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Environmental assessment of building properties—Where natural and social sciences meet: The case of EcoEffect

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Abstract

The EcoEffect method of assessing external and internal impacts of building properties is briefly described. The external impacts of manufacturing and transport of the building materials, the generation of power and heat consumed during the operation phase are assessed using life-cycle methodology. Emissions and waste; natural resource depletion and toxic substances in building materials are accounted for. Here methodologies from natural sciences are employed. The internal impacts involve the assessment of the risk for discomfort and ill-being due to features and properties of both the indoor environment and outdoor environment within the boundary of the building properties. This risk is calculated based on data and information from questionnaires; measurements and inspection where methodologies mainly from social sciences are used. Life-cycle costs covering investment and utilities costs as well as maintenance costs summed up over the lifetime of the building are also calculated.

The result presentation offers extensive layers of diagrams and data tables ranging from an aggregated diagram of *environmental efficiency* to quantitative indicators of different aspects and factors. *Environmental efficiency* provides a relative measure of the internal quality of a building property in relation to its external impact vis-à-vis its performance relative to other building properties.

Keywords: Environmental assessment; Building property; Life-cycle assessment; EcoEffect; Indoor environment; Outdoor environment

1. Background

Since some decades ago, there has been a concern for resource depletion and environmental pollution associated with building properties and surrounding infrastructures. In addressing such impact of the built environment, there is a recognition of the existence of alternative building materials, fuels for energy supply, source for water supply and options for wastewater treatment as well as technologies for waste handling and disposal. Nevertheless, for long time, the choice between such alternatives was dictated by factors such as differences in prices and aesthetic values.

A new important dimension in discriminating between different options is the environmental dimension. This aspect is important since buildings are one of the spatially big new additions to the natural environment that consume a lot of materials and energy during their long lifetime. For this and other reasons, the building sector's energy consumption is significantly high in comparison to other sectors.

According to UNEP's *Sustainable Building and Construction*, the building and construction sector (i.e. including production and transport of building materials) in OECD countries consumes 25–40% of all energy used (as much as 50% in some countries) [1]. The utilities associated

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with the buildings represent a significant impact of the sector. On average, one-third of energy end-use in the developed world goes for heating, cooling, lighting, appliances, and general services in non-industrial (i.e. residential, commercial and public) buildings [1]. Construction is believed to consume around half of all the resources humans take from nature. Besides, the built environment accounts for some 40% of world greenhouse gas emissions [1].

To give a full picture of the concern associated with building properties, the comfort aspect of building spaces should be combined with the demand for lower environmental impacts of the buildings on the immediate and remote environment, within and outside the used space. Comfort includes subtle components of well-being and indoor health concerns.

There is a need for tools focusing on assessment of the performance of buildings and generating valuable information that can be used by the actors in the building sector to produce building properties with habitable indoor environment and low environmental impact.

2. Assessment tools

During the last decade, the building sector has witnessed the development of two types of environmental assessment tools.

The first group of these tools includes those, which purely are based on criteria system. The second group includes those tools that use life-cycle assessment (LCA) methodology.

The criteria-based tools have a system of assigning point values to a number of selected parameters on a scale ranging from "small" to "large" environmental impact. Among the criteria-based tools BREEAM (Great Britain) [2], GBTool (Canada) [3], LEED (US) [4], EcoProfile (Norway) [5], and Environmental Status (Sweden) [6] can be given as noticeable examples.

Most of the LCA-based environmental assessment tools are used as in the selection of design options of the buildings and building materials during the design phase. The advantage here is the ability to calculate the consequences of specific combinations of building materials, building designs and local utility options (i.e. energy supply, waste management and transport type). Examples of tools of this second category that contain LCA component are: Bees (USA) [7], Beat (Denmark) [8], Envest (UK) [9], ATHENA (Canada) [10], EcoQuantum (Netherlands) [11], Team (France) [12], Equer (France) [13], and KCL-Eco (Finland) [14].

Almost none of these tools include the indoor environment. There is, thus, a need for developing a method and a corresponding user-friendly tool that combines internal environment (i.e. indoor environment and outdoor environment) with the external environment with the aim of avoiding problems associated with the problem of optimization of parts, instead of optimization of the "whole."

3. EcoEffect

The EcoEffect method is an LCA-based tool for assessment of both the internal and the external environment of a building property. It is useful in the assessment of existing buildings as well as buildings at design phase. The tool can be applied for two purposes. Firstly, it can be applied for environmental declaration where the focus is external communication. Secondly, it can be used for environmental management of building properties where internal goals and measures for improvement are formulated and followed up by companies working with management of building properties.

The total system under assessment, including the study object, namely the building property is referred to as the "environment." It is then classified into internal environment defined by the jurisdictional boundary of the property and external environment covering everything else from local to global environment.

4. The internal environment

The internal environmental impact defines the risk that people within the boundary of the building property will be affected or disturbed due to "surrounding conditions". "Surrounding condition" includes technical aspects such as the physical features of the building or and other aspects e.g. vicinity to a source of nuisance. The indoor environment and the outdoor environment constitute the internal environment.

The indoor part of the internal environmental impact is divided into two major categories of dichotomies, namely comfort/discomfort and health/ill-being. Discomfort is about one-time nuisance from sources such as noise or draft. Experience of the problem associated with the sources ceases once the affected people move away from the source or once the source disappears. Ill-being, on other hand, implies a prolonged effect on people's health even after a one-time exposure to the source e.g. allergy and arthritis. The results from assessment of the indoor environmental impact are presented in terms of health problems (both discomfort and ill-being) and internal environmental factors. The factors reflect controllable surrounding conditions that affect people e.g. indoor thermal climate.

The outdoor environment is part of the internal environment covering all parts of the building property excluding the indoor part. It refers to the physical conditions on the ground that belong to the building property, namely car parks, playgrounds, water surfaces, paths, resting areas with benches, etc. with a focus on its microclimate and biodiversity.

The internal impact categories in terms of health effects and environmental factors that are included in EcoEffect are shown in Table 1.

Moreover, radon (indoor), warm water temperature (indoor), electromagnetic field (indoor and outdoor), and PCB (outdoor) are assessed in comparing different building properties. Sampling is used in the case of PCB while the rest are assessed through appropriate measurement mechanisms. Each one of the aforementioned categories depends on a number of factors and parameters that make up a problem hierarchy. A building property is assessed using parametric "load values." Aggregation of the parameters is done using weights resulting in a weighted load value per category. Further description of the work on indoor environment is available in Hult [15,16]. Westerberg et al. [17] has a full account of the work on outdoor environment.

5. The external environment

The external environmental impact assessment is carried out mainly in terms of emissions and depletion of natural resources.

Table 1
Health effects and environment factors of the internal environment

Health effects	Environmental factors	
	Indoor environment	Outdoor environment
Allergy	Air quality	Air pollutants
Arthritis	Thermal comfort	Noise
SBS (Sick Building Syndrome)	Noise	Shade
Noise-driven sleeping difficulty	Day light	Wind
Outdoor health effects		Biodiversity
		Biological production
		Storm water

5.1. The emission problem

The contribution of each unit of emitted pollutant to different types of environmental problems expressed in terms of environmental impact categories is calculated. For a given building property, an external environmental impact load value for each impact category is calculated according to a procedure depicted in Fig. 1. This is applicable o the emissions and waste related to the energy and material use of the building property during its lifetime, normally 50 years.

Impact categories covered in the current version of EcoEffect are climate change, eutrophication, acidification, stratospheric ozone depletion, ground-level ozone, human toxicity, and ecotoxicity. These are associated to emissions to air and water. Another group of impact categories related to solid wastes includes: radiation from radioactive material, building and demolition waste, hazardous waste as well as slag and ashes.

The final result of the procedure shown in Fig. 1 is the weighted external environmental load value for a certain impact category. Effect factors are the characterization factors for which internationally acceptable values are available in the literature. In reality, the magnitude of the impact expressed in terms of each endpoint problem within the impact category depends, among other things, on where the emissions occur. In the presence of knowledge about the probability of occurrence of the impact caused by the emissions, a reduction factor with a value of less than one can be used. Currently, due to the absence of such

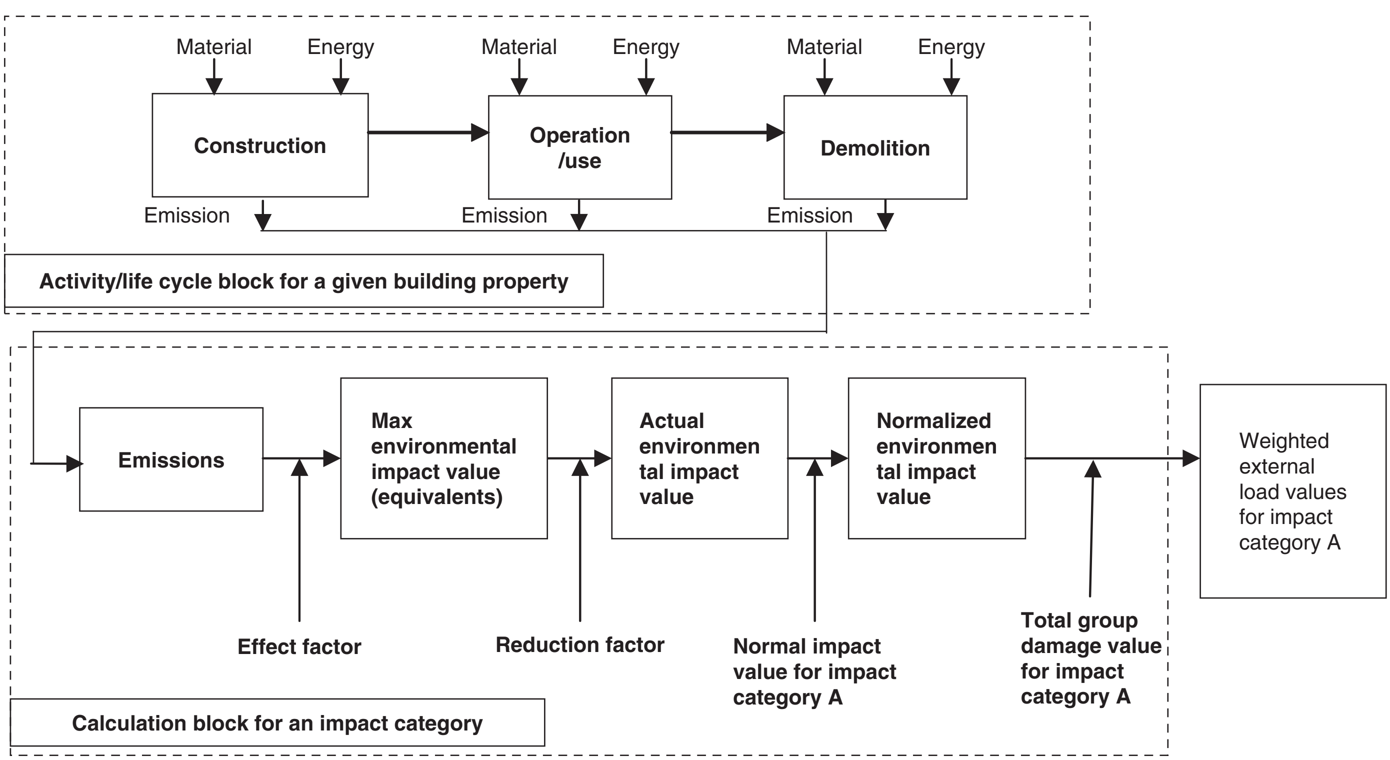

Fig. 1. The calculation steps of the weighted external impact load value for a given impact category A.

knowledge and subscribing to the precautionary principle, a reduction factor of one is used in the current version of EcoEffect. This implies that all the emitted substances are assumed to give rise to an environmental impact. The normal values reflect the type of the impact category. For local impacts such as eutrophication, national data is used as much as possible in calculating the normal values.

Normalisation is done in order to make the environmental load values dimensionless, through which weighted comparison becomes simplified. The total group damage value for an impact category is described in Section 6 of this paper.

5.2. Depletion of natural resources

The extent to which reduced availability of natural resources poses a problem to future generations depends on several factors such as rate of depletion, resource substitutability, resource recyclability, and regeneration time for renewable resources. Different types of natural resources are grouped in the form of depletion categories. A relative value of depletion weight for aggregating the categories will be developed based on damage values as in the case of the emission and waste impact categories. This will simplify the aggregation of resource depletion with the rest of the external environmental impacts. The depletion categories considered in EcoEffect with corresponding references in brackets are metals (copper), fuel (oil), minerals (sand), and organic resources (wood).

6. Weighting

The damage value in terms of group damage value and personal damage value is the basis for the calculation of weights in both the external and internal environmental impact parts of EcoEffect. In the case of external environmental impact, the damage value describes the severity of a given damage/nuisance (also called endpoint problem), if it occurs, to the group of people considered to be exposed to the damage. It is, thus, called a group damage value. The sum of group damage values of all endpoint problems within a certain impact category results in the total group damage value for that category.

In the case of internal environmental impact, damage value refers to the individual's exposure to a given damage/nuisance. One of the major components in both the individual damage value and the group damage value is the characterization of how people's way of life is affected by different types of disabilities using the concept of disability adjusted life years (DALY) [18]. The difference in the calculation basis between the internal environmental impact and the external environmental impact is that in the case of the external environmental impact, data on the number of people affected within a certain area and under a certain time is required. For each endpoint problem, a group damage value that reflects its relative significance in comparison with the other problems is calculated. The total group damage value of each impact category can be multiplied with the corresponding environmental load value resulting in weighted environmental load values (see Fig. 1).

As mentioned earlier the DALY value, sum of years lived with disability (YLD) and years of life lost (YLL), plays a vital role in the calculation of damage values. The whole concept of weighing in EcoEffect depends on retrieving DALY values for different endpoint problems. The range of endpoint problems includes from widely known diseases to subtle and milder nuisances of discomfort. A procedure for calculating the *disability weight* (dw), which is a basis for calculating DALY values, is developed. This approach is based on a health descriptive system called European Quality of Life indicator or EuroQol (EQ-5D+) [19]. In the external impact assessment part, for those endpoint problems where YLD values are not easily available, it is done by proxy using different types of economic loss as a basis. The types of loses include predictable actual economic loss (e.g. 10% reduction on the economy), those resulting in potential economic loss (reduced market value of building property on a beach due to noise disturbance) and those resulting in indirect economic loss (e.g. reduced recreation values due to impact on a forest). Full description of the weighting method in EcoEffect can be found in Eriksson et al. [20].

7. Life-cycle costing and toxic chemicals

In addition to the different impact categories associated with the internal environment and the external environment the building properties can also be compared based on their life-cycle costs. The life-cycle cost covers investment costs and costs for utilities and services (i.e. power, heating, water, wastewater, and cleaning) as well as maintenance costs summed up over the lifetime of the building. Costs that have no evident relation to the environmental impact of the building properties are not accounted for. This is because the main interest in the economic part of the EcoEffect method is to simplify discussions about investments on environmental improvement measures. The problem of toxic substances embedded in different building materials are also included [21]. Information about the *location* and *amount* of the toxic substances is used to describe the problem. This information pair would help characterize the whole building in serving as a learning tool for developers in the selection of building materials. For the tenants it gives an idea while selecting a place to live in.

8. Result presentation

The result presentation in EcoEffect offers extensive layers of diagrams and data tables ranging from an aggregated diagram of *environmental efficiency* to quantitative *indicators* of different aspects and factors. *Environmental efficiency* provides a relative measure of the internal

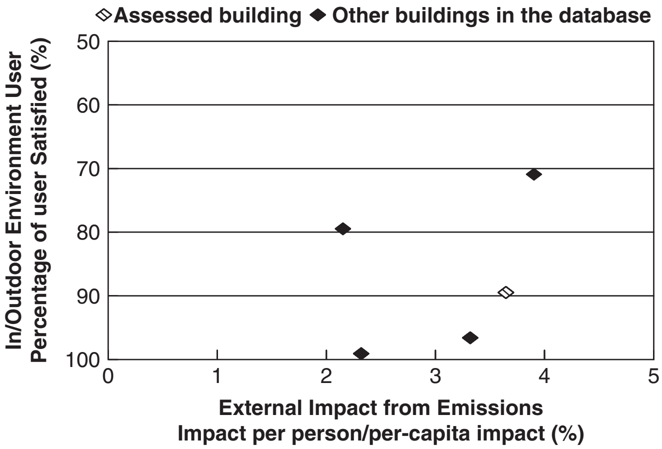

Fig. 2. Environmental efficiency—the most aggregated form of presenting an EcoEffect assessment (each diamond represents a certain building).

quality of a building property in relation to its external impact vis-à-vis its performance relative to other building properties (Fig. 2).

The underlying parameters of the *environmental efficiency* layer and other layers of result can be examined all the way down to the input data by clicking down the result layers. The results are presented in the form of assessing the impact on the external environment and the quality of the indoor environment using different units, e.g. on per-person basis. Different indicators can also be generated in comparing the building properties by combining specific parameters and factors of interest. Indicators give a perspective on the functional unit equivalence by generating selected parameters per m^2 and per person-hour (for office buildings).

In the EcoEffect method, there is a direct association between the characteristics of buildings or activities and the environmental impacts. A change in the material and energy flow or in the physical form of the building properties can directly be shown as a change in the environmental impact result.

This implies that the EcoEffect tool can be used in the formulation and follow-up of quantitative environmental goals for each impact category e.g. a certain building should not contribute to the problem of climate change more than a certain amount. The method can specifically be used by building property companies that use environmental management system according to ISO 14001 or EMAS (i.e. eco-management and audit scheme of the EU). The method is developed so that it can be used in early phases of planning and design and as well as by managers of building property during its operation phase.

9. EcoEffect as a meeting place of the *two cultures*

Different concepts and tools from the ‘‘Two cultures’’ (Snow [22]), namely social sciences and natural science are used in the EcoEffect method in both data collection and processing as well as in the use of the results generated.

The internal environmental part has to do with social science concepts and methodologies such as surveys used to ‘‘measure’’ what people feel and think. The experience of the occupants is at the core part of the whole assessment work. The tool accounts for what the occupants think and feel about the different aspects of the indoor and outdoor environment. By doing so, it brings about an understanding of the occupants' subjective experience. EcoEffect employs quantitative metrics to the different parts of the object of study by combining questionnaires, measurements, and inspections. In some cases a sort of triangulation of these three methods of collecting data can be used to explain why some results look the way they do.

The external assessment is based on knowledge from natural sciences drawing on the physics and chemistry of pollutants in the natural environment, namely air, water, soil, and the biosphere, including the human body. It utilizes results and structures of models that incorporate conversion mechanisms, and dose–response and other cause–effect relationships. The impact of the material and energy flows expressed in terms of emissions and natural resource depletion is determined using a number of models and concepts developed in different fields of research. In the aggregation of different impact categories, however, the EcoEffect method gives way to a combination of both social science and natural science based approaches.

10. Conclusion

The development phase of both the EcoEffect method and its computer-based tool that uses the method has been carried out largely under a strong participation of the end-users, the stakeholders in the building sector. This was done through representations in the board that was overlooking the research project of developing the method and the computer-based tool. There were also seminars and workshops that were used as forums for dialogue between the research group and the stakeholders. The participants had the chance to express the requirements and interests of different stakeholders and users explicitly. They represented the knowledge about the business aspects, the legislation issues, and, to some extent, the need of the end-users, namely occupants. To what level they reflected these different interests, sometimes conflicting, in a balanced way is not easy to articulate.

The areas covered, stakeholders involved, and the stages included in the EcoEffect assessment are mapped out in Table 2 originally developed for *Sustainable Building and Construction* [1]. The bold ones are those included directly and indirectly when assessment is carried out using the EcoEffect tool.

The challenge in developing the EcoEffect tool has been to simultaneously combine a higher degree of comprehensiveness with an easy to understand approach in a user-friendly interface. For a building to perform best according to the EcoEffect assessment, it has to have a higher indoor environment quality as experienced by the occupants and a lower environmental impact.

Table 2
Stages, stakeholders, environmental impact in the building process vis-à-vis EcoEffect's focus

Stage	Siting/design	Construction/refurbishment	Use	Demolition/deconstruction
Actors	• **Developers** • **Owners** • **Architects and engineers** • Finance institutions • Government authorities	• Owners • **Architects and engineers** • **Contractors** • Material suppliers • Labourers • Government authorities • Finance institutions	• **Owners** • **Tenants** • **Building managers** • **Operation and maintenance personnel** • Government authorities	• Contractors • Recyclers • Salvagers • Landfill/incinerat or managers • Government authorities
Actions and inputs	**Choices affecting:** • **Land use** • **Material use** • **Energy and water needs** • Aesthetics • Transport and mobility	• **Building materials**[a] • **Chemicals** • **Energy** • **Water** • Labour • Equipment	• **Chemicals** • **Energy** • **Water** • Labour	• Chemicals • Energy • Water • Labour • Equipment
Environment-related impacts and risks	• **Landscape alteration** • Transport patterns • **Building performance (e.g. energy efficiency)**	• **Raw material extraction and transformation impacts**[b] • Waste • **Run-off** • Noise • Traffic • Landscape impairment • Dust • **Pollutant emissions and discharges**	• **Indoor emissions**[c] • Waste • Wastewater • Heat • **GHGs** • Soil compaction and contamination • **Traffic**	• Waste • Noise • Dust • Release of hazardous materials • Soil/water/air pollution (if landfilled/incinerated)

[a]E.g. wood, steel and other metals, cement, stone, aggregate, bricks and other ceramic products, paint and other coatings, glass, plastics.
[b]E.g. air/water/soil pollution, deforestation, energy use, resource depletion.
[c]E.g. VOCs, formaldehyde, ammonia, carcinogens, fibers, dust, radiation.

The fact that the method covers a large number of areas gives rise to encroachment of different levels of uncertainties into the assessment results. The higher degree of comprehensiveness, on the other hand, avoids sub-optimization. Input data uncertainty and model uncertainty constitute the major part of the total uncertainty. Further studies should be done in fine-tuning the data and the methods used as well as in characterizing whether or not the uncertainties are significant enough to hamper the interpretation of the results from the comparative assessment.

Parts that are currently under development and awaiting future development include expanding the applicability of the EcoEffect method to management of housing areas; assessment and presentation of natural resource depletion as well as waste and wastewater; and possibilities of using CAD program as a vehicle for input data transfer to the EcoEffect tool. Some of these require further method development while some await only implementation.

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