Chapter 3 – Use of rating systems in the process towards sustainable construction

Coordinator: *Ricardo Mateus*
Contributors: *Ricardo Mateus, Luís Bragança, Rijk Blok, Mauritz Glaumann, Christian Wetzel, Dimitrios Bikas, Christina Giarma, Ilker Kahraman, Yesim Aktuglu*

3.1 INTRODUCTION

Since the large scale industrialization occurred, the profit oriented human activity has led to a constantly growing environmental degradation. Nowadays, that the actual severity of the problem in hand is impossible to ignore and the spectrum of the future consequences emerges in its full extent, several actions towards the adaptation of sustainability principles in the most problematic sectors of human activity are undertaken. One of these sectors is building sector, incorporating the production, transport, use and replacement of building materials, the use of the building itself (energy consumption for lighting, ventilation, heating and cooling, water consumption etc), the reuse of the building or its materials, the demolition of the building and the disposal of the demolition products. The energy consumed in operating buildings serves as indication of the building sector's contribution to the total environmental aggravation induced by human activity. According to (OECD, 2003), in the European OECD countries, the building sector consumes the highest amount of energy (40%) in comparison to the transport (22%) and industry sectors (38%). Given the fact that the afore-mentioned quantities include the energy amounts consumed only for the operation of the building, while other processes – unbreakably bonded to construction – such as manufacture and transport of building materials, are not co-calculated, an estimation regarding the impact of the building sector on the environment can be drawn.

Due to the increasing awareness about the consequence of the contemporary model of development in the climate change and to the growing international movement toward high-performance/sustainable buildings, more and more the current paradigm of building is changing. This is changing both the nature of the built environment as well the actual way of designing and constructing a facility. This new approach is different from the actual practice by the selection of project teams members based on their eco-efficient and sustainable building expertise; increased collaboration among the project team members and other stakeholders; more focus on global building performance that on building systems; the heavy emphasis placed on environmental protection during the whole life-cycle of a building; careful consideration of worker health and occupant health and comfort through all phases; scrutiny of all decision for their resource and life-cycle implications; the added requirement of building commissioning; and the emphasis placed on reducing construction and demolition waste (Kibert, 2005).

Although there are several definitions for a sustainable building, generally speaking, it uses resources like energy, water, land, materials in a much more efficient way than conventional buildings. These buildings are also designed and used in order to produce healthier and more productive living, work and living environments, from the use of natural light and improved indoor environmental quality (Syphers et al, 2003). Therefore, sustainable building aims the proper balance between the three dimensions of the sustainable development: Environment, Society and Economy.

Building sustainability assessment involves various relations between built, natural and social systems. Therefore it comprises hundreds of parameters, most of them interrelated and partly contradictory. To cope with this complexity and to support the sustainable building design, it is necessary to implement a real methodological work. The main objective of a systematic approach is to define sustainable building concept through tangible goals in order that, as a result of the sustainable design process, it is possible to achieve the most appropriate balance between the different sustainability dimensions (Mateus et al, 2008).

The development of assessment methods and the respective tools is a challenge both for the academia and in practice. An issue of prime importance is that of managing the flows of information and knowledge between the various levels of indicator systems. An important constraint to these methods is that the specific definition of the terms “sustainable building” or “high performance building” is complex, since different actors in the building’s life-cycle have different interests and requirements (Cole, 1998). For instance, promoters will give more attention to economic issues, whereas the end users are more interested in health and comfort issues (Haapio et al, 2008).

During the last two decades a significant number of environmental and sustainability assessment tools for buildings have been developed. The first commercially available environmental assessment tool for buildings was the Building Research Establishment Assessment Method (BREAM). This method was established in the UK in 1990 and together with the following two rating and certification systems it provides the basis for the other approaches used throughout the world: Sustainable Building Tool (SBTool), developed through the collaborative work of representatives from 20 countries; and the Leadership in Energy and Environmental Design (LEED), developed in the U.S.A.. In general, these methods are characterized by assessing a number of partial building features and aggregating these results into an environmental rating or sustainability score (Assefa et al, 2010).

In the SBTool the approach is to weight different indicators, taking into account weighting factors that are fixed at the national level. Each “score” is the result of the comparison between the studied building and the national reference. This scheme allows an international comparison of buildings from different countries. Other tools, for instance, BREEAM and LEED, are based upon credits. The maximum number of credits available for each indicator is related to its weight in the overall score, which is expressed by a rating (e.g. from Pass to Excellent in BREEAM).

There are also LCA-based tools available that are especially developed to address the building as whole, such as, for example, Eco-Quantum (Netherlands), EcoEffect (Sweden), Envest2 (U.K.), BEES 4.0 (U.S.) and ATHENA (Canada). The majority of these tools are developed according to a bottom up approach, i.e. a combination of building materials and components add up to a building, even though they are designed to consider the whole building, including energy demand, etc (Erlandsson et al, 2003). Tools to support decision-making in accordance with principles of performance-based design have also been developed, mainly in research communities.

The aim of this paper is to present some different building environmental or sustainability assessment methods developed in some of the countries represented in the COST Action C25. This Chapter will begin by presenting an overview about the international context on the LCA methods and sustainability assessment tools. Afterwards, some different European methods will be presented: SBTool^{PT} (Portugal); DGNB (Germany); ERB Tool (Sweden) and GREENCALC Tool (Netherland). This subchapter highlights the list of indicators of different methods and presents their contribution for the sustainability of buildings through the presentation of some case studies. At the end of this chapter other internationally recognized approaches are summarized in order that the differences at the level of the list of indicators could be highlighted. The methods briefly presented are: BREEAM (U.K.); LEED (U.S.A.) and CASBEE (Japan).

3.2 OVERVIEW ON THE LCA METHODS AND BUILDING SUSTAINABILITY ASSESSMENT TOOLS AND THEIR CONTRIBUTION FOR THE SUSTAINABILITY OF BUILDINGS

3.2.1 Introduction

In the context of diminishing the adverse effects of the building construction, operation, renovation, demolition and final disposal processes, continuing and intensifying efforts are made. Indispensable tools in the hands of those trying to support the implementation of sustainable practices and strategies in the building construction sector are the building and building materials' environmental performance assessment methods. Such methods, along with LCA (Life Cycle Assessment) methods, can serve not only as research tools, but also as means of persuasion of practitioners to consider environmental aspects in the selection of the materials and systems they use, as well as in the design and construction of buildings.

In the following, the potential of Life Cycle Assessment and building environmental performance assessment methods to promote the implementation of environmentally friendly strategies and techniques in the building construction sector is discussed. On the basis of presenting results produced by the application of such methods to buildings and products in Greece, the kind of conclusions and directives that can be derived is revealed. Furthermore, based on a recent study on the LCA of building envelopes' components typically used in Greece, a set of interesting observations, which can also be taken into account in every day practice, is presented. In the first part of the chapter, a reference is made to terms that are widely used in connection to several aspects of a building's or a material's environmental performance (environmental performance, Life Cycle Assessment etc.). The distinctions are clearly made and the differentiations among them are underlined. Additionally, some widely used methods for the buildings' environmental performance assessment and LCA methods are reviewed, while legislation issues such as certification of low energy consumption, product labelling etc are also addressed.

3.2.2 LCA and building environmental performance assessment

3.2.2.1 Terms and aspects

According to (Braganca et al, 2008a), Life Cycle Assessment is a systematic approach to the evaluation of the potential environmental impacts of a product or service over its life cycle. The basic framework for LCA includes 8 basic steps (goal and scope definition of LCA, inventory analysis, impact assessment, interpretation, reporting and critical review, limitations, relationships between the LCA phases and conditions for use). The LCA study itself includes the first 4 of the afore-mentioned stages (Pre Consultants, 2007).

The LCA studies vary from relatively simple to extremely complex, depending on the factors taken into account, the complexity of the assembly studied and on the kind and number of impacts assessed. Given the fact that the LCA analysis of solely a building is a difficult task, the application of LCA in buildings, which incorporates various materials and elements, with different characteristics, different life durations, attacked by different aggressive agents and fulfilling varying performance demands becomes extremely complex. This difficulty is widely acknowledged (Blok et al, 2008; Glaumann et al, 2008).

The LCA methods are not designed especially for the building and construction sector. In fact, they can model and assess any product or service. Consequently, they can be used to evaluate the environmental impact of every building material, component or system. In the context of a very complex, detailed approach, the sophisticated LCA tools available can be used to study a building. However, a building is not a static ensemble of the materials of which it is constructed and of the systems it includes. The construction, operation or demolition of a building on a site affects the site itself (reduction or increase of the area covered by plants or trees, etc.), while the site affects in a determinative way several important decisions regarding the design and construction of the building. The constructions near the building under study are also of great importance relatively to its design, construction and operation (access of primary occupancy spaces to daylight, noise level, restrictions for the building's dimensions and shape etc.). Furthermore, the demands deriving from the occupants needs set limits for the minimum acceptable performances of the building components and systems. It is evident that the environmental performance assessment of buildings, taking into account all those aspects and therefore adopting a holistic approach, extends far beyond the LCA of its components and systems. Issues regarding the site, the design of the building, the operation energy and many others must be addressed. This approach is attempted by the constantly developing building's environmental performance assessment methods and rating systems. Several of the tools corresponding to such methods incorporate LCA criteria into the assessment they conduct (e.g. SBTool (Larsson, 2007), Green Globes (GBI)). A rating system that does not include LCA criteria is LEED (Braganca et al, 2008a). Concluding, the environmental performance assessment of a building can include but cannot be entirely based on LCA criteria.

3.2.2.2 Software and tools

In the following, a short reference to tools widely used for LCA and buildings' environmental performance assessment is made. This review could be extended to include not only more detailed descriptions of the cited tools, but also to other methods developed for the same purposes.

i) LCA tools

One of the oldest, yet widely known and applied, tools for the analysis of the environmental and economic profile of building materials is BEES (Building for Environmental and Economic Sustainability) (Lippiat, 2002). Including an extensive database regarding the amounts of chemical substances emitted throughout the life cycles of the most commonly used building materials, BEES can be used either to draw a picture of a material's environmental profile or to compare the environmental performance of materials belonging to the same category. This comparison is based on the final scores attributed to the materials compared. The final score for each material is derived from the summation of the scores calculated for each one of the ten or six impact categories available (depending on the material). An estimation of a material's economic profile is also possible.

SimaPro (Pre Consultants., 2007) is a sophisticated software for the life cycle analysis of materials and components. Including extensive databases for materials of various kinds and providing the possibility of using several methods for the impact assessment and selecting different disposal scenarios, SimaPro can provide analyses of different levels, extending from a simple single material to very complex systems. The possibility of presenting the results in different ways is also provided.

ii) Buildings' environmental performance assessment tools

BREEAM is the earliest building rating system for environmental performance (Gowri, 2004). Evolving from a design checklist to a comprehensive assessment tool, it has widely been used in various countries and is recognised by the UK building industry as the benchmark for assessing environmental performance.

GBTool is the software implementation of Green Building Challenge (GBC) method (iiSBE, 2004). GBC method is a method for the assessment of buildings' environmental performance and it is developed, under the responsibility of iiSBE, on the basis of the collaboration of more than 20 countries. It assesses several aspects of a building's environmental profile, providing this way a rather extended and detailed estimation of the building's performance in relation to environment. In GBTool 2002, these aspects are categorised into the following 7 thematic categories, called performance issues: 1) resource consumption, 2) environmental loadings, 3) indoor environmental quality, 4) quality of service, 5) economics, 6) pre-long-term performance, 7) social and economic aspects. Each performance issue includes several performance categories, which include numerous performance criteria and sub criteria. The scores attributed to the building's environmental performance parameters range from –2 to +5, with 0 corresponding to the minimum acceptable performance for the relevant occupancies within the region (determined by the existing regulations or common practices of the region) and +5 being attributed to the highest possible performance. A re-structured version of GBTool, including the assessment of economic and social variables, called SBTool, has recently been completed.

LEED (Leadership in Energy and Environmental Design) has been developed by the U.S. Green Building Council (U.S. Green Building Council, 2001). LEED is a rating system, classifying the environmental performance of a building into four categories. The estimation of a building's environmental performance is based on the total points the building gathers during the assessment of various criteria. Finally, the building is attributed the characterisation certified, silver, gold or platinum, according to its total score. Although LEED is a rather simple for the user to apply (list of conditions and requirements that are fulfilled or not), it is based on a complicated and extensive system of building regulations.

iii) Application of LCA and Buildings' environmental performance assessment tools

The application of the tools mentioned and of similar ones for buildings or materials in a region presupposes the existence of extended databases (for the raw materials, the manufacture processes, the transport and construction processes, etc), of statistical data about several aspects of the built environment in the region and of national or regional regulations about environmental issues, which could serve very well as benchmarking mechanisms (Giarma et al, 2005). A network of information and legislation of this kind is not available for many countries. This fact is further revealed by a series of investigations regarding European countries (Kontoleon et al, 2008; Blok, 2008; Broniewicz, 2008; Gervasio et al, 2008; Grecea et al, 2008; Glaumann et al, 2008; Kahraman, 2008).

3.2.3 Use of LCA and building environmental performance assessment in case studies in Greece

In the following section, the potential of Life Cycle Assessment and building environmental performance assessment methods to promote the implementation of environmentally friendly strategies and techniques in the building construction sector will be revealed through the presentation of some results derived by the application of such methods for buildings in Greece and building components that correspond to the current state of the art in Greece.

3.2.3.1 Application of buildings' environmental performance assessment tool

In a study conducted in 2002 (Giarma et al, 2002), the environmental performance of a three storey, recently constructed office building in northern Greece was assessed. It is composed of a ground floor with two storeys above it of 625m2 each and a basement of 726m^2. The reason that this particular building was selected to be studied was that during its design and construction, several sustainability issues were taken into consideration and, consequently, several measures and techniques were applied in order to improve its environmental profile (integration of passive solar systems, design enhancing natural ventilation, shading devices reducing the energy used for cooling, etc). This assessment was conducted with the use of GBTool 2002. In the context of this tool, scores for seven major performance issues (each one including several performance categories comprising numerous performance criteria and sub criteria, to all of which a score is attributed as well) are calculated. Finally, an overall score is attributed to the building. The score scale extents from -2 to +5 with 0 corresponding to the minimum acceptable performance for the relevant occupancies within the region, determined by the existing regulations or common practices of the region, -2 to unsatisfactory performance and +5 to the highest achievable performance. The results revealed that the implementation of environmentally friendly strategies led to a considerable improvement of the building's environmental profile in relation to a typical office building in Greece.

This building has formed the reference case building or several parametrical studies conducted later. In (Bikas et al, 2005), the effect of the use of photovoltaic technology on this building was studied. With the use of PHIVOS, a tool that uses readily available climate data from 25 stations in Greece and simple PV product parameters to calculate energy production of on-grid photovoltaic systems, the yearly energy output in case that PV elements (the type of the photovoltaic elements used was a-si and the inverter's efficiency was 0,95) were integrated into the east façade, the west façade, the north façade the south façade, the roof and, finally, all the surfaces of the afore-mentioned building. These results were then used as inputs for the building's environmental performance assessment in every case with the use of GBTool 2002. Due to the limited space, only the differentiations in the total scores are presented in Figure 3.1.

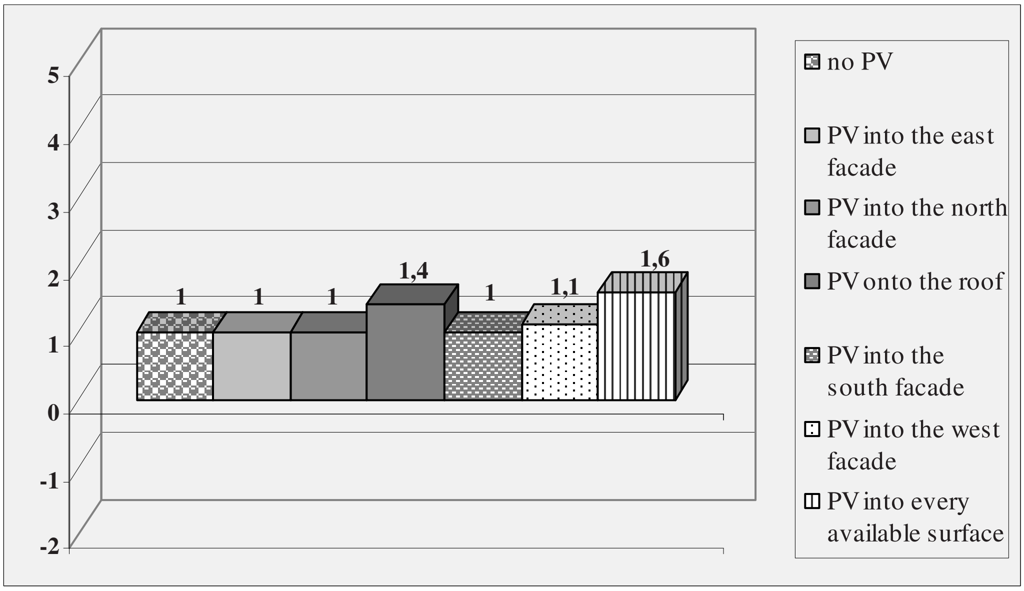


Figure 3.1. Total scores for a building's environmental performance, depending on the surfaces into which PV elements are integrated, as they are derived by the study presented in (Bikas et al, 2005).

Based only on this diagram, one could easily reach the conclusion that the integration of PV elements into the east, north or south façade of the building would not cause any severe alterations in its environmental profile. On the contrary, the integration of PV elements onto the roof could have an impressive effect.

Another parameter that was analytically investigated with the use of GBTool 2002 was the influence of urban context on the building's environmental performance. Considering the aforementioned office building (Giarma *et al*, 2008) and, in a more recent study, a virtual office building in Greece (Arailopoulos *et al*, 2009), the graphic of Figure 3.2 was used to calculate the angles f and a for a number of hypotheses for S, H and H_A. The results revealed that in the dense urban fabric of cities, with the margins of alterations in the values of the variables studied being small, the effect of these parameters on the total performance of the building, even on the performance category relating to the indoor environmental quality is negligible (Tsikaloudaki *et al*, 2005). This is not the case for locations were the sites available are bigger and the range of the possible alterations of S is large (Giarma et al, 2008). Keeping in mind these results might work in favour of environmentally friendlier decisions during the design of the building.

Some parameters e.g. the percentage of a building's facades covered by glazing in Greece (Giarma *et al*, 2008) have been investigated with the use of such tools Each one of these studies reached conclusions, regarding the effect of the alteration of each parameter to the to the environmental profile of the building, that can undoubtedly be used in the context of decision making in relation building under study.

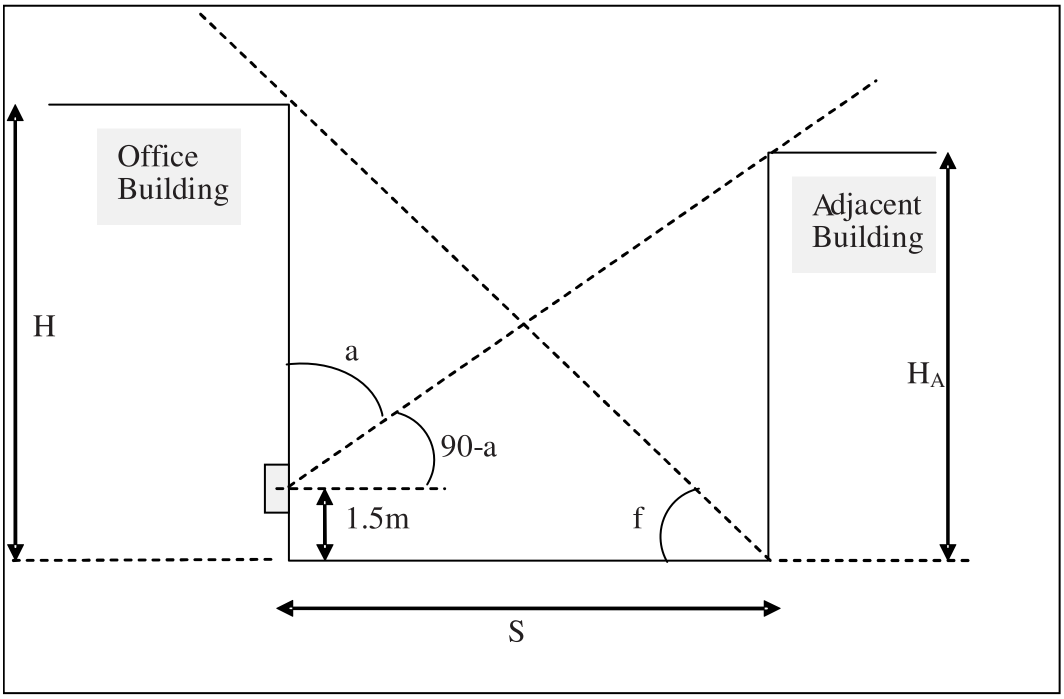


Figure 3.2. Graphical display of the main variables used to study the effect of urban context on the environmental performance assessment of a building in (Tsikaloudaki et al, 2005) and (Giarma et al, 2008).

3.2.3.2 Application of LCA tools

In the context of a recently completed diploma thesis, an analysis of the buildings' life cycle in Greece was attempted, with the use of SimaPro software (Arailopoulos et al, 2009). The method applied for the impact assessment was Eco–indicator 99 (which is included as an option in the version of SimaPro that was used). This analysis was focused on a typical building's envelope components. The assessment was conducted for a series of typical assemblies, including the most commonly used materials in Greece. Due to the fact that there are not, at least in view of the authors, databases including information about the environmental profiles of the building materials commonly used in Greece of such kind and extent that could be used directly for the analysis conducted by a sophisticated software such as SimaPro, a series of simplifications and assumptions had to be adopted for the study to be conducted. Nevertheless, the results of a general level that are reported here are considered to be rather reliable.

More specifically, it was found that, in case that a mean transport distance of 100 km from the material's production site to the construction site is considered for all the materials used, transport is a severely aggravating process for the life cycle of all the components examined. The contribution of transport to the final figures calculated for most impact categories is more than 50%.

Furthermore, the fact that the disposal scenario for each component and material plays an important role for the final environmental profile that is derived for the component under study was revealed. For example, in the case of a typical concrete column, including interior and exterior plasters and thermal insulation, the contribution of the column's disposal scenario to the total score calculated for the impact category "climate change" (including the production of materials, the construction of the column, etc.) is more than 50%.

Other results related, among others, to the relative contribution of its component to the total environmental aggravation caused by a building (the operation energy is not taken into consideration) have also been derived. These results are not presented here due to the limited space of this section.

3.3 METHODOLOGY SBTOOL^{PT}

3.3.1 Framework

The Sustainable Building Tool - SBTool is a building sustainability assessment method that result from the collaborative work of several countries, since 1996 and it was promoted by the International Initiative for a Sustainable Built Environment (iiSBE). This international involvement supported its distinction among the others methodologies, since SBTool was designed to allow users to reflect different priorities and to adapt it to the regional's environmental, sociocultural, economy and technological contexts.

The Portuguese version of SBTool - SBTool^{PT} - was developed by the Portuguese chapter of iiSBE, with the support of University of Minho and the company EcoChoice. In this methodology all the three dimensions of the sustainable development are considered and the final rate of a building depends on the comparison of its performance with two benchmarks: conventional practice and best practice. This methodology has a specific module for each type of building and in this section the module to assess residential buildings (SBTool^{PT} – H) was used.

The physical boundary of this methodology includes the building, its foundations and the external works in the building site. Issues as the urban impact in the surroundings, the construction of communication, energy and transport networks are excluded. Regarding the time boundary, it includes the whole life cycle, from cradle to grave.

Table 3.1 lists the categories (global indicators) and indicators that are used in the methodology to access residential buildings. It has a total of nine sustainability categories (summarizes the building performance at the level of some key-sustainability aspects) and 25 sustainability indicators within the three sustainability dimensions.

The methodology is supported by an evaluation guide and its framework includes (Figure 3.3):

i) Quantification of performance of the building at the level of each indicator presented in a evaluation guide;
ii) Normalization and aggregation of parameters;
iii) Sustainable score calculation and global assessment.

In order to facilitate the interpretation of the results of this study the main steps of the SBTool^{PT} approach will be presented in the next sections.

3.3.2 Assessment procedure

3.3.2.1 Quantification

The evaluation guide presents the methodologies that should be used by the assessor in order to quantify the performance of the building at level of each sustainability indicator.

At the level of the environmental parameters, SBToolPT uses the same environmental categories that are declared in the Environmental Product Declarations. At the moment, there are limitations with this approach due to the small number of available EPD. Therefore the authors of the methodology decided to develop a Life-cycle Assessment (LCA) database that covers many of the building technologies conventionally used in buildings (Bragança et al, 2008b). Nevertheless, since the LCA did not cover all building technologies used in the assessed building, in this study was necessary to use one external LCA tool (SimaPro).

At the level of the societal performance, the evaluation guide presents the analytical methods that should be used to quantify the parameters.

The economical performance is based in the market value of the dwellings and in their operation costs (costs related to water and energy consumption).

Table 3.1. List of categories and sustainability indicators of the SBTool^{PT} methodology.

Dimension	Categories	Sustainability indicators
Environment	C1 – Climate change and outdoor air quality	P1 – Construction materials' embodied environmental impact
	C2 – Land use and biodiversity	P2 - Urban density P3 – Water permeability of the development P4 - Use of pre-developed land P5 – Use of local flora P6 – Heat-island effect
	C3 – Energy efficiency	P7 – Primary energy P8 – In-situ energy production from renewable
	C4 – Materials and waste management	P9 – Materials and products reused P10 – Use of materials with recycled contend P11 – Use of certified organic materials P12 – Use of cement substitutes in concrete P13 – Waste management during operation
	C5 – Water efficiency	P14 – Fresh water consumption P15 – Reuse of grey and rainwater
Society	C6 – Occupant's health and comfort	P16 – Natural ventilation efficiency P17 – Toxicity of finishing P18 – Thermal comfort P19 – Lighting comfort P20 – Acoustic comfort
	C7 – Accessibilities	P21 – Accessibility to public transportations P22 – Accessibility to urban amenities
	C8 – Awareness and education for sustainability	P23 – Education of occupants
Economy	C9 – Life-cycle costs	P24 – Capital cost P25 – Operation cost

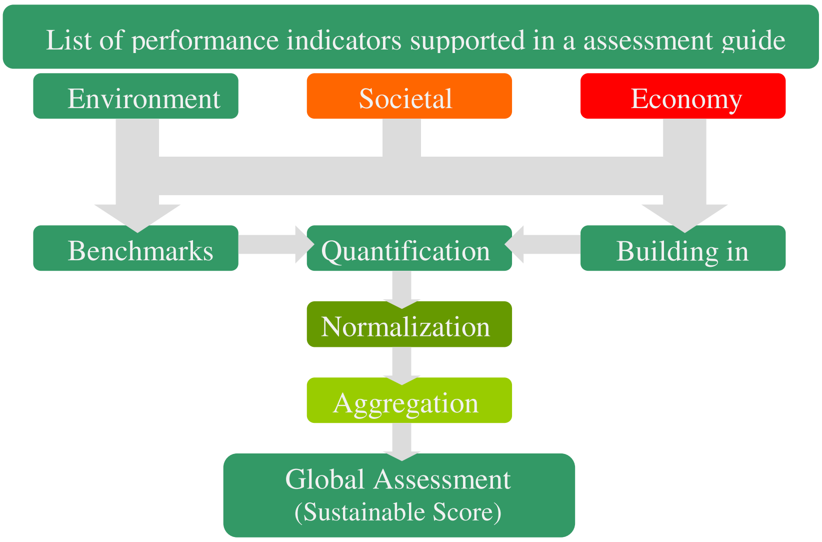


Figure 3.3. Framework of the SBTool^{PT} methodology.

3.3.2.2 Normalization and aggregation of parameters

The objective of the normalization is to avoid the scale effects in the aggregation of parameters inside each indicator and to solve the problem that some parameters are of the type "higher is better" and others "lower is better". Normalization uses the Diaz-Balteiro et al. (2004) equation (Equation 3.1).

$$\overline{P_i} = \frac{P_i - P_{*i}}{P_i^* - P_{*i}} \forall_i \tag{3.1}$$

In this equation, P_i is the value of i^{th} parameter. P^*_i and P_{*i} are the best and worst value of the i^{th} sustainable parameter. The best value of a parameter represents the best practice and the worst value represents the standard practice or the minimum legal requirement.

Normalization in addition to turning dimensionless the value of the parameters considered in the assessment, converts the values between best and conventional practices into a scale bounded between 0 (worst value) and 1 (best value). This equation is valid for both situations: “higher is better” and “lower is better”.

In order to facilitate the interpretation of results, the normalized values of each parameter are converted in a graded scale, as presented in Table 3.2.

Table 3.2. Conversion of the quantitative normalized parameters into a qualitative graded scale.

Grade	Values
A+ (Above best practice)	$\overline{P_i} > 1{,}00$
A	$0{,}70 < \overline{P_i} \leq 1{,}00$
B	$0{,}40 < \overline{P_i} \leq 0{,}70$
C	$0{,}10 < \overline{P_i} \leq 0{,}40$
D (Conventional practice)	$0{,}00 < \overline{P_i} \leq 0{,}10$
E (Bellow conventional)	$\overline{P_i} \leq 0{,}00$

The aggregation consists on a weighted average of the indicators into categories and the categories into dimensions in order to obtain three single indicators. These three values are obtained using the equation (3.2) and the final result gives the performance of the building at the level of each sustainability dimension.

$$I_j = \sum_{i=1}^{n} w_i . \overline{P_i} \tag{3.2}$$

The indicator I_j is the result of the weighting average of all the normalized parameters $\overline{P_i}$. w_i is the weight of the i^{th} parameter. The sum of all weights must be equal to 1.

In the definition of the environmental indicators’ weights the methodology uses the US Environmental Protection Agency’s Science Advisory Board study (TRACI) and the societal weights are base on studies that were carried out in the Portuguese population (Bragança *et al*, 2008a).

3.3.2.3 Global assessment and labelling

The last step of the methodology is to calculate the sustainable score (SS). The SS is a single index that represents the global sustainability performance of the building, and it is evaluated using the equation (3.3).

$$SS = w_E x I_E + W_S x I_S + W_C x I_C \tag{3.3}$$

Where, *SS* is the sustainability score, I_i is the performance at the level of the dimension *i* and w_j is the weight of the dimension j^{th}.

Table 3.3 presents the weight of each sustainable solution in the assessment of the global performance.

Table 3.3. Weight of each sustainability dimension on the methodology SBTool^{PT} – H.

Dimension	Weight (%)
Environmental	40
Societal	30
Economy	30

Normally, the majority of the stakeholders would like to see a single, graded scale measure representing the overall building score. Such score should be easily for building occupants to understand and interpret but also one which clients, designers and other stakeholders can work with. However, due to the possible compensation between categories, in the SBTool^{PT} approach the global performance of a building is not communicated using only the overall score. The performance of a building is measured against each category, sustainable dimension and global score (sustainable score) and is ranked on a scale from A+ to E

3.3.3 Case study

3.3.3.1 Description of the building

The case-study for Building Sustainability Assessment Methodology SBTool^{PT} is a multifamily cooperative housing building block that is the Portuguese pilot -project of the European Program "SHE: Sustainable Housing in Europe" (http://www.she.coop).

The Portuguese pilot project was the second phase of the Ponte da Pedra housing state that was built in the municipality of Matosinhos, Northern Portugal (Figure 3.2). It is a multifamily social housing project, which promoter is NORBICETA - União de Cooperativas de Habitação, U.C.R.L. This project has two building blocks, a footprint of 3105m^2, a total gross area of 14.852m^2 and 101 dwellings. It was co-sponsored by the project SHE and by the National Housing Institute (INH) and had the support of the FENACHE (national federation of social housing cooperatives), FEUP (Faculty of Engineering of the University of Porto) and UM (University of Minho). This project aimed to demonstrate the real feasibility of sustainable housing in Portugal and it succeed since it proved the practical feasibility of building a residential building with lower environmental impacts, higher comfort and lower life-cycle costs, when compared to a conventional one.

During the design phase, the project team adopted a series of priorities in order to create a sustainable affordable building block. The most important priorities were:

i) To use pre-developed land: this housing state was built in an area that was occupied by decayed industrial buildings (Figures 3.4 and 3.5). By contributing to the regeneration of the land and to the improvement of around urban area, this project had a positive local impact. On the other hand, due to the fact of not using new land it will contribute for the maintenance of local biodiversity;

ii) Energy efficiency: the primary energy consumption is about 25% of the local's conventional practice; it uses efficient lighting in public spaces; and solar collectors for hot water (Figure 3.6);

iii) Water efficiency: building is equipped with a rainwater harvesting system that guarantees at about 100% of the water supply for green areas and toilets (Figure 3.7); and it is equipped with low water flow devices (Figures 3.8 and 3.9).

iv) Improvement of the indoor air quality: all window frames are equipped with ventilation grids (Figure 3.10).

v) Management of household waste: all kitchens are equipped with containers for each of the four types of household solid waste (Figure 3.11); the outside containers are located nearby the building's entrance.

vi) Controlled costs: compared to the first phase of the Ponte da Pedra housing state (that have the same type of architecture but uses the conventional building technologies) the construction cost was about 9% higher. The promoter assumed part of this higher capital cost and the dwellings were sold at a price 5% higher than the first phase. According to the promoter, the turn-off of this higher capital cost will about 5 to 6 years. Nevertheless, dwellings were sold at an average price that was 20% below the local's average market practice.

Figure 3.4. General exterior view of the building blocks.

Figure 3.5. Aspect of the local before the intervention.

Figure 3.6. Hot water solar collectors (thermodynamic system).

Figure 3.7. Rainwater tank (construction phase).

Figure 3.8. Low flow showers.

Figure 3.9. Double flush toilets (6/3 l).

Figure 3.10. Ventilation grids on window frames.

Figure 3.11. Containers for solid waste separation.

3.3.3.2 Assessment results

Table 3.4 presents the values obtained in the assessment of the performance at the level of each sustainability category and dimension. Analysing the results it is possible to verify that all priorities adopted by the project team (described above) were recognised by the SBTool^{PT} methodology and therefore almost all categories (except one) have a performance grade above the conventional practice. The analysed building is only worst than the conventional practice in the category C1 “Climate change and outdoor air quality”. This situation results from the fact that the building uses solid clay bricks on the exterior cladding (one material with greater embodied environmental impacts than the conventionally used materials). In compensation, building is above the best practice’s benchmarks at the level of three categories: C5 “Water efficiency”, C8 “Awareness and education for sustainability”, C9 “Life-cycle costs”. The good performance at the level of the water efficiency is mainly influenced by the implementation of the rainwater harvesting system; the good performance on category C8 is because all dwelling have a complete user manual that guides the inhabitants for the sustainable management of it; and the good economy performance is quite dependable on the lower market price of the dwellings (20% lower than average local's market practice).

Table 3.4. Results obtained from the SBTool^{PT} – H for each sustainability category and dimension.

Dimension	Category	Performance (normalized value)	Performance (qualitative value)	Weight (%)	Dimension Performance (I_A)
Environmental	C1	-0,20	E	13	B
	C2	0,56	B	20	
	C3	0,72	A	32	
	C4	0,10	D	29	
	C5	1,03	A+	6	
Societal	C6	0,60	B	60	B
	C7	0,74	A	30	
	C8	1,13	A+	10	
Economy	C9	1,20	A+	100	A+

Table 3.5 resumes the obtained results at the level of each dimension of the sustainable development and the global performance (Sustainable Score). According to the results this building has an A grade, which means that it is considered the best practice in the Portuguese context.

Table 3.5. Results obtained from the SBTool^{PT} – H for the global assessment.

Dimension	Performance (normalized value)	Performance (qualitative value)	Weight (%)	Sustainable Score (SS)
Environmental	0,41	B	40	A
Societal	0,69	B	30	
Economy	1,20	A+	30	

Being this pilot-project nationally and internationally recognized has a good sustainability practice it is possible to conclude that the SBTool^{PT} – H is well adapted to the Portuguese's environmental, societal and economy contexts.

3.4 DGNB CERTIFICATION SYSTEM

3.4.1 Framework

The DGNB Certification System was developed by the German Sustainable Building Council (DGNB) to be used as a tool for the planning and evaluation of buildings in this comprehensive perspective on quality. As a clearly arranged and easy to understand rating system, the DGNB system covers all relevant topics of sustainable construction, and awards outstanding buildings in the categories bronze, silver, and gold. Six subjects affect the evaluation: ecology, economy, social-cultural and functional topics, techniques, processes, and location. The certificate demonstrates, in a quantifiable way, the positive effects of a building on the environment and on society.

Figure 3.12. Logo of the DGNB certification system.

The DGNB certificate is based on the concept of integral planning that sets, at an early stage, the aims of sustainable construction. In this way, sustainable buildings can be designed based on the current state of technology, – and they can communicate their quality with this new certificate.

The basis for the system was developed on the building type “New Construction of Office and Administration buildings”. On this basis, further systems for completely different building types such as retail, industrial, educational and housing were developed and are ready to be used and internationally adapted. In 2010 the DGNB will introduce certification systems for hotels, existing building and interiors. In this section, the “New Construction Office and Administration” module, in the version 2008, is presented.

As a second-generation certification system, the label excels with a high degree of flexibility. The basis of the evaluation, which was developed with a wide consensus, is a list of topics and the criteria for sustainable construction that are included within that list. These criteria are weighted differently, depending on the building type to be evaluated. Thus, each version of the system, hence each building type, has its own evaluation matrix.

During the development of the certificate, 6 topics were defined, which with a total of 63 individual criteria, represent the relevant sectors of sustainable construction. The topics considered by the certificate are (Figure 3.13):

i) Ecological Quality;
ii) Economical Quality;
iii) Socio-cultural and Functional Quality;
iv) Technical Quality;
v) Quality of the Process;
vi) Quality of the Location.

During the testing of the system, the development of 14 criteria was postponed. Therefore, the certification for “New Construction Office and Administration” in the version 2008 is based on the following 49 criteria (Table 3.6). Forty three of these criteria evaluate the building’s quality. Six separate criteria specify the quality of location.

3.4.2 Methodical principles of the certification system

The German Sustainable Building Certificate is a transparent and comprehensible rating system that was developed based on real-world circumstances. It defines the quality of buildings in a comprehensive way, and enables auditors to conduct an evaluation systematically and independently.

Figure 3.13. Topics of the DGNB certification system.

3.4.2.1 Supporting software

User-friendly software supports the auditor with the documentation and evaluation process. The software visualizes the capabilities of a building in a way that is concise and easy to understand. Already during the planning process, it marks the influencing parameters were the building can be optimized with regard to sustainability.

3.4.2.2 Flexibility

The basis for the system was developed on the building type “New Construction of Office and Administration buildings”. On this basis, further systems for completely different building types will be developed. As a second-generation certification system, the label excels with a high degree of flexibility. The basis of the evaluation, which was developed with a wide consensus, is a list of topics and the criteria for sustainable construction that are included within that list. These criteria are weighted differently, depending on the building type to be evaluated. Thus, each version of the system, hence each building type, has its own evaluation matrix. An example is the matrix for the evaluation of new office and administration buildings on Figure 3.14.

On this basis, the German Sustainable Building Certificate can be adapted, in a practicable way, to the individual requirements of different building types. Similarly, it can be adapted to regional requirements or social developments, for example to the increasing importance of individual criteria like indoor air quality or CO_2-emissions of a building. The strength of the system is also based on the involvement, from the beginning, of interested parties during the development of new variations. A supplementary commenting procedure ensures that the requirements of the construction and real estate sector are systematically queried and included into the system.

3.4.2.3 Aggregation

The topics are weighted differently in the overall assessment of the building, depending on their relevance. The economical, ecological, socio-cultural and functional quality have the same weighting (22.5% each). Process Quality is weighted with 10% and the quality of the location is not included in the final grade but is presented separately.

Each topic is divided into several criteria. For instance, the energy consumption, acoustical quality, or land consumption are considered for the evaluation of a building. For each criterion, measurable target values are defined, and a maximum of 10 points can be assigned. The measuring methods for each criterion are clearly defined.

Table 3.6. List of criteria of the DGNB certification system

Main Criteria Group	Criteria Group	Criterion
Ecological Quality	Impacts on global and local environment	01 - Global Warming Potential 02 - Ozone Depletion Potential 03 - Photochemical Ozone Creation Potential 04 - Acidification Potential 05 - Eutrophication Potential 06 - Risks to the Regional Environment 08 - Other Impacts on the Global Environment 09 - Microclimate
	Utilization of resources and waste arising	10 - Non-renewable primary energy demands 11 - Total primary energy demands and proportion of renewable primary energy 14 - Potable water consumption and sewage generation 15 - Surface area usage
Economical Quality	Life-cycle costs	16 - Building-related life cycle costs 17 - Value stability
Socio-cultural and Functional Quality	Performance, health, comfort and user satisfaction	18 - Thermal comfort in the winter 19 - Thermal comfort in the summer 20 - Indoor Hygiene 21 - Acoustical comfort 22 - Visual comfort 23 - Influences by users 24 - Roof design 25 - Safety and risks of failure
	Functionality	26 - Barrier free accessibility 27 - Area efficiency 28 - Feasibility of conversion 29 - Accessibility 30 - Bicycle comfort
		31 - Assurance of the quality of the design and for urban development for competition 32 - Art within Architecture
Technical Quality	Quality of the techni - cal implementation	33 - Fire protection 34 - Noise protection 35 - Energetic and moisture proofing quality of the building's Shell 40 - Ease of Cleaning and Maintenance of the Structure 42 - Ease of deconstruction, recycling and dismantling
Quality of the Process	Quality of the planning	43 - Quality of the project's preparation 44 - Integrated planning 45 - Optimization and complexity of the approach to planning 46 - Evidence of sustainability considerations during bid invitation and awarding 47 - Establishment of preconditions for optimized use and operation 48 - Construction site, construction phase 49 - Quality of executing companies, prequalifications
	Quality of the construction activities	50 - Quality assurance of the construction activities 51 - Systematic commissioning

Table 3.6 (cont.). List of criteria of the DGNB certification system

Main Criteria Group	Criteria Group	Criterion
Quality of the Location (Location is presented separately, and is not included in the overall grade of the object)		56 - Risks at the micro location
		57 - Circumstances at the micro location
		58 - Image and condition of the location and neighbourhood
		59 - Connection to transportation
		60 - Vicinity to usage-specific facilities
		61 - Adjoining media, infrastructure development

At the same time, each criterion has a weighting factor: it can flow threefold into the evaluation of its respective topic. This way, for instance, the energy consumption of an office building is of more importance than the acoustical comfort. The weighting factor can also be zero – the consideration of motorway bridges does not require the criteria for indoor air quality.

3.4.2.4 Evaluation

Each criterion can be assigned a maximum of 10 points, depending on the documented or calculated quality. All criteria are weighted with a factor from 0 to 3, because individual criteria are treated as either more or less relevant. The evaluation matrix on Figure 3.14 shows the structure of the system. The degree of compliance with the requirements of the certification is calculated in accordance with the evaluation matrix. From a total degree of compliance of:

i) 50 to 64,9 % - the bronze certificate is awarded;
ii) 65 to 79,9% - silver;
iii) Above 80 % - gold.

Alternatively, the total degree of compliance is indicated by a total degree of compliance of:

i) 95% corresponds to grade 1,0;
ii) 80% corresponds to 1,5;
iii) 65% corresponds to 2,0;
iv) 50% corresponds to 3,0;
v) 35% corresponds to 4,0;
vi) 20% corresponds to 5,0.

3.4.2.5 Presentation of results

Each criterion influences the overall result in a clearly differentiated way. A software-supported computation displays the building's performance: by reaching a set degree of performance, it is assigned the bronze, silver, or gold award. Furthermore, grades are given for the total performance of the building as well as for the individual topics. Figure 3.15. shows the assessment output. This output shows the performance of an entire building in a glance since the software-generated evaluation diagram summarizes the results of the topics and individual criteria.

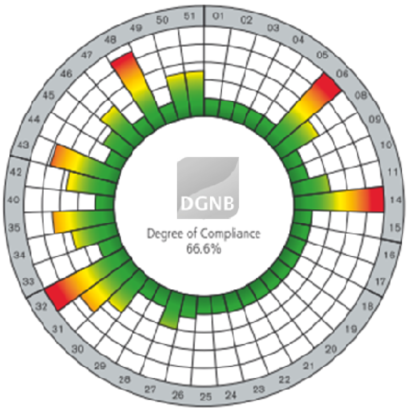
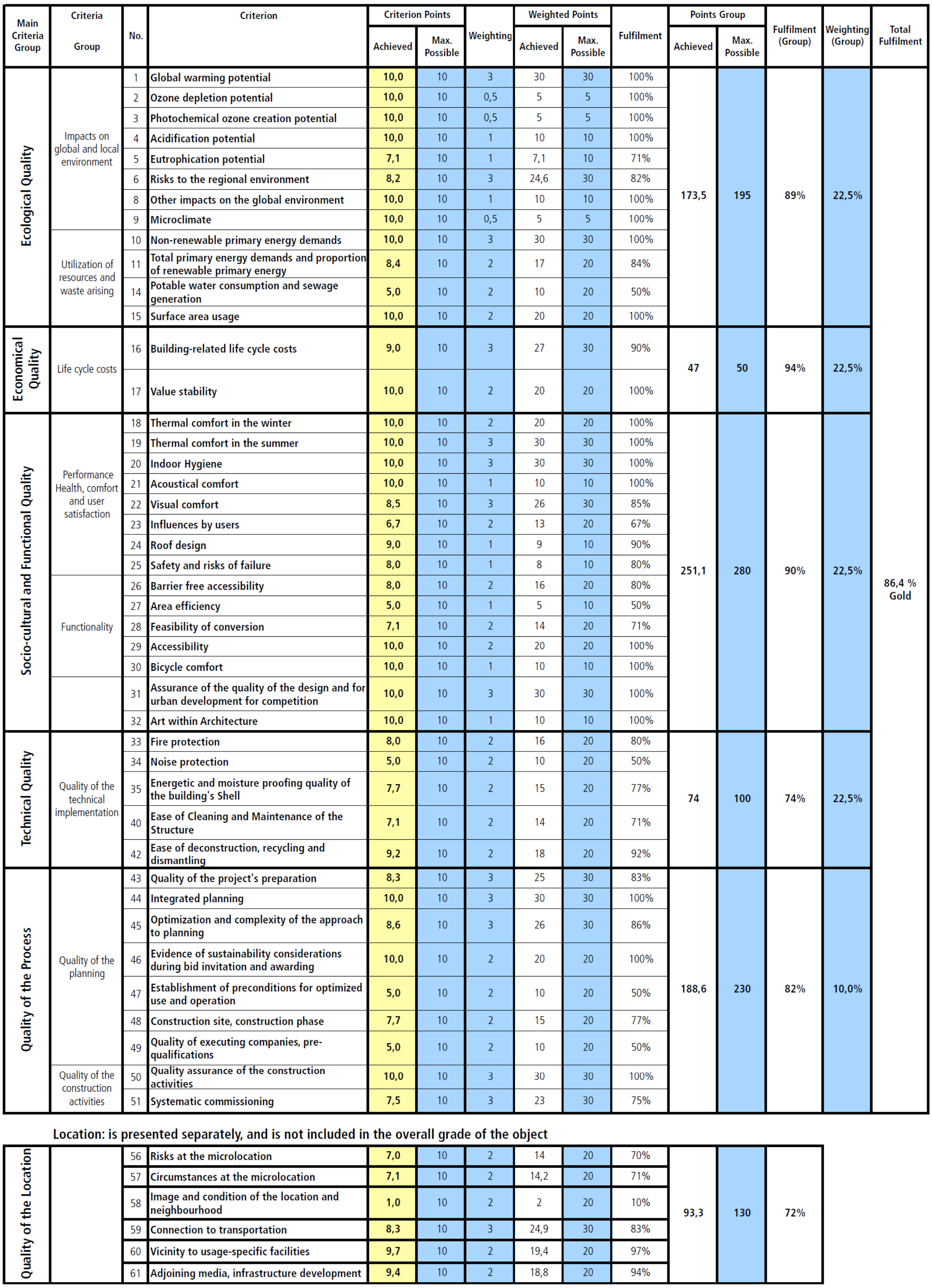


Figure 3.15. Assessment output of the DGNB certification system for a hypothetical case study.



Main Criteria Group	Criteria Group	No.	Criterion	Criterion Points Achieved	Criterion Points Max. Possible	Weighting	Weighted Points Achieved	Weighted Points Max. Possible	Fulfilment	Points Group Achieved	Points Group Max. Possible	Fulfilment (Group)	Weighting (Group)	Total Fulfilment
Ecological Quality	Impacts on global and local environment	1	Global warming potential	10,0	10	3	30	30	100%	173,5	195	89%	22,5%	86,4 % Gold
		2	Ozone depletion potential	10,0	10	0,5	5	5	100%					
		3	Photochemical ozone creation potential	10,0	10	0,5	5	5	100%					
		4	Acidification potential	10,0	10	1	10	10	100%					
		5	Eutrophication potential	7,1	10	1	7,1	10	71%					
		6	Risks to the regional environment	8,2	10	3	24,6	30	82%					
		8	Other impacts on the global environment	10,0	10	1	10	10	100%					
		9	Microclimate	10,0	10	0,5	5	5	100%					
	Utilization of resources and waste arising	10	Non-renewable primary energy demands	10,0	10	3	30	30	100%					
		11	Total primary energy demands and proportion of renewable primary energy	8,4	10	2	17	20	84%					
		14	Potable water consumption and sewage generation	5,0	10	2	10	20	50%					
		15	Surface area usage	10,0	10	2	20	20	100%					
Economical Quality	Life cycle costs	16	Building-related life cycle costs	9,0	10	3	27	30	90%	47	50	94%	22,5%	
		17	Value stability	10,0	10	2	20	20	100%					
Socio-cultural and Functional Quality	Performance Health, comfort and user satisfaction	18	Thermal comfort in the winter	10,0	10	2	20	20	100%	251,1	280	90%	22,5%	
		19	Thermal comfort in the summer	10,0	10	3	30	30	100%					
		20	Indoor Hygiene	10,0	10	3	30	30	100%					
		21	Acoustical comfort	10,0	10	1	10	10	100%					
		22	Visual comfort	8,5	10	3	26	30	85%					
		23	Influences by users	6,7	10	2	13	20	67%					
		24	Roof design	9,0	10	1	9	10	90%					
		25	Safety and risks of failure	8,0	10	1	8	10	80%					
	Functionality	26	Barrier free accessibility	8,0	10	2	16	20	80%					
		27	Area efficiency	5,0	10	1	5	10	50%					
		28	Feasibility of conversion	7,1	10	2	14	20	71%					
		29	Accessibility	10,0	10	2	20	20	100%					
		30	Bicycle comfort	10,0	10	1	10	10	100%					
		31	Assurance of the quality of the design and for urban development for competition	10,0	10	3	30	30	100%					
		32	Art within Architecture	10,0	10	1	10	10	100%					
Technical Quality	Quality of the technical implementation	33	Fire protection	8,0	10	2	16	20	80%	74	100	74%	22,5%	
		34	Noise protection	5,0	10	2	10	20	50%					
		35	Energetic and moisture proofing quality of the building's Shell	7,7	10	2	15	20	77%					
		40	Ease of Cleaning and Maintenance of the Structure	7,1	10	2	14	20	71%					
		42	Ease of deconstruction, recycling and dismantling	9,2	10	2	18	20	92%					
Quality of the Process	Quality of the planning	43	Quality of the project's preparation	8,3	10	3	25	30	83%	188,6	230	82%	10,0%	
		44	Integrated planning	10,0	10	3	30	30	100%					
		45	Optimization and complexity of the approach to planning	8,6	10	3	26	30	86%					
		46	Evidence of sustainability considerations during bid invitation and awarding	10,0	10	2	20	20	100%					
		47	Establishment of preconditions for optimized use and operation	5,0	10	2	10	20	50%					
		48	Construction site, construction phase	7,7	10	2	15	20	77%					
		49	Quality of executing companies, pre-qualifications	5,0	10	2	10	20	50%					
	Quality of the construction activities	50	Quality assurance of the construction activities	10,0	10	3	30	30	100%					
		51	Systematic commissioning	7,5	10	3	23	30	75%					

Location: is presented separately, and is not included in the overall grade of the object

Quality of the Location		56	Risks at the microlocation	7,0	10	2	14	20	70%	93,3	130	72%
		57	Circumstances at the microlocation	7,1	10	2	14,2	20	71%			
		58	Image and condition of the location and neighbourhood	1,0	10	2	2	20	10%			
		59	Connection to transportation	8,3	10	3	24,9	30	83%			
		60	Vicinity to usage-specific facilities	9,7	10	2	19,4	20	97%			
		61	Adjoining media, infrastructure development	9,4	10	2	18,8	20	94%			

Figure 3.14. Example of an evaluation matrix for a building that was awarded with a Gold certificate.

3.5 ERB TOOL

3.5.1 Framework

A number of voluntary environmental assessment methods have been developed since mid-1990. During recent years the interest in, and use of, such methods has greatly increased. Most countries now have access to assessment tools, either their own or internationally applied tools with different characters.

The first tools developed, such as BREEAM and GBTool (later SBTool), were rather limited regarding their content but over time the methods have been increasingly extended to incorporate indicators regarded as measuring the 'sustainability' of buildings in one way or another. Life Cycle Assessment (LCA) has also been introduced into some methods, but so far has not achieved any wider use because of its complexity and a lack of basic data.

In 2005, a broad research group in Sweden published a comprehensive building assessment method called EcoEffect that included all environmental factors with a potential impact on people and the environment. The method used LCA for assessment of building materials and energy use. At that time environmental assessment of buildings was not acknowledged as it is today. For people who were not familiar with this kind of assessment it looked complex and the market had not yet conceded the need to spend considerable amounts of money on building labelling.

In 2005 the question was raised in Sweden as to whether this complexity and the associated relatively high assessment costs were necessary to meet the target of utilising market forces to encourage developers to voluntarily build more environmentally benign buildings. This discussion was accentuated by the fact that the terms 'green building' and 'sustainable building' were unclearly defined and subsequently interpreted differently in different methods and countries.

Furthermore, it became clear that it might be fruitful to distinguish between a tool for environmental analysis of buildings and a tool for environmental rating of buildings. An analysis tool can be more complex and suitable for professionals and academic purposes, while a rating tool has to be more understandable and suitable for market communication. An analysis tool must be strong in the area of calculating environmental impact, while the rating tool has to focus more on assessment efficiency, environmental trends and building technology.

Such considerations led to the development of a rating tool that would:

i) Restrict the number of indicators as much as possible
ii) Find easy ways to assess indicators and thereby keep costs low and attract wider attention
iii) Avoid weighting, which creates an ambiguity that afflicts most previous systems.

In addition, it was concluded that it would be simpler in the future to add an indicator, if needed, rather than to remove an in-built indicator because it was found to be less significant. This new tool was simply called Environmental Rating of Buildings (ERB).

A brief outline of the ERB tool is presented below. A more comprehensive description of the development process and comparisons with tools from other countries are given in Malmqvist et al. (2009). The tool manuals and background reports shown in the reference list are currently only available in Swedish, however.

3.5.1.1 System layout

The target tool limitations led to the decision to:

i) Only assess the building (site and surroundings omitted).
ii) Mainly assess performance (procedures and features omitted).
iii) Focus on the areas of energy, indoor environment and hazardous substances.
iv) A high rated building should also have satisfied users.

With these general goals, the main structure of the system became:

ENERGY	INDOOR ENVIRONMENT	MATERIALS & CHEMICALS
Energy use Energy demand Energy source	Sound environment Air quality Thermal climate Daylight Moisture Legionella risk	Elimination Avoidance

Figure 3.15.1 General lay-out of the ERB tool.

The first edition of ERB is designed for houses and offices. There is one version for new buildings and one for existing buildings. New buildings have to verify their anticipated performance within two years of use. Assessment of existing buildings and verification of new buildings includes a user questionnaire regarding the indoor environment.

ERB has a three-level ranking system. Each indicator is given a score classified BRONZE, SILVER or GOLD. These are aggregated to a rating for the whole building.

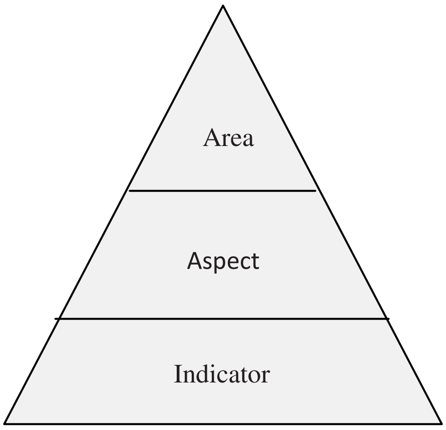


Figure 3.15.2 Ranking system of ERB. Indicators are given scores which are aggregated to scores for aspects, then areas and at last an overall score(rating) for the whole building.

Most indicators have one simple and one more sophisticated way to make the assessment. The simplified assessment is to encourage non-specialists to make the assessment themselves. It is somewhat more difficult to achieve a good rating with the simplified assessment. A brief description of the aims of the indicators and how they are measured is given below.

3.5.2 Assessment procedure

The indicators are presented one by one in Table 3.7.

3.5.2.1 Aggregation

To arrive at a rating for the whole building, aggregation is necessary. However, the weightings applied in most rating tools are based on opinions, for example questionnaires to stakeholders or environmental experts. This becomes quite subjective.

Table 3.7. List of indicators of the ERB Tool.

Issues	Indicators	Aim	Measure
Energy	Energy use	To reward low energy use.	kWh/m2,yr according to the Swedish interpretation of the (EU) European Energy Performance of Buildings Directive (EPBD). This measure is based on energy bills and is thus affected both by the building design and the users' behaviour. Electricity use by tenants is not included mainly because it is paid for by the tenants and data on the amounts are normally not available.
	Energy demand: a) winter	To reward buildings with low mean U-value and high heat exchange rate in ventilation.	Heating power needed to cover transmission and ventilation losses when dimensioning winter temperature.
	Energy demand: b) summer	To reward buildings with low or no cooling demand in summer.	Maximum solar heat load through windows in summer.
	Energy source	To reward use of abundant energy (solar, wind water) in particular and use of biofuels.	Fractions of energy sources used (tenant electricity is included with figures from bills or as default values).
Indoor environment	Acoustic environment	To reward buildings where users are not disturbed by noise (from traffic, installations, appliances, neighbours, etc.).	New buildings: Sound class. Existing building and verification: Subjective assessment and user questionnaire.
	Indoor air quality: a) Radon	To reward buildings with low radon content indoors	Becquerel content in the indoor air (Bq/m^3)
	Indoor air quality: b) Ventilation	To reward good supply of outdoor air.	Air change rate and facilities to increase it. User questionnaire.
	Indoor air quality: c) Traffic pollution	To reward buildings with low traffic-related pollution in the indoor air	When close to roads with heavy traffic, monitoring of N_2O content (µg/m^3)
	Moisture prevention	To reward buildings without moisture impairments and with moisture preventing constructions.	New buildings: Follow certain guidelines and employ a moisture prevention expert. Existing buildings: Inspection by a moisture prevention expert.
	Thermal climate: a) Winter	To reward buildings with low risk of thermal discomfort during winter.	Simplified – a factor based on size and U-value for windows. Sophisticated: Simulation of operative temperatures. User questionnaire.
	Thermal climate: b) Summer	To reward buildings with low risk of thermal discomfort during summer.	Simplified – a factor based on size and solar transmission for windows. Sophisticated: Simulation of operative temperatures. User questionnaire.
		To reward buildings with good internal daylight.	Simplified: Window area by floor area. Sophisticated: Calculation of daylight factors.

Table 3.7 (cont.). List of indicators of the ERB Tool.

Indoor environment (cont.)	Risk of legionella	To reward buildings with low risk of legionella in tap water systems.	Cold and hot water temperatures
Materials and chemicals	Hazardous materials: a) Elimination	Existing buildings: To reward investigation and elimination of hazardous materials. New buildings: To reward documentation of constituent materials and their composition	Existing buildings: Investigation and elimination of certain well-known hazardous materials, such as PCB, asbestos, lead, etc. New buildings: Documentation of constituent materials in the building envelope and the structure, including amounts, place and composition – a digitalised logbook.
	Hazardous materials: b) Avoidance (only new constructions)	To reward the avoidance of building materials with hazardous properties.	Checks that no hazardous substances above certain limits have been incorporated according to the digitalised logbook (limits according to the Swedish Chemicals Agency).

Furthermore, in most assessment tools poor scores in one area can be compensated for by higher scores in another. This might encourage clients to look for indicators that are cheapest to assess to compensate for poor scores, reducing the environmental ambition. It also means that even high rated buildings may have serious drawbacks on some issues. The aims when developing aggregation in ERB were that:

i) Any building with a high environmental rating should not have serious deficiencies in any area.
ii) Subjective weighting is avoided.

These targets led to an aggregation system based on the premise that any poor score has an impact on the final rating, i.e. poor scores persist throughout the aggregation process. This is very demanding, but guarantees that a high rated building has no serious drawbacks. However, to make it slightly easier to achieve a good building rating, this principle was slightly softened at the mid-level of the aggregation, as shown in Table 3.8.

Table 3.8. Aggregation process for ERB

Aggregation from indicator to aspect	Lowest score is received
Aggregation from aspect to area	One step higher score than the lowest is received if at least 50% of the scores are higher than the lowest
Aggregation from area to building rating	Lowest score is received

This means that a building can get a rating that is at most one level higher than the lowest score on any issue, i.e. when aiming for GOLD, no individual score can be below SILVER, or when aiming for SILVER no individual score can be below BRONZE, etc. This system always encourages the client to improve the weak properties of the building. Figure 3.16 shows an example of aggregation.

Building	Area	Class	Aspect	Class	Indicator	Class
SILVER	Energy	GOLD	Energy use	GOLD	Bought energy	GOLD
			Energy need	SILVER	Heat loss number	SILVER
					Solar heat load	GOLD
			Energy source	GOLD	Fraction of energy carriers	GOLD
	Indoor environment	SILVER	Noise	GOLD	Noise	GOLD
			Air quality	GOLD	Radon	GOLD
					Ventilation	GOLD
					N_2O to indoor air	GOLD
			Moisture	SILVER	Moisture prevention	SILVER
			Thermal climate	GOLD	Thermal climate winter	GOLD
					Thermal climate summer	GOLD
			Daylight	BRONZE	Daylight	BRONZE
			Water	BRONZE	Legionella	BRONZE
	Material & chemicals	SILVER	Documentation	SILVER	Documentation of materials and chemicals	SILVER
			Verification	SILVER	Verification that hazardous materials are not included	SILVER

Figure 3.16 Example of the ERB aggregation process, including an overview of the tool. Example shown is for a new building that received a SILVER rating.

3.5.2.2 Ways of making the assessment easier

To simplify assessment, especially for non-professionals, Excel spreadsheets have been developed for:

i) Aggregation
ii) Ventilation and transmission losses in winter
Energy source rating, including fuel ratios of all Swedish district heating systems.

3.5.3 Case study

The system with all its necessary manuals, committees, assessment processes including independent auditors, assessment taxes, etc. was finalised this year (2010). Before summer three buildings had been awarded their final rating, nine had been audited and a number had started the process. Some major building owners' organisations have decided to urge their members to classify their buildings according to ERB. To illustrate the wide span of applications of the ERB tool, the assessments for two buildings are shown below, one large office building and one single family house.

3.5.3.1 Office building: Hagaporten 3, Stockholm

Assessed as an existing building

Year of construction:	2008
Office area:	30 000 m^2
Owner:	Skanska Fastigheter Stockholm AB
Architect:	Strategisk arkitektur
Building rating:	GOLD
Assessment approved:	30 April 2010

Figure 3.17. External view of the of the Hagaporten 3 office building (case study).

Building	Area	Class	Aspect	Class	Indicator	Class
GOLD	Energy	GOLD	Energy use	GOLD	Bought energy	GOLD
			Energy need	SILVER	Heat loss number	SILVER
					Solar heat load	SILVER
			Energy source	GOLD	Fraction of energy carriers	GOLD
	Indoor environment	GOLD	Noise	GOLD	Noise	GOLD
			Air quality	SILVER	Radon	SILVER
					Ventilation	GOLD
					N_2O to indoor air	SILVER
			Moisture	SILVER	Moisture prevention	SILVER
			Thermal climate	GOLD	Thermal climate winter	GOLD
					Thermal climate summer	GOLD
			Daylight	GOLD	Daylight	GOLD
			Water	GOLD	Legionella	GOLD
	Materials & chemicals	GOLD	Documentation	GOLD	Documentation of materials and chemicals	GOLD
			Verification	GOLD	Verification that hazardous materials are not included	GOLD

Figure 3.18. Aggregation chart with indicator assessments of the Hagaporten 3 office building.

3.5.3.2 Single family house: Villa Trift 3.0, Lund

Assessed as a new building

Year of construction	2010
Living area:	132 m^2
Owners:	Kiran & Krister Gerhardsson
Architect:	Pecan Studio
Building Rating:	SILVER
Assessment approved:	14 June 2010

Figure 3.19. External view of the of the Villa Trift single family house (case study).

Building	Area	Class	Aspect	Class	Indicator	Class
SILVER	Energy	GOLD	Energy use	GOLD	Bought energy	GOLD
			Energy need	SILVER	Heat loss number	SILVER
					Solar heat load	GOLD
			Energy source	GOLD	Fraction of energy carriers	GOLD
	Indoor environment	SILVER	Noise	GOLD	Noise	GOLD
			Air quality	GOLD	Radon	GOLD
					Ventilation	GOLD
					N_2O to indoor air	GOLD
			Moisture	SILVER	Moisture prevention	SILVER
			Thermal climate	GOLD	Thermal climate winter	GOLD
					Thermal climate summer	GOLD
			Daylight	BRONZE	Daylight	BRONZE
			Water	BRONZE	Legionella	BRONZE
	Materials & chemicals	SILVER	Documentation	SILVER	Documentation of materials and chemicals	SILVER
			Verification	SILVER	Verification that hazardous materials are not included	SILVER

Figure 3.20. Aggregation chart with indicator assessments of the Villa Trift single family house.

3.6 GREENCALC+ TOOL

3.6.1 Framework Greencalc+

Greencalc+ is a tool in which the various impacts on the environment are assessed. It measures the sustainability of the built environment. The three main themes are material use, water use and energy use. It expresses the result in a so-called environmental index (Milieu-index).

One of the main problems in these assessments usually is the aggregation and evaluation of different impact categories. Greencalc tries to solve this problem by using a method called "Monetarising". Monetarising is the process of valuing the (hidden) costs of the environmental effects. For this reason Greencalc+ expresses all the effects in a single, monetary, unit (€). The use of the "Hidden Environmental Costs" solves this aggregation problem. Fig 3.21 shows where the monetarisation takes place in the assessment process.

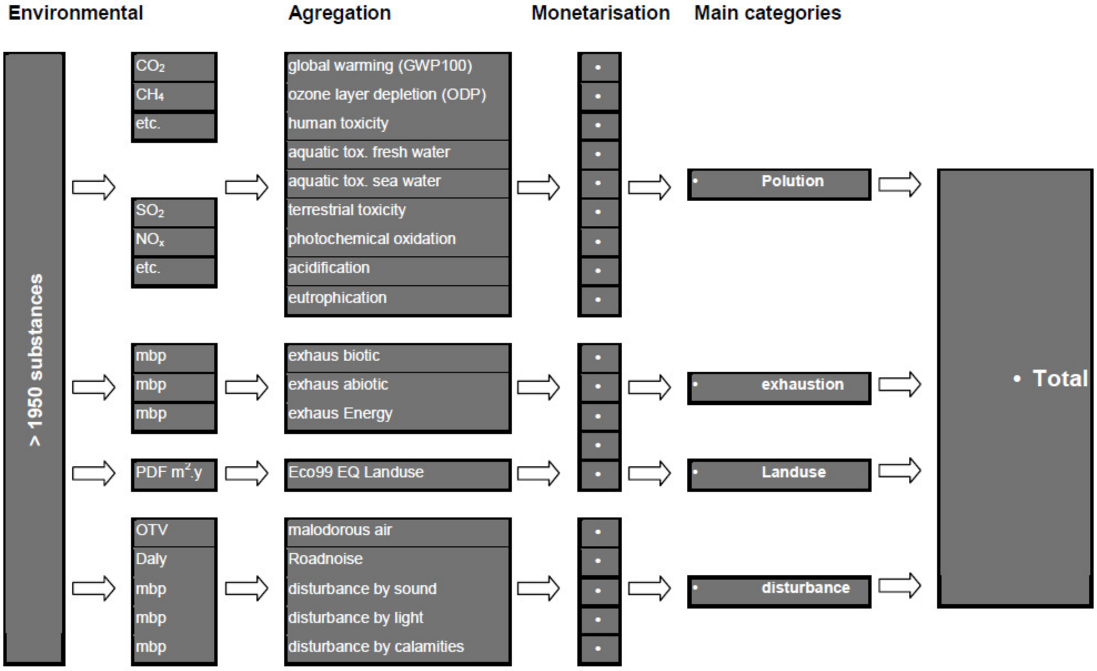


Figure 3.21. Greencalc+ method using Monetarisation

Greencalc can be seen in the light of the developments in sustainable building by several organizations. First known manuals and guidebooks were based on early experiments by individuals and starting organization. NIBE, in Dutch: "Nederlands Instituut voor Bouwbiologie en Ecologie", first developed lists with "environmental classifications of building materials" and also SEV, "Sustainable housing", provided recommendations for sustainable building. The development of Greencalc was the result of an increasing need for models to further assess the environmental quality of buildings. Greencalc was first developed to assess office buildings and is later adapted to make it possible to assess other buildings as well, including housing.

Greencalc is now a tool that makes it possible to assess and compare the environmental impact of a building, (or even a neighbourhood).

3.6.2 Assessment procedure

In Greencalc a single number that expresses the sustainability level of the building, the MIG, (in Dutch: "Milieu Index Gebouw" meaning "Environmental Building Index") is calculated. Assessed are the Energy efficiency, the Water consumption, the Material use and possibly the Disturbances (nuisances).

The now latest version is called Greencalc+. It was developed by NIBE with DGMR consultants. The foundation SUREAC, "SUstainable Real Estate Accountancy & Certification" is now responsible for and further use and development of Greencalc+.

The assessment with Greencalc+ will result in a simple number mostly between 100 and 2000. The higher the number, the better the resulting sustainability is assessed. The number 100 corresponds with an average building quality in the year 1990 (for the Dutch situation). The number 2000 (for now a far away goal that still lies in the future) means that a quality of the building is assessed as 20 times the average building quality of 1990.

This goal of an increased building quality of 20 times the quality of 1990 was formulated to be achieved over the following 50 years (calculated from early 1990). The main goal has been formulated as a reduction of the environmental burden (or pressure) with a factor of 2. On the basis of setting this goal, was the expectation that in 2050 the world population will have increased with a factor of 2 and that the average prosperity should have increased with a factor 5. Furthermore the following simple Equation 3.4 was used:

$$B = N \times P \times E \tag{3.4}$$

in which,
B = environmental burden,
N = total Word population,
P = average Prosperity of a world citizen,
E = aggregated Environmental effects per unit of prosperity

In order to reduce B with a factor of 2, given the increase in population and prosperity, E should reduce with a factor of 20: ($\frac{1}{2} = 2 \times 5 \times 1/20$)

Most current best practice show at time of writing show results with scores of MIG of about 250 – 300, (which is still a remarkable long way off from the set goal in 2050: 2000). Best scores so far have the Dutch project for TNT (score 632), Veenendaal and, number two, Rijkswaterstaat building in Terneuzen (score 323).

Because it shows that apart from the building design also the operation of the building proves extremely important in the resulting impacts, Greencalc+ also makes it possible to assess the use and operation of a the building. This operation is expressed in the MIB, (operation building index)

For the Energy module the calculations are based on the Dutch Building Energy standards. For the Materials module the product-database comes from the so- called TWIN-model (Haas 1997). This model differs from standard LCA damage assessment methods. The usual problem with LCA calculations and other assessment methods and tools is that environmental impacts and other sustainability effects are very difficult to aggregate. The use of weighting factors etc. therefore becomes necessary. It becomes almost impossible to compare and evaluate environmental impacts because they all have very different effects and are all of a different nature and are all calculated and expressed in different units.

As mentioned before, Greencalc solves this problem by using a method called "Monetarising". Monetarising is the process of valuing the (hidden) costs of the environmental effects. It expresses all the effects in a single, monetary, unit (€). The use of the "Hidden Environmental Costs" solves the aggregation problem. The hidden environmental costs are defined as the costs necessary to prevent (or undo) all negative environmental effects associated with the used process or material. These hidden costs are the cost resulting from the effects and damage caused by using a particular process or material. These can be the costs necessary to prevent the damage or the costs necessary for the repair of the damage to the environment.

3.6.3 Prevention costs

Greencalc chooses to use the prevention costs (rather than the cost necessary for repair). The prevention of negative impacts and its associated costs however is far from easy. It still poses many problems. The average user of the tool, architect, designer, client need not be bothered by this, for the scientific reliability however it requires some discussion.

A major problem for example is to what level the prevention of impacts should be reduced. In other words where lays the acceptable sustainability level of a given impact? What is for example a sustainable or acceptable level of CO2 concentration in our atmosphere? What is, resulting from that acceptable concentration level an acceptable emission level or an acceptable reduction level? Assumed that this sustainable emission level can be calculated, it is then assumed that the contributions to this reduction are then evenly divided, between for example transport related CO2 and building material CO2, in line with the cost effectiveness of the measures (thus ignoring political or branch dependent effects). Furthermore it can be argued that small differences in the accepted sustainability levels between different impacts can result in very different outcomes favouring some materials over others. See also figure 3.21

Another problem is calculating the costs of the prevention of this damage. For a large part, these are virtual (future) measures (not yet in place). Greencalc tries to solve all these problems in a clear and consistent way however. Still most of these cost calculations can only be followed by experts. The method uses "cost effectiveness curves", (expressing that the first measure for reduction of impacts are relatively simple and low cost measures, whereas the last measures to actually reach the required sustainability level involve more difficult and expensive measures). Estimating these costs proves difficult and results show a wide range in the expected accuracy of the chosen numbers. Furthermore it can be argued that (the development of) the cost effectiveness curves are likely to be subject to political decisions, allocation of research funds, market developments etc.. Also sometimes rather subjective assumptions seem unavoidable.

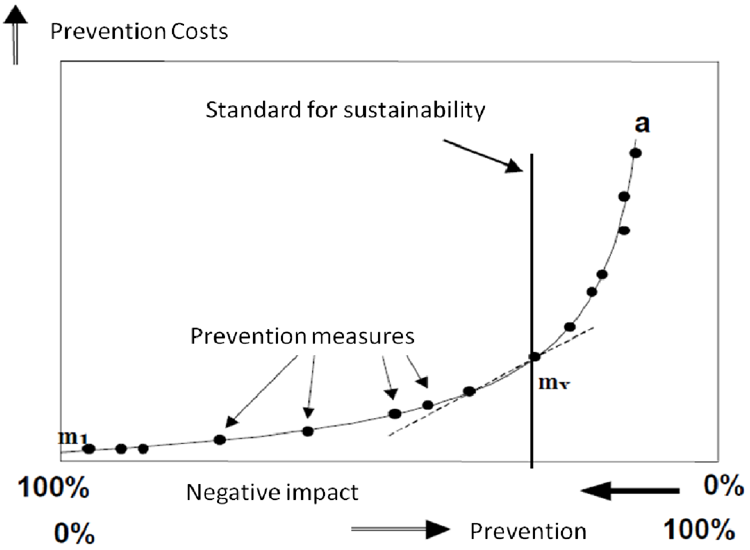


Figure 3.22 Using Cost effectiveness curves in calculating prevention costs (figure adapted from www. Greencalc.com)

For further backgrounds on the methods of Monetarising as the basis for Greencalc+ is referred to [NIBE 2002].

3.6.4 Design

However difficult perhaps the background, the use of one simple monetary unit give Greencalc+ strong advantages namely the ease of use and the easy way that simple results can be generated and made visible. Because all the effects are expressed in Euro's, it is very easy to aggregate and compare the results. It makes the tool very useful already in an early design stage, for example assessing with the client the level of required sustainability or evaluating in an early stage the effects of different measures.

One of its strong features is the wizard. In 5 simple steps a complete building (design) can be assessed and with simple steps the effects and influence of changes/ improvements for alternatives can be made visible. The Greencalc Wizard makes it possible to assess a building within a limited time span. The Tool generates results on different levels. It can show results on the level of building elements, building products, or on the level of energy, water and mobility. Results are calculated in hidden environmental costs (euro's). Like in a standard LCA method the numbers can never be used in an absolute way but the results are always shown in comparison with a reference building. This reference building is given an index of 100. Then the final Building Index of the assessed building, the MIG, is calculated using Equation 3.5.

$$MIG = 100 \times C_{ref} / C_{ass} \qquad (3.5)$$

C ref = environmental costs of a automatically generated reference building
C ass = environmental costs of assessed building

In the MIG the use and operation of the building can be included. (In order to compare the assessed building with a standard reference building, the program calculates a standard building user which is generated for the reference building. It uses fixed numbers based on for example standard working hours, standard m2 per user etc.)

The steps that are being followed are:

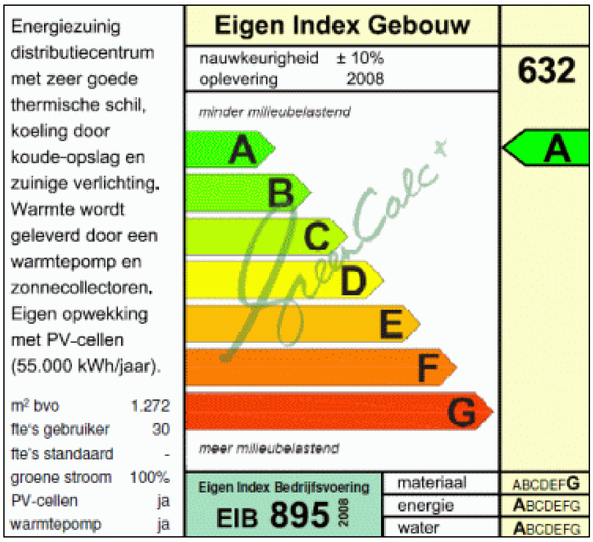
i) Quantification of all effects
ii) Monetarisation of the effects
iii) Aggregation of effects and costs
iv) Comparing with a reference projects

The way that the Monetarising process works is given below (The first four steps are similar to a standard LCA approach):

i) Determining the amounts of materials
ii) Determining the involved substances
iii) Classification and calculation of equivalent amounts (LCA) of
  - Pollution: emissions (global warming potential, ozone layer depletion, humane toxicity, eutrophication etc.)
  - Exhaustion (depletion of fossil fuels, biotic and abiotic depletion
  - Land use
  - Disturbances, hinder due to stench, traffic noise, production noise, light and probability of calamities are regarded.
iv) Aggregation
v) Monetarisation
vi) Total effects

Also because these costs are subject to a constant changing market it is not clear what the accuracy of the values are at the time of calculating. How to compare buildings build under different market situations? If CO2 prevention or storage becomes less expensive than expected before, does this mean that the sustainability results improve without taking any actions towards real improvement to our buildings?

Figure 3.23. TNT Veenendaal, Distribution centre in the Netherlands with currently the highest Greencalc score (632)



Energiezuinig distributiecentrum met zeer goede thermische schil, koeling door koude-opslag en zuinige verlichting. Warmte wordt geleverd door een warmtepomp en zonnecollectoren. Eigen opwekking met PV-cellen (55.000 kWh/jaar).

m² bvo	1.272
fte's gebruiker	30
fte's standaard	-
groene stroom	100%
PV-cellen	ja
warmtepomp	ja

Eigen Index Gebouw

nauwkeurigheid ± 10%
oplevering 2008

632

minder milieubelastend

meer milieubelastend

Eigen Index Bedrijfsvoering
EIB 895 2008

materiaal	ABCDEF**G**
energie	**A**BCDEFG
water	**A**BCDEFG

Figure 3.24. The way that the “Milieu Index” is expressed by Greencalc+

Figure 3.25. The electricity is generated by 300 PV panels on the roof

3.7 METHODOLOGIES BREEAM AND LEED

3.7.1 Framework of BREEAM

The Building Research Establishment Environmental Assessment Method (REEAM) was created in 1990. Versions are updated regularly according to changing UK Building Regulations and different versions have been created for different building types.

Categories of this assessment process are: Management; Health and Wellbeing; Energy; Transport; Water; Material and Waste; Land use and Ecology; and Pollution.

For these areas, performance credits are awarded. According to the weightings of categories credits are formed in order to produce a single overall score. The building is then rated on a scale of: pass, good, very good, excellent or outstanding (Figure 3.26). Although this method was initially developed for the United Kingdom’s context, there are nowadays some modules that could be applied at the European level or in such a different context like the Middle East.

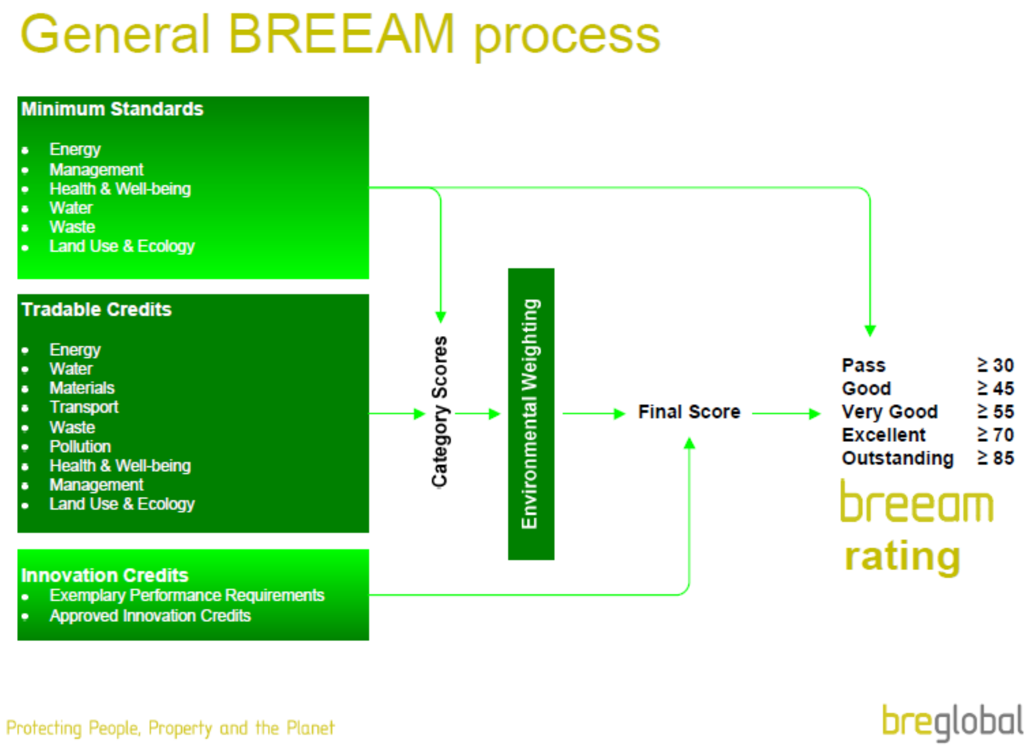


Figure 3.26. Framework of BREEAM methodology (source: BREEAM, 2009).

3.7.1.1 Indicators

The number and type of issues varies from building type. Table 3.9 presents the categories and the criteria of the BREEAM methodology for Europe. This approach has 9 categories and 70 criteria.

3.7.1.2 Aggregation

Rather than using an aggregation method, this methodology is based in a system of credits. Credits are awarded according to the conditions that are fulfilled. Nevertheless, issues of major importance have higher credits.

Since this approach could be used in the Middle East, the system of credits was adjusted in order to consider the local environmental, social and economy context. Table 3.10 presents the weight of the main categories of the BREEAM Europe and compares it to the ones of the BREEAM Gulf.

Table 3.9. List of categories and issues of the BREEAM Europe method (BREEAM, 2009)

Main Categories	Issues
1. Management	1. Commissioning 2. Considerate constructors 3. Construction site impacts 4. Building user guide 5. Life cycle costing
2. Health & Wellbeing	6. Daylighting 7. View out 8. Glare control 9. High frequency lighting 10. Internal and external lighting levels 11. Lighting zones and controls 12. Potential for natural ventilation 13. Indoor air quality 14. Volatile organic compounds 15. Thermal comfort 16. Thermal zoning 17. Microbial contamination 18. Acoustic performance 19. Office space (issue not assessed in the offices scheme)
3. Energy	20. Reduction of CO2 emissions 21. Sub-metering of substantial energy uses 22. Sub metering of high energy load and tenancy areas 23. External lighting 24. Low or zero carbon technologies 25. Building fabric performance & avoidance of air infiltration 26. Cold storage 27. Lifts 28. Escalators & travelling walkways
4. Transport	29. Provision of public transport 30. Proximity to amenities 31. Cyclist facilities 32. Pedestrian and cyclist safety 33. Travel plan 34. Maximum car parking capacity 35. Travel information point 36. Deliveries and manoeuvring
5. Water	37. Water consumption 38. Water Meter 39. Major leak detection 40. Sanitary supply shut-off 41. Water recycling 42. Irrigation systems 43. Vehicle wash
6. Materials	44. Materials specification (major building elements) 45. Hard landscaping and boundary protection 46. Reuse of building façade 47. Reuse of building structure 48. Responsible sourcing of materials 49. Reuse of building façade 50. Insulation 51. Designing for robustness

Table 3.9 (cont.). List of categories and issues of the BREEAM Europe method (BREEAM, 2009)

Main Categories	Issues
6. Materials	52. Materials specification (major building elements) 53. Hard landscaping and boundary protection 54. Reuse of building façade 55. Reuse of building structure 56. Responsible sourcing of materials 57. Reuse of building façade 58. Insulation 59. Designing for robustness
7. Waste	60. Construction Site Waste Management 61. Recycled aggregates 62. Recyclable waste storage 63. Compactor / Baler 64. Composting 65. Floor finishes
8. Land Use and Ecology	66. Reuse of land 67. Contaminated land 68. Ecological value of site and Protection of ecological features 69. Impact on site ecology 70. Long term impact on biodiversity
9. Pollution	71. Refrigerant GWP - Building services 72. Preventing refrigerant leaks 73. Refrigerant GWP - Cold storage 74. NOx emissions from heating source 75. Flood risk 76. Minimising watercourse pollution 77. Reduction of night time light pollution 78. Noise attenuation

Table 3.10. List of categories and weightings of BREEAM Europe and BREEAM Gulf methods (BREEAM, 2009)

Category	BREEAM Europe (%)	BREEAM Gulf (%)
Management	12	8
Health and wellbeing	15	15
Energy	19	13
Transport	8	6
Water	6	30
Materials	12.5	9
Waste	7.5	5
Land use & ecology	10	7
Pollution	10	7

3.7.2 Framework of LEED

The Leadership in Energy and Environmental Design (LEED) was developed by the United Stated Green Building Council (USGBC). This is a voluntary process that can be applied to any building type.

LEED produces a whole-building approach for sustainability issues according to performance criteria in key areas. According to the weightings of categories, credits are formed in order to produce a single overall score. The building is then rated on a scale of: Certified (40 + points); Silver (50 + points); Gold (60 + points); and Platinum (80 + points).

This method in the 2009 version uses the U.S. Environmental Protection Agency's TRACI environmental impact categories as the basis for weighting each credit.

TRACI is a computer software tool developed by the U.S. EPA to assist with impact assessment for Life Cycle Assessment, Industrial Ecology, Process Design, and Pollution Prevention. The TRACI categories were selected because they represent a comprehensive, currently available complement to LEED which is appropriate for the North American building market. This environmental method was developed to assist with impact evaluation for life-cycle assessment, industrial ecology, process design, and pollution prevention. Figure 3.22 present the framework of the TRACI Tool and Figure 3.23 shows how the results are integrated in the LEED 2009 assessments.

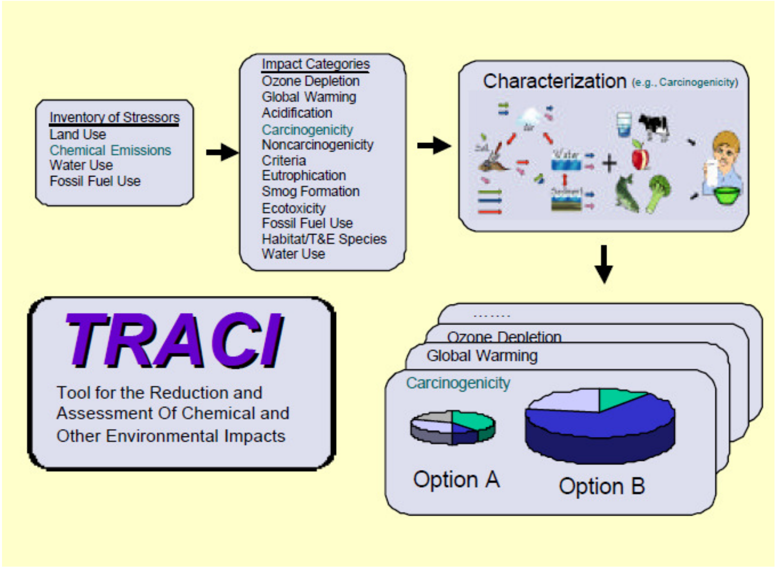


Figure 3.27. Framework of the TRACI Tool (Source: USGBC, 2009a).

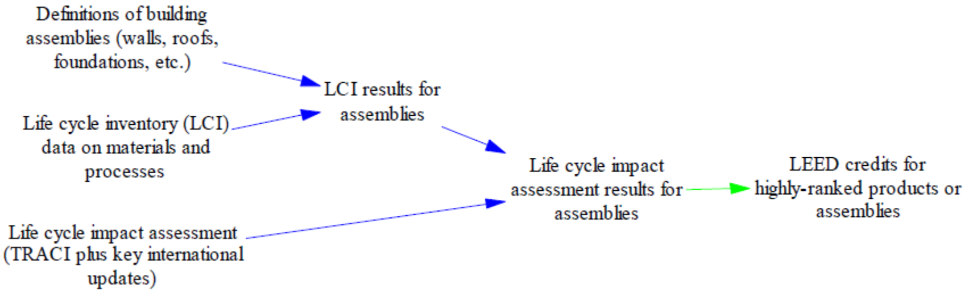


Figure 3.28. The use of the results from TRACI in the LEED 2009 (source: Gregory, 2007).

LEED 2009 also takes into consideration the weightings developed by the National Institute of Standards and Technology (NIST); these compare impact categories with one another and assign a relative weight to each.

Together, the two above mentioned approaches provided a more objective foundation for determining the point value of each credit in LEED 2009.

3.7.2.1 Indicators

In LEED there are different tools for different building types. Additionally there are specific tools for each life-cycle stage that is intended to be assessed. Accordingly the list of indicators is different from tool to tool and Table 3.11 lists the categories, pre-requisites and sustainability indicators of LEED 2009 for New Construction and Major Renovations Projects.

Table 3.11. List of categories, pre-requisites and indicators of LEED 2009 for New Construction and Major Renovations Projects (USGBC, 2009b)

Categories	Pre-requisites	Criteria
1. Sustainable sites	Construction Activity Pollution Prevention Required	1.Site Selection 2.Development Density and Community Connectivity 3.Brownfield Redevelopment 4.Alternative Transportation 4.1 Public Transportation Access 4.2 Bicycle Storage and Changing Rooms 4.3 Low-Emitting and Fuel-Efficient Vehicles 4.4 Parking Capacity 5.Site Development 5.1 Protect or Restore Habitat 5.2 Maximize Open Space 6.Storm water Design 6.1 Quantity Control 6.2 Quality Control 7.Heat island effect 7.1 Non-roof 7.2 Roof 8.Light Pollution Reduction
2. Water Efficiency	Water Use Reduction Required	9.Water Efficient Landscaping View out 10.I innovative Wastewater Technologies 11.Water Use Reduction
3. Energy and atmosphere	1. Fundamental Commissioning of Building Energy Systems Required 2. Minimum Energy Performance Required 3. Fundamental Refrigerant Management Required	12.Optimize Energy Performance 13.On-site Renewable Energy 14.Enhanced Commissioning 15.Enhanced Refrigerant Management 16.Measurement and Verification 17.Green Power
4. Materials and Resources	Storage and Collection of Recyclables Required	1. Building Reuse 18.1 Maintain Existing Walls, Floors and Roof 18.2 Maintain Existing Interior Non-structural Elements 2.Construction Waste Management 3.Materials Reuse 4.Recycled Content 5.Regional Materials 6.Rapidly Renewable Materials 7.Certified Wood

Table 3.11 (cont.). List of categories, pre-requisites and indicators of LEED 2009 for New Construction and Major Renovations Projects (USGBC, 2009b)

Categories	Pre-requisites	Criteria
5. Indoor Environmental Quality	1. Minimum Indoor Air Quality Performance Required 2. Environmental Tobacco Smoke (ETS) Control Required	8.Outdoor Air Delivery Monitoring 9.Increased Ventilation 10.Construction Indoor Air Quality Management Plan 27.1 During Construction 27.2 Before Occupancy 11.Low-Emitting Materials 28.1 Adhesives and Sealants 28.2 Paints and Coatings 28.3 Flooring Systems 28.4 Composite Wood and Agrifiber Products 12.Indoor Chemical and Pollutant Source Control 13.Controllability of Systems 30.1 Lighting 30.2 Thermal Comfort 14.Thermal Comfort 14.1. Design 14.2. Verification 15.Daylight and Views 32.1 Daylight 32.2 Views
6. Innovation in design		16.Innovation in Design 17.LEED Accredited Professional
7. Regional Priority		18.Regional Priority

3.7.2.2 Aggregation

Rather than using an aggregation method, this methodology is based in a system of credits. Credits are awarded according to the conditions that are fulfilled. As in BREEAM, issues of major importance have higher credits. The weight of each category in the overall performance varies depends on the building type under assessment. Table 3.12 presents the weight of the main categories of LEED 2009 according to the type of project.

3.7.3 Comparison between BREEAM and LEED

BREEAM and LEED are the two most used worldwide sustainability certification schemes. Therefore there is a lot of published data showing the pros and cons of the two approaches. Table 3.13 presents a summary of the main details and differences of the two schemes. Figure 3.29 summarizes the differences at the level of the main sustainability categories and the importance of each in the overall score.

Table 3.12 presents the coverage of the key-issues on sustainable building by the two schemes. The presented key-issues are those that are normally considered relevant, at international level, in a sustainability assessment and certification methodology.

Table 3.12. Weight of the main categories of LEED 2009 according to the type of project. (USGBC, 2009a)

Main categories	Weights according to the type of project (%)				
	Schools	Commercial	Existing buildings	New construction	Core & shell
1. Sustainable sites	24	21	26	26	28
2. Water efficiency	11	11	14	10	10
3. Energy and atmosphere	33	37	35	35	37
4. Energy and atmosphere	14	14	10	14	13
5. Indoor environ. quality	19	17	15	15	12
6. Innovation in design	6	6	6	6	6
7. Regional priority	4	4	4	4	4

Table 3.13. Main details and differences of LEED and BREEAM International

Field	Scheme	
	LEED	BREEAM International
Organization	USGBC	BRE
Start date	1998	1990
Inspector	USGBC	Authorized assessors
Experts	LEED accredited professionals	BREEAM assessors
Levels of certification	Certificate/Silver/Gold/Platinum	Pass/Good/Very Good/Excellent/Outstanding
Certificate fees	$ 2.250 - $ 22.500 + Consultant* (if the building can get platinum then the fee for the certificate taken back)	£ 1500 + assessor + consultant * (voluntary)
Other Fees	$ 220 – Credit explanation request $ 500 – Objection to the score	----
Revision of the indicators and criteria	If it is necessary	Every year
Certificate types	One type certificate after the construction	Two different certificates Design and After Construction
Reference documents	$ 200 fee (open to public)	Open for only assessors
Regulations	American ASHRAE standards	European and UK legislation.
Weights	Independent from the context. Calculated credits of LEED are linked to the US Dollar (especially the energy credits).	Varies accordingly to the context (e.g. in BREEAM Gulf, water is a key-issue – rather than in energy in the standard UK schemes)
Special buildings	----	If there a building does not fit neatly into one of the existing schemes, by the help of BREEAM Bespoke BRE can develop assessment criteria specially tailored to a building.

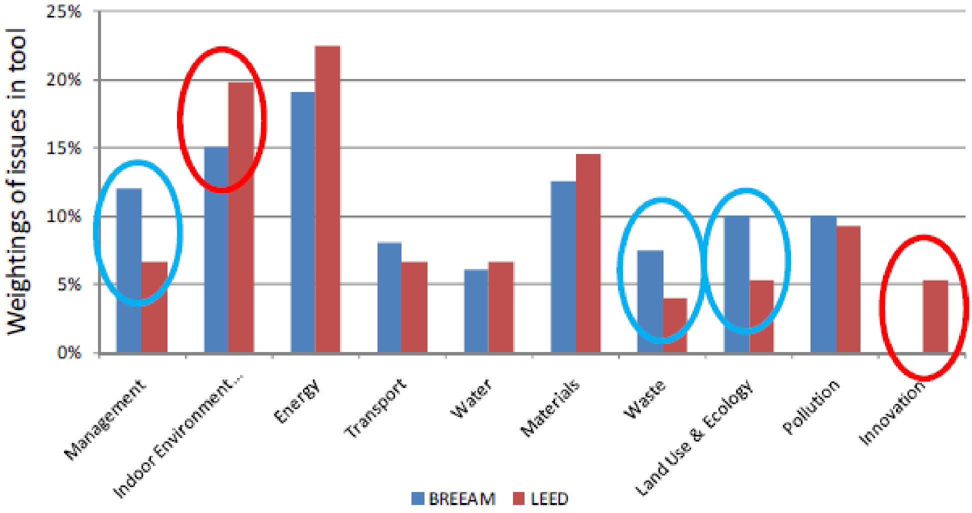


Figure 3.29. Sustainability categories and the importance of each in the overall score. (source: Saunders, 2008).

Table 3.14. Coverage of key-areas on sustainable building by LEED and BREEAM International (Ding, 2008)

Key-areas on sustainable building	Issues covered	
	LEED	BREEAM
GENERAL		
Energy Saving	★	★
Preparation of building usage guideline		★
Re-use of land or rehabitated land use	★	★
Enough space for recycling of waste	★	★
Maximization of green areas	★	
Decreasing the heat islands	★	
ELECTRO MECHANICAL SYSTEMS		
Commissioning (Automatic activation)	★	★
Minimizing lighting level		★
Comfort components for lighting	★	★
Fresh air level	★	★
Thermal comfort components	★	★
Observation of energy consumption	★	★
Decreasing the lighting dirtiness	★	★
Encouraging the use of renewable energy in the field	★	
WATER USAGE SAVINGS		
Usage of water saving equipment	★	★
Leaking sensors		★
Landscape design with water saving plans	★	
Observation of water usage	★	★
ENVIROMENTAL POLLUTION		
Calculations for reducing CO2 emissions		★
Preventing the pollution during construction	★	★
Calculating the ecological value of the land		★
Reducing the heat carrying fluid impacts for ozone layer	★	★
Reducing the emissions of NOX		★
Reducing the impacts of insulation layers to global warming		★
Reducing the risk of torrent	★	★

Table 3.14 (cont.). Coverage of key-areas on sustainable building by LEED and BREEAM International

Key-issues on sustainable building	Issues covered	
	LEED	BREEAM
MATERIAL		
Sustainable material selection	★	★
Recycled material choice	★	★
Re-use of building skeleton and shell	★	★
Regional material selection	★	
HUMAN HEALTH AND PROSPERITY		
Acoustic Performance		★
Low volatile component material use	★	
Day light and dazzling applications	★	★
High frequency lighting		★
Preventing the interior air pollution	★	★

3.8 METHODOLOGY CASBEE

3.8.1 Background

Comprehensive Assessment System for Built Environment Efficiency (CASBEE) is an assessment tool which is based on the environmental performance of buildings. In Japan, a joint project of industrial, governmental and academic was initiated by being supported by the Housing Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), in April 2001. This led to the establishment of a new organization, the Japan Green Building Council (JaGBC)/ Japan Sustainable Building Consortium (JSBC) and its secretariat administered by the Institute for Building Environment and Energy Conservation (IBEC). Additionally for R&D of the Comprehensive Assessment System for Building Environmental Efficiency, JaGBC, JSBC and subcommittees are working together (IBEC, 2010a).

Since 2001, when the development procedure of CASBEE has been started, JaGBC/ JSBC is working on development and updating the CASBEE systems with different tools, such as CASBEE for new construction, CASBEE for existing building, CASBEE for renovation, CASBEE for heat island, CASBEE for urban development, CASBEE for an urban area + buildings, CASBEE for home (detached house), and CASBEE property appraisal.

Development of CASBEE which is started from perception that a new system had to be clearly based on the perspective of sustainability resulted as the concept of closed ecosystems became important for determining environmental capacities while dealing with environmental assessments. For this reason, a hypothetical enclosed space which is bounded by the borders of the building site is proposed in this assessment system in making environmental assessments of buildings. And the environmental loadings can have a definition as “the negative environmental impact that extends outside to the public environment beyond the hypothetical enclosed space”. And also the progress of environmental performance within the hypothetical enclosed space has a definition as “the improvement in living amenities for building users” (IBEC, 2010b).

For CASBEE, Eco-Efficiency is defined as to enable the integrated assessment of two factors, inside and outside the building site. The original definition which is “values of products or services”/ environmental load, modelled into another definition which is beneficial output/ “input + non-beneficial output”. Then the definition of BEE in CASBEE turned into “building environmental quality & performances”/ “building environmental loadings” (IBEC, 2010b).

CASBEE has a list of aims while being developed, which are defined below:

i) The system should be designed to motivate high assessments to superior buildings, thereby;
ii) Enhancing incentives to designers and others;
iii) It is aimed that the assessment system should be simple as possible;
iv) It is aimed that the system should be applicable to building in a wide range of applications;
v) It is estimated that the system should take into consideration issues and problems special and important to Japan and Asia.

CASBEE is developed in a suitable position according to architectural design process, which starts from the pre-design stage and continues through design and post design stages. This method is composed of four assessment tools, serve at each stage of the design process and to take care of the building life cycle, which are (IBEC, 2010c):

i) CASBEE for pre-design(CASBEE-PD);
ii) CASBEE for new construction(CASBEE-NC);
iii) CASBEE for existing building(CASBEE-EB);
iv) CASBEE for renovation(CASBEE-RN);

With the increasing BEE value, which BEE (Building Environmental Efficiency) is developed as a new indicator for assessment steps to follow the eco-efficiency concept; the total environmental performance of buildings is signed from the top performance level. Also CASBEE family has other tools, such as CASBEE-HI (to alleviate the heat island effect) which is an extended tool, and CASBEE-UD (CASBEE for urban development) which is a new tool. The first 4 assessment tools correspond to the individual stages of the building’s lifecycle. Additionally, some local authorities use CASBEE in their building administration as a reference for reporting systems about their sustainable building subject. By this way, building owners can prepare a document about their plans dealing with the environmental performance of their buildings to the people who want to learn. In April 2004, first Nagoya presented "CASBEE Nagoya" and later Osaka, Yokoama, Kyoto and other cities declared their intention about the use of CASBEE. Nevertheless CASBEE tools will be in need of some modifications due to the local features, such as climate, etc. (Endo *et al*, 2009).

While the World Business Council on Sustainable Development (WBCSD) (www.wbcsb.org) indicates the principle about eco-efficiency as to get the max outcome in the meaning economic value while putting the min effort about environmental impacts, the aim of the CASBEE tools can be written as presented in Table 3.15 (Kibert, 2005).

Table 3.15. Aims of the four tools of the CASBEE system

Tool ID	Tool name	Aim
Tool-0	Pre-design Assessment Tool	It is for the use of owners and planners. It will be used to identify the Project context, to select the suitable site, and to define the main impact of the Project.
Tool-1	DfE(Design for the Environment) Tool	It will be helpful for designers and engineers to make a simple check, while they are improving the Building Environmental Efficiency(BEE) during the design stage.
Tool-2	Eco-Labelling Tool	It will be used to give rating the building in terms of BEE after construction has ended and to define the basic feature value of the rated building in the market.
Tool-3	Sustainable Operation and Renovation Tool	It will be used to inform owners and managers of the buildings about how to progress the BEE of their building during operating the building

3.8.2 Structure and assessment method

In this section the structure and assessment method of the CASBEE- NC (new constructions) tool will be presented.

In the application of the system, the person who deals with the tool fills out two assessment forms at each design stage which are the Main Sheet and the Score Sheet.

The assessment outcomes for each assessment items are named as scores for Q, which is for "building environment quality & performance" and for LR which is for "reduction of building environmental loadings on the score sheet". LR is not representing only the L: Building Environmental Loading itself, but also represents the level of performance in minimizing building environmental loadings imposed outside the hypothetical boundary.

The assessment procedure is based in a score sheet. This sheet is structures in two assessment categories and six sections (Table 3.16). Scores are given according to the scoring criteria for each assessment item. Scoring system is a five-level scoring system, where "3" defines an "average. In weighting, each assessment criteria is weighted to sum up to 1.0. The scores are multiplied by a weighting coefficient and results into SQ, which is the total score for Q, or SLR which is the total score for LR.

Table 3.16. Main assessment categories and sections of the score sheet n the CASBEE system

Assessment categories	Section
Q-Building Environment Quality & Performance	Q-1 indoor environment Q-2 quality of service Q-3 outdoor environment on site
LR-Reduction of Building Environmental Loadings	LR-1 energy LR-2 resources & materials LR-3 off-site environment

3.8.3 Results

Results of this method are presented in the result sheet. This sheet is divided into three sections, as presented in Table 3.17.

Table 3.17. Sections and contents of the result sheet in the CASBEE system (IBEC, 2010a)

Sections	Content
1- Project outline	The identity of the project or building is defined as building name, type, location, floor area of the building, etc.
2 – Result from CASBEE score sheet	The results by category are shown as a summary in the form of a radar cart, bar graphs and numerical values. It presents information on BEE - Building Environmental Efficiency, which is calculated from the results of Q and L.
3 - List of important assessment items excluded from comprehensive assessment for building environmental efficiency that are important for the efficiency.	3.1 - quantitative assessment indicators which are for typical building environmental loads, they should be calculated and the results, dealing with primary energy consumption in operation, water consumption volume and life cycle CO2, etc. should be entered. 3.1 - design process assessment, this area is mainly for controlling the important titles about environmental considerations, related with building management.

In CASBEE, assessment values for Q and LR differs from 1 to 5 and the Building Environmental Efficiency is calculated using Equation 3.6.

$$\mathrm{BEE} = \frac{\mathrm{Q}}{\mathrm{L}} = \frac{25\mathrm{x}(\mathrm{SQ}-1)}{25\mathrm{x}(5-\mathrm{SLR})} \tag{3.6}$$

Where, BEE is the Building Environmental Efficiency, SQ is the score for the Building Environment Quality & Performance (*Q*), and *SLR* is the score for the Reduction of Building Environmental Loadings (*LR*).

In the performance assessment classification, the higher the Q value and the lower the L value is, better is the solution. There are five levels of performance: C (Poor), B^{-}, B+, A and S (Excellent), corresponding to the areas presented of the diagram presented in Figure 3.25.

The BEE rating which is determined by finding the intersection of Q(Building Environmental Quality and Performance) and L(Building Environmental Loadings), is a number, which generally is in the range of 0.5 to 3, that corresponds to a building class, from class S(highest for BEE of 3.0 or higher)to classes A (BEE from 3.0 to 1.5), B+ (BEE from 1.5 to 1.0), B- (BEE from 1.0 to 0.5) and C (BEE less than 0.5), where high ratings (S and A) are succeeded by buildings with high environmental quality and performance and low environmental loadings, while higher resource consumption and lower environmental quality produces below-standard ratings(B- or C) (Kibert, 2005).

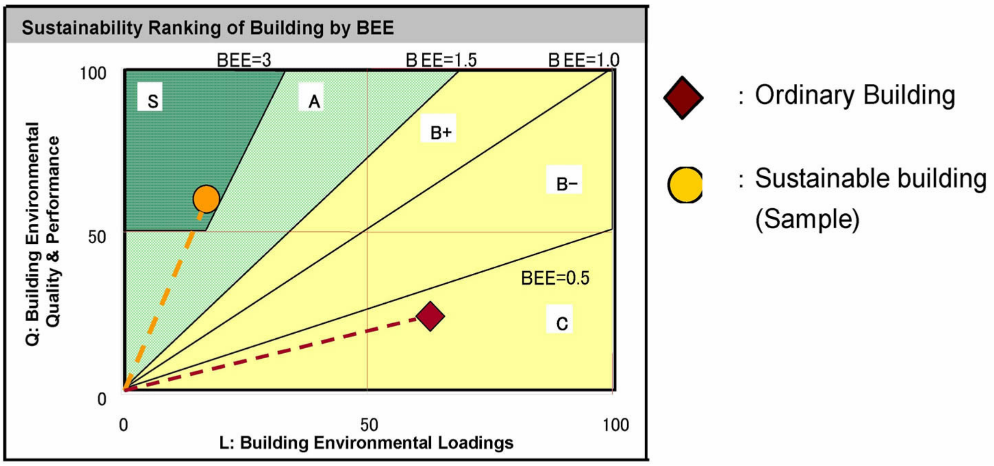


Figure 3.30. Sustainability raking of building by BEE (source: IBEC, 2010a).

3.9 CONCLUSIONS

The actual environmental, societal and economy context shows that he case for creating sustainable affordable housing is substantial.

Sustainable design, construction and use of buildings are based on the evaluation of the environmental pressure (related to the environmental impacts), social aspects (related to the users comfort and other social benefits) and economic aspects (related to the life-cycle costs). The sustainable design searches for higher compatibility between the artificial and the natural environments without compromising the functional requirements of the buildings and the associated costs.

The usability, reliability and fitness for purpose of the different sustainability assessment tools has been carefully evaluated by researchers in the area, leading to the publication of some important conference and journal papers in recent years. To date, scoring of the indicator systems is best developed in methods that use environmental information for single properties like LCA tools. These tools may be linked to different phases of the building design process, from the initial definition or technical design phase to a building in use, in order to obtain an overall picture of the attainment of sustainability targets. These include tools for the performance based design and building approach and other building rating schemes.

Although there are subjective aspects to the majority of assessment tools, hindering their adoption, they still have an important role to play, not only in evaluating the impacts of an actual building, but also, and even more importantly, in guiding the appropriate design for the attainment of performance objectives. The greatest constraint to sustainability assessment is that assessment involves subjective rating and depends above all on the planned function of the building, as well as on its socio-economic and cultural heritage context. Additionally, one of the most important aspects influencing the results is the list of indicators and their respective parameters, since the result relies on the performance obtained in each indicator. The definition of a list of indicators and respective parameters to be adopted on an international scale is one solution to explore in order to make the evaluation methods more objective.

Due to the abovementioned reasons, and despite numerous studies in the area of building sustainability assessment, there is a lack of a commonly accepted methodology to assist architects and engineers in the design, construction and refurbishing stages of a building. Nevertheless, in spite of the limitations of the different methods, the increasingly widespread use of assessment methods is having direct and indirect impacts on the promotion of sustainable building design. Many countries either have or are in the process of developing domestic assessment methods, which is making the need for international exchange and coordination increasingly relevant. Sustainability in the building sector has gained an international forum and the Green Building Challenge, for example, is organizing several major international conferences which are having a noticeably positive effect on the promotion of this concept. Furthermore, both the International Organization of Standardization (ISO) and the European Committee for Standardization (CEN) are making important progress towards the standardization of sustainability indicators and horizontal methods in building sustainability assessment. Therefore it is expected that in a near future there will be a Pan-European method to assess the sustainability of buildings.

REFERENCES OF CHAPTER 3

Anon.2003. Environmentally Sustainable Buildings: Challenges and Policies. OECD Policy Brief. OECD.

Assefa G, Glaumann M, T Malmqvist, Eriksson O. 2010- Quality versus impact: Comparing the environmental efficiency of building properties using the EcoEffect tool. Building and Environment 45, Issue 5, pp. 1095-1103.

Arailopoulos, A., Chastas, P. 2009. LCA in buildings with the application of SimaPro software and of the Eco-indicator 99 method. Diploma Thesis in the Department of Civil Engineering of Aristotle University of Thessaloniki (in Greek), Thessaloniki.

Bikas, D., Giarma, C., Papalexandrou, M. 2005. A study of the effect of the use of photovoltaic technology on the environmental performance of a building in northern Greece. Proc. of International Conference SB05Tokyo: "2005 World Sustainable Building Conference", Tokyo, September 27-29, 2005. Conference CD, article code nr 01-123.

Blok, R. 2008. Survey of sustainable approaches in the Netherlands; Government policies. International Seminar "Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering". Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5. p. 2.51 – 2.55.

Blok, R., Gervasio, H.2008. Guidelines to perform Life Cycle Analysis of buildings. International Seminar "Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering". Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5, p 5.1 – 5.8.

Boverket. Miljöklassad byggnad - Manual för ny/projekterad byggnad. Utgåva version 2.0 2010. Intresseföreningen Miljöklassad Byggnads Tekniska Råd. Boverket mars 2010.

Boverket. Miljöklassad byggnad - Manual för befintlig byggnad. Utgåva version 2.0 2010. Intresseföreningen Miljöklassad Byggnads Tekniska Råd. Boverket mars 2010.

Bragança, L.; Mateus, R. 2008a. Global Methodology for Sustainability Assessment: Integration of Environmental LCA in Rating Systems. International Seminar "Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering". Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5. p. 2.3-2.14

Bragança, L.; Mateus, R. 2008b. New Approach to Environmental Life-cyle Analysis in Sustainability Rating Systems. Proceedings of the International Conference "CINCOS'08: Congresso de Inovação na Construção Sustentável". Curia, Portugal: October, ISBN 978-989-95978-0-8. p. 331-345.

Broniewicz, M. 2008. Survey of sustainable approaches in Poland. International Seminar "Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering". Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5. p 2.56 – 2.60.

Cole RJ. 1998 Emerging trend in building environmental assessment methods. Building Research and Information; 26. pp 3-16.

Diaz-Balteiro L, Romero C. 2004. In search of a natural systems sustainability index. Ecological Economics; 49, pp 401-405.

Ding, G.K.C. 2008. Sustainable construction – the role of environmental assessment tools. Journal of Environmental Management, 86, pp. 451-464.

DGGE. 2005. Caracterização Energética Nacional. Direcção Geral de Geologia e Energia, Avaiable online on [http://www.dgge.pt] in 12/11/2007.

Endo, J., Murakami, S., Toshiharu, I. 2009. Common Ground, Consensus Building, and Continual Improvement: Standards and Sustainable Building (STP1503). Vol. STP 1503, pp. 63-73. Avaiable online on http://md1.csa.com/partners/viewrecord.php?requester=gs&collection=TRD&recid=200903300041484CE&q=Endo%3B+Junko%2C+CASBEE&uid=1151006&setcookie=yes at 10.11.2010.

Erlandsson M., Borg, M. 2003. Generic LCA-methodology for buildings, constructions and operation services – today practice and development needs. Building and Environment 38, pp. 919-938.

GBI. LCA Made Easy with Green Globes and the Athena EcoCalculator for Assemblies. Green Building Institute. (retrieved from http://thegbi.org/news).

Gervásio, H., Simões da Silva, L., Mateus, R., Bragança, L., Survey of sustainable approaches in Portugal, Proceedings of Seminar: "Sustainability of Constructions: Integrated approach to Life- time Structural Engineering", Dresden, October 06 – 07, 2008, pp 2.61 – 2.70.

Giarma, C.S., Koimtsidou, T.K. 2002. Environmental assessment of an office building with the use of the GBC method. Diploma Thesis in the Department of Civil Engineering of Aristotle University of Thessaloniki (in Greek), Thessaloniki.

Giarma, C., Bikas, D. 2005. Towards the effective use of a modified version of GBTool for the environmental performance assessment of buildings in Greece. Proc. of International Conference SD04MED: "Sustainable Construction: action for Sustainability in the Mediterranean region", Athens, June 09-11, 2005, Conference CD.

Giarma, C., Bikas, D., Kontoleon, K.J. 2008.Virtual office in Greece: a first approach to sustainability issues, International Seminar “Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering”. Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5 p 5.9 – 5.17.

Glaumann M, Malmqvist T, Svenfelt Å, Carlsson PO, Erlandsson M, Andersson J, Winzell H, Finnveden G, Lindholm T, Malmström T-G. Miljöklassning av byggnader. Slutrapport April 2008. Boverket April 2008.

Glaumann, M., Assefa, G., Borg, R.P. 2008. Guidelines Basic LCA application. Residential building case study – Gronskar, Sweden, International Seminar “Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering”. Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5. p.: 5.18 – 5.26.

Glaumann, M., Wallhagen, M. 2008. Survey of sustainable approaches in Sweden. International Seminar “Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering”. Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5.p 2.78 – 2.95.

Gowri, K. 2004. Green Building rating systems: an overview. ASHRAE Journal, 46 (11): 56-59.

Grecea, D., Ungureanu, V. 2008. Survey of sustainable approaches in Romania. International Seminar “Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering”. Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5. p 2.71 – 2.77.

Greencalc.com www. website

Gregory, A. Norris. 2007. The LCA-into-LEED Project: Progress Summary and Work Plan. Available online on ttp://www.therightenvironment.net/Downloads/Progress_ Summary_LCA-into-LEED_11-05-07.pdf.

Haapio A., Viitaniemi P. (2008) A critical review of environmental assessment tools. Environmental Impact Assessment Review 28, pp 469-482.

IBEC. 2010a. Comprehensive Assessment System for Built Environment Efficiency (CASBEE). Available online on www.ibec.or.jp/CASBEE/english/index.htm at 9/12/2010.

IBEC. 2010b. Background of the Comprehensive Assessment System for Built Environment Efficiency (CASBEE). Available online on www.ibec.or.jp/CASBEE/english /backgroundE.htm at 9/12/2010.

IBEC. 2010c.Overview about the Comprehensive Assessment System for Built Environment Efficiency (CASBEE). Available online on www.ibec.or.jp/CASBEE/english/overviewE.htm at 9/12/2010.

iiSBE. 2004. An overview of the GBC method and GBTool.

INAG 2004. Inventário Nacional de Sistemas de Abastecimento de Água – Versão Preliminar (in portuguese). Instituto da água, 150p.

INE 2001. Recenseamento Geral da Habitação – Censos 2001. Instituto Nacional de Estatística (in portuguese)

Kahraman, I. 2008. Survey of sustainable approaches in Turkey. International Seminar “Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering”. Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5.p 2.96 – 2.102.

Kibert, Charles J. 2005. Sustainable construction: green building design and delivery, John Wiley & Sons, New Jersey, United States of America.

Kontoleon, K.J., Bikas, D., Giarma, C. 2008. Survey of sustainable approaches in Greece. International Seminar “Sustainability of Constructions – Integrated Approach to Life-time Structural Engineering”. Dresden, Germany: October. Cost Action C25. ISBN 978-3—86780-094-5. p 2.44 – 2.50.

Larsson N. 2007. An overview of SBTool September 2007 Release, (retrieved from http://greenbuilding.ca).

Lippiat, B.C. 2002. BEES 3.0, Building for Environmental and Economic Sustainability. Technical Manual and User Guide, National Institute of Standards and Technology.

Malmqvist T, Glaumann M, Svenfelt Å, Carlson P-O, Erlandsson M, Andersson J, Wintzell H, Finnveden G, Lindholm T and Malmström TG. A Swedish Environmental Rating Tool for Buildings. Accepted for publication in Energy (special issue for Dubrovnik conference 2009).

Mateus, R.; Bragança, L.; Koukkari, H. 2008. Sustainability Assessment and Rating ff Portuguese Buildings. International Conference “World SB08 Melbourne – Connected, Viable, Liveable”. Melbourne, Australia: September

Mateus, R. 2009. Avaliação da Sustentabilidade da Construção: propostas para o desenvolvimento de edifícios mais sustentáveis. Phd Thesis. University of Minho, Portugal. (In Portuguese).

NIBE, www. Nibe.org Nederlands Instituut voor Bouwbiologie en Ecologie

PRé consultants, 2007. Introduction to LCA with SimaPro 7.

Roodman, D. M.; Lessen, N. 2005. A Building Revolution: how ecology and health concerns are transforming construction. Worldwatch Paper, 124, 67p.

Saunders, T. 2008. A Discussion Document Comparing International Environmental Assessment Methods For Buildings, http://www.breeam.org.

Sundkvist Å, Eriksson O, Glaumann M Bergman S, Finnveden G, Stenbeck S, Winzell H. Miljöklassning av byggnader – Inventering av metoder och intressenternas behov. TRITA-INFRA-FMS 2006:1, ISSN 1652-5442

Syphers, G.; Baum, M.; Bouton, D.; Sullens, W. 2003. Managing the Cost of Green Buildings. State of California – State and consumer services agency. October.

Tsikaloudaki, K., Giarma, C. 2005. Investigating the impact of urban context on the environmental performance of buildings Proc. of International Conference SD04MED: "Sustainable Construction: action for Sustainability in the Mediterranean region", Athens, June 09-11, 2005, Conference CD.

USGBC 2001. LEED, Leadership in Energy and Environmental Design, Rating System, version 2.0.

USGBC. 2009a. Getting LCA into LEED: A back grounder on the first LCA pilot credit for LEED, available on http://www.usgbc.org/LEED.

USGBC. 2009b. LEED 2009 for New Construction and Major Renovations Rating System, available on http://www.usgbc.org/LEED.