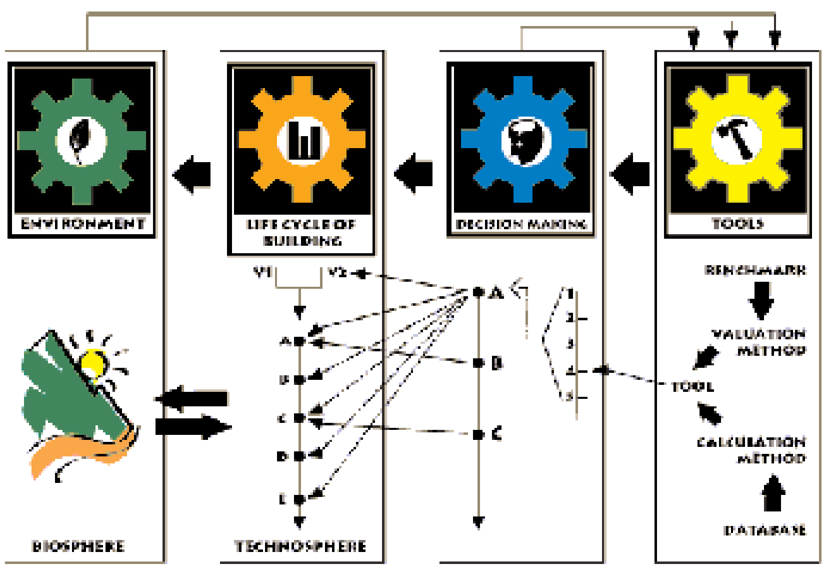
CONTEXT AND METHODS FOR TOOL DESIGNERS



Annex 31

Energy-Related Environmental Impact of Buildings

International Energy Agency

Energy Conservation in Buildings and Community Systems Programme

ANNEX 31

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INTRODUCTION

The art of tool design is rapidly evolving, in concert with the sophistication of users, improvements in information technology and increased market demand for green buildings. This report provides an overview of the most important issues currently facing tool developers, along with recommendations on the next steps. Many of the critical assumptions about building lifetimes, energy flows and occupant behaviour are addressed. The needs and motivations of actors are carefully analysed. Methods for connecting tools with users are discussed, and examples are given for how tool developers can best present results.

ESTABLISHING SCOPE AND CONTEXT

Assumptions

When assessing the environmental performance of buildings over their life cycle, a number of critical assumptions are required concerning the scope and context. Some assumptions relate to the building itself (expected lifetimes, maintenance, end of life scenarios), and others relate to the energy flows, the energy chains, and the user's behaviour. These critical scope and context issues are addressed in this section.

Building's Life Expectancy
The question of the building's life expectancy is not easily answered. According to the intended use of the building, its location, and the choice of construction methods the lifetime will change. Most buildings turn over due to technological (functional) obsolescence, not because of a failure in design. Lifetimes are also subject to uncertainties in the economic situation, evolution of urban plans, and changes in life styles. Even if statistical trends existed, lifetimes are rarely known for certain. Since LCA methods require an estimate of lifetime, the best approach is to conduct a sensitivity analysis to better understand the impact of this critical assumption. Different lifetime scenarios can be standardised for this purpose.

The choice of this data is not neutral since energy consumption dominates the building's use phase. Extending lifetimes from 50 to 100 years can result in a possible doubling of certain impacts. We also need to pay attention to the meaning of the results of the environmental assessment in the distant future, because the distant future will probably be different from the extrapolations we make today.

Servicing, Maintenance, Refurbishment
The practices concerning servicing must be defined and the elementary processes utilising energy must be specified.

Since a building is an assembly of elements, each having its own life expectancy, we need to optimally define replacement strategies, distinguishing individual replacements from more elaborate refurbishment. The replacement frequencies are to be initial estimations, based upon past experience. This is complicated, however by the interdependence of assemblies. In some cases, the need to replace one element entails replacing a larger assembly of which it is an integral part.

Answers to this question can be sought among maintenance companies, asset-management firms or technical centres. This would also allow the identification of any differences in how often materials are replaced; between individual and collective housing; rental and ownership; housing and commercial buildings.

We have to keep in mind that the environmental performances of the building are decreasing with time, if no maintenance is performed. Generally the environmental assessment methods can't model this phenomenon properly. Maintenance work has itself environmental effects, but it does advantageously restore the initial performance of the building or technical equipment. Strictly speaking, it would be necessary to define rules of degradation of performance versus time.

Furthermore, what are we going to replace a defective element with? Practice shows that we rarely replace it with an identical element (products evolve, tastes change, choice criteria also). Just the same, the assumption which is generally selected is a replacement with an identical item, whether for products or for energy. This is the assumption that is easiest to control (we have available data for the calculations), knowing that we cannot really predict future evolution.

So we do not have a good handle on product replacement. And we have an even poorer handle on adaptations of the building (functional adaptation, enlargement) and changes in intended use (offices transformed into apartments, for example).

Demolition / Deconstruction

Given the distance in the future of the demolition / deconstruction phase, we are obliged to make assumptions or to construct scenarios for the end of the life of the building. Assumptions have to deal with demolition technique, waste treatment, waste recovery and assignment to next uses. Tools are particularly sensitive to assumptions concerning waste processing. A solution may be to adopt contemporary techniques, and some methods have chosen this solution; but this has to be seen as a convention, not as a prediction. An assessment method may purely and simply exclude this phase, given the uncertainties. We can also choose to give less weight to the environmental effects that will occur in the future in comparison with those which are occurring in the present and which are therefore better known.

Energy Consumption and Related Impacts

For building products and materials, energy consumption and related impacts per unit weight of material are sensitive to the assumptions adopted: the processes studied, the "mix" of electrical power chosen (since the nature and proportion of power production sources vary from one country to another).

When comparing different tools, major differences in the consumption of primary energy can be due to the different databases used, and to the chosen limits of the system analysed. Total energy consumption relating to a material is calculated in different ways, depending on which forms of energy consumption are taken into account (extraction, manufacturing processes, transport, feedstock).

Considering the operation phase of a building, some energy uses are poorly known, as for instance electricity consumption from artificial lighting in dwellings. In such cases, assumptions have to be made.

Energy Changes and Evolution of Energy Chains

In terms of energy, past experience indicates that buildings may change their energy sources during their life (particularly for the heating, the hot water production, the cooking). What assumptions should be made? The evolution of the energy context is difficult to predict (geopolitical context, economical context, new local opportunities, evolution of technology, development of renewable energy), and therefore, in general, the models consider the same energy source for an entire building's life. But this can generate inconsistency. This is the case for example, if we adopt a lifetime for the building of 80 years and an energy source whose world reserves are now estimated at 40 years.

The energy chains may also change. This is the case for the electricity chain since the present average distribution of production sources risks becoming quite different 50 or 100 years hence. And incidentally, the electricity production sources are evolving even from year to year. Electricity may also be produced locally (Combined Heat and Power plants, photovoltaics, micro-hydro power plants, wind turbines) and not only centrally. One way of taking into account the influence of these factors on the environmental effects is to simulate a set of political and economical scenarios.

The Occupants' Behaviour

The occupants' behaviour has a large influence on the environmental effects of the building during its use phase. This behaviour is not known in advance and it varies according to the individuals. To reflect upon the diversity of behaviour we can model them through the use of scenarios. Given the influence on the results of parameters linked to the occupants' behaviour, we need to carefully choose the parameters and set them down in detail.

Use-related factors, and their impact on the environmental quality of a building, are particularly poorly dealt with in calculations. A few general assumptions are commonly accepted, based on standard equipment and so-called "average" behaviour. However, the influence of use is not modelled. In particular, the sensitivity of equipment installed in housing (of varying effectiveness) has not been analysed according to types of user (the thriftiness of their behaviour may vary, for instance, in choosing heating temperatures and managing lighting). The conditions of use, at least for items such as energy, water and wastes, could be defined in a standard way, and then progressively adjusted as new information becomes available from new surveys. As the behaviour of users is difficult to predict during the design phase, different behaviour scenarios could be studied for a single building design in order to better relate the influence of users' behaviour (conventional, ecological) on the results.

A French study has shown that the influence of users' behaviour on the environment can be of the same order as the influence of design (green / not green).

Users' Transportation

The transport of users falls more within an urban scale approach, calling for an analysis of sites, rather on the scale of an individual building. However, there is currently no consensus between developers as to whether or not to take the transport of users into account in building environmental assessment tools (this brings us back to the question of the choice of system limits). And when it is taken into account, there is no consensus on how to model it.

It should be noted that when user transportation is taken into account, it has a significant influence on the environmental impacts.

Transparency of Assumptions

Since we cannot multiply the simulations of scenarios infinitely, when undertaking an environmental assessment we must be conscious of necessary uncertainties, and extrapolations. The results are very sensitive to these assumptions and must be analysed prudently. When analysing the results, we need to review all these assumptions. Databases (for products or energy chains) have to be used cautiously with all the assumptions in mind.

Transparency of assumptions is an important requirement. Given the sensitivity of the results to the set of assumptions, performing sensitivity analysis is necessary. The environmental tools must be flexible regarding assumptions and must allow sensitivity analysis.

Tool developers must justify and make explicit their assumptions. It would be useful if they also suggest a set of relevant scenarios to be studied.

Selecting Output Sets Related to Actor's Needs

Actor's Motivation and Needs

Previous reports have discussed the interrelationship between biosphere and technosphere, and the role of decision-makers involved in the building process. The decisions that need to be taken during the planning process and lifetime of a building and which affect or consider these interrelationships have also been structured in previous sections. The outcome is a catalogue of decision stages with particular relevance to energy matters, health and the environment.

The aim here is not only to help actors identify and recognise the connection between the decisions they take and their effect on health and the environment, but also to positively and negatively influence them. The provision of such information is essential to effective decision-making around issues of energy conservation, sustainable development, health and environmental protection. Moreover, the information must be tailored to suit the specific interests, knowledge areas and responsibilities of the individual decision-makers (actors) involved.

The following section of this report analyses what information is required in order to effectively integrate energy-related and environmental issues in the investigation and decision making stages. The analysis, or more accurately said, a set of requirements, is intended to form the basis of a comparative assessment of tools, methods and data. These, in turn, will be assessed according to whether they fulfill the actors' necessary information requirements or whether further (or new) development of tools is necessary. This approach has been chosen in order to address issues resulting from the everyday problems encountered by actors in practice.

This discussion is intended to complement the Annex 31 Directory of Tools, and Types of Tools, both of which provide an overview of the state of the art and the strengths and weaknesses of existing tools. Ideally a discussion on tool design issues will provide tool developers with a more scientific understanding of how to support and promote energy saving and environmentally responsible approaches to the planning, building and operation of buildings.

Structuring The Information Requirements

The actors' information requirements can be structured according to various aspects as detailed individually below. Each is addressed methodically with a summary to conclude:

a) Motivation, authority, responsibility and personal interest
b) Subject of information required
c) Information detail, adaptability and presentation form

Motivation, Authority, Responsibility and Personal Interest

Although the individual actors' information requirements do have to be allocated to the specific role and approach of each actor, differing degrees of motivation as might apply to an individual person can nevertheless be defined as follows:

Motivation level 1 (individual dimension)
The interests of the individual for his or her health, comfort and quality of life are covered by motivation level 1. This applies in particular to the individual user of a building or the building owner where the building is intended for his or her own use. This might also apply to individual spokespersons of third parties representing their health and comfort interests. It covers the personal motives of the 'user' or a representative of the family or of the colleagues. The motivation of the 'planner" or 'building owner' to secure the interests of third parties (here the users) vary from moral and ethical dimensions (personal honour, sense of responsibility, professional approach...) to marketing aspects and economic constraints (image, long term tenancy...).

Here, motivation level 1 generally involves concrete information regarding air quality, comfort levels, health issues etc. at the level of a room and during the use phase of a building. Ensuring an adequate quality of life in the general sense represents the link between local and global approaches.

A special case is the 'construction company' which not only concerns itself with the aforementioned issues but also with the health and safety interests of their workers at the workplace during the construction, maintenance and demolition phases of a building.

In addition to all of the above, the interests of users and workers are represented and ensured by legislation.

Motivation level 2 (local / regional dimension)
Motivation level 2 considers the local and regional dimension i.e. the direct environment of the building, estate or town, or the estate or town itself and its immediate vicinity. In exceptional circumstances the regional point of view can be extended to national issues.

The actors' motivation is a result of individual interests (i.e. a personal user) or out of the aspiration and need to protect third party interests. Typical information requirements include land usage, land surface treatment, the effect on ground water and landscape, local air pollution, pollutants from buildings, the use of regional natural resources, and so on.

The planner's deliberations require further information regarding local mass flow (building materials, products, waste) and personnel transport. A typical subject is the 'use' phase, although this can be extended to include the construction and possibly also maintenance and demolition phases of a building.

Motivation level 3 (global dimension)
The global dimension covers motivations concerning sustainable development and environmental protection. The environment, at once a source of raw material and power and at the same time our living environment should be protected, on the one hand, through the reduction in the use of natural resources and the maintenance of regenerative natural systems, and on the other, through reduced environmental pollution. In addition to this flora and fauna needs to be protected to ensure biological diversity.

At the level of health and quality of life, this addresses the reduction of harmful emissions. Information regarding the (global) energy and mass flows (use of resources, emissions, waste) as well as their effects on the environment are required. Typical subjects of analysis are the individual building during its complete life cycle or building stock in its dynamic development.

The integration of the global dimension in the actors' considerations is gradually becoming more widespread with 'users', 'planners (design teams)' and 'building owners'. One reason for problems until now has been the inability to provide the respective actors with the relevant information. Even when sufficient motivation already exists, insufficient information obstructs objective decision-making and restricts intentions to an ideological level.

To summarise, it can be observed that the respective actors' degree of motivation corresponds well with their degree of influence on the environment. In principle it is therefore possible to address the energy and environmentally related information requirements with regard to point/individual, local/regional, and global causes and effects.

Phase	Building owner	User	Design Team	Contractor	Operator
Pre-construction			local global		
Construction	local (global)		local (global)	*individual* local (global)	
Use	***individual*** ***local*** global	***individual*** ***local*** global	***individual*** ***local*** **global**		*individual* local global
Maintenance	local (global)	individual **local**	*local* global	*individual* local (global)	
Demolition			*local* (global)	*individual* local (global)	
Disposal			*local* global		

Table 1 *The motivation levels of actors according to the life cycle phases of a building*

(italic = indirect - third-party, **bold = particular motivation**)

Table 1 matches the motivation levels of the actors to the life cycle phases of a building. Note that the information is not required during this phase, but during the decision-making and preparatory process for this stage.

The Subject of the Required Information

During the decision finding process, information regarding a variety of subjects is required. Each actor is interested in a specific subject matter. In order to develop a structure for the description and assessment of methods and tools it is necessary, amongst other matters, to differentiate these according to subject matter or application area. In general actors require information regarding the following subject areas (functional units):

- building products (shell and finishing materials)
- building processes
- building construction solutions = elements (shell element, finishing element)
- technical systems = elements (heating system, electrical installation...)
- entire buildings
- infrastructure, provision of energy and service.

Example: The purchaser of a building receives an energy certificate or building certificate detailing the (assessed) properties of the building with regard to its energy-related and ecological quality. He allows this information to inform his buying decision.

Special case: Developers and clients require information to help inform their personal decision when preparing an investment. At the same time they are interested in information with a high marketing value for potential buyers or users (for example an energy pass, building pass or certificate).

Subject	Building owner	User	Design Team	Contractor	Operator
building product					
- shell			■	■	
- finishing	■		■	■	■
- associated products		■	□	■	■
building process			□	■	
element					
- shell	□	□	■	□	
- finishing	■	■	■	□	■
- technical services	□	□	■	□	■
entire buildings	■	■	■		
infrastructure	□	□	■		■

Table 2 *Localising the required information with regard to the actor and functional unit*

(■ = major interest area; □ = interest area)

Information Detail, Adaptability and Presentation Form

During the decision making process the actors place differing demands on the information required. These vary according to degree of detail, degree of interpretation, presentation form as well as the adaptability and variety of analysis possibilities. In principle the possible interest areas can be summarised in the following cases:

Case 1 – passive role (the receipt (and passing on) of information)

Information is required in a highly summarised form in the form of (already evaluated) end results. The aim is to consider the results of energy and environment related assessment procedures in combination with other aspects (such as cost, profit, building time etc.) within a complex decision-making frame.

Often the knowledge basis or available time is insufficient to question the available information or to allow a detailed analysis. The actor must therefore make the assumption that the information is correct and trust the professional judgement of the assessor. As a result there is the need for generally accepted conventions for supplying and assessing information.

Case 2 – active role (preparation, assessment and provision of information)

Detailed initial information is required which can be actively converted and assessed in different degrees of simplification. It should be possible to analyse the information during the working phase in order to deliver specific results. Furthermore the provision of suggestions as to how to improve the solution, enable further work and an assessment of comparable solutions would represent sensible additions.

After the preparation and assessment phases, the information tailored to the needs of third parties, needs to be presentable without extra effort and perhaps with a concluding summary. Table 3 illustrates the relationship between the degree of participation and the actor and Table 4 the relationship between actor and the required level of information.

Example: The planner is designing an environmentally friendly low-energy house. He uses a planning aid to calculate the energy required to heat the house as well as to calculate the energy and mass flow during the buildings lifetime. By analysing the performance of individual building elements according to energy and mass flow and by varying the thermal insulation and technical services he arrives via an iterative process at a design solution that fulfils the original aims. The results are documented and are handed over to the client in the form of an energy certificate or building pass.

Role	Building owner	User	Design Team	Contractor	Operator
Passive *receipt*	■	■	□	□	□
Passive *passing on*	■		□	□	□
Passive *processing*	□		■	■	□
Table 3	*Relationship actor/degree of activity in obtaining and processing information*				

(■ = typical; □ = possible)

Level of information	Building owner	User	Design Team	Contractor	Operator
Summarised	■	■			
Detailed			■	■	■
Table 4	*Relationship actor/required level of information detail.*				

Conclusion

It is clear that the different areas of interest and the specific information requirements of the actors can only be addressed by methods and tools designed for the purpose. Systematising the information requirements is one way to create a typology of tools, and ultimately support all phases of the planning process.

Developers of methods and tools are recommended to concentrate more on the specific information requirements of individual actors. The developer should analyse the working method and decision-making process of the individual actors in order to effectively implement the necessary compatibility and integration of methods and tools.

The following sections suggest a separation of methods and tools into methodical processes and active and passive aids. The methods are based on calculation and/or assessment processes based upon theoretical models or empirical opinion. The active tools permit the use of methods and models whilst the passive tools (tools as instruments, resources) help summarise, present and pass on information. In certain cases particular solutions can be allocated to methods, tools and instruments at the same time.

Example: BREEAM is based upon the assessment and simplified presentation of information – here using a point system with weighting factors. Tools in the form of software packages exist to help create the BREEAM scale. The result is a certificate, usable as an instrument by the client to demonstrate and market the environmental properties of his or her building.

CONNECTING TOOLS TO USERS

Introduction

This part aims at describing the relationship between environmental assessment tools and their users. Two types of user will be distinguished, and the main functions of the tools will be presented. Then the third sub-part will try to explain the meeaning of "relevant output sets".

The Tool Users

First of all, two types of user should be distinguished:

- those who implement the assessment tool, hereinafter referred to as "assessors", and
- those for whom the results are intended, and who use them to make decisions, hereinafter referred to as "decision-makers".

With some tools, the "assessor" and the "decision-maker" may be the same person. However, this is not generally the case, at least for the time being.

Today, most "assessors" are engineers, consultants or researchers. Currently it is very common for tools to be developed by the same consulting and design firms that ultimately use the tool. Proprietary tools provide a competitive advantage and an expedient method for field testing and validating tool effectiveness. Typically the proprietary tools are bundled and marketed as a service to clients.

Where proprietary tools incorporate a simple method, or a user-friendly interface, others may use them after appropriate training (these include architects, design and engineering firms, contracting authorities). At present, it should be noted that private sector firms and public sector agencies are developing a number of tools, and that almost all such developers are gradually integrating improvements.

A "decision-maker" may be a contracting authority (that is to say a building owner), or may be a design team (architects, engineers) who propose soundly-argued options to their contracting authority or client. Decision-makers may also be larger bodies, such as local or regional authorities. It all depends on the tools' purpose and the project phase involved (such as programming or design, for instance).

At present, all known tools require a competent person to help interpret their results, even if they are supposed to be targeted and adapted to building owners, for instance. An iterative dialogue should preferably be established between assessors and decision-makers, involving any other parties concerned with the project. When an assessor simply submits the results of an assessment to a decision-maker, it is generally impossible for the results to be used in a detailed and relevant way. It is therefore very beneficial when an assessment tool can establish a dialogue between the parties involved, exposing any envisaged solutions to their different viewpoints.

The fact that a tool targets a given "decision-maker" partly defines the limits of the system studied, as decision-makers each have their own questions and concerns. Decision-makers must be informed of which parameters they are able to change in order to reduce impacts.

Furthermore, tools must try to speak the language of their target users, while simultaneously dealing with a field unfamiliar to them. The indicators used by the tool must reconcile "building" and "environmental" approaches. To achieve this, decision-makers need meaningful, understandable results, which reveal causal relationships between sources and their resulting impact factors and effects. Decision-makers need to be given a didactic presentation of the results. However, environmental information must not be truncated on the assumption that decision-makers may not be interested in some issues. Compromises must therefore be made, and each developer defines his own.

Decision-makers must:

- be better educated about the environment (phenomena, complexity of causal chains, interactions between impacts),
- be given user-friendly, transparent tools which speak their language and present tutorials to train them,
- be able to prioritise the environmental themes (with the help of specific tools if necessary).

The Functions of Tools

In a schematic way, a tool may have 3 kinds of “function”:

- predictive,
- decisional,
- educational.

Tools that are recognised and already used are essentially assessment tools for "predictive" purposes. In other words, using predictive models, they produce outputs, comparable to environmental effects, based on input data representing the characteristics of a building project. They are therefore able to analyse a given project, process several variants, and carry out sensitivity studies.

However, most existing tools are not, strictly speaking, "decision-making" tools, which offer technical and architectural design solutions, or recommend options more or less automatically, taking into account certain environmental objectives defined from the outset. This runs slightly counter to the demands of some users, such as architects, who expect tools to provide advice or optimise design. Nevertheless, in view of the multidisciplinary aspect of environmental issues, which is due to the diversity of both impacts and possible technical solutions, professionals would certainly not react well to claims that tools can pull ready-made solutions and decisions "out of a hat". Good tools, it seems, must simply provide relevant information to help a decision-maker make the right decision at the right time, with full knowledge of the facts.

It should nevertheless be added that most tools, although they mainly carry out predictive calculations, can give decision-makers advice through the study of variants, showing the advantages of specific sets of parameters.
The "educational " value of current tools is, in our opinion, not sufficient, although the variety of their outputs has the merit of providing a more or less comprehensive panorama of environmental questions, which must be taken into account. In themselves, raw results only allow an incomplete understanding of the causal chains involved in environmental phenomena (source -> impact factor -> effect -> impact).

Most often, environmental tools are designed to meet only one, or in certain cases two of these 3 functions. Ideally, regarding actors' needs, a tool should probably include all 3 functions.

Relevant Output Sets

A question must be asked before relevant outputs are discussed: relevant to whom or what? Any output must be relevant to the decision-maker for when it is intended, and relevant to the problem in question; in other words, to the objective of the assessment, as the two are linked.

This part has to be connected with those dealing with the different motivation levels of decision-makers, from economical profitability to global environmental concern.

A distinction will be made between the outputs themselves (nature, unit of measurement, functional unit), and the way it is organised and presented (absolute or relative values, concepts of reference or scale, breakdown of results).

The outputs are supposed to present the environmental impacts of a construction operation, directly or indirectly, depending on the tool. These environmental impacts relate to very diverse geographic scales:

- global scale,
- regional scale,
- local scale,
- indoor scale.

Logically, a tool should deal with these four geographic scales, as the risks and rewards are important at all four levels.

The question of relevant outputs is related to the type of user of each tool. It is important that the nature of the results and the way they are presented should answer the questions and concerns of decision-makers, while not obscuring the environmental phenomena, of course.

As far as energy is concerned, for example, what form of output should be provided? Energy consumption (final, primary)? Emissions (and the associated effects)? An indicator of the depletion of various fuels? Other results?

Decision-makers must be informed as objectively as possible about the environmental effects of various types of energy consumption (indicating the sources concerned), while being provided with assessments which enable them to deal with other concerns more or less linked to the environment, which are sometimes expressed in a specific way. The following concerns may be mentioned:

- the acquisition of an energy-efficiency label, with reference to final or primary consumption targets,
- compliance with specifications or regulations,
- the thermal comfort of the occupants,
- the possible taxation of specific atmospheric pollutants,
- the cost of operating the building's power systems.

The results will therefore concern classical environmental effects and impacts linked to various forms of energy consumption identified within the system studied, and could concern other aspects such as: final and/or primary energy consumption, emissions of specific pollutants, winter and summer thermal comfort.

The fact that decision-makers are provided with information which is close to their usual fields (e.g. energy consumption) provides them with reference points, and helps them to link together the technical solutions applied in their projects and their effects on the environment.

On a strictly environmental level, outputs are relevant if they are significant in terms of impact factors and environmental effects, and if they correspond to sources which the decision-maker can influence. Other possible forms of outputs are instead just informative.

Many environmental assessment tools do not currently include cost analysis (investment and running cost). A building owner or an architect for example needs to assess the variants under design in terms of cost, as this is a key criterion in decision-making. In practice, economic constraints are always taken into account when optimizing the design of a building. Until environmental tools integrate cost analysis (either by integration or by external link), designers will have to juxtapose their own economic estimation tools, more or less adapted to environmental choices.

In addition, parties (building owners and others) need information on their rights and responsibilities, that is legal aspects, since "green" solutions are generally new and not widely spread and tested, and since they sometimes generate new responsibilities for certain parties.

Conclusion

We can distinguish two types of tool user, the "assessor" who implements the assessment tool, and the "decision-maker" who has to translate assessment results into decisions. In most cases, the "assessor" and the "decision-maker" are not the same person.

At present, almost all known tools require a competent person to help interpret their results, even if they are supposed to be targeted and adapted to building owners, for instance.
It is very beneficial when an assessment tool can establish a dialogue between the parties involved, exposing any envisaged solutions to their different viewpoints.

Furthermore, tools must try to speak the language of their target users, while simultaneously dealing with a field unfamiliar to them. The indicators used by the tool must reconcile "building" and "environmental" approaches. To achieve this, decision-makers need meaningful, understandable results that reveal causal relationships between sources and their resulting impact factors and effects. They need to be given a didactic presentation of the results. They must be better educated about the environment, and be able to establish environmental priorities.

About their functions, the tools are generally “predictive”, to a certain extent “decisional”, and not enough “educational”. Most of the time, environmental tools are designed to meet only one or two of these 3 functions. Ideally, regarding actors’ needs, a tool should probably include all 3 functions.

About the relevance of output sets, any output must be relevant to the decision-maker for whom it is intended, and relevant to the problem in question, that is in other words, to the objective of the assessment, as the two are linked.

It is important that the nature of the results and the way they are presented should answer the questions and concerns of decision-makers, while not obscuring the environmental phenomena, of course.

Logically, a tool should deal with four geographic scales (global, regional, local and indoor), as the risks and rewards are important at all four levels.

On a strictly environmental level, outputs are relevant if they are significant in terms of impact factors and environmental effects, and if they correspond to sources which the decision-maker can influence. Other possible forms of outputs are instead just informative.

In addition to environmental results, and considering the decision-maker viewpoints and concerns, it would be relevant that environmental assessment tools, either by integration or by external link, allow cost analysis and deal with legal aspects.

Choosing an appropriate tool that meets the demands and desires in the actual situation and coincides with methodological preferences of the user is a precondition for the successful use of a tool. This is also a precondition for the generation of results that are comprehensible and relevant for the user. A “typology” can assist potential tool users in identifying tools that fulfil their demands.[1]

[1] [Rialhe & Nibel, 1999]
Rialhe A. (IED), Nibel S. (CSTB), Four French assessment tools for the analysis of building environmental quality – Implementation and comparison, Result from an ATEQUE sub-group, « Recherches » collection nb 110, Plan Urbanisme Construction et Architecture, Paris, January 1999, French language, 110 pages.

EVALUATION METHODS FOR TOOL DESIGNERS

Introduction

This chapter describes the theoretical concepts that underlie design and application of assessment tools for buildings. It also summarizes many of the key issues and options that must be resolved in order to create an effective evaluation tool.

The organization of this report loosely follows the steps taken by a tool designer, beginning with a clarification of the tool's intended use, and ending with questions about how best to present the results. Between these two points, the report explores the methodology leading to the "measurement" of the environmental potential effects or impacts induced by the 'building system', (generally a building during its life cycle). This measurement method supposes how to structure the criteria to be studied, to define indicators and scales, to properly establish and delimit the causal chains (source ⟶ loading ⟶ effect ⟶ impact), and to elaborate calculation models and aggregation rules.

Intended Use

Evaluation tools are primarily intended for decision support. For this reason, many of the issues related to tool design cannot be addressed without first clarifying the intended users, and the types of decisions for which they need support. The full ranges of possible users, and the decisions they make at each stage in the life cycle of a building, are presented elsewhere in this publication.

At this stage, tool designers must address the following theoretical concepts:

Scalability

Scalability is a concept that refers to the ability of a tool to adapt to the level of sophistication of the user. It is possible to design a tool so that it can be used at a simplistic level, or, through cascading levels of detail, allow users to move deeper into the details and assumptions, so as to enter and view information at the level they feel most comfortable. Scalable tools have the advantage of 'one-stop' shopping, and also allow the user to increase their sophistication over time. Scalable tools also provide a more coherent output for each user and phase. Scalability requires much greater investment in the user interface.

Specificity

Specificity refers to the level of detail used by the tool to model the environmental effects and impacts. Specificity must vary to reflect both the users needs and the availability of data. From a theoretical perspective, it is important to recognize that the ideal level of specificity will change with each phase of the building life cycle. During the upstream design phases, for example, the level of specificity must be low since available information is the weakest, and least precise. Precision can increase as the design progresses, enabling a more accurate environmental evaluation. It is interesting to note that, paradoxically, an assessment tool can have the greatest impact in the early design phase (during the first architectural choices) when the level of specificity must be very low. As the design progresses, and more data become available, the potential range of actions is narrowed, as is the possibility for significantly improving environmental performance. Such changes in specificity imply that tool designers either create separate, nested tools for each phase, or that a single tool be developed that uses default values during the upstream design stage.

Default Values

Default values are typical or average values that can be used when specific details on the building are lacking. Default values can improve the utility of a tool, by allowing the user to save time in areas where precise data is simply not warranted. Default values also make it possible to use a single tool at different phases in the life cycle, or with different user sophistication levels. A common approach is to begin all evaluations with a 'close' proxy, containing default values at all levels of specificity. In this fashion, a single tool can then be scaled to different users, and used throughout the entire design process, at each lifecycle of the building.

Output Sets and Indicators

As mentioned above, an assessment tool must be adapted to the decision-makers' needs, - to their context, interests and areas of influence. This implies a close correspondence between the output set of a given tool (the information it generates) and what the decision-makers need to know. In fact for the potential users, the nature of the output set is probably the first question they ask before choosing a tool.

Scope of output
For the tool developers, the question is how far to go in adapting output sets to the actor's concerns. Two main options are available to tool designers:

1. to design the output set to closely match standardized and comprehensive environmental impact lists, including related physical phenomena; or
2. to design the output in ways that directly address the concerns of actors, including direct environmental impacts, related performance issues like maintenance and repair periods, and features unrelated to the environment but relevant to decision-making like operating costs and financial profitability.

The first option may appear abstract to many actors involved with a building project, since they may be unfamiliar with concepts like eutrophication and ozone depletion; they may also have little influence over how the building performs in such areas. The second option risks hiding important environmental impacts and misleading the actors. Increasingly it may be possible to adopt a composite approach that includes both a standard output for environmental phenomena, and some of the key non-environmental decision criteria of interest to the actors.

Regardless of the scope covered in the output set, it is necessary for tool designers to:

- avoid redundancy,
- maximize the objectivity of outputs,
- include the most significant environmental impacts attributed to the building sector, and
- focus on those outputs which are amenable to improvement by the user (for building designers this includes the large majority of environmental impacts, but for other actors the list may be much less).

Hierarchical Frameworks

Often the number of the desirable or desired outputs is high. As it is necessary that output information is easily exploitable and readable, it should be structured and organized for easy reference and examination. In this context, a key concept is the hierarchical framework. The framework generates a tree structure of outputs, implying a certain number of aggregations. Each output of level N is the aggregated result of the outputs of level N-1. Figure 1 illustrates one possible output structure[2]. All the detailed outputs must remain accessible so that the method is transparent, and to enable interpretation of the aggregated results.

Tool designers are faced with a difficult choice when trying to structure the outputs for decision-makers. The level at which an output is subsumed within another category will affect its profile relative to other impacts. Thus how to structure the framework is not a neutral decision, and can influence the final decisions made by actors. To some extent all hierarchical frameworks contain a kind of implicit pre-prioritization of the environmental issues.

Another difficulty with hierarchical frameworks is that they commonly result in combinations of outputs that are very different in nature. This in turn requires very different analytical methods, and a more complex tool.

Indicators

Macro Level Outputs (Level N)	Sub-Categories (Level N-1)
Resource consumption	• Energy • Land • Water • Materials
Environmental loadings	• Airborne emissions • Solid waste • Liquid waste • Other loadings
Quality of indoor environment	• Air quality • Thermal quality • Visual quality • Noise and acoustics • Controllability of systems
Longevity	• Adaptability • Maintenance of performance
Process	• Design and construction process • Building operations planning
Contextual factors	• Location and transportation • Loadings on immediate surroundings

Figure 1 *Example of a hierarchical framework*

[2] Adapted from " Green Building Challenge " [GBC framework, 1998]. This is the result of an international committee, and the structure continues to evolve.

Tool designers must for reasons of practicality reduce the size of output sets to something that is easy for users to review and understand. This is accomplished by selecting indicators. An indicator can be defined as a synthetic variable, giving indications, describing or measuring the state of a phenomenon or a situation. For example the annualized energy consumption per square meter has often been used as an indicator of performance for buildings.

Indicators are conceptual tools. They improve the utility of output sets by reducing the number of outputs required, and by expressing performance in clear and precise terms. Indicators are used to measure progress towards an objective, by providing a standard measurement unit through which evaluation modeling and monitoring can be conducted. For indicators to be relevant and effective they must be linked to a functional unit - a dwelling unit or occupant, for instance. Aggregating a number of sub-indicators creates a new, more significant indicator (an indicator indicator). Indicators are most effective when they are[3]:

- relevant to specific project or program
- clearly linked to a goal and objective
- understandable for project team and community
- focused on a long range view
- based on reliable information
- measurable by a standard and objective method
- calculated from data that is available and affordable

Tool designers are faced with a difficult choice when selecting indicators, due to the diversity of possibilities, the complexity of some phenomena involved, and the lack of precedents. Usually the decision must reflect the availability of data, and the familiarity of indicators to users. Also it is possible to choose indicators that reflect multiple objectives, and therefore provide especially efficient evaluations.

Different types of indicators serve different purposes. Indicators can be **Quantitative** (e.g. water consumption in m^3/year), or **Qualitative** (e.g. type of heating terminal units). It should be noted that qualitative does not necessarily mean subjective.

Indicators can be **Results** oriented (e.g. Illuminance levels), or **Means** oriented (e.g. type of solar protection installed to avoid sun glare).

Means oriented indicators can be either **Operational** (e.g. technical solutions) or linked to **Management** (e.g. organizational rules).

Indicators can be **Extensive**, coming from the sum of the «additive» values (e.g. energy consumption in kWh/year), or **Intensive**, coming from a behavioral model (e.g. the operative temperature of a room). With intensive indicators it is necessary to decide on which rooms the assessment has to be applied, and then to carry out an aggregation.

Performance and Limit/target values

[3] Drawn from «Green Building Performance Curriculum» [GBP Curriculum, 1998]

The determination of an indicator, criterion by criterion, is generally not sufficient to give decision-makers relevant information to make their choices. The notion of assessment includes in itself the comparison with reference values, implicit or explicit. That is what we call performance assessment. In fact, the assessment procedure can be broken down into two steps, as shown in the following figure:

Building design data

1st step — Indicator determination (model)

Indicator value

2nd step — Performance determination

Performance score

Figure 2 Assessment procedure: two steps

The aim of the assessment of performance is to position, by comparison to reference values, the results of assessments made according to each criterion. This assessment is made relative to a performance scale specified for each indicator.
The scale is characterized by:

- a lower limit, equivalent to a statutory value for the indicator, or one frequently met in practice,
- an upper limit, also called target value, equivalent to a maximum value for the indicator but currently achievable,
- a performance function (Figure 3) that makes the link between the value of the indicator and a numeric value from - 2 to + 5 for example (as in GBC framework).

The performance function is specific to each criterion; it is not necessarily linear. It should be noted that the maximum performance (value 5) is achievable for a given criterion but it is not very plausible to get a performance of 5 on all criteria, because of contradictory requirements that appear between certain criteria.

The calibration of the scale is a difficult task; it is not neutral because the judgment of the decision-makers will be based on the performance score. In addition, it is necessary to make the scale sensitive to variations of design characteristics, as well as avoiding saturation. The calibration of the scales must be consistent between the different criteria. In addition, the value of all the indicators must remain accessible for the user -in order to properly interpret the results, the performance score must not delete the numerical value of the indicator.

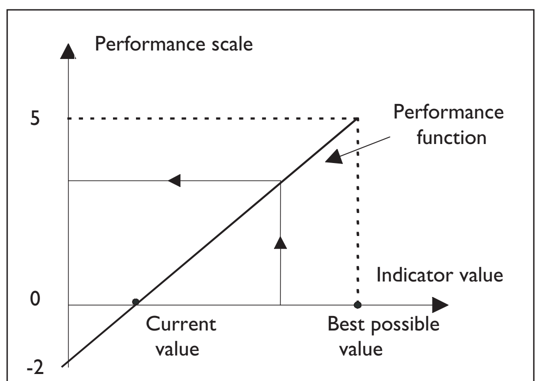

Figure 3 *Performance function*

This method of assessing performance, through a simple numerical scale, includes several advantages:

- to give decision-makers benchmarks, to make results understandable,
- to offer the possibility to aggregate different assessments, by weighting and aggregating the scores,
- to place side by side quantitative and qualitative indicators, as all the results are expressed at the end in the same terms,
- to compare different variants of building projects, and to see in which extent the variants are different within the scale.

For certain assessment criteria, the performance scale may be «contextual», that is dependant of the features (strengths / weaknesses) of the site.

PRESENTATION OF RESULTS BY TOOLS

The presentation of results is a communication and marketing issue that presents many issues for tool designers. This section will address only the most common options for presenting information to users.

Numerical and graphic presentation
As most environmental ratings are numerical, the presentation of results using tables of values is common. Such tables can be usefully supplemented by a graphic presentation. The graphs allow users to visualize performance and communicate the project to others. By reviewing results, numerical or graphic, the decision-maker should easily obtain answers to his or her starting questions. The user should also be able to identify the sources responsible for the environmental effects and impacts.

Representation of uncertainties
The interpretation of indicator values requires that they be presented with information about the level of uncertainty. Uncertainties exist at the level of inputs, models, and databases. These uncertainties can be presented in the form of intervals (to be calculated) when the uncertainty is important [Le Téno, 1996]. Tool designers must especially avoid misleading users by presenting numerical values with too many significant figures, giving the illusion of precision.

Most of inter-tool comparisons have shown significant variations in the results. The decision-maker should be aware of such uncertainties, and the tool developers should find adequate means to present them. In general, current tools do not present uncertainties well. Uncertainty can also be related to the assumptions that underlie the modeling. Tool designers may want to remind users about the key assumptions, as part of the presentation and interpretation of results. Users must be reminded that environmental phenomena are complex and interdependent. Indeed, the limited knowledge on the cause to effect chains mentioned above, the necessity to make many assumptions, plus the difficulty to collect accurate input data on the building project, necessarily implies uncertainties in the final results.
Utility of the performance concept

A performance scale allows a summary presentation of results according to various criteria, in graphic presentation. Once a type of scale is defined (i.e. a scale from –2 to +5), all the results can be presented in an homogeneous way. In the absence of the performance concept, it is necessary to define a scale with more or less reference values. Regardless, the users need reference values to be able to appreciate and interpret the results. Reference values may include current practice, best practice, regulatory minimum, historical practice and so on.

Charts
Three types of chart are usually encountered: the spider web, the curve, and the bar chart. The figures below show examples of these three types.

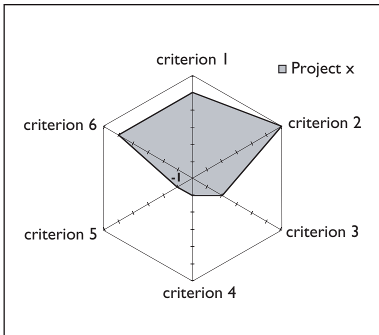

Figure 4 *Spider web chart*

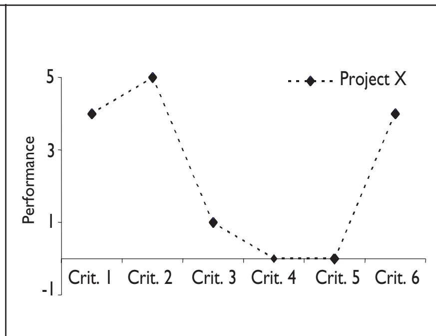

Figure 5 *Curved chart*

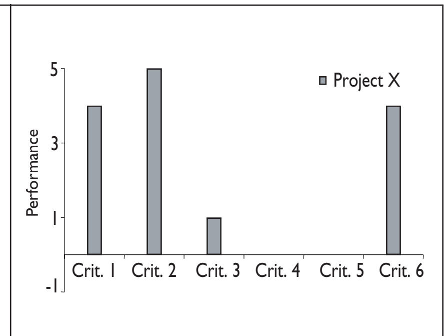

Figure 6 *Bar chart*

With the spider web and the curve, the points are connected between them, with the result that an area is implicitly generated under the line. In certain cases that may distort the visual interpretation of the results. But the most important thing is the way the sub-criteria have been aggregated into main criteria. As was already said, the aggregations leading to the final profile contain in themselves a kind of hierarchisation of the environmental issues. This fact is really likely to modify the interpretation of results, if no attention is paid to it. For example, if the large-scale pollution criteria are aggregated too far compared to the other impacts, they will take relatively less importance according to the decision-makers.
The bar chart is probably more practical than the other ones, in particular when sub-profiles are to be generated. This type of diagram also makes it possible to present a variety of information on a same graph, as shown in Figure 7.

This figure represents the utilization phase (UP) of a pilot project (REX HQE in Castanet Tolosan, southwestern France). The results are derived from the French tool EQUER (developed by the Ecole des Mines in Paris).

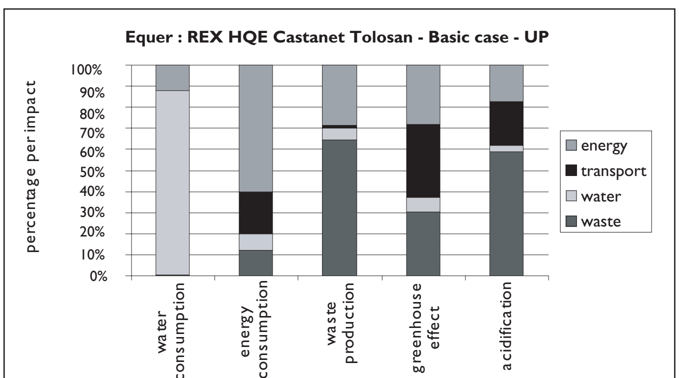

Figure 7 *Example Graph showing effects of four sources on five indicators*

Output sets structuring and explanatory sub-profiles

As seen before, the final environmental profile is the result of aggregations. Its interpretation is made difficult in view of the loss of information induced. However it is necessary to make the results as transparent as possible. In order to communicate on the project, to understand the results of performances, and take the right decisions in full knowledge, decision-makers need assistance. For this purpose, it is necessary that the tool enable the user to split up the final profile into detailed sub-profiles containing intermediate performance values. In this way the characteristics of the building responsible for the final results become accessible to the user. The following figure shows an example of sub-profile (ESCALE method, developed by CSTB in France).

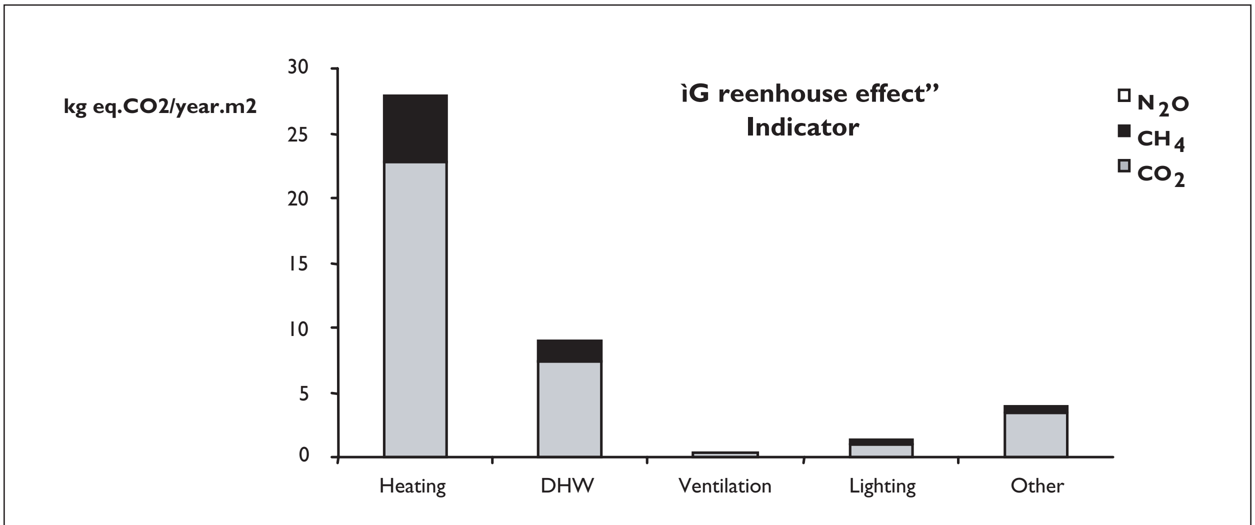

Figure 8 *Example of sub-profile (ESCALE method)*

A hierarchical presentation of the results has the advantage of providing both aggregated results, and detailed results. The aggregated results help to inform users about global environmental performance of buildings. The detailed results are particularly interesting for the designers who have to work on variants.

The specifications of a well-structured output set could be as follows (inspired by the discussions of a French working group, see [Rialhe & Nibel, 1999]):

- the results must be distinguished according to building life-cycle phases,
- the results must distinguish between flows and impacts related to energy and flows and impacts related to other sources,
- during the utilization phase, in view of its relative importance in the overall assessment, a distinction should at least be made between indicators: water consumption, energy consumption, effects linked to atmospheric emissions, activity waste, radioactive waste, and sources: infrastructures relating to water, energy, activity waste and transport,

- to be understandable to the parties involved, the results must be structured and capable of being broken down (however, a preferred method of dis-aggregation has not been specified, and several methods may exist),
- the sources of observed effects must be easily identifiable, at least for the main categories, and if possible in a more detailed way.

Conclusions and Recommendations

This report has reviewed many of the key theoretical concepts and issues that must be addressed by tool developers during the design of an assessment tool. It is clear that the difficulties faced by tool developers are substantial, given the large number of issues covered.

Discussion of these issues has identified a number of areas where a special need exists for progress in tool development. These high-priority issues are summarized in point form below.

Relationship with the building design process
Paradoxically, an assessment tool can have the greatest impact in the early design phase, when the available information is the least precise. As a deduction from this paradox, it seems necessary that an assessment method can be used starting from a rough description of the building, and that it can then be adjusted to accommodate the increasingly detailed levels of available data. To this end, it may now be necessary for tool designers to establish new 'simplified' models from the existing detailed models.

Output sets and indicators
In order to make output sets relevant, it is necessary for tool designers to avoid redundancy, to maximize the objectivity of outputs, to include the most significant environmental impacts attributed to the building sector, and to focus on those outputs which are amenable to improvement by the user (generally the building designer).

Tool designers must pay attention to the way they structure the output set. The level at which an output is subsumed within another category will affect its profile relative to other impacts. Thus how to structure the framework is not a neutral decision, and can influence the final decisions made by actors. To some extent all hierarchical frameworks contain a kind of implicit pre-prioritization of the environmental issues.

An indicator must be expressed in clear and precise terms, relevant and effective. Some requirements and characteristics are associated to indicators.

The calibration of the performance scale is a difficult task; it is not neutral because the judgment of the decision-makers will be based on the performance score. In addition, it is necessary to make the scale sensitive to variations of design characteristics, as well as avoiding saturation. The calibration of the scales must be consistent between the different criteria. In addition, the value of all the indicators must remain accessible.

Any environmental assessment tool should justify the value of the weighting coefficients included in it. These coefficients must remain apparent and logical for the decision-maker.

System boundaries
Setting system boundaries is more difficult and critical than it appears at first sight, and tool designers must learn to describe boundaries in more explicit ways, and also must justify their choices. In any event, if a source leads to non-negligible flows, if reliable calculations of flows are available, and if decision-makers can affect this source, it would be a mistake not to include it in the system.

Calculation models
Tool developers should inform users about the validation procedures and results.

Aggregations and weighting
It is recommended that the weighting coefficients used within tools be more explicit and objective. It may be a mistake to aggregate criteria that are difficult to combine.
Tool developers must be aware that aggregation methods - such as the weighted sum - present certain drawbacks, that can be limited if the tools are sufficiently « transparent ».

Presentation of results
The decision-maker should be able to identify the sources responsible for the environmental effects. Therefore a basic knowledge of environmental problems is a prerequisite. The decision-maker should also be aware of uncertainties, and the tool developers should find adequate means to present them. In general, current tools do not present uncertainties well.

In addition and in parallel to the results, the main assumptions used may be reminded to the user, insofar as the results must be interpreted regarding the starting assumptions.

- The decision-makers need reference values to be able to appreciate and interpret the results of the assessment. A performance scale is useful for this purpose.
  The « performance scale » is delimited by two reference values (current practice and best possible practice). In addition, the scale allows a homogeneous presentation of the results according to various criteria.
- It is necessary that the tool enable the user to split up the final profile into detailed sub-profiles, so that intermediate performances and characteristics of the building responsible for the results become accessible to the user. That is what we called a « hierarchical» presentation of the results.
- A list of specifications for a well-structured output set has been suggested.
- The user must not perceive the tool as a « black box ». Transparency is a strong requirement.

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NOTE: In Jensen a list of different methods for weighting of impact categories is given, here slightly modified.

Method	Methodology	Characteristic
Energy requirement	Equal energy requirement	Proxy
MIPS	Equal material displacement	Proxy
SPI	Equal space consumption	Proxy, Technology
Abatement energy	Equal space consumption including energy for abatement of environmental burden	Technology
Abatement costs	Equal modeled costs for abating emissions according to national targets	Technology, monetarisation, authorized targets
Abatement costs / Tellus	Equal costs for abating emissions	Monetarisation, authorized standards
DESC	Equal projected generic costs for abatement of burden according to national goals derived per impact category	Technology, monetarisation, authorized targets
EPS	Willingness to pay to avoid / restore the concerned effect safeguard subjects to normal status	Monetarisation, technology
Molar method	Equal critical volume scores, based on mole density	Authorized standards
Critical volume method	Equal critical volume scores weighted subjectively	Authorized standards
Critical surface time method	Equal critical volume scores weighted subjectively	Authorized standards
Ecoscarcity approach	Equal scores over proportional distances to political targets	Authorized standards
Effect category method	Equal scores over proportional distances to political targets	Authorized standards
Distance to target	Equal scores of distances to political targets optionally additionally weighted subjectively	Authorized standards
NSAEL	Equal Scores of overshoots of sustainable targets optional weighted subjectively	Authorized standards
Eco Indicator '95	Equal scores of distances to science-political targets contributing to equally weighted safeguard subjects	Authorized standards
Iso-utility functions	Equal panel scores on relative (negative) utilities of actual impact scores	Panel
Iso-preference approach	Equal panel preferences for elasticities in relative impact scenarios	Panel
Delphi technique	Equal expert panel scopes on actual impacts	Panel
Questionnaire	Equal industry/science panel scores on impact categories	Panel
Panel questionnaire	Equal societal group panel scores on impact categories	Panel
Structured dialogue	Panel agreement on weights based on argumentation	Panel
Argumentative evaluation	Societal group consensus on the interpretation of product systems comparison w. inputs from normalization, environmental problem weights by a political panel and a sensitivity analysis	Panel
Expert panel prioritization	Equal interpretation of product systems comparison using a qualitative valuation of normalization data and expert panel scores on criteria time, space and hazard	Panel