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Life Cycle Management

Leadership in Energy and Environmental Design (LEED) A critical evaluation by LCA and recommendations for improvement

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Abstract

Goal, Scope and Background. LEED (Leadership in Energy and Environmental Design) is a scoring system that evaluates the environmental friendliness of buildings. It is composed of 69 credits, each one providing a score of one (i.e., one point) if implemented. However, since each credit does not always provide the same type and magnitude of benefits for the environment, a higher rating is not always synonymous with lower impacts. The goal of this paper is to evaluate the actual extent of the benefits and burdens of LEED, identify the critical credits and develop a new scale that will correct these miscorrelations.

Methods. The various LEED credits are qualitatively analysed. It is possible to quantify the actual outcomes and thus perform a life-cycle assessment (LCA) on 45 credits applied to an actual California office building. This allows comparing the benefits of the different credits among each other. Commuting of the employees is included in the system. The LCA is performed with the help of SimaPro 7, combining the ecoinvent 1.2 inventory database and the impact assessment methodology IMPACT 2002+ v2.1, adapted to North America. Impacts are evaluated for human health, ecosystems quality, climate change, and resource consumption. Impacts of the different credits are aggregated in one indicator to allow the design of a new scoring system that assigns to the different credits an amount of points (i.e., a score) that are related to the actual benefits. A school and a residential building are also modeled in order to perform a sensitivity study.

Results and Discussion. Operation, especially employee commuting and electricity consumption, dominates the impacts associated with the building. It appears that waste generation have limited but not negligible impacts, whereas water consumption has small impacts. Since the building is situated in California, heating is not an important source of impacts. As a result, credits that provide the most environmental benefits are the ones geared toward increasing the fraction of green electricity, reducing energy consumption, reducing employee commuting, and increasing waste recycling, along with the ones favoring the reuse and recycling of the building structure. The ones targeting reduction of water and land use, and recycling content in the furniture appear to be less beneficial. The scores of the different LEED credits range from -128 to 606. Negative credits are due to credits that lead to more burdens than benefits, for example, the one requiring the construction of a multifloor parking lot (with a score of -128). The most beneficial credit (with a score of 606) is the one requiring that electricity comes from at least 50% green power.

Conclusions and Outlook. Comparing the new scale with the observations on site shows that the LEED credits actually implemented are not always the most beneficial for the environment. This issue should be addressed in order to make LEED more efficient. The proposed rating system should help correct these discrepancies. The amount of reduction in employee commuting that the related credits really achieve, actual impacts of land and water use, along with the benefits of improved indoor air quality are among the main future challenges of the present study.

Keywords: Credits; ecoinvent database; green buildings; IMPACT 2002+; leadership in energy and environmental design (LEED); life cycle assessment (LCA); office building

Introduction and Objectives

The construction and building industry accounts for a substantial fraction of the overall environmental impacts of society (Junnila and Horvath 2003). In the United States, buildings account for an important part of the impacts of the entire economy: 12% of potable water consumption, 30% of waste output, 30% of raw materials use, 30% of global warming potential (GWP), 68% of electricity consumption, and 39% of total energy use (USGBC 2005). A recent initiative, Leadership in Energy and Environmental Design (LEED) (LEED 2003) is providing a scoring system for 'green buildings'. However, the definition of what comprises green is ambiguous. This paper quantifies the environmental benefits and burdens of the different LEED requirements, called credits, so that these credits can be analyzed and compared. The various LEED credits are translated into quantities that can be used as inputs into life-cycle assessment (LCA). This analysis reveals how much of an environmental benefit LEED provides and which credits bring the largest benefits. The credits with larger benefits should be given more importance in the LEED program through a higher score (i.e., number of points) attribution. Whether the score given to a particular credit is adequate is addressed, and a new scoring system is suggested. The features addressed in this paper are:

- Qualitative and quantitative evaluation of the practical implications of the different LEED credits.
- Evaluation of the benefits and burdens of the different LEED credits based on LCA.
- Identification of the LEED credits that are the most impacting.
- Comparison with observations showing which credits are actually implemented.
- Possible revision of the LEED scoring system based on the magnitude of the benefits evaluated.

Note that throughout this paper, the term 'weight' refers to the weighting scheme between the different damage categories evaluated, whereas the term 'score' refers to the importance that each LEED credit should provide to the building when implemented.

Only the main results are presented in this paper. The detailed results are presented in the supporting information and can be obtained by contacting the corresponding author.

Description of LEED

LEED is a rating system developed by the U.S. Green Building Council (USGBC) to assess the environmental sustainability of building designs. It is a voluntary, consensus-based framework for developing high-performance, sustainable buildings. A building design can be certified by the U.S. or Canadian Green Building Council. Certification helps providing increased market exposure, and aims at placing the building among the 'greenest' buildings in North America.

To earn LEED certification, the applicant project must satisfy all of the prerequisites and a minimum number of credits (each one providing one point) that will allow a LEED rating level. The LEED rating system comprises of 9 prerequisites and 60 elective credits grouped into 6 categories (LEED 2003): sustainable sites (1 prereq. and 14 points), water efficiency (5 points), energy & atmosphere (3 prereq. and 17 points), materials & resources (1 prereq. and 13 points), indoor environmental quality (2 prereq. and 15 points), and innovation & design process (5 points). The different ratings a building can obtain are: LEED certification (26-32 points), Silver (33-38 points), Gold (39-51 points), and Platinum (52-69 points). The market penetration of LEED certification has been steadily increasing over the years. Currently LEED guidelines are adopted in all 50 U.S. states (largely dominated by California) and about 11 countries. Since the start in year 2000, more than 1500 projects have registered to achieve various levels of LEED certification. To date, the market is dominated by the government and the non-profit sectors, together accounting for nearly 75 percent of all LEED-registered projects. The most frequent project type is office buildings, followed by secondary and higher education buildings.

The critical literature on LEED is rather sparse. Matthiessen and Morris (2004) evaluated the frequency at which each credit is targeted when new projects apply for a LEED rating. Comparing their findings with the results of this paper shows that important discrepancies are observed between the rate of implementation of credits and their actual benefits. Scheuer and Keoleian (2002) evaluated the energy consumption and solid waste generation of 20 credits. One of their recommendations is to include assessments such as water consumption, global warming potential, ecotoxicity, human toxicity, acidification, resource depletion and land use. This paper works in this direction by evaluating the impacts of 45 credits on a broad scope of impact categories that can be grouped in four damage categories: human health, ecosystem quality, climate change, and resources.

1 Methodology

The LEED requirements are analyzed and quantified. In order to create a basis for comparison, assumptions are made in order to come up with a standard, non-LEED certified building. The basis for the standard building is a recently built Chiron office building in Emeryville, California. The data for a standard and a LEED building for each credit are used as inputs into the LCA software SimaPro 7 (PRé Consultants 2006), combining the ecoinvent inventory database (Frischknecht 2003, Frischknecht 2005) and the IMPACT 2002+ life-cycle impact assessment (LCIA) methodology (Jolliet et al. 2003) adapted to North America. The environmental benefits and burdens of 45 LEED credits are evaluated. The credits analyzed are from the categories sustainable sites (10 credits analyzed from a total of 15 credits), water efficiency (5/5), energy & atmosphere (16/20), and materials & resources (14/14). It is not possible to quantify the benefits of credits from indoor environmental quality (0/17) and innovation & design process (0/5). Impacts (i.e., burdens and benefits) are evaluated for the damage categories human health, ecosystem quality, climate change, and resource consumption. Results are then compared to the overall impacts of a standard office building, as well as with a residential and a school building within uncertainty analysis. The analysis reveals which credits have the largest benefits. The four damage category indicators are combined into one indicator. This information is used to adjust the scoring system in LEED so that the scores (i.e., number of points) properly reflect the actual environmental benefits that each credit provides.

1.1 Life-cycle assessment of LEED credits

1.1.1 Goal and scope per credit

This LCA aims to identify and analyze the advantages and disadvantages of the different LEED credits, i.e., to assess the benefits and burdens of the different credits. LCA is performed for each LEED credit. Benefits or burdens are compared to the impacts of the overall building and the benefits (or burdens) of the other credits. Each of the LEED credits is converted into quantifiable aspects in order to link these aspects to inventory databases and impact assessment methodology.

Standard building. In order to compare the benefits (or burdens) for each LEED credits, a standard building is analyzed. The primary parameters specified for the standard building are the parameters targeted by the LEED requirements, such as building footprint, materials (concrete, steel, wood, plastics, etc.), transportation (vehicles), electricity and natural gas usage, water usage, and waste produced. The materials needed for a standard building are obtained by using parameters valid for an office building for approximately 500 persons. Using construction cost estimation (Turner Construction 2005), ratios of material mass per square footage are obtained and used to calculate the mass for several building materials. Data on water use, energy consumption and waste generation are obtained from an office building in Emeryville housing 443 employees (Chiron Corporation 2005). These data are adjusted for 500 people since this is the basis for the standard building. **Table 1** presents a summary of the most important parameters used to model an office building along with the main differences relative to a residential building and a school. The data of the latter two are used for uncertainty analysis.

<< insert Table 1 around here >>

The data for the office building are compared to the data presented in Junnila et al. (2006). Most of the data, such as electricity and construction materials used, compare closely, except for the heating and natural gas data. Since our standard building is based on a building located in California, whereas the buildings presented in Junnila et al. (2006) are situated in Finland and Wisconsin, the heating numbers are lower by approximately a factor of 7. This difference appears logical given the climatic differences.

Interpretation of LEED credits. The LEED design recommendations are analyzed and interpreted into quantitative values. A summary of these interpretations is presented in **Table 2**. Several credits, specifically the ones related to indoor environmental quality and innovation & design process, are not quantified due to current lack of knowledge, data, and methodology. In total, 45 credits (from a total of 69) are quantified.

<< insert Table 2 around here >>

1.1.2 Inventory analysis

The life-cycle inventory (LCI) analysis is mainly based on the ecoinvent database v1.2 (Frischknecht 2003, Frischknecht 2005). As a matter of comparison, five of the most important processes used in this study, cars (car production, gasoline production and gasoline use), electricity (U.S. grid mix), structural steel, concrete, and water, are compared using the Economic Input–Output Analysis-based LCA (EIO-LCA) approach (Hendrickson et al. 1998), utilizing U.S. data. Since land use and wastes are flows that are not incorporated into the EIO-LCA model, these flows could not be compared. It is observed that the difference between the CO_2/MJ ratios for EIO-LCA and ecoinvent is stemming from the fact that in Europe a higher fraction of electricity comes from hydropower and nuclear energy, whereas more than 50% of the U.S. mix is based on coal. Thus the average European mix is assumed to produce less CO_2 per MJ of electricity output because of the supposedly lower CO_2 burdens of hydropower and nuclear energy. The ratios for ecoinvent are approximately 30% lower than for EIO-LCA.

The ecoinvent database is chosen for the analysis. Indeed, for a detailed analysis, ecoinvent is practical since several flows (e.g., waste management, sources of electricity) are not detailed enough in EIO-LCA to be usable for the comparison of the different LEED credits. The use of ecoinvent can be considered acceptable since technology (and thus energy consumption and emissions of pollutants) can be assumed fairly similar between the U.S. and Europe. The electricity mix and car mileage are adapted to current U.S. situation. The mix for renewable electricity is assumed to be 70% wind, 20% biomass and 10% photovoltaic. A sensitivity study shows that the actual fractions used for the renewable mix do not change the results significantly. For example, variation within the renewable electricity mix varies the inventory of the benefits provided by the credit EA 6 (50% green power) by less than 5%.

1.1.3 The impact assessment methodology

The impact categories are based on the IMPACT 2002+ LCIA methodology (Jolliet et al. 2003) adapted to North America. IMPACT 2002+ considers 14 midpoint categories: human toxicity, respiratory effects (due to inorganics), ionizing radiation, ozone layer depletion, photochemical oxidation, aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification/nitrification, land use, global warming, non-renewable energy consumption, and mineral extraction. These midpoint categories can be related to four damage categories: human health, ecosystem quality, climate change, and resource consumption. These are expressed, respectively, in disability-adjusted life years (DALY), potentially disappeared fraction of species per m^2 per year ($PDF \cdot m^2 \cdot yr$), kg CO_2-eq and MJ of primary non-renewable energy. Normalization is performed at damage level. The IMPACT 2002+ method presently provides midpoint characterization factors, damage factors, normalized midpoint characterization factors and normalized damage factors for almost 1500 different LCI results (Jolliet et al. 2003, Humbert et al. 2005a, Humbert et al. 2005b). The idea of normalization (Jolliet et al. 2003) is to analyze the respective share of each impact in the overall damage of the considered category. More specifically, in IMPACT 2002+, expressed in '$pers \cdot yr$', it represents the average impact in a specific category 'caused' by a person during one year in North America (calculated for the year 2005). One '$pers \cdot yr$' corresponds to, respectively, 0.014 DALY, 40,000 $PDF \cdot m^2 \cdot yr$, 14,000 kgCO_2-eq and 256,000 MJ for the four damage categories presented.

Table 3 presents the impact assessment results of the main processes used in this study.

<< insert Table 3 around here >>

2 Results of the Impact Assessment

This section summarizes the benefits and burdens per credit.

2.1 Standard (non-LEED) office building

The impacts of a standard, not LEED rated office building are shown in **Fig. 1**. Over 50 years, operational impacts comprising energy and water consumption, waste generation, and transportation (mainly for employee commuting) dominate. The share between operation and construction & decommissioning for energy consumption is comparable to the findings of Scheuer and Keoleian (2002) (95% and 5%, respectively, for a lifespan of 75 years). Climate change and resource consumption are logically correlated. Values in the category ecosystem quality are lower than in the three other categories. This is understandable since, globally, the impacts on ecosystem quality are dominated by land use (farming) and terrestrial ecotoxicity (mainly by heavy metals discharges into soil), and neither farming nor discharges of heavy metals into soil have the buildings industry as main contributor.

<< insert Fig. 1 around here >>

Fig. 2 details the impacts of the operation phase (for one year). Commuting dominates the impacts in all categories. Electricity use (mostly for air conditioning) is also an important source of impacts. Heating has lower impacts, but the building studied is situated in California, thus requires only modest heating in the winter. Note that if the building would be situated in a cold region that does not use air conditioning in the summer, the impacts caused by increasing natural gas consumption would approximately be compensated by a reduction of impacts caused by reduced electricity consumption, thus the overall share of energy consumption would stay in the same range. Impacts related to waste generation (assumed to be 100% landfilled) are small, and impacts related to water consumption are negligible.

<< insert Fig. 2 around here >>

2.2 Comparison per damage category

Direct and tangible benefits regarding indoor environmental quality and innovation & design process cannot be quantified based on currently practiced LCA. However, comfort levels of inhabitants would definitely be enhanced following guidelines of indoor environmental quality. Innovations and design processes vary on a case-by-case basis and thus cannot be modeled on a standard basis. Hence the results are compared for the first four LEED categories. The following figures present the net benefits (or burdens) of the different credits per damage category studied (i.e., climate change, human health, ecosystem quality, and resource consumption).

2.2.1 Climate change benefits

Fig. 3 shows the net benefits (i.e., difference between the base case and the LEED case) of the different credits for the climate change damage category. Sustainable sites, energy & atmosphere, along with the credits related to the reuse of building in material & resources, all reduce climate change potential. The benefits of the two former categories are primarily due to savings in operation as opposed to construction. Credit EA 6 (50% of electricity based on green power) is clearly the most advantageous credit. Note that in the current LEED system, credit EA 1 can provide up to 10 points, one for each 5% increment in energy savings. Credit SS 7.1 Alt.2 that specifies the use of minimum 50% of parking spaces underground or covered by a structure creates more CO_2 emissions than a non-LEED case. Indeed, the construction of reinforced concrete multifloor parking garage will emit more CO_2 (especially from cement production) than the amount that the avoided asphalt will reduce. Credit MR prereq.1 is related to increased waste recycling. The reason for a negative effect is that wastes are dominated by paper, which, if produced from a sustainable forest, can contribute to capture and sequestration of carbon when landfilled (assuming 27% of carbon released after 100 years) (Frischknecht 2003). This result should be interpreted with caution though, but as it will be seen later, the overall contribution of this credit is positive since it provides substantial benefits in the three other impact categories.

<< insert Fig. 3 around here >>

2.2.2 Human health benefits

Fig. 4 shows the net benefits of the different credits for the human health damage category. Normalized values for human health are dominated by energy & atmosphere and material & resources. The main benefits in energy & atmosphere are due to credit 6 (use of 50% of electricity from green power). Two credits provide negative benefits: SS 4.3 (use of bioethanol instead of gasoline) and SS 7.1 Alt.2 (construction of a parking garage). Indeed, throughout the overall life cycle, the former releases more air pollutants than gasoline (Seungdo and Dale 2006); the latter replaces an asphalt parking lot with a concrete structure, which releases more air pollutants.

<< insert Fig. 4 around here >>

2.2.3 Ecosystems quality benefits

Fig. 5 shows the net benefits of the different credits for the ecosystem quality category. Normalized values for ecosystem quality are generally lower than those accounted for human health. The main benefits are due to sustainable sites. As opposed to other impact categories, water efficiency accounts for a non-negligible part of impacts on ecosystem quality, on the same order of magnitude as energy & atmosphere and material & resources. Negative values are observed for the credit SS 4.3 (replacement of 3% of the car with bioethanol) on the account of the burden caused by the land use required for bioethanol production. The same goes for the credit MR 6 (5% of building furniture replaced with rapidly renewable materials), where the biobased plastics causes a burden on ecosystems because of land use for biobased plastics production.

<< insert Fig. 5 around here >>

2.2.4 Resource benefits

Fig. 6 shows the net benefits of the different credits for the resource consumption category. These benefits are in most cases comparable to climate change, and are primarily due to benefits resulting from savings in operation. The categories energy & atmosphere and sustainable sites followed by material & resources provide high benefits for most of the credits.

<< insert Fig. 6 around here >>

2.3 Weighting

Because credits do not have consistent benefits throughout the four damage categories, a weighting system has to be used to compare the four damage categories and reduce this information to only one indicator (such as the LEED scoring system). Weighting is a very subjective part of LCA. It partly depends on the scale of exposed population. We suggest taking into account all four damage categories evaluated in this study. Indeed, impacts on human health and ecosystem quality appear fairly obviously as negative for most people, but also our society tends to be more and more aware of the negative aspects of the consequences of climate change and resource consumption (e.g., social consequences and impacts on ecosystems of increasing sea level because of climate change; and inter- and intra-national conflicts along with social tensions and injustices related to the extraction of resources). The authors suggest adopting an equal weighting, i.e., 25% for human health (HH), ecosystem quality (EQ), climate change (CC), and resources (R). As different people will assign different weights to each category, a weighting set assigning the same weights to each category tends to represent an average between multiple individual choices. Sensitivity studies are performed with two other sets of weights (see 2.4.5 Weighting for results). Credits that are not evaluated in the present study keep a score of one. However, a thorough study should be done to assign them more precise scores. The result of the weighting is still expressed in pers·yr, indicating that a credit with a final score of one represents a benefit corresponding to the overall impacts caused by one person during one year in North America. Most of the results represent only a fraction of this annual damage, thus in order to make the different scores easier to read, every score is multiplied by 40. The factor 40 has the advantage to assign a score of approximately one to the credits providing limited overall benefits. Thus in this new scale, a score of 40 represents a benefit corresponding to the overall impacts caused by one person during one year in North America. **Table 4** lists the credits studied herein along with the score that each credit should receive based on the equal weighting scheme. The range indicated in brackets shows how the score of each credit would vary depending on the weighting scheme chosen (explained in more detail in the section 2.4.5 Weighting). The theoretical scores vary from -128 to 606. This indicator reflects the theoretical overall magnitude of the benefits provided by the credit. For example, a credit with a score of 60 provides 20 times more overall benefits than a credit with a score of 3. Note that a graphical representation of these scores is also presented in **Fig. 7**.

<< insert Table 4 around here >>

Credit EA 1 focuses on energy performance. Each 5% saving increment results in 62 points. Credit EA 6 focuses on green power. As shown, it is one of the most important credits to achieve in order to reduce the environmental impacts of a building. Furthermore, it is technically easy to implement. The only limitations are market availability and price. However, as experienced in California, if the electricity comes from efficient wind plants, the price is not much higher than for average grid electricity. Note that the credit EA 6 provides the amount of benefits depicted in the different figures and tables only if the contract is renewed after 2 years and kept for the lifespan of the building. If the contract is not renewed after 2 years, the total benefits represent only 4% of the ones presented in Table 4, i.e., a score of 24. As mentioned earlier, credit SS 7.1 Alt. 2 (multifloor parking garage made of reinforced concrete) creates more burden than it provides benefits. Alternatives 1 (shade - no benefits or burdens) or 3 (open-grid pavement – provides benefits) should be used instead of the alternative 2 to achieve the goal aimed by credit SS 7.1 (reduction of heat island effect). The overall benefits of the credit SS 4.3 (replacement of 3% of the cars with bioethanol-fueled vehicles) are slightly on the negative side. Indeed, based on current data (Seungdo and Dale 2006), the use of bioethanol reduces resources consumption and CO_2 emissions, but has more effects on human health and ecosystem quality than gasoline. Thus the credit SS 4.3 is extremely sensitive to the weighting scheme chosen and should be considered with care. Other types of fuels should be investigated in order to identify potential alternatives to bioethanol. Used in the credit MR 2.1 and 2.2, the recycling of concrete (crushing it to make aggregate) seems to create as much impacts as the extraction of virgin aggregates in a quarry would do. The real benefits of recycling concrete are the avoided impacts of the transportation from the quarry to the ready-mixed concrete plant. Thus if this trip is more impacting (longer) than the one between the recycling plant and the ready-mixed concrete plant, then recycling concrete makes sense. Table 4 also reports the frequency with which each credit is targeted when applying for LEED certification (discussed later).

2.4 Sensitivity Analysis

A sensitivity analysis should be done in order to strengthen the results and identify the sources for improvement. Uncertainty and sensitivity analysis have to be performed at five levels: 1) type of building (e.g., office v. residential v. school), 2) effectiveness of the various credits (e.g., will people really use public transportation if the building is situated close to a bus stop?), 3) inventory analysis (e.g., results should be supplemented with the EIO-LCA model, origin of the electricity mix), 4) impact assessment methodology (e.g., while the GWP of different materials is fairly well known, high uncertainties exist for the evaluation of the damage on human health and ecosystems), and 5) weighting scheme. The estimated uncertainties associated with each one of the five sources of uncertainties discussed below are qualitatively indicated in Table 4.

2.4.1 Type of building

The approach used in this study is applied to a hypothetical residential and school building, and the results are compared to an office building. The main differences between an office building, a residential building, and a school of the same physical size are mentioned in Table 1. These assumptions suggest that the credits MR 1.1 to MR 7 should stay with the same values since it is assumed that the functional unit for the comparison between different types of buildings is the size of the building. The results are depicted in **Fig. 7**. They show that since office buildings tend to generate more road traffic and electricity consumption than schools or residential buildings, benefits related to these two categories are higher for office buildings than for the other two. Furthermore, residential buildings generate the lowest traffic, thus the benefits associated with traffic reduction are the lowest for this type of a building. Benefits related to energy savings are fairly equal between a school and a residential building. The benefits related to the creation of a place dedicated to recycling of wastes (MR Prereq. 1) is very dependent on the actual recycling rates achieved. The interpretation of this credit should be corroborated with actual observations on site. The benefits related to water savings are higher for residential buildings, but since these credits provide only marginal benefits, the uncertainty related to the type of buildings is not significant. It is possible to conclude that even if the actual benefits of each credit can vary by up to a factor of 3 depending on the type of building, globally, the ranking between the different credits stays approximately the same. Uncertainty is medium high for the categories sustainable sites and energy & atmosphere, and low for the others.

<< insert Fig. 7 around here >>

2.4.2 Effectiveness of the various credits

The effectiveness of some credits is fairly easy to estimate whereas the effectiveness of others can vary widely. The uncertainty of the effectiveness of credits related to energy consumption or recycling content is low. For example, if it is required to reduce the energy consumption by 5%, the uncertainty associated with the effectiveness is quasi negligible since the uncertainty will reside within the type of building, but not within the effectiveness of the implementation of the measure. Indeed, we know that it is 5% of the energy that will be saved! Credits related to the reduction of commuting are the ones with the highest uncertainty in effectiveness. For example, providing suitable means of storing bicycles and convenient shower facilities for 5% of building occupants does not mean that 5% of people will use a bike to commute. Overall, it can be considered that the uncertainty associated with the effectiveness is low (i.e., less than a factor of 2) for credits related to water efficiency, energy & atmosphere and material & resources, whereas it is high (i.e., between a factor of 2 and 10) for credits related to sustainable sites.

2.4.3 Inventory analysis

Inventories are often burdened with significant uncertainties and variabilities. However, several of the important sources of variability are correlated between the different credits. As an example, the electricity mix used is one of the main sources of variability. However, since a change in the electricity mix will affect in the same way all credits where electricity is dominating the impacts, the overall ranking of the different credits appears not to be very sensitive to the electricity mix. The same observation is valid for the mileage used to estimate the benefits related to the reduction in car commuting. Overall, it can be considered that the uncertainty associated with the inventory analysis is low (i.e., less than a factor of 2) for credits related to water efficiency and energy & atmosphere, whereas it is medium high (i.e., between a factor of 2 and 5) for credits related to sustainable sites and material & resources.

2.4.4 Impact assessment methodology

The main impact assessment used in this study, IMPACT 2002+ v2.1 for North America (adaptation of Jolliet et al. (2003) to North America), takes into account 14 midpoint categories. This is considered to represent a broad spectrum. Furthermore, two of the four damage categories evaluated, climate change and resource consumption, are based on internationally accepted characterization factors (i.e., GWP potential and energy content of fuels). Thus they are associated with low uncertainty. The two other damage categories, human health and ecosystem quality, contain higher uncertainties. In order to reduce them, several categories based on European data were newly modeled for North America.

In order to strengthen the results, an evaluation was also done with the LCIA methodology CML (v2.03 implemented in SimaPro 7) (Guinée et al. 2002). The 10 midpoint categories evaluated are human toxicity, photochemical oxidation, ozone layer depletion, fresh water aquatic ecotoxicity, marine aquatic ecotoxicity, terrestrial ecotoxicity, acidification, eutrophication, global warming (GWP100), and abiotic depletion. Two sets of weights are used. An equal weighting for each one of these 10 categories, and a respective weighting of 0.1, 0.1, 0.05, (i.e., 0.25 for the categories related to human health), 0.05, 0.05, 0.05, 0.05, 0.05, (i.e., 0.25 for the categories related to ecosystem quality), 0.25 for global warming, and 0.25 for abiotic depletion. Both sets of weights give results showing similar trend to the results obtained with the IMPACT 2002+ methodology. Note that the latter set of weights gives results closer to IMPACT 2002+ than the former. However, two main differences are observed. First, credits aiming at reducing land use show less benefits with CML than with IMPACT 2002+ since no impact categories related to land use are currently associated with the version 2.03 of CML implemented in SimaPro 7. However, since Guinée et al. (2002) advise to take into account land use, these differences should be reduced if the evaluation is done with a complete version of CML. The second difference is related to the credits aiming at reducing the use of steel and aluminum (these credits are mainly part of the material & resources category). Indeed, these credits show a much higher importance with CML than with IMPACT 2002+ (up to two orders of magnitudes). This is due to the high ecotoxicity related to freshwater and aquatic ecosystems given by CML to inorganics emitted during the production of metals. This specificity to CML is already reported by Dreyer et al. (2003). However, these differences do not change the fact that both LCIA methodologies show similar trend when similar sets of weights are used.

The main uncertainty associated with the impact assessment methodologies relates to the evaluation of the damage on ecosystems caused by water scarcity and land use. The effects on ecosystems quality due to the reduction of biodiversity caused by land use are taken into account using the characterization factors suggested by Eco-indicator 99 (Goedkoop and Spriensma 2000). However, this methodology, while being the only currently available, is fairly limited, and does not fully address the issue of land use. The impacts caused by the treatment and distribution of water are taken into account in the present evaluation. However, the impacts on biodiversity caused by the withdrawal of water from natural ecosystems are not addressed in any manner as no accepted and efficient methodology is currently available within the LCA community to do so. If the building is situated in a region with plenty of clean, fresh water, this may not be an issue. However, if the building is situated in a region with water scarcity, as it is the case in California, each gallon consumed increases the pressure on biodiversity. The issues of water and land use should be better investigated in order to better evaluate the benefits of the credits related to these two parameters.

2.4.5 Weighting

As mentioned earlier, sensitivity studies were performed with two sets of weights different from the one suggested (equal weighting). The first set of weights is the one suggested by Goedkoop and Spriensma (2000) in the LCIA methodology Eco-indicator 99 (i.e., 33.8% HH, 40% EQ, 6.2% CC, 20% R). The second set of weights is a set aiming at reducing sensitivity of results to uncertainties (i.e., 20% HH, 10% EQ, 35% CC, 35% R). The rationale behind the latter is that the damage category ecosystem quality has the highest uncertainty among the four categories. The category human health also has higher uncertainties than climate change and resources. Both sets give similar results to equal weighting. The choice of set of weights appears to be important only for the credits that have some negative benefits, or for credits that provide benefits only for one damage category. The credits that are sensitive (i.e., having a score that varies by more than 50% and by more than 1 point) to the weighting set are SS 3, SS 4.3, SS 5.2, WE 2, EA 4, MR 6, and MR 7. The only credit that has a score that changes signs depending on the set of weights is the credit SS 4.3 (use of bioethanol instead of gasoline). Indeed, the use of bioethanol is positive for climate change and resource consumption, but negative for human health and especially ecosystem quality (mainly from land use). Overall, it can be stated that the set of weights has a limited influence on the overall ranking of the different credits. The influence of the weighting scheme chosen on the final score of each credit is indicated in brackets in Table 4.

2.4.6 Other sources of uncertainty

Hidden, unquantified benefits, for example, the health benefits from increased comfort in a building, are limitations to the quantification of the benefits of the different LEED credits by traditional LCA methodologies.

3 Discussion and Recommendations for Improvements

It is clear that some credits provide larger benefits than others: a large spread between the different credits is observed. However, results are fairly consistent throughout the four damage categories. Sustainable sites (SS), energy & atmosphere (EA) and a few material & resources (MR) credits dominate the benefits. This is mainly due to reduction in car commuting (for SS), energy savings (for EA and MR), and green power (for EA). Overall, water efficiency appears not to be a critical category. The results suggest different scores for different credits. The suggested scores that should be assigned to each credit are presented in Table 4.

Credits that bring a score of one might not be implemented. However, they often have hidden benefits that might not be correctly evaluated. In order to enhance the chance of having a certain variety of credits implemented, some other rules should be applied, for example, "at least one credit per category."

The LEED rating (Certified, Silver, Gold, or Platinum) that a building applying for certification would obtain when following the scale suggested in Table 4 should be modified to reflect the suggested changes. Note that if the equal weighting scheme is applied to the overall annual impacts of a standard office building (average of the values presented in Fig. 1, divided by 50 years, and multiplied by the factor 40, to be comparable to the scores attributed to each credits), its impacts score is approximately 8,000. Furthermore, if all the LEED credits are implemented, the overall benefits achieved would correspond to a score of approximately 3,000. This is an interesting result. Indeed, it means that even if all the LEED credits are implemented, the overall impacts of a standard office building would be reduced by less than 40%.

When the new scoring system is compared with the practice, some interesting discrepancies appear. For example, as shown by Matthiessen and Morris (2004), among the projects applying for a gold or a platinum rating, virtually none applied for the credits MR 1.1, MR 1.2, MR 1.3 and MR 3.2, less than 20% targeted the credits EA 6 and EA 1 (for more than 15% reduction), and less than 40% targeted the credits SS 2, SS 4.4 and EA 2.3. Altogether, these credits represent a score of less than 17 in the current system, but more than 2,000 points over 3,000 that would be obtained for the entire set of credits. This leads to the suspicion that most of the buildings that are rated platinum have an overall reduction of impacts of less than 15% of the total impacts of the same building without certification.

The new scoring system presented in this paper, along with a new scale for the ratings, should help correct and avoid the type of discrepancy just presented. Adapting the scale to the new scoring system is difficult. Indeed, the meaning of platinum is fairly arbitrary. An example of scale could be: 1000, 1500, 2000 and 2500 points to be rated Certified, Silver, Gold and Platinum, respectively.

3.1 Limitations and further research

Although the study aims at quantifying the benefits of LEED, it has several limitations. Most importantly, the categories indoor environmental quality and innovations & design process are not included since results from these sections are currently not addressed by LCA methodologies. Second, as discussed in section 2.4.4, the impacts resulting from water consumption and land use are currently not well understood and poorly evaluated, whatever the impact assessment methodology chosen. Third, hidden benefits should be more thoroughly investigated, and qualitative and quantitative evaluation is to be done in order to take them into account when assigning a certain score to a specific credit. The interpretation of each credit should be corroborated with actual observations of different LEED-rated buildings. Also, further research needs to be conducted on possible other critical credits that should be added to the list of LEED credits in order to improve its relevance. Finally, the concept of environmental benefits achieved per dollar invested should be explored in order to suggest the credits to first focus on and invest available money in order to maximize the efficiency of LEED implementation.

4 Conclusions

The LCA findings suggest that the quantifiable benefits of LEED have high variations when compared to one another. The magnitude and variation of these benefits are indicated in Table 4. The energy & atmosphere category, aiming at reducing the non-renewable energy consumption in the operation phase, provides the most benefits. The credits of sustainable sites, aiming at reducing the impacts of commuting, also provide large benefits, although the credit 4.3 (use of bioethanol instead of gasoline) can be positive or negative, depending on the weighting scheme chosen. Other credits of sustainable sites provide only marginal benefits, with credit 7.1 being positive or negative, depending on the alternative chosen. The initial credits of materials & resources (aiming at reusing the structure of the building) provide high benefits, whereas the rest have low benefits. The category water efficiency appears to provide only marginal overall benefits.

Within the evaluated credits, it appears that the ones providing the most environmental benefits are the one geared toward green power (if used over the entire lifespan of the building), reducing energy consumption, reducing commuting, increasing the recycling of wastes, and reusing the structure of the building during renovation. Credits related to water efficiency, building footprint reduction or recycled content in the furniture appear to provide much less benefits.

Important discrepancies are observed between the LEED credits that have high benefits and a low target rate (e.g., credit EA 6), as well as LEED credits that have low benefits and high target rates (e.g., credit WE 1.1).

The main practical proposition is the new scoring system suggested in Table 4. Indeed, this new scoring system should help address the issue of discrepancies by providing scores that are proportional to the actual environmental benefits associated with the implementation of each credit. A higher LEED rating would then be more certainly related to lower impacts. Because of the different uncertainties and possible other considerations for including certain credits in LEED, an improved scoring systems does not necessarily need to be solely based on the present LCA results, however, the information provided by LCA should be considered when revising the scoring system.

The LEED point system should reflect environmental impacts. Despite the different limitations mentioned above, this paper is an attempt to making LEED a more effective rating system with the goal of lowering the environmental burden of buildings.

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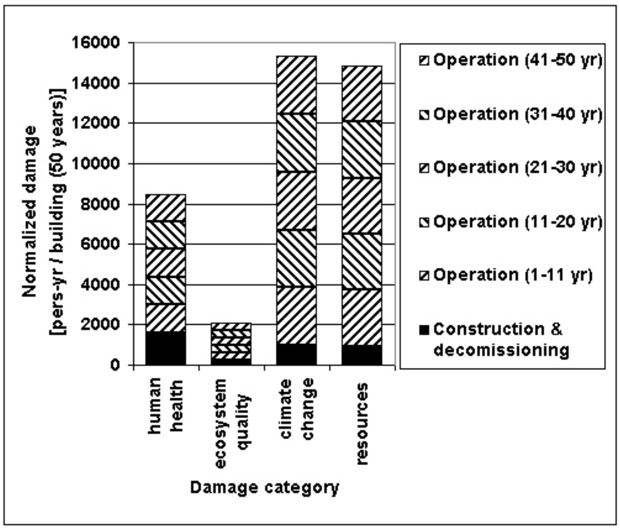

Fig. 1: Total impacts (based on IMPACT 2002+) of a standard (non-LEED) office building

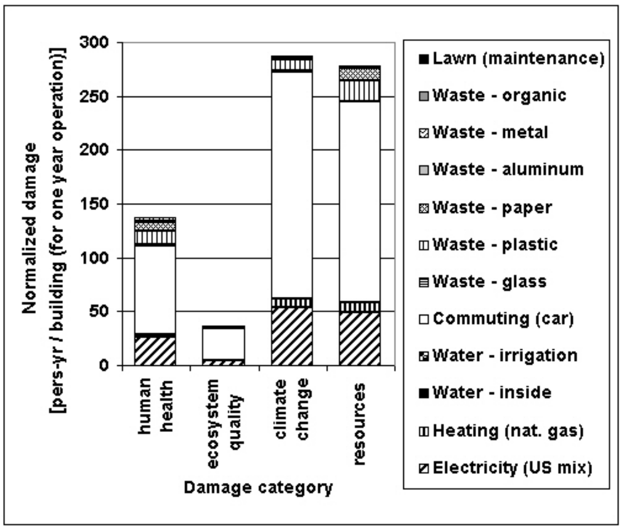

Fig. 2: Operational impacts (based on IMPACT 2002+) of a standard (non-LEED) office building (during one year)

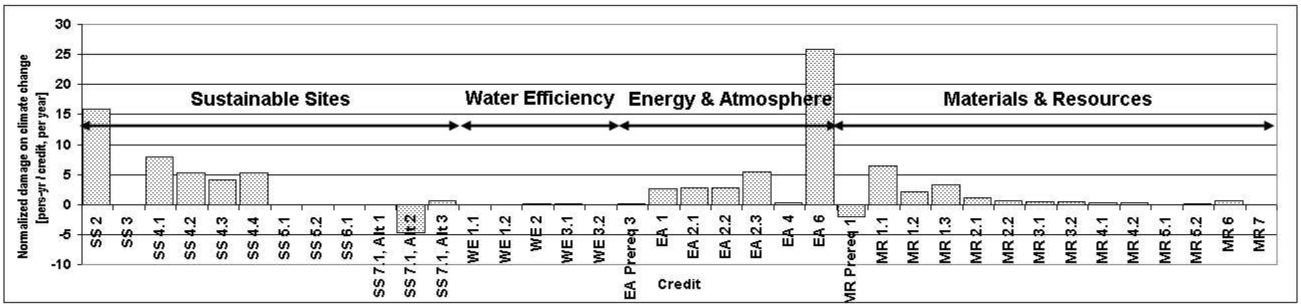

Fig. 3: Benefits (based on IMPACT 2002+) of the different credits on climate change

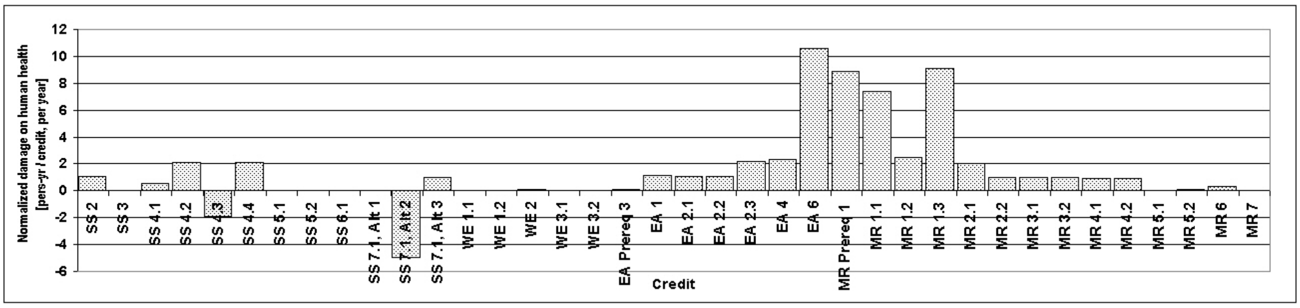

Fig. 4: Benefits (based on IMPACT 2002+) of the different credits on human health

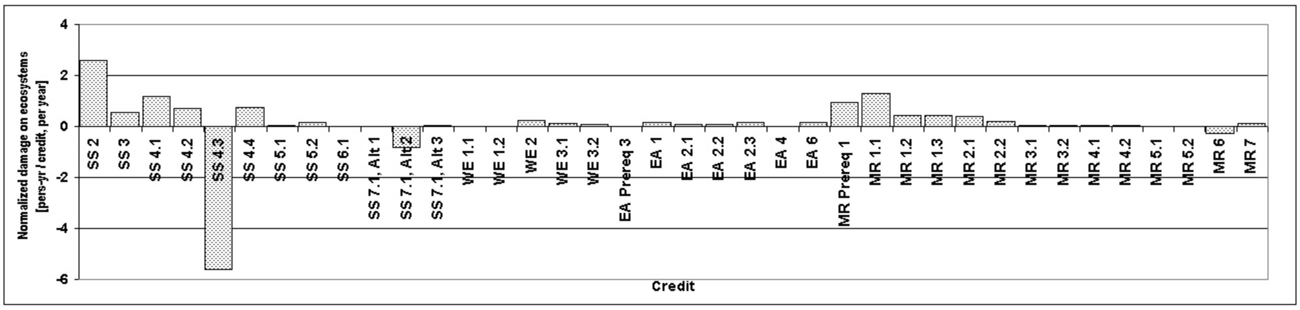

Fig. 5: Benefits (based on IMPACT 2002+) of the different credits on ecosystem quality

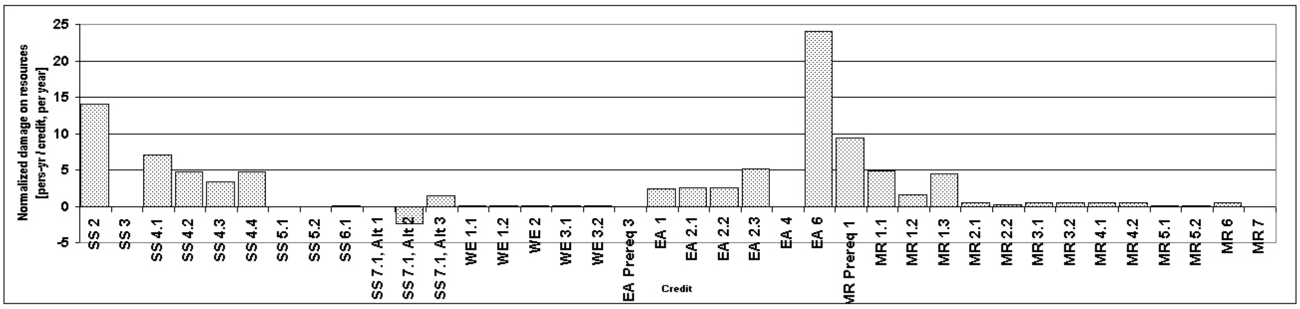

Fig. 6: Benefits (based on IMPACT 2002+) of the different credits on resources

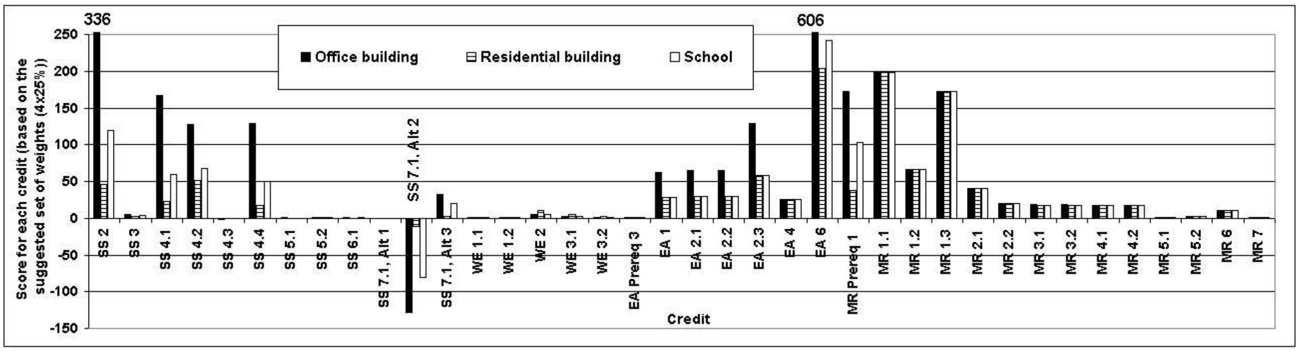

Fig. 7: Influence of the type of building on the final point system.

Table 1: Main parameters of the three types of buildings studied

Parameter	Office building	Residential building	School building
Number of persons	500 employees	100 residents	100 employees + 1000 students
Structure (4 stories)	footprint: 3710 m^2; 15992 t of concrete; 1384 t of steel		
Interiors	sheetrock: 1457 t; steel: 583 t; ceramics: 146 t; wood: 583 t; plastics: 146 t; equipment: 10 t (electronic) and 100 t (mechanical)		
Transportation associated with the building	500 cars (50 km/car·day)	50 cars (50 km/car·day)	students: 50% by car (10 km/car·day), 50% by public transportation (10 km/pers·day); employees: 100 cars (50 km/car·day)
Size of the parking lot	560 spaces	50 spaces	350 spaces
Days in use per year	260 days/yr	350 days/yr	230 days/yr
Electricity (kWh/pers·day)	8	10	employees: 8; students: 1
Natural gas (MJ/pers·yr)	3200	20000	employees: 3200; students: 1000
Potable water (liter/pers·day)	40	300	employees: 40; students: 20
Waste generation (kg/pers·yr)	glass: 25; plastics: 117; paper: 182; aluminium: 3; other metals: 30; organics: 20	glass: 25; plastics: 117; paper: 182; aluminium: 3; other metals: 30; organics: 20	employees: same as in an office students: 5 times less than employees

Table 2: Interpretation of the different LEED credits for a standard office building

LEED credit (summary)	Key parameters used in the modeling in this paper
Sustainable Sites (SS)	
Prerequisite 1: Design sediment & erosion control plan.	n/a
Credit 1: Avoid development of inappropriate sites.	n/a
Credit 2: Increase localized density by utilizing sites that are located within an existing minimum development density of 60,000 ft^2/acre	50% less land use, agricultural land saved: 10,165 m^2·yr/yr 10% less cars, 650,000 km/yr driven less
Credit 3. Develop on a site classified as brownfield, and provide remediation required by EPA.	100% less land use, agricultural land saved: 26,331 m^2·yr/yr. Land is completely reused.
Credit 4.1: Locate within ½ mile of commuter rail or subway station and ¼ mile from bus station.	5% less cars driven to work, 325,000 km/yr driven less or driven by public transportation
Credit 4.2: Bicycle security and convenient changing/shower facilities for 5% or more of building occupants (15% for residential).	5% less cars, 162,500 km/yr driven less Impacts of extra bikes and showers are assumed negligible.
Credit 4.3: Provide alternative fuel vehicles OR install alternative refueling stations for 3% vehicle parking capacity.	3% of the cars concerned, i.e. 195,000 km/yr driven with bioethanol instead of gasoline.
Credit 4.4: (rehab) Add no new parking AND provide preferred parking for carpools for 5% of building occupants OR (new buildings) provide preferred parking for carpools for 5% of building occupants.	2.5% less cars, 162,500 km/yr driven less (2 passengers per car pool assumed) 2.5% less paved area (416 m^2·yr/yr of land saved)
Credit 5.1: (green field sites) Limit clearing of vegetation around the site OR (previously developed sites) restore 50% of the remaining open area.	5,310 m^2·yr/yr land conversion from constructed urban land to green urban land
Credit 5.2: Designate open space equal to building footprint.	25% land saved or building area, 5,083 m^2·yr/yrland saved
Credit 6.1: Decrease storm water by 25%.	5,083 m^3/yr less in the network
Credit 6.2. Storm water treatment.	n/a
Credit 7.1: **Alt. 1)** Provide shade for at least 30% of the site's non-roof impervious surfaces; OR **Alt. 2)** place a minimum of 50% of parking spaces underground or covered by structured parking; OR **Alt 3.)** use an open-grid pavement system for a minimum of 50% of the parking lot area.	Alt. 1) no impacts, no benefits. Alt. 2) 50% less parking lot: 8,310 m^2·yr/yr land saved. Parking structure: 11,362 t concrete and 795 t steel extra. Alt. 3) 8,310 m^2·yr/yr from asphalt to open-grid pavement; 8,310 m^3/yr less runoff in the network
Credit 7.2: Use highly reflective and emissivity roofing.	n/a
Credit 8: Avoid night sky pollution.	n/a
Water Efficiency (WE)	
Credit 1.1: Reduce irrigation water by 50%	50% less irrigation water, 1,500 m^3/yr saved
Credit 1.2: No irrigation water (reduction by 100%)	100% less irrigation water, 3,000 m^3/yr saved
Credit 2: 50% reduction of municipal potable water going into for sewage OR treat 100% wastewater to tertiary standards.	40% (2,080 m^3/yr) potable water saved 50% of 80% (80% of potable water going into sewage)
Credit 3.1: Use 20% less potable water.	20% (1,040 m^3/yr) potable water saved
Credit 3.2: Reduce potable water use by an additional 10% (30% total).	½ the benefits of Credit WE 3.1
Energy & Atmosphere (EA)	
Prerequisite 1: Commissioning, verification and documentation.	n/a
Prerequisite 2: Follow ASHREA standard or local energy code.	n/a
Prerequisite 3: No CFCs in building HVAC systems	1 kg/yr of CFC-11 avoided (gross assumption)
Credit 1: Per point (10 total possible): reduce regulated energy consumption by 5%	Per point: 5% (regulated) electricity (41,600 kWh/yr) saved and 5% natural gas (80,000 MJ/yr) saved
Credit 2.1: Supply 5% of building energy with on-site renewable energy.	5% electricity (52,000 kWh/yr) and 5% natural gas (80,000 MJ/yr) replaced by photo-electricity and solar heat respectively
Credit 2.2: Supply 10% of building energy with on-site renewable energy.	Same benefits as Credit EA 2.1
Credit 2.3: Supply 20% of building energy with on-site renewable energy.	2 times the benefits of Credit EA 2.1
Credit 3: Additional commissioning and review.	n/a
Credit 4: No HCFCs/Halons in refrigeration equipment and fire systems.	Assumption: 5 kg/yr R-22 and 5 kg/yr Halon-1211 avoided
Credit 5: Install continuous metering equipment.	n/a
Credit 6: Enter into a 2-year contract to purchase green power for 50% of the building's electricity.	50% electricity (520,000 kWh/yr) from U.S. mix replaced by renewable mix (contract is assumed to continue after 2 yr)
Materials & Resources (MR)	
Prerequisite 1: Provide an easily accessible area dedicated to the separation, collection and storage of materials for recycling for the entire building.	Fraction diverted from landfill to recycling: 75% for glass (9,375 kg); 50% for plastic (29,250 kg); 75% for paper (68,250 kg); 75% for aluminum (1,125 kg); 75% for other metal (as steel) (11,250 kg); 50% for organic (5,000 kg)
Credit 1.1: Maintain at least 75% of existing building structure and shell (excluding windows and non-structural roofing material).	concrete and steel: 75% less concrete (11,994 t); 75% less steel (1,038 t)
Credit 1.2: Maintain an additional 25% (total 100%) of existing building structure and shell (excluding windows and non-structural roofing material).	1/3 the benefits of Credit MR 1.1
Credit 1.3: Maintain 50% of non-shell (interior walls, doors, floor coverings and ceiling systems).	50% non-shell saved (i.e., 729 t of sheetrock, 291 t of steel, 73 t of ceramics, 291 t of wood, and 73 t of plastics)
Credit 2.1: Recycle and/or salvage at least 50% (by mass) of construction, demolition and land clearing debris.	Diverted from landfill to recycling: 50% of concrete (7,996 t) and 50% of steel (692 t)
Credit 2.2: Recycle and/or salvage an additional 25% (75% total).	½ the benefits of Credit MR 2.1
Credit 3.1: Specify salvaged or refurbished materials for 5% of building materials (including furniture).	5% of interior and equipment saved (i.e. 73 t of sheetrock; 29 t of steel; 7 t of ceramics; 29 t of wood; 7 t of plastics; 0.5 t and 5 t of electronic and mechanic equipment respectively)
Credit 3.2: Same as Credit MR 3.1, but for 10%.	Same benefits as Credit MR 3.1
Credit 4.1: Use materials with recycled content (post consumer + 1½ post industrial) for 5% of total materials (mechanical & electrical excluded).	5% of interior saved (i.e. 73 of sheetrock; 29 t of steel; 7 t of ceramics; 29 t of wood; and 7 t of plastics)
Credit 4.2: Same as Credit MR 4.1, but 10%.	Same benefits as Credit MR 4.1
Credit 5.1: Specify minimum of 20% of building materials manufactured within 500-mile radius (= 800 km).	Original distances from the final manufacturer: steel: 1,000 km; concrete: 50 km (not considered here); interiors and equipment: 1,000 km. Distance saved: 176,327 t·km

Credit 5.2: Of regionally specified materials, specify minimum 50% extracted, harvested or recovered (as well as manufactured) within 500 miles (= 800 km).	Original distances before the final manufacturer: steel: 1,000 km; concrete: 500 km (not considered here); interiors and equipment: 1,000 km. Distance saved: 390,565 t·km
Credit 6: Specify rapidly renewable materials for 5% building materials.	Assumption: plastic-based furniture represents 5% of the value of the building, thus one needs its entire mass to make 5% of the total building value. Assumption: plastics (146 t) replaced by bio-based plastics (146 t)
Credit 7: Use minimum of 50% of wood based materials certified in accordance with the Forest Stewardship (FSC) guidelines.	Less impacts on biodiversity and erosion. 291 ha·yr/yr from intensive to FSC forest (wood yield: 2 t/ha·yr)
***Indoor Environmental Quality (EQ)*: 2 Prerequisite and 15 Credits**	n/a
***Innovation & Design Process (ID)*: 5 Credits**	n/a

Table 3: Impact assessment results (based on IMPACT 2002+) of the main processes used in this study

Damage category:	human health (DALY)	ecosystem quality (PDF·m^2·yr)	climate change (g CO_2-eq)	resources (MJ primary non-renewable)
electricity (U.S. mix) (per kWh)	3.6E-7	0.16	720	12
electricity (renewable mix) (per kWh)	7.6E-8	0.15	26	0.42
natural gas (per MJ)	9.1E-9	2.3E-3	69	1.3
water (per m^3)	7.0E-7	4.5	560	10
concrete (per kg)	9.0E-8	0.064	140	1.2
steel (per kg)	3.9E-6	1.8	2700	46
plastics (landfilled) (per kg)	3.0E-6	0.32	2600	84
paper (landfilled) (per kg)	1.3E-6	0.99	-28	31
car (gasoline) (per km)	1.8E-7	0.18	450	7.3
truck delivery (per t·km)	1.7E-7	0.081	160	2.8

Table 4: Suggested scoring system (i.e., number of point that each credit should receive) based on the LCA developed in this paper (note that the score in the present LEED rating scheme is systematically 1)

Credit	LCA based score[a] (range)	Uncertainty or variability relative to:					Credit targeted in practice? (Matthiessen and Morris 2004)[b]
		type of building	effectivenes s of the credit	inventory analysis	impact assessment	weighting	
SS 2	336 (208-439)	medium	high	low	low	low	rarely
SS 3	6 (2-9)	low	low	low	high	high	rarely
SS 4.1	167 (102-219)	medium	high	medium	low	low	often
SS 4.2	127 (90-159)	medium	high	negligible	low	low	most of the time
SS 4.3	-1 (-79-66)	medium	low	medium	medium	high	rarely
SS 4.4	129 (92-161)	medium	medium	low	low	low	sometimes
SS 5.1	0 (0-1)	low	low	low	high	high	few times
SS 5.2	1 (1-2)	low	low	low	high	high	few times
SS 6.1	1 (1-1)	low	low	high	high	high	few times
SS 7.1 Alt 1	0 (0-0)	medium	medium	low	low	low	
SS 7.1 Alt 2	-128 (-142- -111)	medium	low	medium	low	low	often
SS 7.1 Alt 3	32 (27-38)	medium	low	medium	low	low	
WE 1.1	1 (1-1)	low	medium	low	high	high	most of the time
WE 1.2	1 (1-1)	low	medium	low	high	high	rarely
WE 2	5 (4-6)	medium	low	low	high	high	rarely
WE 3.1	3 (2-3)	medium	low	low	high	high	most of the time
WE 3.2	1 (1-2)	medium	low	low	high	high	rarely
EA Pre. 3	2 (1-2)	high	low	low	low	high	n/a
EA 1	62[c] (44-79)	medium	low	low	low	low	[d]
EA 2.1	64 (43-83)	medium	low	low	low	low	rarely
EA 2.2	64 (43-83)	medium	low	low	low	low	rarely
EA 2.3	129 (86-166)	medium	low	low	low	low	rarely
EA 4	25 (22-32)	high	low	low	low	high	sometimes
EA 6	606 (402-783)	medium	low	low	low	low	rarely
MR Pre.1	172 (172-205)	medium	high	low	low	low	n/a
MR 1.1	199 (175-221)	low	low	low	low	low	rarely
MR 1.2	66 (58-74)	low	low	low	low	low	rarely
MR 1.3	173 (173-183)	low	low	medium	low	low	never
MR 2.1	41 (40-41)	low	medium	medium	low	low	always
MR 2.2	20 (20-21)	low	medium	medium	low	low	often
MR 3.1	19 (19-20)	low	medium	medium	low	low	rarely
MR 3.2	19 (19-20)	low	medium	medium	low	low	never
MR 4.1	17 (17-18)	low	high	medium	low	low	most of the time
MR 4.2	17 (17-18)	low	high	medium	low	low	rarely
MR 5.1	1 (1-1)	low	high	low	low	low	most of the time
MR 5.2	3 (2-3)	low	high	low	low	low	rarely
MR 6	11 (5-16)	low	medium	high	medium	high	rarely
MR 7	1 (1-2)	low	medium	medium	high	high	few times

[a] All missing scores are set to 1 by default. An analysis should also be performed on them in order to adapt their score if necessary.
[b] Nomenclature used: in parenthesis is the fraction of LEED projects that target the specific credit, based on Matthiessen and Morris (2004): most of the time (>80%), often (60%-80%), sometimes (40%-60%), few times (20%-40%), rarely (<20%).
[c] 10 fold increment (i.e., for each 5% increase, 62 points should be received, up to 620 points)
[d] >80% (first 5%), 40-60% (second 5%), < 20% (third 5% and above)