standard
Pavement density	90% of the standard
Landscaping/ disruption density	95% of the standard
Development density	85% of the standard
Category 3. Stormwater, Heat-Island & Landscaping	
Stormwater run-off	Around 50%
Erosion degree and run-off level of contamination	Almust no erosion and no run-off turbidity
Heat island effect	Expected 2 C increase
Native planting	80% of total
Landscaping design strategy	
Category 4. Water & Wastewater	
Landscaping water efficiency	90% of the standard
Non-potable water use for irrigation	0% non-potable water for irrigation
Non-potable water use for toilet	0% non-potable water for toilet
Harvesting rainwater for reuse	0% rainwater harvesting
Installation of high efficiency fixtures	95% of the standard
Availability of dual wastewater system	0% graywater collected

Indicator	**Quantitative/ Qualitative Statement**
Category 5. Energy	
Use of renewable energy	0% renewable energy use
Computer modeling for energy optimization	low utilization
Exploring passive lighting, heating and ventilation	Fair consideration
Energy controls utilization	Average level of utilization
Envelope insulation and air leakage	100% of the standard
Building orientation	Good orientation
Lighting fixtures efficiency	78% of the standard
Heating and cooling system efficiency	95% of the standard
Appliances efficiency	80% of the standard
Category 6. Resources	
Collection of recyclable waste at the construction stage	40% is expected to be recycled
Collection of recyclable waste at the operation stage	30% is expected to be recycled
Collection of recyclable waste at the demolition stage	60% is expected to be recycled
Right-size building	120% of the standard
Design for disassembly (DfD)	High measures have been taken
Durability of building materials and products	Average consideration
Selection of products based on LCA	poor utilization
Locally produced materials	35% produced locally
Use Ozone depletion refrigerants	5% of total
Category 7. IEQ	
Ventilation effectiveness and CO2 concentration	85% of the standard
Temperature and relative humidity	Satisfied
Air filtering and venting of combustion gases and odors	Almost the best efficiency
Environmental Tobacco Smoke (ETS)	Smoking is prohibited in all building areas
Noise and vibration	Highly satisfied
Exposure to Radon	Almost no exposure
Lighting Quality	Satisfied
Access to daylight and outside view	75% of the building has access to daylight

5.2.2.3 Ranking

The interpretation phase at the macro-assessment level is similar to the interpretation phase at the micro-assessment level and it consists of two steps ranking and weighting. The objective of the ranking step is to provide a score of 0 to 6 for each indicator at the macro-assessment level. Table 106 shows the scores of the indicators at the macro-level.

Justification of the Scores

The ranking guidelines provided in section 3.3.3 in Chapter III have been used to rank each indicator. Similar to ranking at the micro-assessment level, where comparison to a standard was required, assumptions have been made. For each indicator a standard (baseline) needs to be developed. These standards are different for different building types and sometimes for different regions. After the baseline has been identified ranges (in percentage of the baseline) are assigned for the scores of 0, 1, 2… 6. For example, the R-19 value of the insulation was assumed to be 100% of the baseline. By looking at the ranking guideline table for this indicator it shows that a value of 100% of the baseline receives a score of 3. Identifying a baseline for each indicator as a basis for scoring the indicator using the 0 to 6 scale is a recommendation for future work. These baselines are determined once for each building type by a third party and the user will not be allowed to change them for consistency.

5.2.2.4 Valuation (Weighting)

Valuation (weighting) is the second step in the interpretation phase at the macro-assessment level of GREENOMETER-7. The objective of this step is to generate scores for the categories at the macro-scale and to generate an overall macro-score for the building. The categories scores and the macro-score are in the 0 to 6 range. The indicators scores- from the ranking step- and the indicators weighting factors are used to generate a score for each category. The weighting factors total must equal 100% for the indicators of the same category as shown in Table 107. Different methods can be used to determine the weighting factors. The weighting factor for each indicator reflects its importance in comparison to other indicators in the same category. Weighting factors have been assigned hypothetically to show how the tool works. In practice, different weighting factors are assigned for different regions to consider the regional variations. Table 109 shows the category scores that were generated by multiplying the indicators scores by the indicators weighting factors then adding them together for each category.

The scores of the categories and their weighting factors are used to generate the building macro-score at the macro-assessment level. The weighting factors total for all categories must equal 100% as shown in Table 108. The weighting factor for each category reflects its importance in comparison to other categories. Weighting factors for the categories have been assigned hypothetically to show how the tool works. In practice, different weighting factors are assigned for different regions to consider the regional variations. Table 109 and Figure 24 show the macro-score of the building and the score of each category at the macro-assessment level of GREENOMETER-7. The micro-score is generated by adding the scores of the categories after multiplying them by the categories weighting factors. Figure 25 shows the overall sustainability score, which is the average of the micro- and macro-scores.

Justification of the Weighting Factors

The weighting factors for the indicators and categories that were used for this case study were selected by the researcher. The selections are based on the researcher personal judgment and readings on the importance of one indicator compared to another or one category compared to another. The total of the weighting factors of the same category must equal 100 and the sum of the weighting factors of all categories must equal 100. For example, in the location category the vulnerability of site to flooding was assigned an importance factor of 15 while the proximity to noise sources was assigned an importance factor of 5 which means that the researcher sees the first indicator 3 times more important than the second indicator. Similarly, an importance factor of 20 was assigned to the location category and an importance factor of 20 was assigned to the land use category. It means the researcher sees the first category as important as the second category.

Similar to the indicator baseline in the ranking step, weighting (importance) factors must be assigned by a third party and the user will not be allowed to change them to keep consistency. Weighting factors may vary for different regions because what is the most important in region A may be second important in region B. The third part can use Expert Choice, a software based on the AHP method, to assist in assigning weighting factors for the indicators and categories.

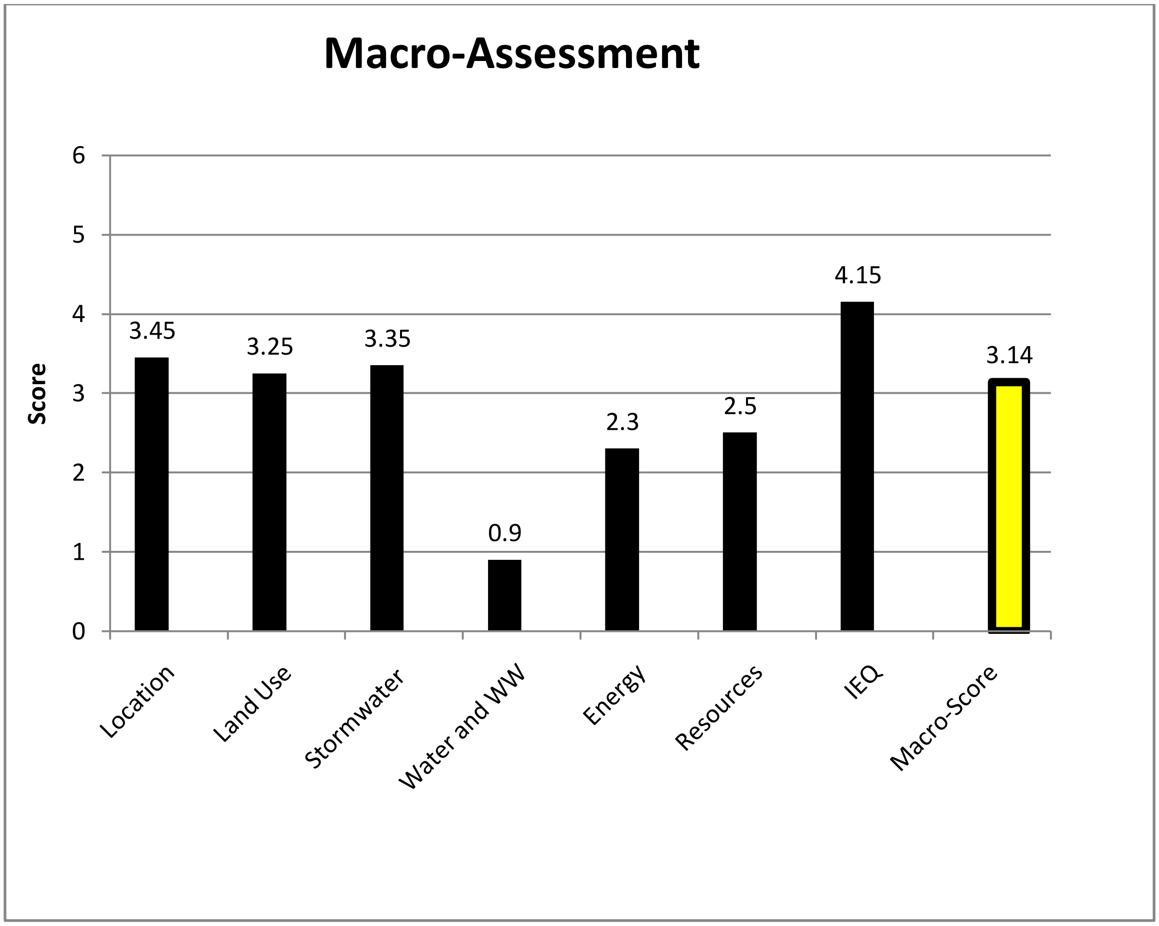

Figure 24: Scores of the categories at the macro-assessment level

Table 106: The scores of the indicators at the macro-level

Indicator	Score (0-6)
Category 1. Location	
Vulnerability of site to flooding	5
Proximity to public transportation	2
Public Transportation Quality	1
Proximity to existing infrastructure	6
Distance between site and centers of employment	0
Proximity to services	2
Proximity to contaminants/ odor sources	6
Proximity to noise sources	5
Impact of adjacent building	4
Availability of renewable energy	0
Availability of potable water	5
Impact of the building on the surroundings	2
Category 2. Land Use &Value	
Ecological sensitivity of the land	5
Agricultural value of the land	3
Contamination and development status of the land	3
Relevance of the footprint of the building	2
Pavement density	3
Landscaping/ disruption density	3
Development density	4
Category 3. Stormwater, Heat-Island & Landscaping	
Stormwater run-off	2
Erosion degree and run-off level of contamination	5
Heat island effect	3
Native planting	4
Landscaping design strategy	4
Category 4. Water & Wastewater	
Landscaping water efficiency	3
Non-potable water use for irrigation	0
Non-potable water use for toilet	0
Harvesting rainwater for reuse	0
Installation of high efficiency fixtures	3
Availability of dual wastewater system	0
Category 5. Energy	
Use of renewable energy	0
Computer modeling for energy optimization	1
Exploring passive lighting, heating and ventilation	2
Energy controls utilization	3
Envelope insulation and air leakage	3
Building orientation	4
Lighting fixtures efficiency	5
Heating and cooling system efficiency	3

Indicator	Score (0-6)
Appliances efficiency	5
Category 6. Resources	
Collection of recyclable waste at the construction stage	3
Collection of recyclable waste at the operation stage	1
Collection of recyclable waste at the demolition stage	4
Right-size building	2
Design for disassembly (DfD)	4
Durability of building materials and products	3
Selection of products based on LCA	1
Locally produced materials	2
Use Ozone depletion refrigerants	6
Category 7. IEQ	
Ventilation effectiveness and CO2 concentration	4
Temperature and relative humidity	4
Air filtering and venting of combustion gases and odors	5
Environmental Tobacco Smoke (ETS)	3
Noise and vibration	5
Exposure to Radon	5
Lighting Quality	4
Access to daylight and outside view	4

Table 107: The weighting factors of the indicators at the micro-level

Category	Indicator	W. Factor
Category 1 Location	Vulnerability of site to flooding	15
	Proximity to public transportation	5
	Public Transportation Quality	5
	Proximity to existing infrastructure	15
	Distance between site and centers of employment	10
	Proximity to services	5
	Proximity to contaminants/ odor sources	5
	Proximity to noise sources	5
	Impact of adjacent building	10
	Availability of renewable energy	10
	Availability of potable water	10
	Impact of the building on the surroundings	5
Category 2 Land Use &Value	Ecological sensitivity of the land	20
	Agricultural value of the land	20
	Contamination and development status of the land	15
	Relevance of the footprint of the building	25
	Pavement density	5
	Landscaping/ disruption density	5
	Development density	10
Category 3 Stormwater, Heat-Island & Landscaping	Stormwater run-off	30
	Erosion degree and run-off level of contamination	10
	Heat island effect	15
	Native planting	15
	Landscaping design strategy	30
Category 4 Water & Wastewater	Landscaping water efficiency	10
	Non-potable water use for irrigation	15
	Non-potable water use for toilet	15
	Harvesting rainwater for reuse	10
	Installation of high efficiency fixtures	20
	Availability of dual wastewater system	30
Category 5 Energy	Use of renewable energy	20
	Computer modeling for energy optimization	15
	Exploring passive lighting, heating and ventilation	20
	Energy controls utilization	5
	Envelope insulation and air leakage	8
	Building orientation	8
	Lighting fixtures efficiency	8
	Heating and cooling system efficiency	8
	Appliances efficiency	8
Category 6 Resources	Collection of recyclable waste at the construction stage	10

Category	Indicator	W. Factor
	Collection of recyclable waste at the operation stage	10
	Collection of recyclable waste at the demolition stage	10
	Right-size building	15
	Design for disassembly (DfD)	10
	Durability of building materials and products	10
	Selection of products based on LCA	20
	Locally produced materials	10
	Use Ozone depletion refrigerants	5
Category 7 IEQ	Ventilation effectiveness and CO2 concentration	25
	Temperature and relative humidity	15
	Air filtering and venting of combustion gases and odors	10
	Environmental Tobacco Smoke (ETS)	10
	Noise and vibration	10
	Exposure to Radon	5
	Lighting Quality	10
	Access to daylight and outside view	15

Table 108: The weighting factors of the categories at the macro-level

Category	Category Weighting Factor (%)
1. Location	20
2. Land Use & Value	20
3. Stormwater, Heat-island & Landscaping	10
4. Water and Wastewater	15
5. Energy	20
6. Resources	10
7. IEQ	15

Table 109: The scores of the categories at the macro-level

Category	Category Score (0-6)
1. Location	3.45
2. Land Use & Value	3.25
3. Stormwater, Heat-island & Landscaping	3.35
4. Water and Wastewater	0.90
5. Energy	2.30
6. Resources	2.50
7. IEQ	4.15
Building macro-score: 3.143	

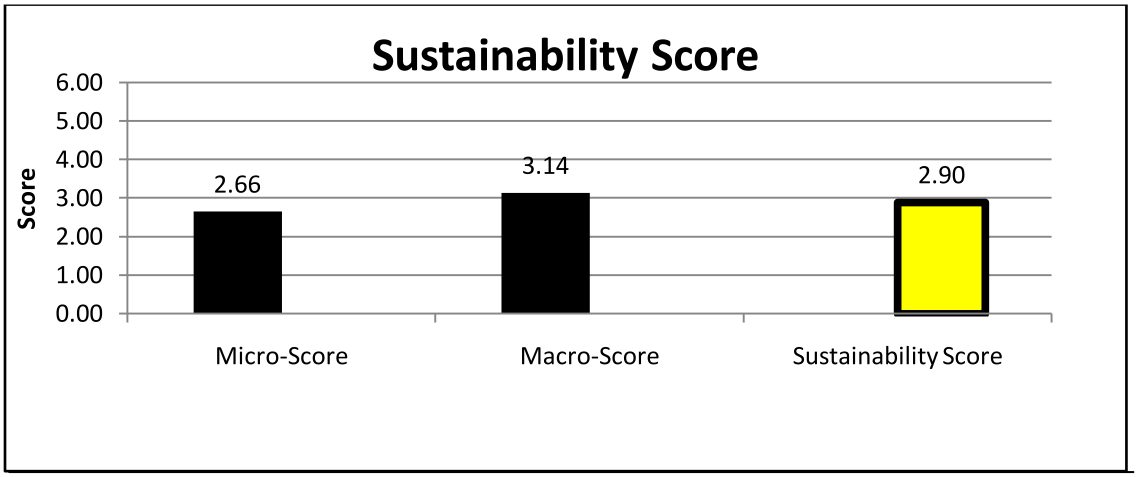

Figure 25: The overall sustainability score

5.2.3 LEED Points

The third part of the case study is to forecast the LEED certification level of the building by matching LEED credits with applicable micro- and macro-assessment indicators from GREENOMETER-7. An advantage of forecasting the LEED points at the conceptual design stage is that the designer can make necessary changes to reach a better certification level if not satisfied with the original certification level. LEED has the following categories: sustainable site (SS), water efficiency (WE), energy and atmosphere (EA), materials and resources (MR), indoor environmental quality (EQ), and innovation and design process (ID). The output is the total LEED point the building is qualified for in addition to the LEED points per category. By reviewing the scores of the categories the designer determines which category needs more attention.

Justification of the threshold for LEED points

The guidelines provided in section 3.4 have been used to determine the threshold score for the indicators of GREENOMETER-7 needed to award LEED points. For example, the building received one LEED point if the score of the proximity to existing infrastructure GREENOMETER-7 indicator is 4 or above. These thresholds need to be adjusted when the third party finalizes the ranking guidelines at the micro- and macro-assessment levels so that the threshold reflects LEED standard. Since GREENOMETER-7 is more restricted than LEED, in some cases LEED points may be awarded even if the score of GREENOMETER-7 indicator is less than 3.

Table 110 shows the LEED points that were awarded per each credit of the sustainable site category. Each credit of this category is matched with one or more GREENOMETER-7 indicators. For the LEED points to be awarded the score of GREENOMETER-7 indicator must exceed the threshold indentified in Table 82 the sustainable site category. For example, one LEED point is awarded if the score of the ecological sensitivity of the land is equal or more than 4. The building was qualified only for 7 of the 19 possible LEED points of the sustainable site category based on the scores of the matching GREENOMETER-7 indicators.

Table 110: The LEED points of the case study based on the sustainable site (SS) category

LEED Credit	**Matching GREENOMETER-7 Indicators**	**Indicator Score**	**LEED Points**
SS-1 Site Selection	Macro-2.1 Ecological Sensitivity of the Land	5	1
	Macro-2.2 Agricultural value of the land	3	0
SS-2 Preferred Location	Macro-2.3 Contamination and development status of the land	3	0
SS-3 Infrastructure	Macro-1.4 Proximity to existing infrastructure	6	1
SS-4 Alternative transportation	Macro-1.2 Proximity to public transportation	2	0
	Macro-1.3 Public transportation quality	1	0
	Macro-1.6 Proximity to services	2	0
SS-5 Site Development	Macro-2.5 Pavement density	3	0
	Macro-2.6 Disruption density	3	0
	Macro-2.7 Development density	4	1
SS-6 Stormwater Design	Macro-3.1 Stormwater run-off	2	0
	Macro-3.2 Erosion degree and level of contamination	5	1
SS-7 Heat-island effect	Macro-3.3 Heat-island effect	3	0
SS-8 Landscaping	Macro-3.4 Native planting	4	1
	Macro-3.5 Landscaping design strategy	4	1
SS-9 Light pollution reduction	Only light areas as required for safety and comfort	NA	1
SS total points from 19 is 7			

Table 111 shows credits of the water efficiency category of LEED and their matching GREENOMETER-7 indicators. For each indicator the LEED points are awarded if the score of that indicator exceeds the threshold identified in Table 83. For example, no LEED points were received based on the score of the landscaping water efficiency indicator because its score is 3 and the threshold to receive the LEED point is 4. The building was not qualified any of the 12 possible LEED points of the water efficiency category based on the scores of the matching GREENOMETER-7 indicators.

Table 111: The LEED points of the case study based on the water efficiency (WE) category

LEED Credit	**Matching GREENOMETER-7 Indicators**	**Indicator Score**	**LEED Points**
WE-1 Irrigation System	Macro-4.1 Landscaping water efficiency	3	0
	Macro-4.2 Non-potable water for irrigation	0	0
WE-2 Water reuse	Micro-2.1.2 % or recycled/ reclaimed water	0	0
	Macro-4.4 Harvesting rainwater for reuse	0	0
	Macro-4.3 Non-potable water use for toilet	0	0
	Macro-4.6 Availability of dual wastewater system	0	0
WE-3 Water use	Micro-2.1.1 Total water use	2	0
	Macro-4.5 Installation of high efficiency fixtures	3	0
WE-4 Innovative wastewater technologies	Treat at least50% of wastewater on-site to tertiary standards	NA	0
WE total points from 12 is 0			

Table 112 shows the credits of the energy and atmosphere category of LEED and their matching GREENOMETER-7 indicators. LEED points are awarded based on the scores of the indicators. The score of the indicator has to exceed the threshold identified in Table 84 for the LEED point to be awarded. For example, the building receives two LEED points if the score of the total energy consumption is 3. The building was qualified for only 7 of the 21 possible LEED points of the energy and atmosphere category based on the scores of the matching GREENOMETER-7 indicators.

Table 112: The LEED points of the case study based on the energy and atmosphere (EA) category

LEED Credit	Matching GREENOMETER-7 Indicators	Indicator Score	LEED Credit
EA-1 Optimize Energy performance	Micro-1.1.1 and 1.2.1 Total energy consumption	3	2
	Macro-5.2 Computer modeling for energy optimization	1	0
	Macro-5.3 Exploring passive lighting, heating and ventilation	2	0
	Macro-5.4 Energy controls utilization	3	0
CA-2 Insulation	Macro-5.5 Envelop insulation and air leakage	3	0
CA-3 Space Heating and Cooling	Micro-1.1.3 or 1.2.3 Energy for heating and cooling	2	0
	Macro-5.8 Heating and cooling system efficiency	3	0
EA-4 Lighting	Micro-1.1.2 Electricity for lighting	4	1
	Macro-5.7 Lighting fixtures efficiency	5	1
EA-5 Appliances	Micro-1.1.5 and 2.2.5 Energy for equipment	5	1
	Macro-5.9 Appliances efficiency	5	1
EA-6 Renewable Energy	Macro-5.1 Use of renewable energy	0	0
EA-7 Refrigerants Management	Macro-6.9 Use of Ozone depletion refrigerants	6	1
	Micro-4.4.4 Ozone depletion potential	3	0
EA total points from 21 is 7			

Table 113 shows the credits of the materials and resources category of LEED and their matching GREENOMETER-7 indicators. LEED points are awarded based on the scores of the indicators. The indicator score must exceed the threshold identified in Table 83 for the LEED point(s) to be awarded. For example, no LEED points were received based on the percentage of resources expected to be recycled indicator because the threshold is 4 and score was 0. The building was qualified for only 1 of the 12 possible LEED points of the materials and resources category based on the scores of the matching GREENOMETER-7 indicators.

Table 113: The LEED points of the case study based on the materials and resources category

LEED Credit	**Matching GREENOMETER-7 Indicators**	**Indicator Score**	**LEED Credit**
MR-1 Waste management	Micro-3.2.2 % of resources output expected to be recycled	0	0
	Macro-6.1 Collection of recyclable waste at the construction stage	3	0
	Macro-6.2 Collection of recyclable waste at the operation stage	1	0
	Macro-6.3 Collection of recyclable waste at the demolition stage	4	1
MR-2 Recycling content	Micro-3.1.2 % of recycled content	0	0
MR-3 Environmentally preferred products	Macro-6.7 Selection based on LCA	1	0
MR-4 Regional Materials	Macro-6.8 Locally produced materials	2	0
MR total points from 12 is 1			

Table 114 shows the credits of the indoor environmental quality category and their matching GREENOMETER-7 indicators. LEED points are awarded based on the scores of the indicators. The score of each indicator must exceed the threshold identified in Table 86 for the LEED point to be awarded. For example, the threshold score for the ventilation effectiveness and CO2 concentration is 4. The building was qualified for 8 of the 11 possible LEED points for the indoor environmental quality category based on the scores of the matching GREENOMETER-7 indicators.

Table 114: The LEED points of the case study based on the indoor environmental quality category

LEED Credit	Matching GREENOMETER-7 Indicators	Indicator Score	LEED Credit
EQ-1 Outdoor Air Delivery Monitoring	Macro-7.1 Ventilation effectiveness and CO2 concentration	4	1
EQ-2 Moisture Control and thermal control	Macro-7.2 Temperature and relative humidity	4	1
EQ-3 Construction IAQ management plan	Develop and implement an IAQ management plan for the construction stage	NA	1
EQ-4 Low-emitting materials	Micro-3.1.4 % of chemical content	6	1
	Micro-4.4.1 Total contaminants output to air	1	0
EQ-5 Indoor chemical & pollution source control	Macro-7.6 Exposure to Radon	5	1
	Macro-7.3 Air filtering and venting of combustion gases	5	1
EQ-6 Lighting comfort	Macro-7.7 lighting quality	4	1
EQ-7 Daylight and view	Macro-7.8 Access to daylight and outside view	4	1
EQ total points from 11 is 8			

Table 115 and Figure 26 summarize the LEED points received for each category and the total LEED points received from all categories. No points were received for the water efficiency category, while only one LEED point was received for the materials and resources category. The building was qualified for a total of 23 LEED points, which does not qualify the building for any certification level. The lowest certification level is certified and it requires a minimum of 26 LEED points.

Table 115: LEED points by category for the case study

LEED Category	LEED Points	Possible Points
Sustainable Site (SS)	7	19
Water Efficiency (WE)	0	12
Energy and Atmosphere (EA)	7	21
Materials and Resources (MR)	1	12
Indoor Environmental Quality (EQ)	8	11
Innovation and Design Process (ID)	0	NA
Total LEED Points from 75:	**23**	
Certification level:	**Not-Certified**	

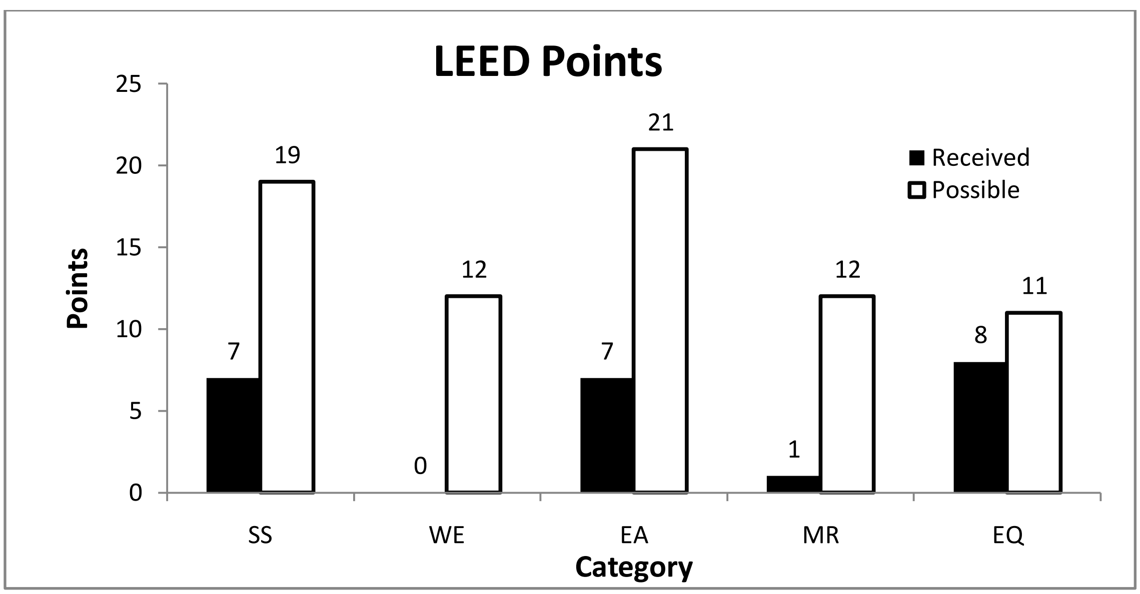

Figure 26: LEED points per category

5.3 Discussion

5.3.1 Micro-Assessment

The building score at the micro-assessment level is 2.655 in the 0 to 6 spectrum, which is less than average. This score is a combination of the scores of the 12 categories at the micro-assessment level. The contribution of each category to this score is based on its weighting factor as shown in Table 102. For example electricity category has a weighting factor of 20%, while water and wastewater category has a weighting factor of 10. It means that the contribution of electricity category score is two times the contribution of the water and wastewater score. When looking for opportunities for improvements it is important to consider the category score as well as its weighting factor.

- **Electricity**

The electricity category score is 3.1 and it has 20% contribution in the building score at the micro-level. It means that the consumption of electricity by the building over its life cycle is in the average range. This score resulted from the combination of 5 indicators with different weighting factors as shown in Table 101.

The total electricity consumption indicator has 40% contribution in the score of the electricity category. The building is expected to consume 825, 904 kwh over its life cycle, mainly in the operation stage, and this level of consumption was given a score of 3 in the 0 to 6 spectrum.

About 38.1% (315,000) of the total electricity consumption is used for space heating and cooling. The electricity consumption for heating and cooling has a 20% contribution in the score of the electricity category and it was given a score of 2. This score can be improved be considering a more efficient heating and cooling system and by considering passive heating and cooling in the design.

Only 2.5% (20,340 kwh) of the total electricity consumption was for lighting. The electricity consumption for lighting has a 20% contribution in the electricity score and it was scored at 4. This score is above average because highly efficient lighting bulbs (CFL bulbs) were considered in the design. This score could be improved by considering passive lighting and by installing lighting controls.

Another score of 2 has been given to the electricity consumption for water heating indicator that has a 10% weighting factor. This score can be simply improved by installing solar water heater.

The last indicator in the electricity category is electricity consumption for appliances and other equipment. It has 10% contribution to the score of the electricity category and it was given a score of 4. It is above average but a better score can be achieved by considering Energy Star appliances and equipment.

- **Fossil Fuel**

The score of the fossil fuel category is 3.6 and it has 10% contribution in the overall score of the building at the micro-level. This score results from the combination of 5 indicators with different weighting factors as shown in Table 101. For this case study electricity is used for heating, cooling and for the range. Fossil fuel is mainly used for transportation.

The total fossil fuel consumption indicator contributes 40% in the score of the fossil fuel category. Its value is 58,000 MMBtu and it was scored at 3. Since the use of fossil fuel is mainly for transportation, improvement in transportation can make improvement in this score.

The fossil fuel consumption for transportation has a 20% weighting factor and it was scored 0. This 0 score has big impact on the fossil fuel score and the overall score of the building. The main reason for this score is the distance between the house and the work location. If changing the building location is not an option, utilizing a highly efficient vehicle can make some improvement.

- **Water and Wastewater**

The score of the water and wastewater category is 1.7 and it has a 10% contribution in the building score at the micro-level. This is a low score and the designer needs to search for options for improvement. This category has 3 indicators with different weighting factors as shown in Table 101.

The total water use indicator has 40% contribution in the score of the water and wastewater category. It has a value of $4.6x10^7$ liter and it was given a score of 2. The score of this indicator can be improved by considering the installation of more efficient fixtures.

The % of recycled or reclaimed water indicator has a weighting factor of 30% and it was given a score of 0. This 0 score contributes badly in the category score and the overall score of the building at the micro level. It is recommended to install a dual wastewater system and recycle the graywater for toilet and irrigation use.

The total wastewater generation is the last indicator in this category. It has a weighting factor of 30% and it was scored at 3. By installing dual wastewater system the score of this indicator also improves.

- **Resources Input**

The score of the resources input category is 2.5 and it has a 5% contribution in the building score at the micro-level. The score is below average and the designer needs to search for options for improvement. This category has 4 indicators with different weighting factors as shown in Table 101.

The total resources input indicator has a weighting factor of 30%. The 692,214 kg of resources input over the building life cycle has been scored at 1. This score means that this building is using too much resource based on the number of occupants. Improvement can be obtained considering a change in the footprint and volume to surface ratio.

The recycled content indicator has a weighting factor of 20% and it received 0 score because the recycled content is only 0.22%. The score of this indicator can be improved by considering building materials and products with a higher recycled content.

The bio-based content indicator has a weighting factor of 20% and it received a score of 2. This score can also be improved by considering materials and products with a higher bio-based content.

The chemicals content indicator has a 30% contribution in the score of the resources input category and it received a score of 6. The chemicals content will be analyzed in more depth in the contaminants output categories. The goal of this indicator is to give preference to materials and products with less chemicals content in general, so it is recommended to consider materials with no or minimum chemicals content whenever possible.

- **Resources Output**

The score of the resources output category is 0 and it has a 5% contribution in the building score at the micro-level. This 0 score has critical impact on the final score, although this category has small weighting factor.

The indicator of resources output that are expected to be recycled has 80% contribution to the score of the resources output score. This indicator received 0 score because only 2.8% is expected to be recycled over the life cycle of the building. It is critical to consider material and products with higher potential to be recycled.

The indicator of resources output that are expected to be wasted has a weighting factor of 20%. Because 97.2% of the resources are expected to be wasted over the life cycle of the building, this indicator received 0 score. The designer needs to consider more options in the design to insure higher recycling rate.

- **Contaminants Output-Total**

The score of the contaminants output-total category is 4 and it has a 10 % contribution in the building score at the micro-level. This category has one indicator so the category score is the same as the indicator score. The 11,612 kg total contaminants output received a score of 4. Based on mass balance, this indicator reflects contaminants generation and contaminant input. There are four routes for contaminants output and the goal is to minimize contaminants output in general. These routes are contaminants output to air, to water, to soil, to landfill, or captured. In this case study 0% of contaminants output is expected to be captured, 4.8% to be sent to landfill, 6.5% to be released to air, 88.7% to be released to water, and 0% to be released to soil.

- **Contaminants Output-Captured**

This category has one indicator and it has a 5% contribution in the building score at the micro-level. A score of 0 has been given to the indicator of captured contaminants output because 0% contaminants are expected to be captured.

- **Contaminants Output-Disposal**

The score of the contaminants output-disposal category is 3 and it has a 3 % contribution in the building score at the micro-level. This category has one indicator so the category score is the same as the indicator score. This score can be improved by considering equipment and products that allow for contaminants properly removal before disposal, it not recyclable.

- **Contaminants Output-Air**

The score of the contaminants output-air category is 2.4 and it has a 15 % contribution in the building score at the micro-level. The contaminants released to air are assessed in more depth and the results are expressed in terms of 10 indicators with different weighting factors as shown in Table 101. The score of this category results from the combination of these indicators. This category covers contribution to global warming, acidification, eutrophication, ecotoxicity, and human health. These indicators are determined using TRACI method.

The indicator of total contaminants released to air has a weighting factor of 30% and it received a score of 1. This is a very low score and it can be improved by considering materials and equipment that emit less contaminants to air over the building life cycle.

The global warming potential indicator has a weighting factor of 30%. No enough information is available to determine its value but a score of 3 has been assumed. In general, the score of this indicator can be improved by minimizing the generation of greenhouse gases throughout the building life cycle.

No enough information is available to determine the values of the remaining indicator using TRACI; however, a score of 3 has been assumed for each. In general, the score of each of these categories (acidification, eutrophication, ecotoxicity, human health-cancer, human health-non-cancer, and human health-criteria) by considering materials and products that are free from the chemicals listed for each category in TRACI.

- **Contaminants Output-Water**

The score of the contaminants output-water category is 3 and it has a 5 % contribution in the building score at the micro-level. The contaminants released to water are assessed in more depth and the results are expressed in terms of 5 indicators with different weighting factors as shown in Table 101. TRACI method is used for calculating the values for the ecotocicity, eutrophication and human health indicators.

The total contaminants to water indicator has a weighting factor of 20%. The value of this indicator in 10,297 kg and it received a score of 3. This score can be improved by considering products and materials that has the potential to release less contaminants to water over the building life cycle.

Values have not been determined for the other indicators (BOD, ecotoxicity, eurtophication, human health-cancer, and human health-non cancer); however, a score of

3 has been assumed for each. In general, the score of each of these indicators can be improved by considering materials that release less contaminants to the water media.

- **Contaminants Output-Soil**

The score of the contaminants output-soil category is 5 and it has a 2% contribution in the building score at the micro-level. This category has only one indicator and its score can be improved by taking measures and selecting materials to insure that less contaminants are released to the soil.

- **Economics**

The score of the contaminants output-soil category is 3 and it has a 10% contribution in the building score at the micro-level. Cost is an important factor in the decision making process. The tool provides information about the total costs of the building life cycle and how the cost is distributed among the stages of the building life cycle.

5.3.2 Macro-Assessment

The building score at the micro-assessment level is 3.095 in the 0 to 6 spectrum, which is about average. This score is a combination of the scores of the 7 categories at the macro-assessment level. The contribution of each category to this score is based on its weighting factor as shown in Table 108. The weighting factor of the category reflects its importance in comparison to other categories. For example, the location category has a weighting factor of 20%, it means that it contributes 20% to the final score of the building at the macro-level. When looking for opportunities for improvements it is important to consider the category score as well as its weighting factor.

- **Location**

The location category score is 3.45 and it has 20% contribution in the score of the building at the macro-level. This score resulted from the combination of 12 indicators with different weighting factors as shown in Table 107Table 101. Unfortunately, the score of this category can only be changed by changing the location of the building site and most of the time this is not an option.

The vulnerability of site to flooding indicator has 15% contribution to the score of the location category and it received a score of 5 because the site is located to in low flooding risk area. This indicator encourages the selection of sites in low flooding risk areas.

The proximity to public transportation indicator received a score of 2 because the closest pus stop to the site is about ½ mile away. On the other hand, the public transportation quality and availability indicator received a score of 1 because pubic transportation is not available in short periods, only one trip in the morning and one in the evening. Each of these indicators contributes 5% to the score of the location category.

The proximity to infrastructure indicator received a score of 6 because the site is located in an urban area. This indicator contributes 15% to the score of the location category.

The distance to the center of employment indicator received a score of 0 and it contributes 10% to the score of the location category. This is a low score because the site is more than 10 km from the major employment center, where the owner is currently working.

The proximity to noise sources indicator received a score of 5 because no major noise sources in the surroundings of the site. This indicator contributes 5% to the score of the location category.

Similarly, the proximity to contaminants sources indicator received a score of 5 because no industrial plants or landfills in the neighborhood. This indicator has a 5% weighting factor.

The availability of renewable energy indicator received a score of 0 because the electricity in that area is not generated form renewable energy. This indicator has a weighting factor of 10%, which means that it has 10% contribution in the score of the location category.

Currently there are no adjacent buildings; however, when new buildings are built in the future it is expected that there will be minimum impact in both buildings. For this reason the impact of adjacent building indicator received a score of 5 and the impact of the building on the surrounding indicator received 5 too.

- **Land Use and Land Value**

The land use and land value category score is 3.25 and it has 20% contribution in the final score of the building at the macro-level. This score resulted from the combination of 7 indicators with different weighting factors as shown in Table 107. The goal of this category is to discourage people from building in or close to sensitive land.

The ecological sensitivity of the land indicator contributes 20% to the score of this category and it received a score 5 because the building site has almost no ecological sensitivity.

The agricultural value indicator received a score of 3 because the land has some agricultural value. This indicator contributes 20% to the score of the land uses and value category.

The contamination and development status indicator received a score of 3 because the site is not a brownfield; however, it was developed before. This indicator contributes 15% to the score of the land use and value category and it encourages locating the building in a previously developed site.

The relevance of the footprint indicator received a score of 2 because the footprint of the building is more than average based on the number of occupants. This indicator contributes 25% to the score of the land use and value category and it encourages reserving land by building the right size building. This score can be improved by reducing the footprint.

The pavement density indicator received a score of 3.This indicator contributes 5% to the score of the land use and value category. The score of this indicator and subsequently the score of the category can be improved by minimizing the pavement area and keep land disruption to minimum.

The landscaping density indicator received a score of 3. This indicator contributes 5% to the score of the land use and value category. This score can be improved by considering keeping the landscape area to minimum to insure less land disruption and less water for irrigation.

The development density indicator received a score of 4. This indicator contributes 10% to the total score of the land use and value. This indicator can be improved by keeping the land area outside the footprint to the minimum, but large enough to ensure to minimize the impact of adjacent buildings on the access of daylight.

- **Stormwater, Heat-Island and Landscaping**

The category of stormwater, heat-island, and landscaping received a score of 3.35 and it has 10% contribution to the final score of the building at the macro-level. This score resulted from the combination of 5 indicators with different weighting factors as shown in table 107.

The stormwater run-off indicator received a score of 2. This indicator contributes 30% to the final score of the score of the stormwater, heat-island and landscaping category. This score can be improved by considering more measure to reduce run-off such as porous pavement, and stormwater reservoirs, and harvesting rainwater.

The erosion degree andrun-off level of contamination received a score of 5, which means that erosion control measures are sufficient.

The heat-island effect indicator received a score of 3. This indicator contributes 15% to the final score of the category. The score of this indicator can be improved by considering green-roof for the building and planting local trees.

The native planting indicator received a score of 4, this score can be increased by considering a higher percentage of local plants. This indicator contributes 15 percent to the total score of the category.

The landscaping design indicator received a score of 4, this score can be increased by considering a better landscape design strategy that reserves more water and reduce the use of chemicals. Special attention has to be paid for this indicator because it contributes 30% to the final score of the category.

- **Water and Wastewater**

The category of water and wastewater received a score of 0.9 and it contributes 15% to the final score of the building at the macro-level. This score resulted from the combination of 6 indicators with different weighting factors as shown in Table 107. The score of this category is very low and the designer needs to find opportunities for improvement.

The landscaping water efficiency indicator received a score of 3. Although it is an average score a better score can be received by considering a more efficient landscaping technique. This indicator contributes 10% to the final score of the water and wastewater category.

The non-potable water use for irrigation indicator received a score of 0. Many options are available to improve this score including harvesting rainwater and collecting graywater for irrigation. This indicator contributes 15% to the final score of the water and water category.

The non-potable water use for toilet indicator received a score of 0 too. This score can be increased by considering the installation of dual wastewater system. Currently, reclaimed water is not an option at the building site. This indicator contributes 15% to the final score of the water and wastewater category.

The rainwater harvesting indicator received a score of 0. This score can be improved by considering a reservoir for rainwater. This indicator contributes 10% to the final score of the water and wastewater category.

The installation of high efficient fixture received a score of 3. By making improvement here, improvement will be noticed at the micro-level too. This indicator contributes 20% to the final score of the water and wastewater category.

The availability of dual wastewater system received a score of 0. This score can be improved simply by installing a dual wastewater system and other indicators will benefit from this category too.

- **Energy**

The score of the energy category is 2.22 and it contributes 20% to the final score of the building at the macro-level. This score resulted from the combination of 9 indicators with different weighting factors as shown in Table 107. The score of this category is below average and opportunities for improvement at the indicator level needs to be explored.

The use of renewable energy indicator received a score of 0. This indicator can be improved by considering generating renewable energy on-site since renewable energy is not available in the area. This indicator contributes 20% to the final score of the energy category.

The computer modeling for energy optimization indicator received a score of 1. This is a very low score it can be improved be incorporating the computer modeling in the design. This indicator contributes 15% to the final score of the energy score.

The indicator of exploring passive lighting, heating, and ventilation received a score of 2. This is an important indicator and improvements here can make improvements elsewhere at the micro- and macro-level. It may involve changing the number of windows and the orientation of the building. This indicator contributes 20% to the final score of the energy category.

The indicator of utilization of energy controls received a score of 3. The designer may consider more improvement in this indicator. It contributes 5% to the final score of the energy category.

The envelop insulation indicator received a score of 3. This is an important indicator that has major contribution in saving energy and cost and it needs to be improved; however, the initial cost is most probably higher. This indicator contributes 8% to the score of the energy category.

The building orientation indicator received a score of 4. The designer may have limited options here, if the building is to be parallel to the street. This is an important indicator and it has major impact on lighting, heating, and cooling needs. It contributes 8% to the final score of energy category.

The lighting fixtures efficiency indicator received a score of 5 because high efficient CFL bulbs were considered in the design. This indicator contributes 8% to the final score of the energy category.

The heating and cooling system efficiency indicator received a score of 3. This score can be improved by considering a more efficient heating and cooling system. This indicator contributes 8% to the final score of the energy category.

The appliances efficiency indicator received a score of 5. Although it is a high score but improvement can be achieved by considering even more efficient appliances. Improvements in this indicator have an effect in the energy category at the micro-level too. This indicator contributes 8% to the final score of the energy category.

- **Resources**

The score of the resources category is 2.5 and it contributes 10% to the final score of the building at the macro-level. This score resulted from the combination of 9 indicators with different weighting factors as shown in Table 107. The score of this category is below average and opportunities for improvement at the indicator level needs to be explored.

The indicator of collection of recyclable waste at the construction stage received a score of 3. Measures can be taken to ensure collection of a higher percentage of the recyclable waste at the construction stage. This indicator contributes 10% to the score of the resources category.

The indicator of collection of recyclable waste at the operation stage received a score of 1. This indicator requires the existence of recycling program in the area in addition to considering recycling in the design. This indicator contributes 10% to the score of the resources category.

The indicator of collection of recyclable waste at the demolition stage received a score of 4. This score can be improved by considering recyclable building materials and products. This indicator contributes 10% to the score of the resources category.

The right-size building indicator received a score of 2. This score can be improved by considering a change in the floor plan or surface area to size ratio. This indicator contributes 15% to the score of the resources category.

The design for disassembly (DfD) indicator received a score of 4. This score can be improved by giving DfD more considerations. This indicator contributes 10% to the score of the resources category.

The durability of building materials and products indicator received a score of 3. This score can be improved by considering more durable materials and products; however, cost may go up. This indicator contributes 10% to the final score of the resources category.

The indicator of selection of products based on LCA received a score of only 1 because LCA was not considered in selecting the majority of the materials and products. This score can be improved by incorporating LCA in the decision making process. This category contributes 20% to the final score of the resources category.

The indicator of locally produced materials received a score of 2. A better score can be obtained by giving a preference to materials that are manufactured locally. This category contributes 10% to the final score of the resources category.

The indicator of use of ozone depletion compounds received a score of 6. This high score has been received because refrigerants that are considered environmentally friendly have been considered. This indicator contributes 5% to the final score of the resources indicator.

- **IEQ**

The score of the IEQ category is 4.15 and it contributes 15% to the final score of the building at the macro-level. This score resulted from the combination of 8 indicators with different weighting factors as shown in Table 107. Although the score is above average, opportunities for improvement at the indicator level can be explored.

The ventilation effectiveness and CO2 concentration indicator received a score of 4. This score can be improved by considering increase in the ventilation rate or incorporating passive ventilation to ensure that CO_2 levels is in the acceptable range most of the time. This indicator contributes 25% to the final score of the IEQ category.

The temperature and relative humidity indicator received a score of 4. This score can be improved by providing controls and by incorporating passive heating and cooling. This indicator contributes 15% t o the final score of the IEQ category.

The air filtering and venting of combustion gases and odors indicator received a score of 5. Adequate fans and filters have been considered in the design. This indicator contributes 10% to the final score of the IEQ category.

The ETS indicator received a score of 3. This score can be improved by preventing smoking inside the building. This indicator contributes 10% to the final score of the EIQ category.

The noise and vibration indicator received a score of 5. Noise and vibration reduction were adequately considered in the design. This indicator contributes 10% to the final score of EIQ category.

The exposure to Radon indicator received a score of 5. No more measures are required to ensure that occupants will not be exposed to Radon. This indicator contributes 5% to the final score of the EIQ category.

The lighting quality indicator received a score of 4. A better score can be obtained by considering natural lighting and adding lighting controls. This indicator contributes 10% to the final score of EIQ category.

The access to daylight and outside view received a score of 4. This score can be improved by adding more windows. This indicator contributes 15% to the final score of the IEQ category.

5.3.3 LEED Points

One of the applications of GREENOMETER-7 is for LEED credits justification. By making correlation between LEED credits and GREENOMETER-7 indicators, it ensures incorporating LCA into LEED. Another advantage is that the building LEED certification level can be forecasted at the conceptual design stage. If a better LEED certification level is desired it is easier to make necessary changes at the conceptual design stage. A correlation is made between GREENOMETER-7 and LEED by matching LEED credits with MREENOMETR-7 indicators from both the micro- and macro-assessment levels.

As shown in table 115, the projected LEED certification level is “Not-Certified” with a total of 23 LEED points. To achieve the desired “Silver” LEED certification the total points must be at least 33. The designer needs to review the results of each LEED category and decide on where need to be done for the building to become qualified for the silver certification. It is recommended that the designer review each category and pick achievable credits first for improvement. The points by category are the following: sustainable site 7 points out of 19, water efficiency 0 out of 12, energy and atmosphere 7 out of 21, materials and resources 1 out of 12, and indoor environmental quality 8 out of 11. From reviewing these scores, it is clear that there are opportunities for improvement in more that one category. It may become a requirement to meet a minimum number of points for each category as a condition for certification even if the total points meet the certification level requirements. For example, it may not be acceptable to give a silver certification level to a building that has no points gained for the water efficiency category.

- **Sustainable Site (SS)**

As shown in table 110, a total of 16 GREENOMETER-7 indicators have been used to justify the points of the 9 credits of the sustainable site category of LEED. The building gained only 9 points from the possible 19 points. Some of the credits can't be met without changing the location of the building which is not an option in this case study. The building lost the single point of the preferred location credit because the building is not located in a previously contaminated land. The building received the point of the infrastructure credit because of the availability of infrastructure at a close distance.

On the other hand, the building did not receive any of the 4 possible points of the alternative transportation credit. With the current status of the transportation system in the area, gaining additional points may not possible.

The building received one of the three possible LEED points of the site development credit. More points can be gained by changing exploring options to raise the score of the credit's indicators.

The building received one of the two possible LEED points of the stormwater design credit. The second point can be gained by exploring options to reduce stormwater run-off.

The building did not receive the single LEED point of the heat-island effect. This score can be gained by exploring options to raise the score of the indicator.

The building received the to possible LEED points of the landscaping credit, both indicators received a score of 4.

- **Water Efficiency**

As shown in table 111, a total of 8 GREENOMETER-7 indicators have been used to justify the points of the 4 credits of the water efficiency category of LEED. The building did not gain any of the possible 12 LEED points of this category.

The building did not gain any of the two possible points of the irrigation system credit. The landscaping water efficiency indicator received a score of 3 while the threshold to gain a LEED point is 4. On the other hand, the non-potable water indicator received a score of 0 while the threshold to gain a LEED point is 4. At least one point can be gained by considering an increase in landscaping water efficiency. This category has high potential for improvement.

Similarly, the building did not receive any of the possible 5 LEEDS points of the water reuse credit. The designer has several options to receive some of these points. The score for each of the four indicators is 0 while the threshold to gain LEED points is 4. One point can be gained by installing a dual wastewater system.

The building did not receive any of 4 LEED points of the water use credit. The total water use indicator received a score of 2 while the threshold to receive one LEED point is 4. The installation of high efficiency fixtures indicator received a score of 3 while the threshold to receive one LEED point is 4. Both indicators require a score of 6 to receive 2 LEED points. The designer may consider installing higher efficiency fixtures to receive at least one LEED point.

The building did not receive the LEED point of the innovative wastewater technologies. To gain this point at least 50% of the wastewater must be treated on-site to tertiary standards.

- **Energy and Atmosphere**

As shown in table 112, a total of 14 GREENOMETER-7 indicators have been used to justify the points of the 7 credits of the energy and atmosphere category of LEED. The building gained 7 of the possible 21 LEED points of this category.

The building received 2 of the 11 possible LEED points of the optimization energy performance credit. The total energy consumption indicator received a score of 3 that qualified the building for 2 LEED points. Up to 8 LEED points can be received based on the score of this indicator. Another LEED point can be received if the score of the computer modeling indicator is 4 or more. Exploring passive lighting, heating and ventilation indicator received a score of 2 while the threshold to gain a LEED point is 4. The building did not receive the LEED point based on the of energy controls utilization indicator because its score is 3 while the threshold to gain the point is 4. The designer may focus on the indicators with scores closer to the threshold first for improvement.

The building did not receive the LEED point of the insulation credit. The indicator score is 3 while the threshold to gain the point is 4. This point can be received by considering improving the insulation performance of the building.

The building did not receive any of the 2 points of the space heating and cooling credit. This credit has two matching indicators and the threshold to gain a LEED point is a score of 4 for each. The score of the efficiency of the heating and cooling system indicator is 3.

The building received 2 of the 2 possible LEED points of the lighting credit. This credit has two matching indicators with a threshold score of 4 for each to receive the LEED credit. The lighting fixture efficiency received a score of 5.

The building received 2 of the 2 possible points of the appliances credit. This credit has a two matching indicators with a threshold of 4 to receive one LEED credit for each. Each of the indicators received a score of 5.

The building did not receive the LEED point of the renewable energy credit. The score of the use of renewable energy indicator is 0 while the threshold to receive the credit is 4.

The building received 1 of the 2 possible LEED points of the refrigerants management credit. This credit has two matching indicators with a threshold of 4 for each to receive the LEED point.

- **Materials and Resources**

As shown in Table 113, a total of seven GREENOMETER-7 indicators have been used to justify the points of the 4 credits of the materials and resources category of LEED. The building gained only one of the possible 12 LEED points of this category.

The building received only one of the 6 possible LEED points of the waste management credit. This credit has 4 matching indicator and the threshold to receive the point is 4 for each. The building receives two or three LEED points if the score of the percentage of resources expected to be recycled is 5 or 6, respectively. The LEED point was received based on the score of 4 for the collection of recyclable waste at the demolition stage.

The building did not receive the LEED points of the recycling content credit. The percentage of recycled content is the only matched indicator with a threshold score of 4 to receive one LEED credit or 6 to receive two LEED credits. No points were received because the indictor score is 0.

The building did not receive the LEED points of the environmentally preferred products credit. The selection based on LCA is the only matching indicator for this credit with a threshold score of 4 to receive one LEED point; however, two LEED points can be received if the score is 6. No points were received because the score of the indicator is 1.

The building did not receive any of the two LEED points of the regional materials credit. Locally produced materials indicator is the only matching indicator for this credit. The building receives 1 LEED point if the indicator score is 4 or 5; however, it receives two LEED points if the score is 6. The score was 2 and no points were received.

- **Indoor Environmental Quality**

As shown in Table 114, a total of nine GREENOMETER-7 indicators have been used to justify the points of the 7 credits of the indoor environmental quality category of LEED. The building gained 8 of the possible 12 LEED points of this category.

The building received one of the two possible LEED points of the outdoor air delivery monitoring credit. Ventilation effectiveness and CO2 monitoring is the only matching indicator for this credit. The score of this indicator was at the threshold score of 4.

The building received one of the two possible LEED points of the moisture and thermal control credit. Temperature and relative humidity is the only matching indicator for this credit. The score of this indicator was at the threshold score of 4.

The building received one of the two possible LEED points of the low-emitting materials credit. This credit has two matching credits with a score of 4 as the threshold for each to receive the LEED point. The score of the percentage of chemical content is 6, while the score of total contaminants output to air is 1.

The building received both of the two possible points of the credit of indoor chemical and pollution source control. This credit has two matching indicators with a score of 4 as the threshold to receive a LEED point for each. Both indicators received a score of 5.

The building received the single possible point of the lighting comfort credit. Lighting quality is the only matching indicator for this credit and it received a score of 4, which is the threshold to receive the LEED point.

The building received the single possible point of the daylight and view credit. Access to daylight and outside view is the only matching indicator for this indicator and it received a score of 4. This indicator has a threshold of 4 to receive the LEED point.

CHAPTER VI

SUMMARY & FUTURE WORK

6.1 Summary

GREENOMETER-7, the tool that has been developed in this study, can be used to measure the sustainability of the building over its entire life cycle while it is still at the conceptual design phase. The fact that GREENOMETER-7 is a tool for use at the conceptual design phase makes it an invaluable tool for improving the sustainability of the building. The conceptual stage has no impact itself but it is the stage where most of the commitments that have impact on the environment are made. Moreover, modifications or change in the design are possible at the conceptual stage because the building is not yet built.

GREENOMETER-7 provides the designer with an easy way to measure the sustainability performance of his/her design alternative and it allows for improvements. Results are expressed as scores on a 7-degree scale of 0 to 6, where 0 means extremely unsustainable, 3 means neutral and 6 means extremely sustainable. The output after each run is a score for the micro-assessment level, a score for the macro-assessment level as well as scores for all categories at both assessment levels. New scores are generated every time a change, addition or modification to the design is explored. The goal is to shift the score as close as possible to 6, the highest sustainability score. As a sustainability tool, GREENOMETER-7 is not limited to environmental impacts. It measures, among others, health, economic and social impacts.

GREENOMETER-7 was developed based on the methodologies of life cycle assessment (LCA) and multi-objective optimization frameworks. All stages of the building life cycle have impact and they need to be included in the assessment. On the other hand, the assessment must be comprehensive and account for most major impacts. Being comprehensive is a challenge, especially when many factors are involved and some of them are conflicting.

The general tool is a template that can be customized to suit different types of buildings such as residential buildings, office buildings, commercial buildings, schools, and industrial buildings. This may require change in the list of categories, weighting factors of the categories and weighting factors of the indicators. For each building type new benchmarks and ranking guidelines need to be developed.

At the micro-assessment level it is essential to develop a database for the most common assessment classes. It is easier for the designer to import an assessment class from a database rather than developing it. In this case the designer only needs to determine the number of functional units applicable for each assessment class in each life cycle stage.

Weighting factors need to be assigned for the categories and the indicators at both micro-assessment and macro-assessment level. Different weighting factors may be assigned for different regions to account for geographic variations. Once the weighting factors are assigned, to keep consistency the designer may not be allowed to change them. However, an organization or engineering firm may decide to use the same weighting factors in different regions. Assigning weighting factor is a subjective step and different methods can be used to assign them. The most common weighting methods are the analytical hierarchy process (AHP), willingness-to-pay (WtP), distance-to-target (DtT), and experts judgments. Although the weighting step is subjective it adds flexibility to the tool so that it can be suit different situations.

Utilizing GREENOMETER-7 to justify LEED points is a unique application of the tool. It allows the designer to obtain the LEED certification level while still at the conceptual design. It also allows for exploring available options if a better certification level is desired.

6.2 Future Work

This study presented the GREENOMETER-7 tool in its general form. Although the framework is completely developed future work needs to be done for the tool to be functional and for improvement.

For the micro-assessment level, a database that includes most of the commonly used assessment classes needs to be developed. The assessment classes can be classified in the database under different categories for easy access. The assessment classes of the same material or equipment may be listed under the same category. It is recommended to develop standardized functional units for different assessment classes such as board feet or cubic meter for the assessment classes of framing lumber.

The general tool needs to be customized to fit different building types. The customization may require modifications in the categories and their indicators to reflect special needs for that type of buildings. This requires developing ranking guidelines and weighting factors for each building type.

For the ranking step, ranking guidelines need to be developed for the all indicators. A baseline needs to be identified for the indicators that require a baseline. Each building type requires unique guidelines and benchmarks.

Weighting factors need to be assigned to the categories and indicators for each building type. Different weighting factors need to be developed for different regions to account for regional variations. Although different methods are available for weighting, Expert Choice software - which is based on the AHP method - can be used.

It is recommended to develop the tool into a software package that is easier to use than MS Excel and it provides simulation and simultaneous comparison of different design alternatives of the same building or different buildings. A software that has the capability to answer the “what if” question so that the designer can easily explore different design options. It is recommended to support the software with a database where the designer can select the assessment classes for each life cycle stage and then assign the number of functional units to them. The scores are automatically generated and updated with every modification in the design. The software needs to be provided with different weighting factor sets to meets different needs and variations. The designer will be able to select the set applicable to his/ her project only at the beginning of the project. The software also utilizes different ranking guidelines to generate the indicator score for different building types.

To handle the volume of data, it is recommended to separate the backend from the frontend of the software. A database such as MS Access should be uses as the backend. On the other hand, MS Excel can be used as the frontend. To suit the needs of different user it is preferred to develop the tool with multiple frontends. These may include MS Excel as well as object oriented programming such as Java, C#, and Visual Basic.

More research is needed in incorporating GREENOMETR-7 into the different LEED certification types. For each LEED certification type, it needs to be determined what GREENOMETER-7 indicators must be matched with each credit and if additional indicators need to be added. More over, it needs to be determined at what score to give LEED points.

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APPENDEX A: USER'S GUIDE

User's Guide

The purpose of this guide is to describe how to use GREENOMETER-7 tool. GREENOMETER-7 in its current version uses MS Excel 2003. This guide provides step-by-step instructions for each step in GREENOMETER-7. Where necessary, screenshots will be provided to assist in understanding the use of the tool.

GREENOMETER-7 evaluates the sustainability performance of a projected building while still at the conceptual design phase by conducting the assessment at two levels: micro- and macro-assessment. The results from both assessment levels are combined to provide an overall sustainability score. The tool in its Excel version consists from 14 tabs. The first 7 tabs are for micro-assessment followed by 5 tabs for macro-assessment. One tab was included here for LEED points and the last tab is a summary.

Micro-Assessment

The micro-assessment consists of the following three phases: inventory, impact assessment, and interpretation. Each phase has two steps. The steps of the inventory phase are hierarchy-analysis and "N" Determination. The two steps of the impact assessment phase are profiling and synthesis. The steps of the interpretation phase are: ranking and valuation (weighting). The first tab in the Excel tool is introduction followed by 6 tabs one for each step. Each tab is described briefly bellow:

Tab 1: Micro-Assessment

This tab is an introduction to the micro-assessment level of GREENOMETER-7. It includes its phases and steps and the objective of each. You do not need to enter any data in this tab.

Tab 2: Hierarchy-Analysis

The hierarchy analysis is the first step in the inventory phase. In this step you will be asked to convert the building life cycle into assessment classes. The building life cycle is divided into phases, then the major activities of each phase are determined. Finally each activity is expressed in terms of the five assessment classes. The assessment classes are E, L, U, O, and M. Here is the definition of each:

- E: for products, material, and equipment entering (E) the site
- L: for products, materials, and equipment leaving (L) the site
- U: for using (U) the products and equipment for the time period between E and L
- M: for maintenance (M) operations on the materials and equipment
- O: for other (O) operations that can't be assigned to one of the other assessment classes.

For example, the light bulb has three assessment classes: E, U, and L). Assessment class E is applicable it first enters the site, assessment class U is applicable in its service life, and assessment class L is applicable when it leaves the site at its end of service. Figure 27 is an example of the hierarchy-analysis; it shows some of the activities of the construction stage for a building and their assessment classes.

Tab 3: "N" Determination

The second step in the inventory phase is "N" determination. The objective of this step is to estimate the number of functional units "N" for each assessment class identified in the previous step. In this step you add two columns to the list from the hierarchy-analysis step; one for the functional unit and the second for the value of "N". Figure 28 shows an example about "N" Determination

Hierarchy-Analysis
Building Life Cycle
Stage I: Construction
Activity 1: Light Wood Framing
E-Wood Framing 2x4
E-Wood Framing 2x6
E-Wood Framing 2x8
E-Wood Framing 2x10
E-Wood Framing 2x12
E-OSB 1.1 cm
Activity 2: Insulation
E- Fiberglass Insulation (R-19/15.9cm)
E- Fiberglass Insulation (R-38/30.5cm)
Activity 3: Siding Installation
E-Wrap
E-Vinyl Siding
Activity 4: Wall/ Ceiling Finishing
E-Drywall (1/2 in)
E-Latex Paint
Activity 5: Floor Finishing
E-Nylon Carpet
E-Ceramic Tile
E-Mortar Type N
Activity 6: Roof Finishing
E-Asphalt Shingles 30x91
E-Underlayment Type-15

Figure 27: An example of the hierarchy-analysis step

Tab 4: Profiling

The profiling step is the first step in the impact assessment phase of the macro-assessment. The objective of this step is to create a profile for each assessment class identified in the hierarchy analysis step. Some of the assessment classes are very common and their profiles may be available from previous studies or in a previously developed database. The profile for each assessment class consists of 12 categories and their indicators. The profile has a variable with a default value of 1 that represents “N”. The values of all indicators are based on one functional unit, i.e. the value of N equals 1. Each category consists of indicators and attributes. You only enter the values of the attributes and the values of the indicators are calculated automatically. Figure 29 shows partial profiles for some assessment classes. The cells of each attribute and indicator are multiplied by N so that their values changed when N is changed. This is the most time consuming step in GREENOMETER-7. The availability of a database of the common assessment classes saves considerable time; otherwise, you need to determine the value for each attribute in the profile.

"N" Determination	Functional Unit	N Value
Building Life Cycle		
Stage I: Construction		
Activity 1: Light Wood Framing		
E-Wood Framing 2x4	1-meter	1047.9
E-Wood Framing 2x6	1-meter	2251.25
E-Wood Framing 2x8	1-meter	53.64
E-Wood Framing 2x10	1-meter	478.54
E-Wood Framing 2x12	1-meter	63.4
E-OSB 1.1 cm	1-meter sq.	725.39
Activity 2: Insulation		
E- Fiberglass Insulation (R-19/15.9cm)	1-meter sq.	380.44
E- Fiberglass Insulation (R-38/30.5cm)	1-meter sq.	212
Activity 3: Siding Installation		
E-Wrap	1-meter sq.	250.84
E-Vinyl Siding	1-meter sq.	232.25
Activity 4: Wall/ Ceiling Finishing		
E-Drywall (1/2 in)	1-meter sq.	798.22
E-Latex Paint	1-kg	175.71
Activity 5: Floor Finishing		
E-Nylon Carpet	1-meter sq.	111.48
E-Ceramic Tile	1-meter sq.	55.22
E-Mortar Type N	1-kg	430.91
Activity 6: Roof Finishing		
E-Asphalt Shingles 30x91	1-meter sq.	334.45
E-Underlayment Type-15	1-meter sq.	334.45

Figure 28: An example of the "N" determination step

Profiling		Assessment Class	Generic	E-Concrete 21MPa	L-Concrete 21MPa	E-OSB 1.1 cm
		F. Unit	?	1-m3	1-m3	1-m2
		N	1	1	1	1
Category	1.1 Electricity					
Indicators	Total Electricity consumption	kwh	0	0	0	0
Indicators	Electricity for lighting	kwh	0	0	0	0
Indicators	Electricity for heating/ cooling	kwh	0	0	0	0
Indicators	Electricity for water heating	kwh	0	0	0	0
Indicators	Electricity for other equipments	kwh	0	0	0	0
Attributes	E. for lighting	kwh	0	0	0	0
Attributes	E. for heating/ cooling	kwh	0	0	0	0
Attributes	E. for water heating	kwh	0	0	0	0
Attributes	E. for other equipments	kwh	0	0	0	0
Category	1.2 Fossil Fuel					
Indicators	Total MMBtu	MMBtu	0	0	0	0
Indicators	MMBtu for space heating	MMBtu	0	0	0	0
Indicators	MMBtu for water heating	MMBtu	0	0	0	0
Indicators	MMBtu for transportation	MMBtu	0	0	0	0
Indicators	MMBtu for Other equipments	MMBtu	0	0	0	0
Attributes	MMBtu for space heating	MMBtu	0	0	0	0
Attributes	MMBtu for water heating	MMBtu	0	0	0	0
Attributes	MMBtu for Transportation	MMBtu	0	0	0	0
Attributes	MMBtu for Other equipments	MMBtu	0	0	0	0
Category	2.1 Water and Wastewater					
Indicator	Total water use	L	0	241	0	0
Indicator	% Recycled/ reclaimed water	%	#DIV/0!	0	#DIV/0!	#DIV/0!
Indicator	Total wastewater generated	L	0	0	0	0
Attributes	Potable water use	L	0	241	0	0
Attributes	Recycled/ reclaimed water use	L	0	0	0	0
Attributes	Wastewater generated	L	0	0	0	0
Attributes	Water Evaporation	L	0	759	0	0
Category	3.1 Resources Input					
Indicators	Total Resources Input	Kg	0	2181	0	7.148
Indicators	% of recycled content	%	#DIV/0!	0	#DIV/0!	0
Indicators	% of biobased content	%	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Indicators	% of chemicals content	%	#DIV/0!	0	#DIV/0!	5.42809

Figure 29: A screenshot of partial profiles for some assessment classes

Tab 5: Synthesis

The second step in the impact assessment phase of micro-assessment is synthesis. The objective of the synthesis step is to develop profiles for higher levels in the hierarchy. The profile of each activity is generated by combining the profiles of their assessment classes after multiplying them by their N values. The profile for each life cycle stage can be generated by combining the profiles of their activities. And finally the profile for the entire life cycle of the building is generated by combining the profiles of all stages of the life cycle. In this step you copy the applicable profiles from the profiling screen or database then you paste them in the appropriate them in the order they appear in the hierarchy. The default N values of 1 is changed to the values received from the "N" determination step. When the N values are changed the entire profile is updated accordingly because each value in the profile is multiplied by the variable N. By using summation equations you can develop profiles for the higher levels in the hierarchy. The profiles of the different life cycle stages can be used for comparison. The highest profile, the profile of the entire life cycle, is the only profile used in the next interpretation phase of the micro-assessment. Figure 30 shows partial profiles of the construction, operation and demolition stage of a building as well as the partial profile of the entire life cycle of the building.

Synthesis			Assessment Class/ Stage	Building Life-Cycle	Stage I: Construction	Stage II: Operation	Stage III: Demolition
Category		1.1 Electricity					
	Indicators	Total Electricity consumption	kwh	825904	0	825904	0
		Electricity for lighting	kwh	20340	0	20340	0
		Electricity for heating/ cooling	kwh	315000	0	315000	0
		Electricity for water heating	kwh	285750	0	285750	0
		Electricity for other equipments	kwh	204814	0	204814	0
	Attributes	E. for lighting	kwh	20340	0	20340	0
		E. for heating/ cooling	kwh	315000	0	315000	0
		E. for water heating	kwh	285750	0	285750	0
		E. for other equipments	kwh	204814	0	204814	0
Category		1.2 Fossil Fuel					
	Indicators	Total MMBtu	MMBtu	85000	0	85000	0
		MMBtu for space heating	MMBtu	0	0	0	0
		MMBtu for water heating	MMBtu	0	0	0	0
		MMBtu for transportation	MMBtu	85000	0	85000	0
		MMBtu for other equipments	MMBtu	0	0	0	0
	Attributes	MMBtu for space heating	MMBtu	0	0	0	0
		MMBtu for water heating	MMBtu	0	0	0	0
		MMBtu for Transportation	MMBtu	85000	0	85000	0
		MMBtu for other equipments	MMBtu	0	0	0	0
Category		2.1 Water and Wastewater					
	Indicator	Total water use	L	4.6E+07	431015	4.5E+07	0
		% Recycled/ reclaimed water	%	0	0	0	#DIV/0!
		Total wastewater generated	L	4.5E+07	0	4.5E+07	0
	Attributes	Potable water use	L	4.6E+07	431015	4.5E+07	0
		Recycled/ reclaimed water use	L	0	0	0	0
		Wastewater generated	L	4.5E+07	0	4.5E+07	0
		Water Evaporation	L	332179	331906	272.556	0
Category		3.1 Resources Input					
	Indicators	Total Resources Input	Kg	692214	679273	12941.3	0
		% of recycled content	%	0.22007	0.22427	0	#DIV/0!
		% of biobased content	%	2.5463	2.59481	0	#DIV/0!
		% of chemicals content	%	0.30909	0.09905	11.3338	#DIV/0!

Figure 30: A screenshot of the synthesis step of micro-assessment

Tab 6: Ranking

Ranking is the first step in the interpretation phase of micro-assessment. For this step only the profile of the entire life cycle is needed. The values received by the indicator are scored using the 0 to 6 scoring system. You use the guidelines provided in Chapter III to determine what score to give for each indicator. Usually the value received from the synthesis step is converted to another value for ranking as specified in the ranking guidelines. For example, the ranking value of the electricity for lighting indicator is percentage ratio of the value received from the synthesis step divided by a standard. Figure 31 shows how the indicators values are converted into 0 to 6 scores.

		Ranking (Micro-Assessment)	Unit	Building life-cycle Value	Value for Scoring	Indicator Score (0-6)
Category		1.1 Electricity				
	Indicators	Total Electricity consumption	kwh	825904.1	95%	3
		Electricity for lighting	kwh	20340	85%	4
		Electricity for heating/ cooling	kwh	315000	110%	2
		Electricity for water heating	kwh	285750	82%	2
		Electricity for other equipments	kwh	204814.1	85%	4
Category		1.2 Fossil Fuel				
	Indicators	Total MMBtu	MMBtu	85000	90%	3
		MMBtu for space heating	MMBtu	0	0%	6
		MMBtu for water heating	MMBtu	0	0%	6
		MMBtu for transportation	MMBtu	85000	130%	0
		MMBtu for Other equipments	MMBtu	0	0%	6
Category		2.1 Water and Wastewater				
	Indicator	Total water use	L	45619894	110%	2
		% Recycled/ reclaimed water	%	0	0%	0
		Total wastewater generated	L	45188606	100%	3
Category		3.1 Resources Input				
	Indicators	Total Resources Input	Kg	692214.34	125%	1
		% of recycled content	%	0.2200742	20%	0
		% of biobased content	%	2.5463009	2.50%	2
		% of chemicals content	%	0.3090888	0.30%	6
Category		3.2 Resources Output				
	Indicators	Total resources output	Kg	798613.82	NA	
		% expected to be recycled	%	2.7614453	2.80%	0
		% expected be wasted	%	97.238555	97%	0
		MMBtu of wasted	MMBtu	0	115%	4
Category		4.1 Contaminants Output-Total				
		Total Contaminants output	Kg	11612.007	95%	4

Figure 31: A screenshot of the ranking step of micro-assessment

Tab 7: Valuation (Weighting)

Valuation is the last step in micro-assessment. The objective of this step is to provide a score in the range of 0 to 6 for each category as well as for the entire life cycle (micro-score). To generate a score for the category, weighting factors must be assigned to its indicators. The weighting factors of the indicators of the same category must to 100. For example, the electricity category has 5 indicators, the total of their weighting factors must be 100. The weighting factors of the indicators reflect their relative importance compared to each other. The score of each category is generated by multiplying the scores of its indicators by their weighting factor, and then add them together. Similarly weighting factors must be assigned to the categories to generate the micro-score of the entire life cycle of the building. The weighting factors of all categories must sum to 100. The micro-score is generated by multiplying the categories by their weighting factors then adding them together. The weighting factors of the categories reflect their relative importance compared to each other. Weighting factors may vary from region to region. The users can use a default weighting factors or can develop their own weighting factors. Figure 32 shows the weighting factors for some categories and the weighting factors for their indicators. Also it shows the scores of these categories and the micro-score of the building. The Analytic Hierarchy process (AHP) is one of the common methods to develop weighting factors.

Building Micro-Score (0-6)

2.66

Weighting (Mico-Assessment)		Indicator Score (0-6)	Indicator Weighting Factor (%)*	Category Score (0-6)**	Category Weighting Factor (%)
Category	1.1 Electricity				
Indicators	Total Electricity consumption	3	40		
	Electricity for lighting	4	20		
	Electricity for heating/ cooling	2	20		
	Electricity for water heating	2	10		
	Electricity for other equipments	4	10	3	20
Category	1.2 Fossil Fuel				
Indicators	Total MMBtu	3	40		
	MMBtu for space heating	6	20		
	MMBtu for water heating	6	10		
	MMBtu for transportation	0	20		
	MMBtu for Other equipments	6	10	3.6	10
Category	2.1 Water and Wastewater				
Indicator	Total water use	2	40		
	% Recycled/ reclaimed water	0	30		
	Total wastewater generated	3	30	1.7	10
Category	3.1 Resources Input				
Indicators	Total Resources Input	1	30		
	% of recycled content	0	20		
	% of biobased content	2	20		
	% of chemicals content	6	30	2.5	5
Category	3.2 Resources Output				
Indicators	Total resources output	0	0		
	% expected to be recycled	0	80		
	% expected be wasted	0	20		
	MMBtu of wasted	4	0	0	5
Category	4.1 Contaminants Output-Total				
	Total Contaminants output	4	100	4	10
Category	4.2 Contaminants Output-Captured				
	% of Contaminants- captured	0	100	0	5
Category	4.3 Contaminants Output-Disposal				
Indicators	Total Contaminants output- disposal	3	100	3	3
Category	4.4 Contaminants Output-Air				
Indicators	Total Contaminants output- air	1	30		
	Global warming potential	3	30		
	Acidification potential	3	4		
	Ozone depletion potential	3	6		
	Photochemical smog potential	3	3		
	Eutrophication potential	3	3		
	Ecotoxicity potential	3	4		
	Human health-cancer	3	10		
	Human health-non-cancer	3	5		
	Human health-criteria	3	5	2.4	15
Category	4.5 Contaminants Output-Water				
Indicators	Total contaminants output- water	3	20		
	BOD	3	10		
	Ecotoxicity	3	15		
	Eutrophication Potential	3	20		
	Human health- cancer	3	20		
	Human health- non-cancer	3	15	3	5
Category	4.6 Contaminants Output- Soil				
Indicators	Total Contaminants output- soil	5	100	5	2
Category	5.1 Economics				
Indicator	Total costs	3	60		
	Total Return	3	20		
	% of return	3	20	3	10

Figure 32: A screenshot of the weighting step of micro-assessment

Macro-Assessment

The macro-assessment consists of two phases: inventory and interpretation. Each phase consists of two steps. The steps of the inventory phase are macro-survey and macro-profile. The steps of the interpretation are similar to the interpretation phase at the micro-assessment, they are ranking and valuation (weighting). The macro-assessment has 5 tabs and they start with tab 8. The first tab is introduction and the other 4 tabs are one tab for each step.

Tab 8: Macro-Assessment

Tab 8 is an introduction to the macro-assessment level of GREENOMETER-7. It describes the phases and steps of the macro-assessment and the objective of each. The user is not required to enter data in this tab.

Tab 9: Macro-Survey

The macro-survey step is the first step in the inventory phase of macro-assessment. The objective of this step is gather information in different area to help in developing the macro-profile in the next step. Macro-assessment has 7 categories and each category has several indicators. You are required to gather information for each of these indicators. Figure 33 shows a partial list of the indicators where information needs to be collected. You need to collect as much as you can of relevant information. It is helpful to review the ranking guidelines before doing this step so that you have an idea about type of information is needed.

		Macro-Survey	Information
Category		1. Location	
	Indicators	Vulnerability of site to flooding	
		Proximity to public transportation	
		Public Transportation Quality and Availability	
		Proximity to existing infrastructure	
		Distance between site and centers of employment	
		Proximity to services	
		Proximity to contaminants/ odor sources	
		Proximity to noise sources	
		Impact of adjacent building	
		Availability of renewable energy	
		Availability of potable water	
		Impact of the building on the surroundings	
Category		2. Land Use & Land Value	
	Indicators	Ecological sensitivity of the land	
		Agricultural value of the land	
		Contamination and development status of the land	
		Relevance of the footprint of the building	
		Pavement density	
		Landscaping/ disruption density	
		Development density	
Category		3. Stormwater, Heat-island & Landscaping	
	Indicators	Stormwater run-off	
		Erosion degree and run-off level of contamination	
		Heat island effect	
		Native planting	
		Landscaping design strategy	

Figure 33: A screenshot of the macro-survey step of macro-assessment

Tab 10: Macro-Profile

Macro-profile is the second step in the inventory phase of macro-assessment. The objective of this step is to develop a quantitative or a qualitative statement for each indicator in all categories. These statements are the bases of scoring the indicators in the next step. It is helpful to review the ranking guidelines before conducting this step to help you determine the type of statement you are required to develop. Figure 34 shows an example of some qualitative and quantitative statements in the macro-profile for a building.

Macro-Profile			Quntitative/ Qualitative Statement
Category		1. Location	
	Indicators	Vulnerability of site to flooding	Height above the 100-year flood plain is 5 meter
		Proximity to public transportation	The distance from a public transportation stop is 550 meter
		Public Transportation Qulaity and Availability	Poor
		Proximity to existing infrastructure	20 meter
		Distance between site and centers of employment	12 km
		Proximity to services	5 km
		Proximity to contaminants/ odor sources	More than 2 km
		Proximity to noise sources	0.9 km
		Impact of adjacent building	Somewhat affected
		Availability of renewable energy	Not available
		Availability of potable water	Strongly satisfied
		Impact of the building on the surroundings	Somewhat affected
Category		2. Land Use & Land Value	
	Indicators	Ecological sensitivity of the land	Not sensitive
		Agricultural value of the land	Some agricultural value
		Contamination and development status of the land	Subsurface is not contaminated. The site was previously developed
		Relevance of the footprint of the building	117% of the standard
		Pavement density	90% of the standard
		Landscaping/ disruption density	95% of the standard
		Development density	85% of the standard
Category		3. Stormwater, Heat-island & Landscaping	
	Indicators	Stormwater run-off	Around 50%
		Erosion degree and run-off level of contamination	Almust no erosion and no run-off turbidity
		Heat island effect	Expected 2 C increase
		Native planting	80% of total
		Landscaping design strategy	Good landscaping design

Figure 34: A screenshot of the macro-profile step of the macro-assessment

Tab 11: Ranking

Ranking is the first step in the interpretation phase of the macro-assessment. Similar to ranking at the micro-assessment, the objective of this step is to convert the statements from the previous step into scores in the range of 0 to 6. The ranking guidelines provided in Chapter III must be used to make the conversion. Figure 35 shows an example of how the statements associated with the indicators are converted into scores in the ranking step of the macro-assessment.

Ranking *(Macro-Assessment)*		Quntitative/ Qualitative Statement	Indicatror Score (0-6)
Category	1. Location		
Indicators	Vulnerability of site to flooding	Height above the 100-year flood plain is 5 meter	5
	Proximity to public transportation	The distance from a public transportation stop is 550 meter	2
	Public Transportation Availability and Quality	Poor	1
	Proximity to existing infrastructure	20 meter	6
	Distance between site and centers of employment	12 km	0
	Proximity to services	5 km	2
	Proximity to contaminants/ odor sources	More than 2 km	6
	Proximity to noise sources	0.9 km	5
	Impact of adjacent building	Somewhat affected	4
	Availability of renewable energy	Not available	0
	Availability of potable water	Strongly satisfied	5
	Impact of the building on the surroundings	Somewhat affected	2
Category	2. Land Use & Land Value		
Indicators	Ecological sensitivity of the land	Not sensitive	5
	Agricultural value of the land	Some agricultural value	3
	Contamination and development status of the land	Subsurface is not contaminated. The site was previously developed	3
	Relevance of the footprint of the building	117% of the standard	2
	Pavement density	90% of the standard	3
	Landscaping/ disruption density	95% of the standard	3
	Development density	85% of the standard	4
Category	3. Stormwater, Heat-island & Landscaping		
Indicators	Stormwater run-off	Around 50%	2
	Erosion degree and run-off level of contamination	Almust no erosion and no run-off turbidity	5
	Heat island effect	Expected 2 C increase	3
	Native planting	80% of total	4
	Landscaping design strategy	Good landscaping design	4
Category	4. Water and Wastewater		
Indicators	Landscaping water efficiency	90% of the standard	3
	Non-potable water use for irrigation	0% non-potable water for irrigation	0
	Non-potable water use for toilet	0% non-potable water for toilet	0
	Harvesting rainwater for reuse	0% rainwater harvesting	0
	Installation of high efficiency fixtures	95% of the standard	3
	Availability of dual wastewater system	9% graywater collected	0
Category	5. Energy		
Indicators	Use of renewable energy	0% renewable energy use	0
	Computer modeling for energy optimization	low utilization	1
	Exploring passive lighting, heating and ventilation	Fair consideration	2
	Energy controls utilization	Average level of utilization	3
	Envelope insulation and air leakage	100% of the standard	3
	Building orientation	Good orientation	4
	Lighting fixtures efficiency	78% of the standard	5
	Heating and cooling system efficiency	95% of the standard	3
	Appliances efficiency	80% of the standard	5

Figure 35: A screenshot of the macro-survey of the macro-assessment

Tab 12: Valuation (Weighting)

Valuation is the last step in macro-assessment. Similar to valuation at the micro-assessment, the objective of this step is to provide a score in the range of 0 to 6 for each category as well as for the entire life cycle (macro-score). To generate a score for the category, weighting factors must be assigned to its indicators. The weighting factors of the indicators of the same category must to 100. For example, the location category has 12 indicators, the total of their weighting factors must be 100. The weighting factors of the indicators reflect their relative importance compared to each other. The score of each category is generated by multiplying the scores of its indicators by their weighting factor, and then add them together. Similarly weighting factors must be assigned to the categories to generate the micro-score of the entire life cycle of the building. The weighting factors of all categories must sum to 100. The macro-score is generated by multiplying the categories by their weighting factors then adding them together. The weighting factors of the categories reflect their relative importance compared to each other. Weighting factors may vary from region to region. The users can use a default weighting factors or can develop their own weighting factors. Figure 36 shows the weighting factors for some categories and the weighting factors for their indicators. Also it shows the scores of these categories and the micro-score of the building. The Analytic Hierarchy process (AHP) is one of the common methods to develop weighting factors.

Weighting
(Macro-Assessment)

Building Macro-Score (0-6)

3.14

	Weighting (Macro-Assessment)	Indicatror Score (0-6)	Indicator Weighting Factor (%)*	Category Score (0-6)	Category Weighting Factor (%)**
Category	1. Location				
Indicators	Vulnerability of site to flooding	5	15		
	Proximity to public transportation	2	5		
	Public Transportation Availability and Quality	1	5		
	Proximity to existing infrastructure	6	15		
	Distance between site and centers of employment	0	10		
	Proximity to services	2	5		
	Proximity to contaminants/ odor sources	6	5		
	Proximity to noise sources	5	5		
	Impact of adjacent building	4	10		
	Availability of renewable energy	0	10		
	Availability of potable water	5	10		
	Impact of the building on the surroundings	2	5	3.45	20
Category	2. Land Use & Land Value				
Indicators	Ecological sensitivity of the land	5	20		
	Agricultural value of the land	3	20		
	Contamination and development status of the land	3	15		
	Relevance of the footprint of the building	2	25		
	Pavement density	3	5		
	Landscaping/ disruption density	3	5		
	Development density	4	10	3.25	20
Category	3. Stormwater, Heat-island & Landscaping				
Indicators	Stormwater run-off	2	30		
	Erosion degree and run-off level of contamination	5	10		
	Heat island effect	3	15		
	Native planting	4	15		
	Landscaping design strategy	4	30	3.35	10
Category	4. Water and Wastewater				
Indicators	Landscaping water efficiency	3	10		
	Non-potable water use for irrigation	0	15		
	Non-potable water use for toilet	0	15		
	Harvesting rainwater for reuse	0	10		
	Installation of high efficiency fixtures	3	20		
	Availability of dual wastewater system	0	30	0.9	15
Category	5. Energy				
Indicators	Use of renewable energy	0	20		
	Computer modeling for energy optimization	1	15		
	Exploring passive lighting, heating and ventilation	2	20		
	Energy controls utilization	3	5		
	Envelope insulation and air leakage	3	8		
	Building orientation	4	8		
	Lighting fixtures efficiency	5	8		
	Heating and cooling system efficiency	3	8		
	Appliances efficiency	5	8	2.3	20
Category	6. Resources				
Indicators	Collection of recyclable waste at the construction stage	3	10		
	Collection of recyclable waste at the operation stage	1	10		
	Collection of recyclable waste at the demolition stage	4	10		
	Right-size building	2	15		
	Design for disassembly (DfD)	4	10		
	Durability of building materials and products	3	10		
	Selection of products based on LCA	1	20		
	Locally produced materials	2	10		
	Use Ozone depletion refrigerants	6	5	2.5	10
Category	7. IEQ				
Indicators	Ventilation effectiveness and CO2 concentration	4	25		
	Temperature and relative humidity	4	15		
	Air filtering and venting of combustion gases and odors	5	10		
	Environmental Tobacco Smoke (ETS)	3	10		
	Noise and vibration	5	10		
	Exposure to Radon	5	5		

Figure 36: A screenshot of the weighting step at macro-assessment

Tab 13: LEED Points

This tab is not part of GREENOMETER-7 but one of its applications. GREENOMETER-7 can be used to forecast while still at the conceptual design phase LEED points the building can get. An advantage of using GREENOMETR-7 to justify LEED points is that LCA can be incorporated into LEED because GREENOMETER-7 a LCA tool. LEED consists of categories and each category has its credits. GREENOMETER-7 is incorporated into LEED by matching LEED credits with GREENOMETER-7 indicators at both micro- and macro-level. A LEED credit can be matched with one or more indicators. Based on this method LEED points are received when a threshold score is reached. For example, one LEED point is received if the score of indicator X equals or more than 4. The threshold for indicators and the number of possible LEED points are provided in Chapter III. The LEED points received from each category are added to determine the LEED certification level. Figure 37 shows the indicators that were matched with each LEED credit. It also shows the score of each indicator and if LEED points were awarded or not based on the threshold. The total number of LEED points and the associated LEED certification level are shown in the top right side of the screenshot.

GREENOMETER-7 into LEED

Total LEED Points

23

NOT-CERTIFIED*

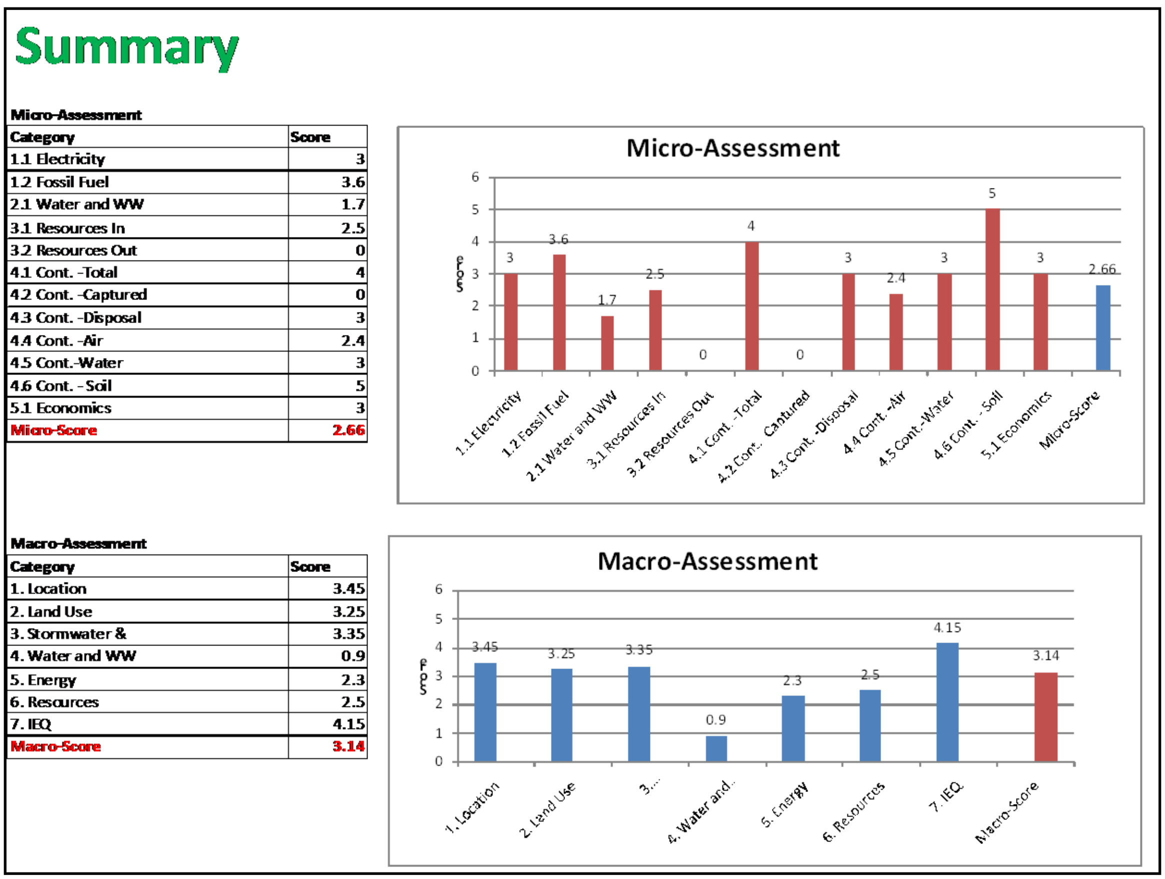
* Certification Level:
0-25: NOT-CERTIFIED
26-32: CERTIFIED
33-38: SILVER
39-51: GOLD
>52: PLATINUM

LEED Category	LEED Credit	GREENOMETER-7 Matching Indicators	Indicator Score	LEED Points
Sustainable Site Category (SS)	SS-1 Site Selection			
		Macro-2.1 Ecological Sensitivity of the Land	5	1
		Macro-2.2 Agricultural value of the land	3	0
	SS-2 Preferred Location			
		Macro-2.3 Contamination and development status of the land	3	0
	SS-3 Infrastructure			
		Macro-1.4 Proximity to existing infrastructure		1
	SS-4 Alternative transportation			
		Macro-1.2 Proximity to public transportation		0
		Macro-1.3 Public transportation quality	1	0
		Macro-1.6 Proximity to services	2	0
	SS-5 Site Development			
		Macro-2.5 Pavement density	3	0
		Macro-2.6 Disruption density	3	0
		Macro-2.7 Development density	4	1
	SS-6 Stormwater Design			
		Macro-3.1 Stormwater run-off	2	0
		Macro-3.2 Erosion degree and level of contamination	5	1
	SS-7 Heat-island Effects			
		Macro-3.3 Heat-island effect	3	0
	SS-8 Landscaping			
		Macro-3.4 Native planting	4	1
		Macro-3.5 Landscaping design strategy	4	1
	SS-9 Light Pollution Reduction			
		Only light area as required for safety and comfort	NA	1
SS Total points from 19 is				7
Water Efficiency (WE)	WE-1 Irrigation System			
		Macro-4.1 Landscaping water efficiency	3	0
		Macro-4.2 Non-potable water for irrigation	0	0
	WE-2 Water Reuse			
		Micro-2.1.2 % or recycled/ reclaimed water	0	0
		Macro-4.4 Harvesting rainwater for reuse	0	0
		Macro-4.3 Non-potable water use for toilet	0	0
		Macro-4.6 Availability of dual wastewater system	0	0
	WE-3 Water Use			
		Micro-2.1.1 Total water use	2	0
		Macro-4.5 Installation of high efficiency fixtures	3	0
	WE-4 Innovative Wastewater Technologies			
		Treat at least 50% of wastewater on-site to tertiary standards	NA	0
WE Total points from 12 is				0
Atmosphere (EA)	EA-1 Optimize Energy Performance			
		Micro-1.1.1 and 1.2.1 Total energy consumption	3	2
		Macro-5.2 Computer modeling for energy optimization	1	0
		Macro-5.3 Exploring passive lighting, heating and ventilation	2	0
		Macro-5.4 Energy controls utilization	3	0
	EA-2 Insulation			
		Macro-5.5 Envelop insulation and air leakage	3	0
	EA-3 Space Heating and Cooling			
		Micro-1.1.3 or 1.2.3 Energy for heating and cooling	2	0
		Macro-5.8 Heating and cooling system efficiency	3	0
	EA-4 Lighting			
		Micro-1.1.2 Electricity for lighting	4	1

Figure 37: A screenshot of the GREENOMETER-7 into LEED

Tab 14: Summary

Tab 14 is the last tab in GREENOMETER-7. It includes summary tables and figures of the micro-assessment, macro-assessment, overall sustainability score, and LEED points. The table and figure of the micro-score show the score of each category of the micro-assessment and the micro-score. The table and figure of the macro-level show the score of each category of the macro-assessment and the macro-score. Another figure and table show the overall sustainability score that was generated from the micro-score and macro-score. Finally, the table and figure of the LEED points show LEED points per category and the overall LEED points from all categories. Figure 38 shows a screenshot of the summary tab of GREENOMETER-7.



Micro-Assessment

Category	Score
1.1 Electricity	3
1.2 Fossil Fuel	3.6
2.1 Water and WW	1.7
3.1 Resources In	2.5
3.2 Resources Out	0
4.1 Cont. -Total	4
4.2 Cont. -Captured	0
4.3 Cont. -Disposal	3
4.4 Cont. -Air	2.4
4.5 Cont.-Water	3
4.6 Cont. -Soil	5
5.1 Economics	3
Micro-Score	2.66

Macro-Assessment

Category	Score
1. Location	3.45
2. Land Use	3.25
3. Stormwater &	3.35
4. Water and WW	0.9
5. Energy	2.3
6. Resources	2.5
7. IEQ	4.15
Macro-Score	3.14

Figure 38: Screenshot of the summary tab of GREENOMETER-7