# Energy-Related Environmental Impact of Buildings

## Annex 31

## Acknowledgements

The material presented in this publication has been developed within Annex 31 of the IEA Energy Conservation in Buldings and Community Systems Programme. Annex 31, entitled "Energy-Related Environmental Impact of Buildings", has benefited from the participation of many agencies and individuals from the member countries. Names and contact information are listed in the Annex 31 Participants section.

Each of the participants in Annex 31 contributed valuable material to the final reports, over an extended period of time, and their effort is greatly appreciated. Substantial research and writing was undertaken with great dedication by two of the section leaders: Sylviane Nibel (F), and Thomas Lützkendorf (De). Marjo Knapen and Chiel Boonstra (NL) also contributed significantly as section leaders for tool applications and comparisons.

Completion of the final reports, CD-ROM and web site were managed by Thomas Green (Ca), with coordination support from Nils Larsson (Ca), project work led by Sebastian Moffatt (Ca), and web site construction by Thomas Lützkendorf (De) and Woytek Kujawski (Ca).

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# ABOUT ANNEX 31

This Highlight Report summarizes the work of the Annex 31 project "Energy-Related Environmental Impact of Buildings" and is based on the research findings of the participating countries. More detailed information is available on the accompanying CD-ROM and Annex 31 website (www.annex31.org).

Annex 31 is a project established under the auspices of the International Energy Agency's (IEA) Agreement on Energy Conservation in Buildings and Community Systems(ECCBS). It examines how energy and life cycle assessment tools and methods can be used to reduce the energy-related impact of buildings on interior, local and global environments.

As the need to address environmental concerns such as resource depletion and greenhouse gas emissions becomes more pressing, the concepts, tools and practical considerations in Annex 31 present an invaluable information resource demanding close attention.

Fourteen countries participated in Annex 31: Australia, Canada, Denmark, Finland, France, Germany, Japan, Netherlands, New Zealand, Norway, Sweden, Switzerland, United Kingdom and United States of America. Canada served as the coordinating agency for the project.

## Target audiences for Annex 31

Annex 31 will be of interest to people engaged in:

- assessing the impact of buildings in terms of their direct and indirect energy use
- developing assessment tools decision-making regarding buildings, including policies, guidelines, practices, materials and systems related to the complete life cycle of buildings

and who are likely to be in one of the following groups:

- policy developers, regulatory groups and others who wish to encourage or mandate the use of building and energy assessment tools and methods
- educators and researchers
- practitioners, including design professionals
- assessment tool developers.

# EXTENT OF ENERGY-RELATED CONSIDERATIONS

Energy is the single most important parameter for consideration when assessing the impacts of technical systems (such as buildings) on the environment. Energy-related emissions are responsible for approximately 80 per cent of air emissions. They are central to the most serious global environmental impacts and hazards, including climate change, acid deposition, smog and particulates.

Buildings and their associated infrastructure exist within the natural environment and are a significant factor in terms of environmental impact. The environmental impact of a building also depends on the site, in terms of climate, outdoor environment, landscape, ecosystems, technical infrastructures and transportation. For example, transportation of people and goods to and from buildings is a factor closely related to the energy use of buildings, as is the supply of services (potable water, waste water and solid waste disposal, communications and energy services).

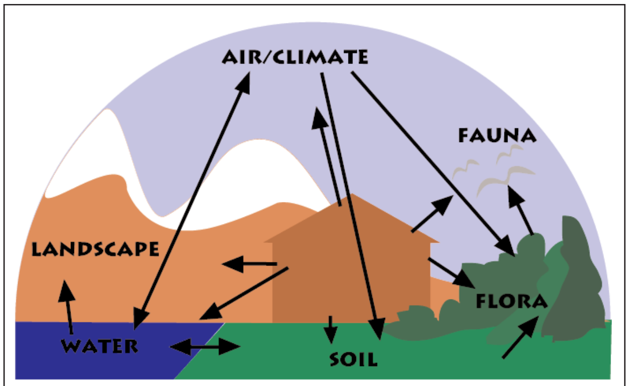



**Figure 1** *Technical systems are contained within the environment*

The choice of one site over another has environmental consequences, and it is important to understand the interface between a building and its site.

The full extent of energy-related impacts become clearer when we consider the life cycle of the building process:

- Production of energy (preliminary stage)
- Manufacture of basic materials (preliminary stage)
- Erection of the building, construction
- Operation and use
- Maintenance measures
- Repairs and renovation
- Modernisation or conversion
- Demolition or deconstruction.

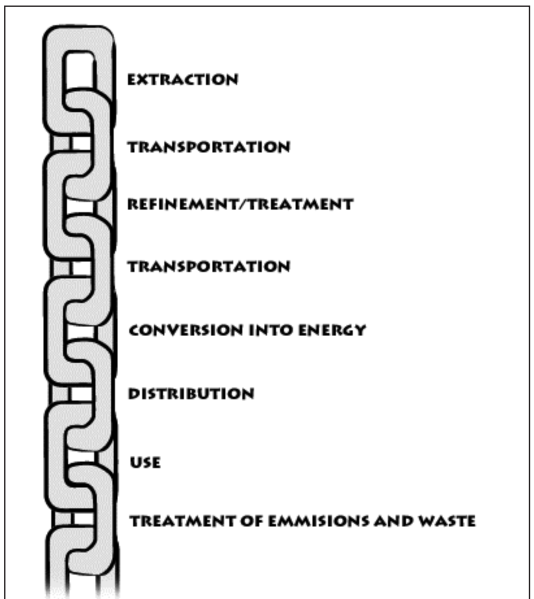



**Figure 2** *Links in a typical energy chain*

During the life cycle of a building, the operation and use phase predominates, both in terms of time and energy use. Typically, 85 per cent of environmental impacts occur during this phase, but this is highly dependent on whether a building stands for 20 or 200 years.

Where one draws the boundaries in assessing the energy-related impact of one or several buildings is part of Annex 31's deliberations.

# OVERVIEW OF ANNEX 31 RESOURCES

Annex 31 presents a comprehensive overview of the theory and practice of life cycle assessment tools for buildings. It consists of four core and seven background reports on assessment tool use and theory. Additional reports including a Directory of Tools, Glossary, and Links to Annex 31 participants and agencies are available on the Annex 31 CD-ROM and website.

**Annex 31 on the Internet**
To access Annex 31, visit www.annex31.org. The printed Annex 31 Highlight Report and CD-ROM are available from the IEA Energy Conservation in Buildings and Community Systems bookshop (bookshop@ecbcs.org) or from the International Initiative for a Sustainable Built Environment (www.iisbe.org).

The 11 main reports are as follows:

## 1) Core reports

The core reports are written for an informed and technical reader familiar with the building sector. No specialized knowledge of environmental assessment methods or tools is required.

### *Environmental Framework*

ENVIRONMENTAL FRAMEWORK

An environmental framework provides the foundation for analysing the energy-related environmental impact of buildings. This report looks at various linkages, data issues, system boundaries and other factors that need to be taken into consideration.

### *Decision-Making Framework*

DECISION MAKING FRAMEWORK

A decision-making framework is required in order to effectively design and develop environmental assessment methods and tools. This report serves to clarify how and when specific participants become involved in decisions at each stage in a building's life cycle. The framework defines the scope of each decision, as well as the types of evaluation criteria and decision-support tools that may be useful.

### *Types of Tools*

TOOLS

Tools inform the decision-making process by helping people understand the consequences of different choices. Tools are the interface between the environmental framework and the decision-making framework. This report describes tool categories, information requirements and key features of effective tools.

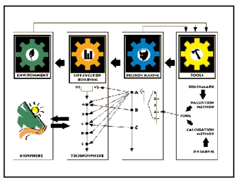
### *LCA Methods for Buildings*

Life cycle assessment (LCA) is a technique for assessing the environmental aspects and potential impacts throughout a product's life, from raw material acquisition through production, use and disposal. This report summarizes how to apply the basic LCA method to building products, single buildings and groups of buildings. It examines problem areas and provides suggestions on how to overcome specific problems.

## 2) Background reports

The background reports are more detailed technically, to provide researchers, instructors and tool developers with additional information on aspects of tool design and use.

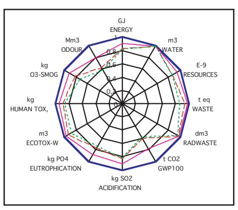
### *Context and Methods for Tool Designers*



This report reviews assumptions that need to be made for the building itself (life duration, maintenance, end of life), the energy flows, the energy chains and the users' behaviour. It looks at what information is required to effectively integrate energy-related and environmental issues in the investigation and the decision-making stages.

### *Comparative Applications:*

*A Comparison of Different Tool Results on Similar Residential and Commercial Buildings*




This report describes an Annex 31 research project that used tools from the participating countries to assess the environmental impact of a single dwelling and an office building. Significant differences in outputs occurred as a result of differences in data infrastructure, system boundaries, data allocation and weighting factors. The results emphasize the importance of transparency in tools.

### *Case Studies of How Tools Affect Decision-Making*

This report explores the use of life cycle assessment tools for projects in six countries to improve the environmental performance of buildings. Each case study includes information on the site, the building, its energy and environmental features, the assessment tool used and the results.

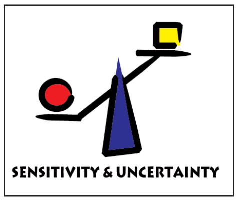
### *Data Needs and Sources*

In this report, a more detailed examination is conducted of data requirements and sources. An attempt is made to inventory as exhaustively as possible the data needed for a complete detailed assessment of impacts at any aggregation level.

### *Assessing Buildings for Adaptability*


Over the course of a building's lifetime, change is inevitable, both in its social, economic and physical context and in the needs and expectations of its occupants. A building that is adaptable can be utilized more efficiently and stay in service longer. This report examines principles, potential benefits, strategies and specific features of building adaptability and discusses evaluation methods.

### *Sensitivity and Uncertainty*




The key purpose of sensitivity analysis is to identify and focus on key data and assumptions that will most influence a result. This contributes to simplifying data collection and analysis without compromising the results. Uncertainty analysis is a parallel consideration. Uncertainty related to life cycle assessment can be significant, and it must be considered when performing comparative assessments. This report describes how to undertake sensitivity and uncertainty analysis, and includes examples of how such exercises can improve decisions.

### *Stock Aggregation*

Stock aggregation evaluates a building stock's performance based on component assessments. For example, total energy use of a building stock can be estimated by adding up, or 'aggregating', the energy estimates for all individual buildings within the stock. Alternatively, a subset of representative buildings can be analyzed and the results factored in proportion to the total number of such buildings in the stock. Stock aggregation can assist with policy development at the local and regional scale. It also offers significant benefits for planners, businesses in the building sector and utilities.

# ENVIRONMENTAL IMPACT AND LIFE CYCLE ASSESSMENT

Operational energy in buildings typically accounts for about half of the energy consumed by developed countries. Transport energy typically accounts for about a third of the energy. This includes a 5 per cent component for transporting construction materials. A further 5 per cent of energy is used to manufacture construction materials, giving a total of 10 per cent embodied energy in construction materials.

The more energy saving measures that are incorporated into buildings, the more important it is to consider the life cycle environmental impacts. Typically, reductions in operating energy occur at the expense of increased embodied energy, embodied emissions, and life cycle material flows. Moreover, as operating energy becomes less significant, the operating demand load for water and materials becomes relatively more important.

## LCA Methodology

1. Goal and Scope Definition
   - Life cycle definition
   - Functional unit
   - System boundaries and data quality requirements
   - Critical review process
2. Inventory Analysis
   - Data collection
   - Refining system boundaries
   - Calculation procedures
3. Impact Assessment
   - Category definition
   - Classification
   - Characterisation
   - Weighting
4. Interpretation of Results
   - Identification of significant environmental issues
   - Evaluation of study
   - Conclusions and recommendations
   - Interpretation for completeness, sensitivity and consistency
   - Reconsider definitions and assumptions made in step 1

Life cycle assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a product. It involves compiling an inventory of relevant inputs and outputs for a clearly defined system, and then evaluating the potential environmental impacts associated with those inputs and outputs. Results are interpreted in relation to objectives established at the outset.

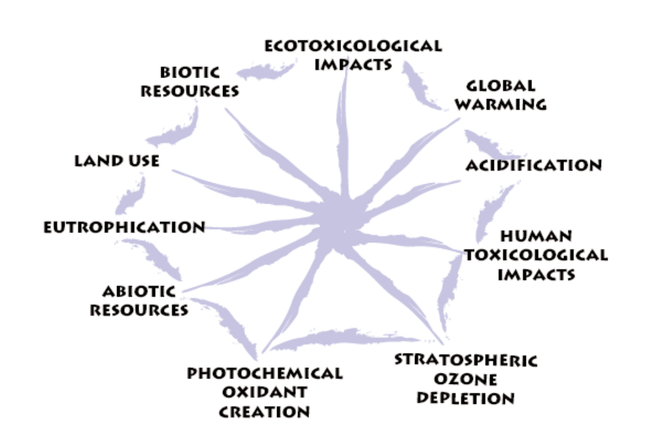



**Figure 3** *Common Effects Considered in LCA*

LCA looks at environmental aspects and potential impacts throughout a product's life, from raw material acquisition through production, use and disposal. LCA is not the only approach to analysing the impact of material goods on the environment, but it is probably the most comprehensive. All LCA tools are based on computer models and database

# TOOL APPLICATION: EXAMPLES

The background report Case Studies: How Tools Affect Decision-Making presents case studies from six countries: New Zealand, Japan, United States of America, Switzerland, Netherlands and Canada. The case studies explore how LCA tools have had an impact on the design and environmental performance of buildings.

All of the case studies demonstrate significant environmental improvements with the application of LCA tools. Utilizing these tools in the design phase creates a positive impact on the environment, and in most instances, it benefits building owners and occupants as well.

## New Zealand: Waitakere Eco-Friendly Home

New Zealand's Eco-Friendly Home is a three-bedroom house, incorporating as many sustainable design principles as practical while appealing to the mainstream market. The 194 $m^2$ house is situated in a new, low-density housing subdivision. The house demonstrates that significant gains can be made in terms of healthy living and reduced impact on the environment without it needing to look too unconventional. The main eco-themes are efficient use of water and energy, healthy materials and safety conscious design.

The design incorporates energy-saving features in the electrical system, appliances and passive solar considerations. Local area wiring is used throughout to control lighting, heating, the security system and some appliances. Individual elements can be programmed to activate at specific times and to react to various circumstances.

Energy-efficient appliances include heat pump air conditioning and hot water systems, induction energy cook tops, consideration of low-embodied energy materials and compact fluorescent lamps. Passive solar design features include high mass, high insulation, shading from summer sun, double-glazed windows and natural ventilation.

The BRANZ (Building Research Association of New Zealand) Green Home Scheme assessment tool applied to this home is a descriptive-based environmental auditing system for new homes, to be applied at the design stage. Fourteen environmental, safety and health issues are addressed as part of the audit system. Each issue has an associated number of credits assigned to it, according to the difficulty in achieving it and its perceived environmental importance. A certificate is issued for designs that achieve a minimum number of credits.

**Figure 4** *Waitakere Eco-Friendly Home*

## Japan: Liberty Tower of Meiji University

Liberty Tower of Meiji University is an example of natural ventilation applied in a high-rise building. STREAM was used to evaluate thermal dynamic simulations; a national tool, HASP/ACLD/ACSS, evaluated hour by hour air conditioning system simulations; a proprietary tool, PMV-3d, evaluated thermal comfort simulations; and another proprietary tool, Life Cycle $CO_2$ and Life Cycle Cost, evaluated life cycle greenhouse gas emissions and cost analyses.

Environmental and mechanical engineers used these tools in the schematic design phase to optimize the size and amount of ventilation windows and improve the design of the wind floor, energy-saving systems, sunshades and windows.

Various other measures were taken to minimize energy loss and consumption; optimize solar and renewable energy use; reduce construction and operating wastes; reduce the need for building occupants to use cars; and improve the quality of both indoor and outdoor environments. Use of the tools increased energy savings, decreased environmental burdens and enhanced the building's marketability.

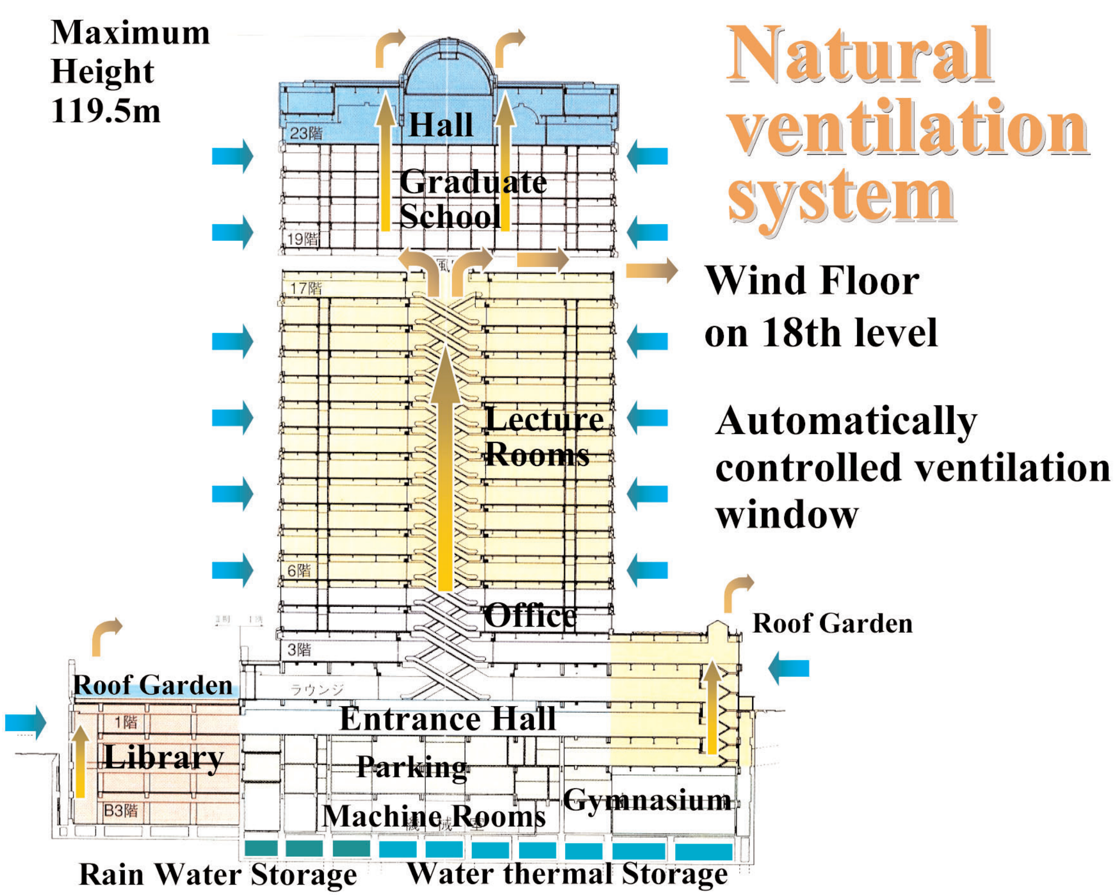



**Figure 5** *Liberty Tower of Meiji University Natural Ventilation System*

# Japan: The Yamanashi Institute of Environmental Sciences

This Yamanashi Institute of Environmental Sciences is a research facility owned by the Yamanashi Prefecture Government. It is an example of building in a cold climate with maximum use of passive tempering techniques and coupling with the local environment. The 6,396 square meter building is designed to harmonize with the site and preserve the local environment.

Measures were taken to minimize energy loss and consumption, optimize solar and renewable energy use, reduce construction and operating wastes, improve the quality of indoor and outdoor environments, use reclaimed water, reduce automobile use, and ensure the longevity of the building.

Tools used in the building assessment and design processes were a private hour-by-hour daylighting simulation tool, and a national hour-by-hour air conditioning system simulation tool. The tools supported design improvement by allowing the design team and environmental and mechanical engineers to optimize the design of sunshades and windows, increase energy savings and decrease environmental burdens. Current usage of tools for similar projects is also expected to enhance marketing of the project.

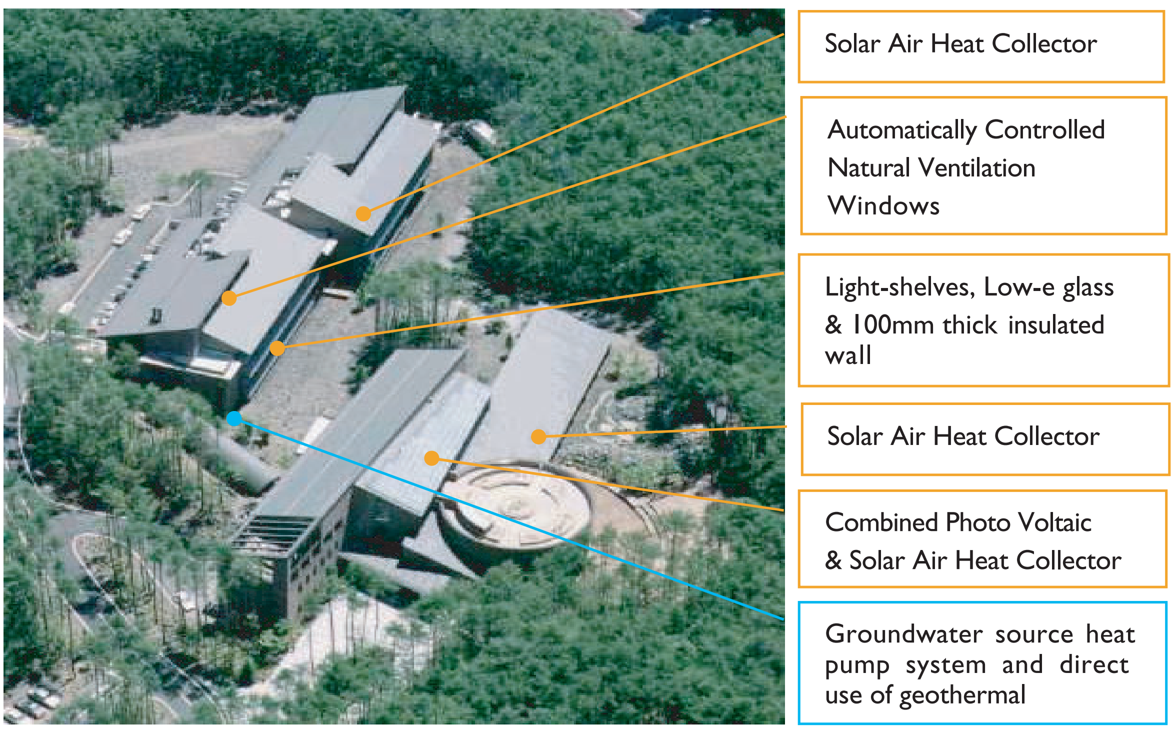



**Figure 6** *The Yamanashi Institute of Environmental Sciences*

# USA: Durant Road Middle School

Durant Road Middle School in Raleigh, North Carolina is a model energy efficient school. The energy efficient design came in under budget by $700,000 and is expected to save $165,000 in annual energy costs. The building uses half the energy consumed by a comparable school that is not energy efficient.

Use of day lighting was the main focus, which not only reduced the amount of energy needed for lighting, but it also reduced the cooling load. The designers used DOE-II and Daylite to analyze and forecast the quality of lighting and energy performance of the school design.

The reduced cooling load allowed use of a 370 ton chiller instead of the 400 ton chiller typically needed for a similar school.

The design's benefits are not limited to environmental interests. Studies have shown that natural daylighting has a positive affect on student attitudes and performance: students are inclined to be more attentive and less hyperactive in daylit classrooms. In addition to student's improved behaviour, teachers have noticed an increased ability to learn.

**Figure 7** *Durant Road Middle School*

# Switzerland: World Wildlife Fund office building

The Norwegian Ecoprofile tool was used in planning a renovation project for the World Wildlife Funds' office building in Geneva. Built in 1978 and renovated in 1997, the four-storey building is an ordinary office building for 100 people, with a total area of approximately 2400 m$^2$.

Planned improvements included lower heat loss due to new windows and better tightness; a new ventilation system (balanced outlet and inlet) with significant higher volumes than originally; some cooling; reduced water consumption; an "air-infiltration-system" wall; better possibilities for temperature control; and some improved cleaning routines.

Not all of the planned improvements were implemented, but the renovated building attained higher ventilation volumes than first planned and a new illumination system was installed. An Ecoprofile evaluation prior to renovating and one afterwards verified significant environmental improvements, especially in energy use and the indoor environment.

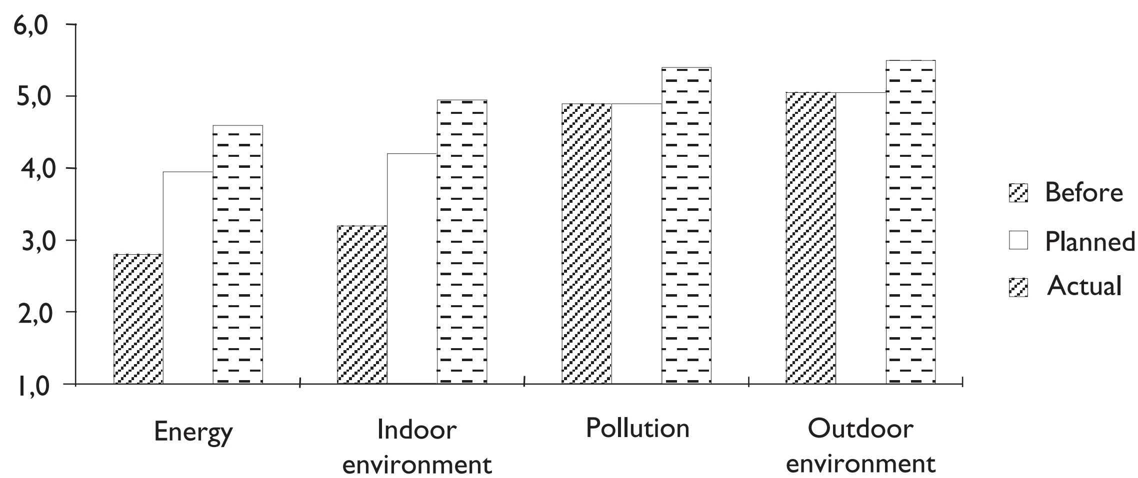



**Figure 8** *World Wildlife Fund office building Ecoprofile assessment results (a higher score corresponds to a positive result of lower environmental burdens)*

# Netherlands: Project XX office building

Project XX was purposely designed and built as a temporary, dismantleable office building. The intent was to investigate whether the environmental load of an office building would be significantly reduced by tailoring its technical life to the 20-year planned lifespan through efficient use of materials.

The building had to be capable of being fully distmantled, and the parts had to lend themselves to reuse or recycling as far as possible. Landfill or incineration were not options. The architect therefore considered materials with a short life, less seasoning, renewable materials and connecting techniques that can be dismantled.

The result is that Project XX has floors made of sand, cardboard air conditioning conduits, sawable columns, wooden frames and recyclable triple glazing. The environmental benchmarks for Project XX were compared to those of a standard office building using Eco-Quantum. If energy consumption during the use phase is included, the environmental load of Project XX is significantly lower than that of the reference office.

The environmental benchmarks for emissions and waste were also lower for Project XX. This means that the materials used in the dismantleable building contribute less to greenhouse effects, acidification, eutophication, ecotoxicity and depletion of the ozone.

**Figure 9** *The wooden frame of Project XX*

In contrast, the environmental benchmarks for raw materials and energy were higher for XX. This is due to the fact that the materials in this building contribute more to the depletion of energy by carriers and that more energy is required for their production than for the materials inthe reference building. Depletion of energy carriers was 24 per cent greater for Project XX than for the reference building.

One factor in this was the use of wooden frames that had to be transported a great distance to the Netherlands. The large triple glazed windows and aluminum weather drip rails were also responsible for higher energy content.

Eco-Quantum also helped at the design stage to optimize the environmental performance of Project XX. For example, aluminum frames had been selected in a previous design for the building. The environmental load of wooden frames proved to be so much lower that they were chosen instead.

# Canada: Revelstoke community energy planning

A planning tool named TIRA contributed to preparing a community energy plan for the City of Revelstoke, a community of 8,507 (1996 Census) in British Columbia. TIRA used data from evaluations of individual building types to estimate costs and benefits for the entire building stock. This stock aggregation approach permitted detailed evaluations of costs and benefits for alternative policies and systems at the community scale.

A community energy plan provides information about how energy is being consumed, which helps decision-makers select those programs and policies most likely to reduce energy consumption and expenditures and to minimize negative impacts on the environment.

Consumption by SectorEstimates of current energy consumption were developed for buildings, transportation, industry and infrastructure. Indicators were developed including financial, economic development, $CO_2$ emissions and per capita energy use.

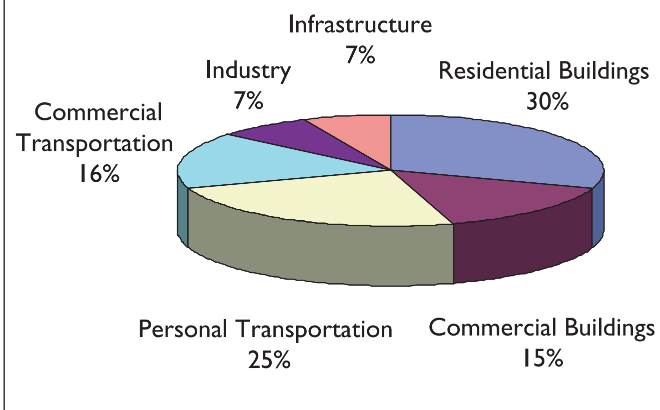



**Figure 10** *Revelstoke Energy Consumption by Sector*

In addition to a status quo scenario, three alternate scenarios were developed:

- Introduce a district energy system
- Retrofit older residential homes
- Retrofit institutional, municipal and school buildings

The major strength of TIRA is its ability to model the resource flows and associated costs of buildings and infrastructure using a rigorous, bottom-up approach. TIRA examined how the three alternative scenarios impacted energy use in Revelstoke.

TIRA allowed for a more quantified and credible estimation of the benefits for each scenario in different building segments. This helped to generate political support for new energy policies and build consensus among the stakeholders in the community.

A Residential Buildings Energy Retrofit program was established in early 1998 to improve the performance of the residential building stock. The City has since agreed to participate in developing a district energy system, and is considering the use of Energy Service Companies (ESCOs) to reduce the cost of local infrastructure. Assuming all three scenarios are fully operational by 2016, there will be an annual decrease in energy consumption of approximately 57,000 GJ per year below status quo projections.

# SELECTED HIGHLIGHTS FROM THE REPORTS

## Environmental Framework

Life cycle assessments (LCAs) of buildings can be customized to include or exclude specific stages in the life cycle, or specific types of environmental loadings and impacts. The figure shown here is a schematic of a building's life cycle and the associated environmental loadings and impacts.

A wide range of assessment tools can be employed to assist in calculating results at stages, with differing scope and level of sophistication. Among the challenges faced by LCAs are accounting for co-products or wastes that are effectively recycled or re-used, accessing data and dealing with variations in data quality.

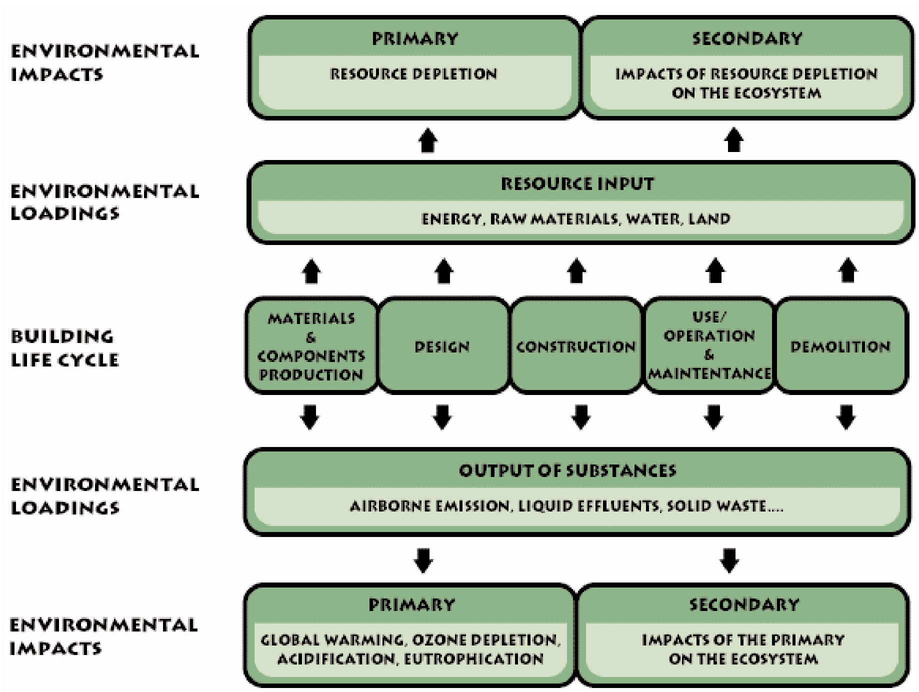



**Figure 11** *Building life cycle and environmental loadings and impacts.*

LCAs involve taking inventory of the following components:

- Base data on energy and raw material processing – The LCA method typically employs rules for limiting the analysis to sensible boundaries. For example, it is usually not worth the effort to account for energy used by human bodies, or energy and materials used by machines that make machines.
- Building products and systems, construction processes, utility and waste disposal services, and property management
- Building elements – Elements are the components of a constructed building. For instance, 1 $m^2$ of

In order to model building operation during occupancy, assumptions are required regarding usage, maintenance, management and so on. These assumptions represent 'scenarios' for the occupancy period. Scenarios should reflect decision-makers' areas of concern and influence.

Traditional LCA methods do not consider impacts on the indoor environment, although most researchers agree that such impacts are especially important and of increasing interest. The central difficulty with completing LCA analysis for buildings is the inaccessibility of data and variations in data quality.

## Decision–making Framework

Compared to later phases, the planning process offers the widest scope for decision-making. Design decisions have a large (mostly indirect) effect on the entire life cycle of a building. They affect the maintenance and recycling ability, as well as the energy expenditure required to run the building. Simulation models and tools assist with the analysis by evaluating different scenarios over the building's or stock's lifetime.

The development of a decision-making framework begins with an analysis of the planning and design process over the life cycle of one building or several. The highly iterative nature of planning and design decisions complicates the process, but the process generally proceeds as follows:

- Establish principles and goals for the project
- Determine user requirements and conditions
- Identify the planning solution (volume, use of space, etc.)
- Create the design solution (articulation of form, choice of colour, etc.)
- Specify material construction (choice of materials, dimensioning, etc.)
- Select technical services/energy concept

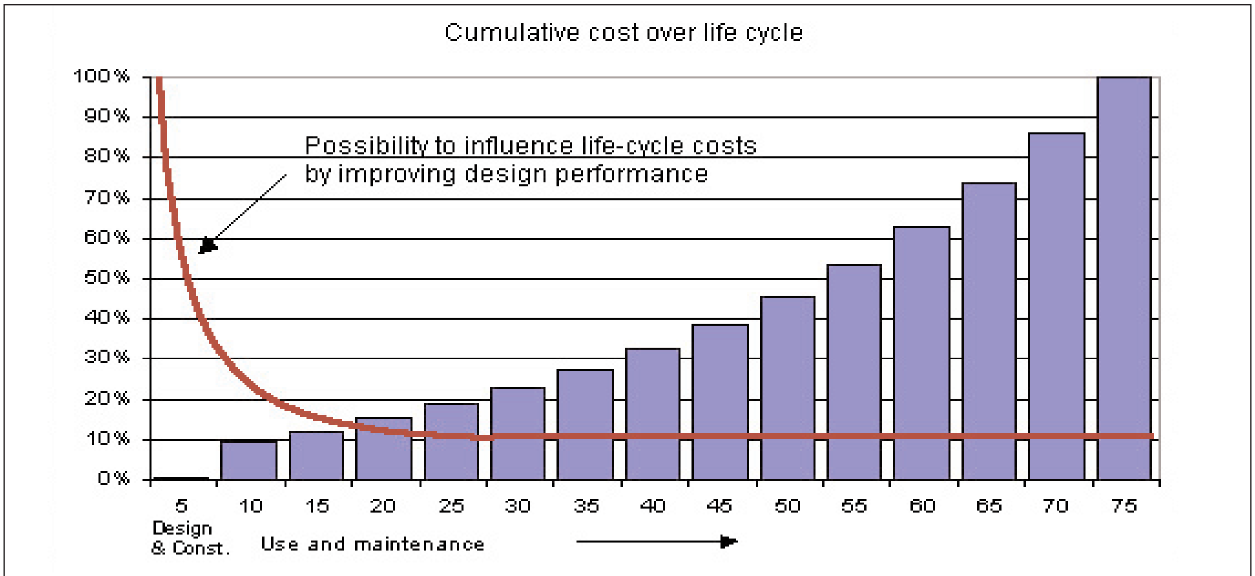



**Figure 12** *Impact of Time on Cost and Influence for a 75-year building life span*

A detailed environmental assessment will contribute to key decisions by addressing the following questions:

- Which kind of building function shall be investigated?
- Which one of two buildings performing the same function is ecologically better?
- Is it better to renovate, demolish or reconstruct a building?
- How might improved performance translate into benefits for other parties?
- How might changes in the original function of a building affect performance (i.e. how adaptable is the building)?

Participants in the decision-making process are referred to as actors. The main ones for the design process include product manufacturers, building designers and consultants, contractors, engineers and building owners. There are also background players who influence buildings indirectly: financers, tenants, property managers and other users, service providers and authorities who enforce standards. A decision-making framework identifies which actor intervenes at each stage.

The integrated design process (IDP) is the best way to address the multi-disciplinary nature of design, and to functionally integrate environmental performance with other major functions. IDP involves a design team with a wider range of technical experts, local stakeholders and partners than is normal. It engages more of these actors at very early stages of a project and uses their expertise to create seminal design decisions. For example, energy modelling and value analysis may be conducted in parallel with concept design work. 'Whole-system engineering' may be used to provide broad thinking about technical options.

By simultaneously addressing the three spheres of sustainability – economy, social welfare and environment – it is possible to improve all three. Only by achieving synergy across a broad range of goals is it possible to significantly reduce the energy-related environmental impacts of buildings

Because IDP involves more extensive decision-making in the early stages of design, more time is needed up front in the design process. However, this additional time is usually recovered, due to early decision-making and better co-ordination between disciplines. IDP allows for effective, controlled public input and improved designs.

Successful decision-making by actors is highly dependant on three significant factors:

- Clear goals and realistic, balanced and measurable environmental performance objectives
- Motivated actors
- An environmental management system.

Success also depends on the information or tools being appropriately matched to the interests and needs of the users. For example, improved performance in green buildings needs to be translated into opportunities for financial incentives, increased productivity, enhanced marketing opportunities, innovative financing schemes, improved technical guaranties and reduced liability and risk for owners and financial controllers. Architects need IDP tools that can accommodate fast-paced decisions and allow for rapid iterations.

Only by simultaneously addressing the three spheres of sustainability – economy, social welfare and environment – is it possible to achieve synergy across a broad range of goals and have significant success in reducing the energy-related environmental impacts of buildings.

# Types of Tools

Decision-support tools for environmental assessment must integrate environmental criteria into an already complex design process. It is essential therefore that decision-support tools minimize complexity and costs. In this context, tools should

- truly measure factors having environmental impacts
- easily adapt to specific buildings and locations
- quickly rank results
- be transparent in their assumptions.

To be effective, a tool must be tailored to the planning phase, the knowledge base of the users, the concerns of the actors, and the applicable assessment criteria and standards. Accordingly, either a wide variety of tools are needed or each tool must be scalable and capable of adapting to the user's needs and knowledge. However, the application of various methods and tools for environmental assessment of buildings can lead to results that are often not directly comparable. This is lost often a result of differences in system boundaries.

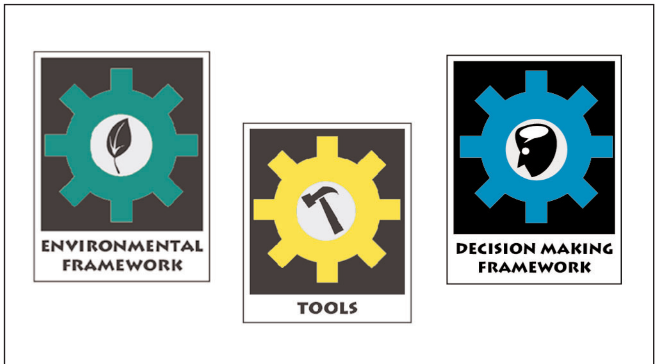



**Figure 13** *Tools are the interface between the environment and the decision-maker*

Annex 31 tools can be grouped into two main categories:

1) Interactive software

Because of the complex interrelations between life cycle states, resource flows and environmental consequences, all LCA tools are based on computer models and databases. Effective interfaces increase the potential for interaction between the user, the model and the associated databases.

LCA tools for building and building stocks help users assess the relationships between building specifications and potential environmental impacts. They translate design and management choices into meaningful statements about environmental effects and impacts.

Designers also use energy and ventilation modelling software to optimize aspects of building performance. Unlike LCA tools, they focus on the operating phase of a building only, and the results do not explore the potential environmental impacts at local, regional or global scales.

2) Passive tools

Passive tools typically lack the degree of customisation, computer support and interactive responsiveness to data input provided by LCA tools and simulation models. Passive tools tend to contribute static information to the process rather than conducting calculations or altering designs. Depending on their type and purpose, passive tools

- aid in forming design objectives
- convey results of pre-determined assessments based on proxies or references
- assist in directing the planning and decision-making processes
- provide outputs of assessment results completed by third parties.

Various examples of passive tools exist: laws, guidelines, checklists, case studies of best practices, product labelling (ecological and quality grading), product descriptions and recommendations are a few examples. The report briefly discusses these and other passive tools, noting users, advantages, disadvantages and examples for each one.

As communities strive for green infrastructure and sustainable urban systems, the impact of building design on the local environment will become more significant. Well-designed buildings can benefit a community by contributing to its industrial ecology and by functioning as part of its neighbourhood infrastructure (generating power, treating wastes, collecting water and so on). Understanding such interactions is a necessary step in assessing life cycle environmental impacts for a specific building design. Since LCA models and tools are currently unable to predict most site-specific impacts, the best alternative may be to combine LCA with more passive and qualitative evaluation tools.

## LCA Methods for Buildings

The use of Life Cycle Assessment (LCA) methods is especially helpful for assessing embodied energy and environmental impacts, since the tools can conveniently analyze extensive product assessment data generated by other sectors. However, in the building sector, strict application of LCA methods is very difficult due to the complexity of processes, inputs and data sources. Hence, a more general approach is common.

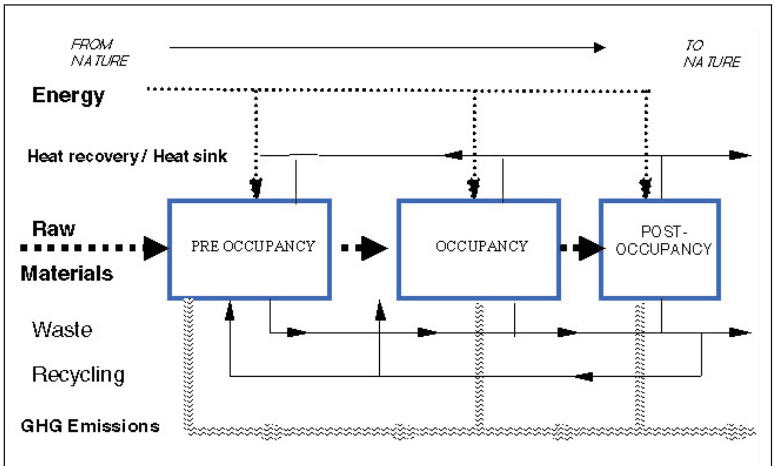



**Figure 14** *Life Cycle Assessment for Buildings*

Buildings have many characteristics that serve to complicate or frustrate the application of standard LCA methods:

- The life expectancy of a building is both long and unknown, causing imprecision, and key factors such as energy sources or energy efficiency can change over time, making predictions of environmental loadings inaccurate.
- Buildings are site specific and many impacts are local, something not normally considered in LCA.
- Buildings, and their components and products, are heterogeneous in their composition. Therefore, much data is needed, and the associated product manufacturing processes can vary greatly.
- The building life cycleincludes specific phases
  - construction, use and demolition
  - which have variable consequences on the environment. For example, in the use phase, the behaviour of users and service operators or facility managers has a significant influence on energy consumption.
- A building is highly multi-functional, which makes it difficult to choose an appropriate functional unit.
- A building creates an indoor living environment, which can be assessed in terms of comfort and health. There are strong links between impacts on the exterior environment and the quality of comfort, indoor air, health and productivity.
- Buildings are closely integrated with other elements in the building environment, particularly urban infrastructure, such as roads, pipes, wires, green space and treatment facilities. Because building design characteristics affect infrastructure demands, it can be highly misleading to conduct a LCA on a building in isolation.

Identifying and accounting for so many complex issues presents a major challenge when assessing the energy-related environmental impact of buildings. Tools are used to help overcome such difficulties; however, even with the most sophisticated tools it is not possible to conduct a comprehensive assessment of a building. Instead, the process must involve narrowing the focus of assessment to the most significant issues. This is referred to as boundary setting.

This report examines six issues in detail: setting boundaries for building assessments; accounting for local impacts; use and maintenance scenarios and building adaptability; the allocation problem; accounting for transportation costs during occupancy phase; and analysing groups of buildings, which is known as stock aggregation.

## Context and Methods for Tool Designers

The art of tool design is rapidly evolving, in concert with the increasing sophistication of users, improvements in information technology and increased market demand for green buildings. Assessing the environmental performance of buildings involves a number of critical assumptions concerning expected lifetimes, maintenance and demolition or deconstruction. 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 standardized for this purpose.

With respect to decision-making, tool developers should give significant attention to the information requirements of individual target audiences. Tools must be designed to be easily understood by users and decision-makers. They must reconcile building and environmental approaches to provide meaningful, understandable results that reveal causal relationships between sources and impacts. Those who are experienced in using assessment tools can handle more detailed and technical information, whereas key decision makers and other non-technical audiences are likely to want concise information presented in plain language. Decision makers need meaningful, understandable results that reveal causal relationships.

Presently, all known tools require a competent person to help interpret their results. Dialogue is an important part of this. Simply presenting the information is insufficient to ensure the intended audience understands the results, the implications and the decisions to be made. An assessment therefore provides a context for discussing issues and potential solutions.

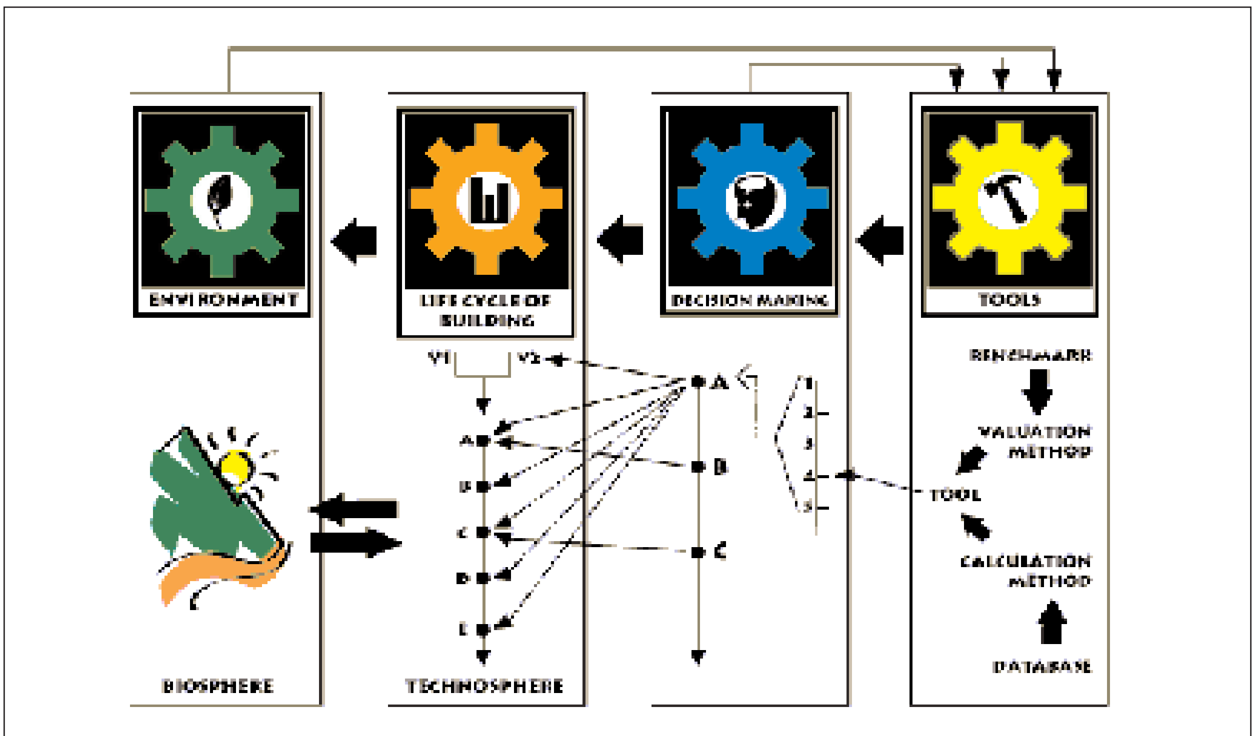



**Figure 15** *Role of Tools in the sustainable building design process*

Evaluation tools are primarily intended for decision support. Paradoxically, an assessment tool can have the greatest impact in the early design phase when available information about a design is the least precise. Ideally, an assessment tool should be able to start with a rough description of a building and accommodate increasing levels of detail as the design develops.

In order to make tool results relevant, tool designers need to

- avoid redundancy
- focus on outputs amenable to improvement by the user.
- include the most significant environmental impacts attributed to the building sector
- maximize the objectivity of outputs

In the final presentation of results, the decision-maker should be able to identify the sources responsible for any environmental effects, and be aware of uncertainties and assumptions used, in order to accurately interpret the assessment results.

In addition to environmental results, and considering a decision-maker's interests and concerns, environmental assessment tools, either by integration or by external link, should allow cost analysis, as this is a key criterion in decision-making.

## Comparative Applications

In this report, the environmental impact of a reference dwelling and an office building were both evaluated with tools from Annex 31 participating countries. The tools are all intended to assist in quantifying or qualifying the environmental profile of a building, or to assist decision-makers in improving the environmental performance of a building design. The result is a demonstration of how tools work and how they guide designers, consultants or researchers into creating more environmentally sound buildings.

With common input data, all tools calculated the environmental impact of the reference buildings in three steps:

1) Without energy in use
2) With energy in use and adapting the building to a local environment
3) With energy in use and environmental improvements the building

The results show the same pattern with all tools: energy use during occupancy is responsible for 75 to 95 per cent of the environmental impact of buildings during their whole life cycle. Reducing energy use thus provides the highest environmental profit. For highly energy-efficient buildings, reducing the environmental impact of building materials becomes more important.

An important conclusion is that it is possible to reduce the operating energy of a building significantly without significant increases in the embodied energy of the building. A second important conclusion is that life cycle embodied energy is likely to be more significant than initial embodied energy. However, without sufficient data regarding the life of components, the significance of recurring embodied energy is difficult to estimate with a high level of confidence.

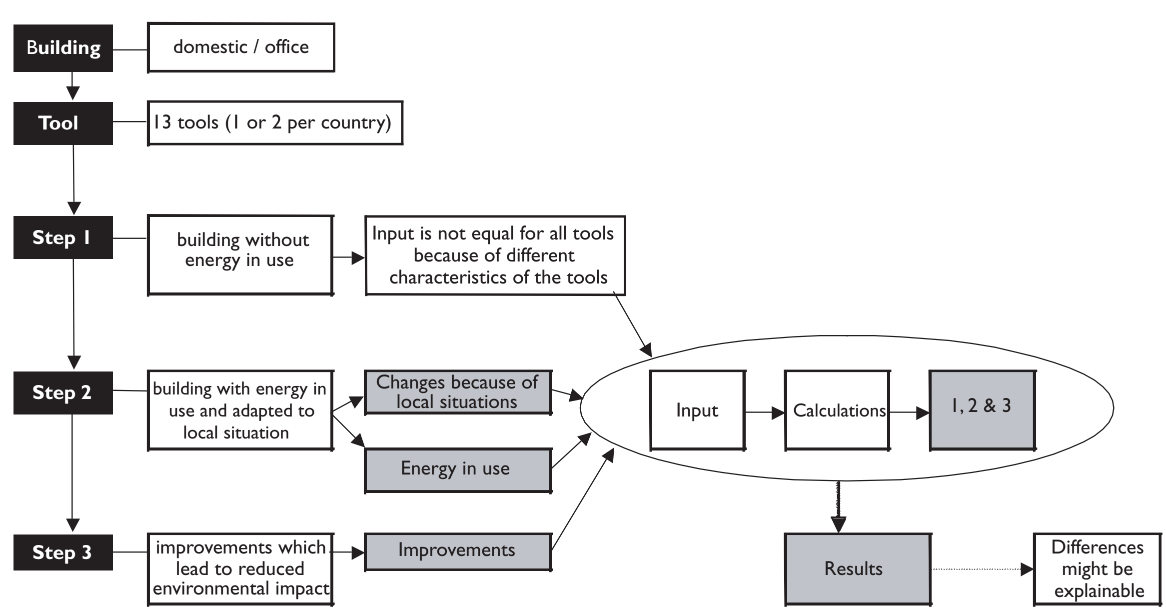



**Figure 16** *Plan of action for the Comparative application of Tools on a reference building*

The comparison study also indicated that the source and quality of data, system boundaries, data allocation, weighting factors and environmental profiles affect the significance of the results and the ability to compare and judge the quality of tools.

Transparency of a tool is one of the most important characteristics. While not every user needs to understand the details of a tool, experts need that

Performing a LCA of a complete building is normally a complex and time-consuming task. Environmental requirements add to the enormous amount of design issues that architects and others have to consider. A tool must accommodate this complexity and time constraint, or it will not be used in the design process.

## Data Needs and Sources

The data needed to assess the energy-related environmental impacts of buildings depend strongly on the type of tool used and, among other considerations, on the aggregation level targeted, such as at the product, building or stock level. Most LCA tools provide a database with generic inventory data, and some have building-oriented data. These data must be checked for their quality and relevance to ensure that an appropriate fit is found between the data inputs and the case under study. A good LCA study should be transparent enough to lead any neutral expert to the same conclusion, providing the assumptions and the assessment method are considered acceptable.

This report offers the following recommendations for developers of tools and databases:

1. LCA software tools, including databases, should satisfy the requirements of the SPOLD (Society for the Promotion of LCA) format in order to cope with comprehensive sets of metadata.
2. Since most LCA tools allow users to modify or implement new impact assessment methods, they should allow the user to implement their own data quality indicator system, since there is no well-recognized standard system.
3. Because of the high specificity of a building and of building products, a building-oriented impact assessment software tool should be able to communicate with external tools devoted to calculating, for example, heating energy consumption, natural lighting (to assess the needs of artificial lighting), indoor air quality, hygro-thermal comfort and so forth.
4. Taking into account the high variability of many inventory data, developers should calculate value intervals or conduct any other uncertainty or sensitivity analysis that is easy to understand.
5. Developers should use existing conceptual models and publish data models to help develop interface with software that performs complementary assessments, such as energy consumption during building occupancy.

# Assessing Buildings for Adaptability

Adaptability refers to the capacity of buildings to accommodate substantial change. As the world faces resource scarcities and ecological crises, a concern for the adaptability of buildings is especially relevant. Existing building stock represents the largest financial, physical and cultural asset in the industrialized world. A sustainable society is not possible until this key resource can be managed sustainably.

The concept of adaptability can be broken down into three simple strategies, which are familiar to most designers: flexibility, convertibility and expandability. Adaptability is closely related to, but different from, two other design strategies that attempt to enhance long-term environmental performance, namely durability and design for disassembly.

Urban areas everywhere are experiencing problems related to poor use of buildings and high flows of energy and materials through the building stock. Demolition rates are rising, and much solid waste is not being recycled. If adaptability is to be a useful design concept, it must be possible to properly distinguish those features of new buildings that will significantly increase their capacity for change, but this is difficult.

Part of the problem is that few buildings exist today that have been intentionally designed for adaptability and put to the test of time. Even when the inevitability of change is fully appreciated, the marketplace offers little incentive for developers and owners to invest in long-term adaptability. Plus, a more fundamental obstacle is the difficulty in accurately predicting future requirements for buildings.

Unless a building is capable of responding to changing circumstances, it is vulnerable to becoming poorly utilized, prematurely obsolete and unable to accommodate new, more efficient technologies. Depending upon the additional investment required to achieve adaptable designs and materials, it should be possible to significantly improve the environmental performance of the world's buildings in at least three ways: more efficient use of space, increased longevity and improved operating performance.

**Key Principles of Adaptability**

*Independence* – Integrate systems within a building such that parts can be removed or upgraded without affecting the performance of connected systems.

*Upgradability* – Choose systems and components that can accommodate increased performance requirements.

*Lifetime compatibility* – Avoid strong interconnections between short-term and longer life components; maximize durability of materials where long lifetimes are required, such as structural elements and cladding.

*Record keeping* – Ensure information on building components and systems is available and explicit for future use.

The high degree of uncertainty about the next 50 years works against investing in adaptability. For this reason the concept of adaptable design may be largely restricted to

- accommodating changes that are expected to occur in the very near future
- applying simple 'common-sense' principles that are known to facilitate a wide range of possible changes
- incorporating 'adaptability' features that can be justified for other reasons
- adopting features that enhance adaptability with little or no additional capital and resource investment.

## Sensitivity and Uncertainty

Sensitivity and uncertainty analysis can be used at many stages of an assessment to achieve the following:

- Test the assumptions and data used for material LCAs.
- Identify the key parameters affecting the embodied energy of an element or building.
- Test the extent to which parameters are important to the life cycle of a building, e.g. maintenance and replacement rates.
- Determine which materials require accurate data for transport energy to be compiled and which do not. This determines which materials are sensitive to location.
- Determine the importance of life cycle embodied energy compared to operational energy for a building.

Sensitivity analyses, when used skilfully, can dramatically reduce the quantity of data and work needed to arrive at robust estimates of the energy related environmental impacts of buildings. It can also identify crucial data that must be thoroughly investigated.

For example, a sensitivity analysis of energy use during the life span of Swedish buildings "from cradle to grave" shows that the occupational phase, excluding renovation, is responsible for about 85 per cent of the total energy use, while manufacturing is responsible for about 10 to 15 per cent.

Renovation during the occupation phase is responsible for about 5 per cent while deconstruction in most cases has insignificant influence on the total energy use. This indicates that the reduction of energy use should be aimed at the occupational phase, or if the aim is to obtain an accurate estimate of the energy use, efforts should be directed to this phase. Detailed sensitivity analyses can reveal which parameters to focus on to reduce environmental impacts or to achieve more accurate results.

Uncertainty analysis can have significant implications for LCAs. It is crucial to take uncertainty into consideration when performing comparative LCAs, as differences between alternatives are important and not absolute values. A conclusion based only on mean values and no confidence interval, such as 95 per cent, might result in selecting a component that in reality is no better or, in extreme cases, even worse.

Although it is widely recognized that uncertainty is an essential part of LCAs, it has seldom been considered. The main reason is that there is no international consensus on how uncertainty should be treated or which method should be used. However, most LCA-inventory tools today have some means of handling uncertainty or sensitivity analyses. The biggest problem seems to be a lack of data. Regardless of which method is chosen, it will require more data to include uncertainty than what is presently collected.

# Stock Aggregation

Stock aggregation refers to the process of evaluating the performance of a building stock using environmental assessments of components or archetypes of the stock. Stock aggregation can help designers understand how their design choices might affect – or be affected by – overall stock performance. It can also provide planners and policy makers at various levels (local to national) with a richer, more powerful database on building costs, energy and resource use, and environmental effects.

Because stock aggregation begins with an analysis of individual buildings, it is referred to as a 'bottom up' approach. The scale of stock aggregation can vary, from housing stock within a single project to national residential, commercial, and institutional building stocks.

In general, stock aggregation can be used to highlight areas where substantial potential exists for improvement in resource use and economic efficiency. It allows for quick "what-if?" analyses; Stock aggregation can assist in analyzing how policies in one area, such as energy security or housing affordability, affect other building impacts (air pollution, energy demand and so forth). It allows policy makers to optimize regulations and market incentives to achieve specific targets. It also can be used to develop priorities for research and development.

For example, stock aggregation methods may be appropriate for utilities that want to better analyze their customer base. A utility can use this approach to investigate the potential for offsetting demand through load management programs, or through energy conservation and efficiency.

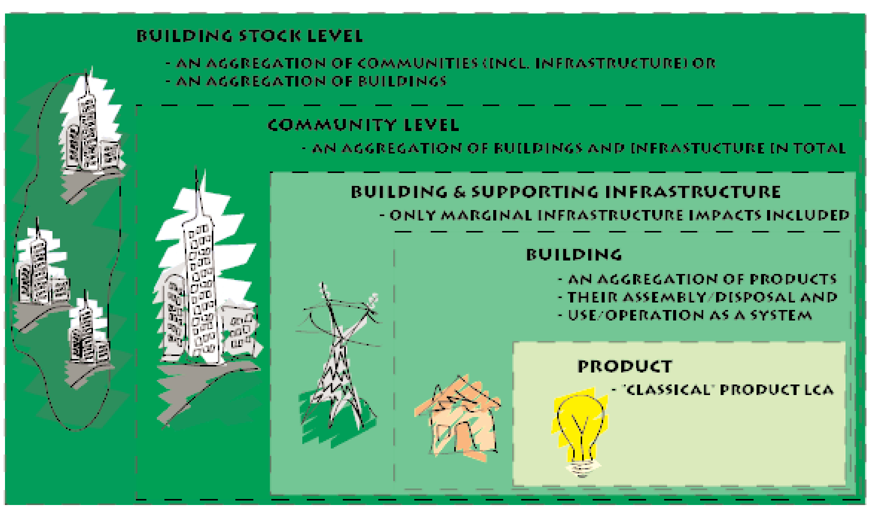



**Figure 17** *Stock aggregation scale of analysis*

Stock aggregation offers a more sophisticated and accurate means for

- local area load management
- long-term load forecasting
- capacity constraint analysis
- investment planning
- business expansion (new territories, and new building-related services)
- integrated resource planning (with optimization of supply and demand options)
- monitoring impacts of policy and programs.

Stock aggregation is often the best method for evaluating stock performance because energy and resource flows are a function of the dynamic relationships between a building's shell and its constituent equipment, systems and operations. In the future, stock aggregation may be especially suitable for towns and cities that want to manage the impacts of growth, or prepare building regulations and guidelines that help the community meet its environmental goals.

# CONCLUSION

The broad variety of perspectives in the typical building process, and the predominance of non-environmental criteria in decision-making, present a major barrier to the development of green buildings. As well, the design process for buildings is culturally specific: every building is a unique construction within its particular surroundings and context, and should be conceived as such.

Annex 31 presents a wealth of practical and theoretical information. On the theory, design and application of energy and life cycle assessment tools for buildings. This highlight reflects only a small portion of the extensive information available on the Annex 31 CD-ROM or at www.annex31.org. Individually and collectively, the core and background reports are a significant resource, with the Directory of Tools, Glossary and Links adding further detail and contacts.

Annex 31 will be of benefit whether one is looking for a general understanding about the energy-related environmental impact of buildings, or insight into practical considerations for developing building assessment tools, their application and presenting results.

Ultimately, the use of relevant environmental assessment tools should lead to

- better knowledge of environmental impacts related to buildings
- an improved dialogue between all parties involved in a building project
- a rationale for choosing environment-friendly solutions
- emphasizing the importance of identifying life cycle environment impacts during the critical early design phase.

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# INTERNATIONAL ENERGY AGENCY

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy program. A basic aim of the IEA is to foster co-operation among the twenty-four IEA participating countries and to increase energy security through energy conservation, development of alternative energy sources and energy research, development and demonstration (RD&D).

## Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. The mission of one of those areas, the ECBCS - Energy Conservation in Buildings and Community Systems Programme, is to facilitate and accelerate the introduction of energy conservation, and environmentally sustainable technologies into healthy buildings and community systems, through innovation and research in decision-making, building assemblies and systems, and commercialisation.

The objectives of collaborative work within the ECBCS R&D program are directly derived from the on-going energy and environmental challenges facing IEA countries in the area of construction, energy market and research. ECBCS addresses major challenges and takes advantage of opportunities in the following areas:

- exploitation of innovation and information technology;
- impact of energy measures on indoor health and usability;
- integration of building energy measures and tools to changes in lifestyles, work environment alternatives, and business environment.

## The Executive Committee

Overall control of the program is maintained by an Executive Committee, which not only monitors existing projects but also identifies new areas where collaborative effort may be beneficial. To date, the following projects have been initiated by the executive committee on energy conservation in buildings and community systems:

| | |
|---|---|
| Annex 1: | Load Energy Determination of Buildings (*) |
| Annex 2: | Ekistics and Advanced Community Energy Systems (*) |
| Annex 3: | Energy Conservation in Residential Buildings (*) |
| Annex 4: | Glasgow Commercial Building Monitoring (*) |
| Annex 5: | Air Infiltration and Ventilation Centre |
| Annex 6: | Energy Systems and Design of Communities (*) |
| Annex 7: | Local Government Energy Planning (*) |
| Annex 8: | Inhabitants Behaviour withRegard to Ventilation (*) |
| Annex 9: | Minimum Ventilation Rates(*) |
| Annex 10: | Building HVAC System Simulation (*) |
| Annex 11: | Energy Auditing (*) |
| Annex 12: | Windows and Fenestration(*) |
| Annex 13: | Energy Management in Hospitals (*) |
| Annex 14: | Condensation and Energy (*) |
| Annex 15: | Energy Efficiency in Schools (*) |
| Annex 16: | BEMS 1- User Interfaces and System Integration (*) |
| Annex 17: | BEMS 2- Evaluation and Emulation Techniques (*) |
| Annex 18: | Demand Controlled Ventilation Systems (*) |
| Annex 19: | Low Slope Roof Systems (*) |
| Annex 20: | Air Flow Patterns within Buildings (*) |

Annex 21: Thermal modelling (*)
Annex 22: Energy Efficient Communities(*)
Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HEVAC simulation (*)
Annex 26: Energy Efficient ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems(*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy Related Environmental Impact of Buildings(*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning(*)
Annex 34: Computer-aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings(*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings(*)
Annex 38: Solar Sustainable Housing
Annex 39: High Performance Insulation systems
Annex 40: Building Commissioning to Improve Energy performance
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-EN)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (COGEN-SIM)
Annex 43: Testing and Validation of Building Energy Simulation Tools
Annex 44: Integrating Environmentally Responsive Elements in Buildings
Annex 45: Energy-Efficient Future Electric Lighting for Buildings

(*) - Completed Annexes