International
Energy
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ENVIRONMENTAL FRAMEWORK

DECISION MAKING FRAMEWORK

TOOLS

LIFE CYCLE OF BUILDING

Technical Synthesis Report
Annex 31

Energy-Related Environmental Impact of Buildings

Energy Conservation in Buildings and Community Systems

Technical Synthesis Report
Annex 31

Energy-Related Environmental Impact of Buildings

Edited by Richard Hobday

Annex 31 Technical Synthesis Report based on the final reports of the project

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Preface

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 programme. 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 for Building 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 (completed projects are identified by (*)):

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 with Regard 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 (LowEx) (*)
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-ENG)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM)
Annex 43: Testing and Validation of Building Energy Simulation Tools
Annex 44: Integrating Environmentally Responsive Elements in Buildings
Annex 45: Energy Efficient Electric Lighting for Buildings
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo)

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser

(*) - Completed

This summary report concentrates on Annex 31: Energy-Related Environmental Impact of Buildings

Annex 31: Energy-Related Environmental Impact of Buildings

Annex 31 was established under the auspices of the International Energy Agency's (IEA) Agreement on Energy Conservation in Buildings and Community Systems. The mandate for the Annex 31 working group was to provide information on how to improve the Energy-Related Environmental Impact of Buildings. More specifically, Annex 31 focused on how tools and assessment methods might improve the energy related impact of buildings on interior, local and global environments. The ultimate objective was to promote energy efficiency by increasing the use of appropriate tools by practitioners. To this end the work of the Annex was divided into two principal subtasks:

1. The preparation of four core reports which provide a comprehensive introduction to the theory of tool design and application.
2. The preparation of seven background reports which provide experts and tool developers with additional information on the design and use of assessment tools.

The reports include a detailed description of assessment tools, and an international directory of tools. Additional reports including a glossary of terms, directory of tools, and links to Annex 31 participants were prepared. All of these outputs were then organized and presented on an Annex 31 web site, with links to other complementary web sites.

Scope

This technical synthesis report contains a summary of the work of Annex 31, the formal duration of which was from 1996 to 1999. It is based on the principal Annex 31 project reports listed under References.

Mission Statement

"Through collaborative research and communications we will encourage development and application of appropriate tools and assessment methods for improving the energy-related environmental impacts of buildings."

CONTENTS

1. About Annex 31

As the need to address environmental concerns becomes more pressing, energy and life cycle assessment tools will become increasingly important resources. Annex 31 presents a comprehensive overview of the theory and practice of life cycle assessment tools for buildings. Fourteen countries participated in Annex 31, each supplying one or more experts to the Annex 31 meetings. They also supported the on-going research work undertaken by these experts, and their colleagues, at their respective national organizations and agencies. The names of all the individuals who participated in the Annex 31 work are listed at the end of this report, together with their affiliations and addresses. The experts who took part in Annex 31 were typically architects, engineers or scientists. All of them brought to the work both a practical and academic understanding of buildings and environmental issues. Many had been involved with the development of methods and tools within their organizations and countries.

Representatives from all participating countries met as a group on at least six occasions, over a period of three years. Sub-committees undertook to research and document the emerging assessment methods and tools, both nationally and internationally. A number of original technical reports was produced on a broad scope of subjects, ranging from theory to application. These original reports were then condensed into a series of summary reports, each with a similar style and level of detail.

Target Audience

Annex 31 was intended to be of interest to people engaged in:

- assessing the environmental 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 the following groups:

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

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

2. Life Cycle Assessment

Life Cycle Assessment (LCA) is a technique for assessing the potential environmental loadings and impacts of buildings. LCA can be a rigorous way to reconcile physical interactions between buildings and other elements of the environmental framework. In LCA the flows of energy and materials are assessed at each stage in the life cycle, and are then summed.

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

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

Depending upon the goals and objectives of the exercise, the LCA method can be customised to include or exclude specific stages in the life cycle, or specific types of loadings and impacts. A wide range of assessment tools can be employed to assist in calculating results at different life-cycle stages, with differing scope and level of sophistication. Because buildings and building stocks have such long lifetimes, they are ideally suited to the LCA method.

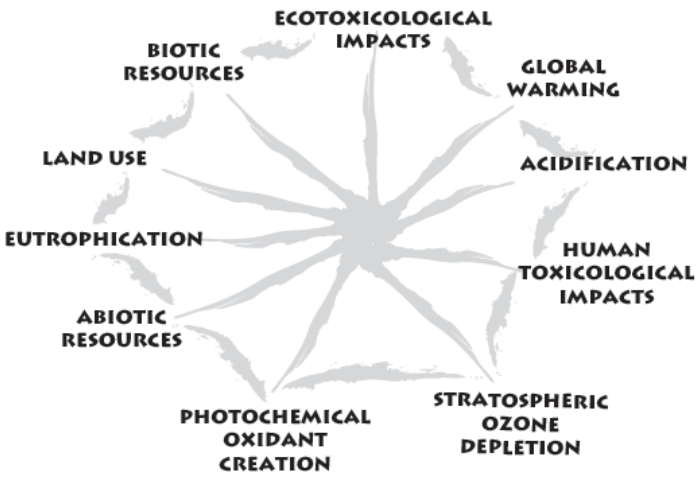

Figure 1: Common effects considered in LCA

Only by considering resource flows at each stage in a building's life-cycle is it possible to obtain an accurate perspective on the environmental impacts. Frequently the repair and running costs are the single highest category of impacts; however the impacts associated with creating new materials and transportation of goods can also be especially significant.

The LCA method typically employs rules for cutting off the analysis at sensible boundaries. Where one draws these boundaries in the energy-related impact of one or several buildings was part of Annex 31's deliberations.

3. Assessment Tools

Improving the environmental performance of buildings and building stocks is best accomplished using tools as decision-making aids. Such tools help to translate insights gained from scientific analysis into the decision-making process in the day-to-day course of business. Tools stimulate communication, make energy and environmental efficiency quantifiable, and ultimately make it possible to set goals and monitor performance. Many countries now have a variety of assessment tools that have been tailored for use by specific users and to fill particular analytical needs.

Annex 31 categorised assessment tools as follows:

- Energy modeling software
- Environmental LCA tools for buildings and building stocks
- Environmental assessment frameworks and rating systems;
- Environmental guidelines or checklists for design and management of buildings
- Environmental product declarations, catalogues, reference information,
- Certifications and labels

Of these, active tools permit the use of methods and models, whilst the passive tools (tools such as instruments, resources) help summarise, present and pass on information.

4. Extent of Energy-Related Considerations

Energy is the single most important parameter when assessing the impacts of technical systems on the environment. Energy resources are becoming scarce as we deplete our stock of fossil fuels, biomass and uranium. 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.

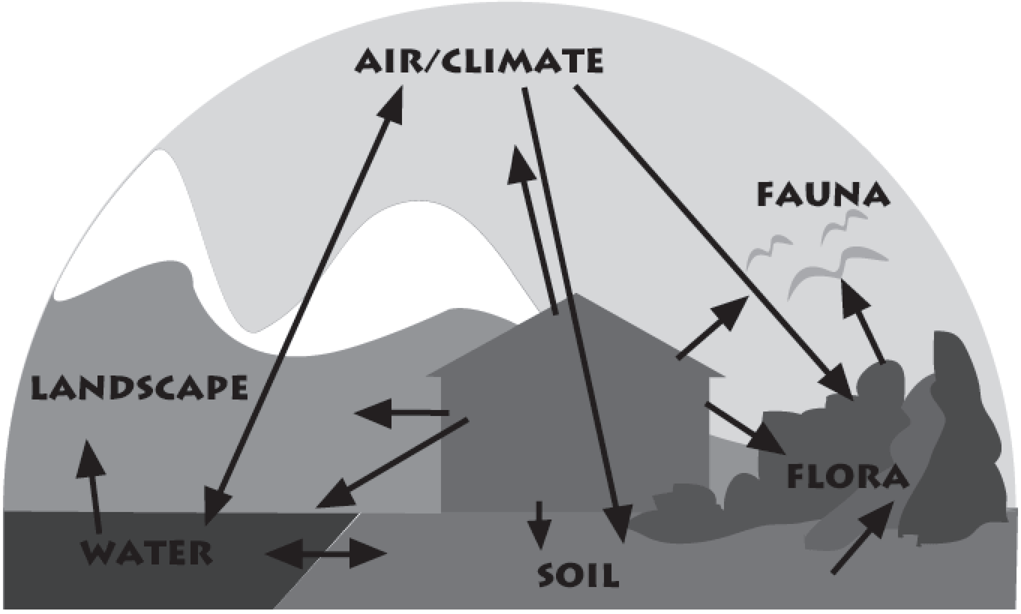

Figure 2: Technical Systems are contained within the environment

Energy use in buildings typically accounts for about half of all the energy consumed by developed countries. Transport energy typically accounts for about a third of the energy of which 5 per cent accounts for the transport of construction materials. A further 5 per cent is used to manufacture construction materials. So, some 10 percent of the total figure is attributable to the embodied energy of these materials.

Buildings have a significant environmental impact beyond that attributable to the energy used in them. Their environmental impact depends on their location and how this influences the climate, outdoor environment, landscape, ecosystems, and technical infrastructures. The transportation of goods and people to and from a building is related to the energy used within it, as is the supply of services (potable water, waste water and solid waste disposal, communications and energy services.)

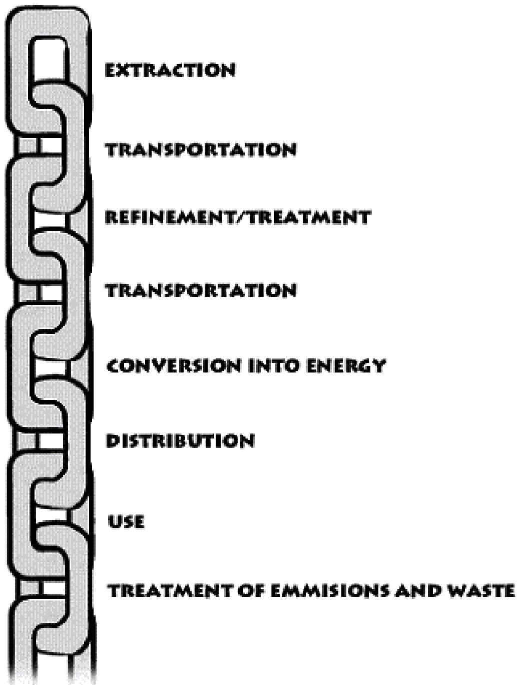

Figure 3: Links in a typical energy chain

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

The sources of the energy consumed in buildings can vary substantially in terms of their environmental impact. Renewable energy sources can have substantially lower impacts and should be much more sustainable long-term if not indefinitely. Also, as more energy saving measures are incorporated into buildings, and direct energy consumption falls, then life cycle environmental impacts become more significant. Typically, reductions in operating energy occur at the expense of increased embodied energy, embodied emissions, and life cycle material flows. Also, as operating energy becomes less significant, the operating demand load for water and materials can assume greater importance.
The full extent of energy-related impacts becomes clearer when the life-cycle of the building process is reviewed:

- production of energy (preliminary stage)
- manufacture of basic materials (preliminary stage)
- erection of building, construction
- operation and use
- maintenance measures
- repairs and renovation
- modernisation or conversion
- demolition or deconstruction

5. Core Reports

Annex 31 presents a comprehensive overview of the theory and practice of life cycle assessment for buildings in four main reports: Environmental Framework; Decision-Making Framework; Types of Tools; and LCA Methods for Buildings. The main findings and conclusions of these core reports are summarised below.

Logos for the core reports

5.1 The Environmental Framework Report

This report provides a detailed description of the concepts and methods used to analyse the energy-related environmental impact of buildings. An environmental framework provides the basis for a consistent and comprehensive description of the physical interactions which arise throughout the lifecycle of buildings. As such it is a prerequisite for the effective design and development of environmental assessment methods and tools.

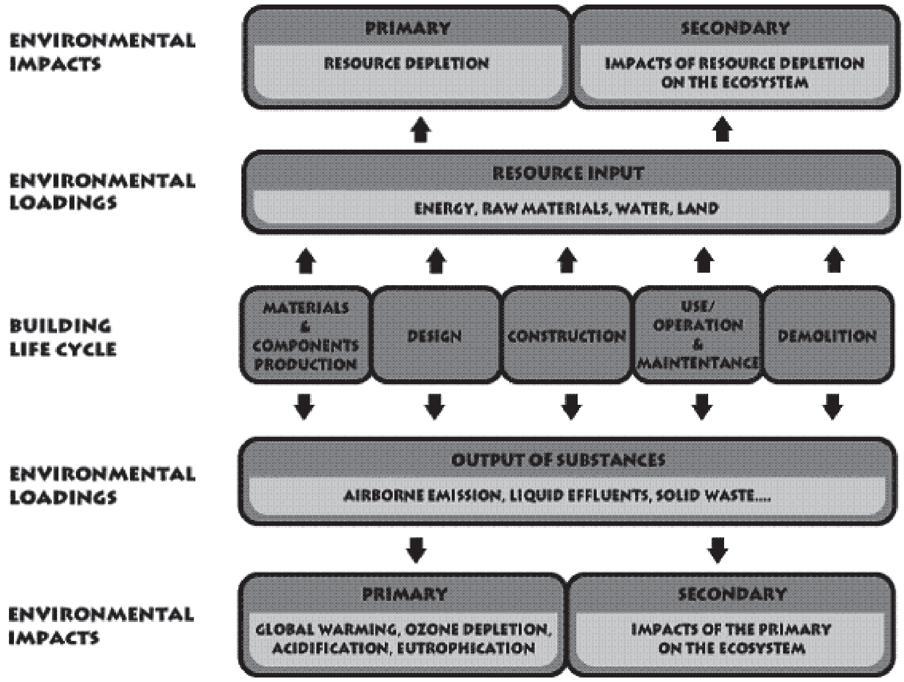

Figure 4: Building Life-Cycle and Environmental Loadings and Impacts

Physical interactions between a building and its environment include the flows of energy, water, materials and other resources, and the corresponding wastes and emissions. They also include the effects of technical systems like buildings on land use and bio-productivity, and on human health, comfort and worker productivity.

The Building as a Functional Unit

When construction projects undergo environmental assessments, this usually involves the building and the plot of land upon which it is situated. The environmental impact may be assessed over a part or all of its life-cycle (depending on the objectives of the study, which may target the renovation phase, or the entire life-cycle). Life cycle assessments can be customised to include or exclude specific stages in the life-cycle, or specific environmental loadings and impacts.

In some cases, the assessment may cover an entire district or town, and include not only buildings but also infrastructures. However, at present, most of the tools available are too limited to undertake work at this level.

Building as a Product, Process and Place

The scope of analysis being undertaken determines the way in which a building is characterised, and boundaries are established. In general, a building can be defined in one of three ways:

1. a "product", or more exactly a complex assembly of products, which are manufactured, used and disposed of. Further, during its use, the product needs to be maintained, and some parts will need to be replaced. Tools carry out the environmental assessment of construction materials and products within this framework.

2. a "process" which through its operation during the utilisation phase is intended to provide a number of services to users, as well as conditions appropriate for living, working, studying, providing health-care, leisure activities, involving input and output flows to make this process function. In order to function, the building, as a process, must therefore be provided with

energy, water, and various resources. It then yields products, namely the services that it renders, and flows: atmospheric emissions, wastewater, industrial wastes, etc. Furthermore, it is linked to infrastructures both upstream and downstream (energy, water, transport, wastes) whose processes also have input and output flows.

3 a "place to live". In this case it is particularly important to assess the building's impact on the comfort and health of users. It should be added that other population groups are also concerned by the building's life-cycle, such as site workers, maintenance staff and neighbours.

Energy analysis tools may choose to ignore specific sources of energy, and specific energy transformations within and outside the building. Such boundaries may be warranted because the quantities of energy involved are negligible, or because of uncertainties, or because the sources are of little interest to the target audiences.

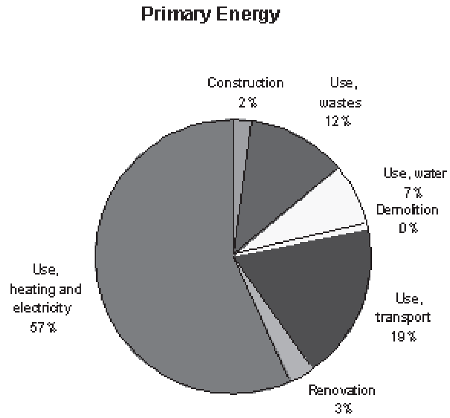

Figure 5 illustrates how energy use breaks down for a single-family house, and emphasises the very significant differences in relative energy use.
Figure 5: Energy use breakdown for a single-family house

In the future, buildings are likely to become a more integrated part of the energy generation system. Solar panels, shared heat pumps, and the cascading and sharing of heat between buildings can all contribute to a more distributed and efficient system in which buildings become an element within the energy supply infrastructure. LCA tools will have to reflect this integration.

In order to provide software input data which characterises the composition of the building (nature and quantity of materials), exact plans and precise, detailed descriptions are required which are consistent with any geometric data. The nature of the materials and the conversion of quantities into units of mass must be unambiguous. This is often not the case, and a substantial amount of work may be required to render the information useable. Another problem occurs when developers use materials in aggregate quantities: as no link to the geometric data is available, this leads to uncertainties in calculating the energy performance of the building, and in any study of variants.

The Importance of Non-Energy-Related Impacts

As the energy performance of buildings improves, other factors contributing to a building's life-cycle impact become relatively more significant. Reductions in operating energy use also effect the embodied energy and material inputs of a building and can do so at the expense of occupant comfort too. The work of Annex 31 was originally directed towards energy consumption (because energy is the key parameter in the environmental impact of buildings) and only then addressed the effects of other factors. However, energy efficiency measures can make conditions worse for building occupants or others (usually when not conducted properly or when users are not well enough informed: such as discomfort, health problems, impacts related to insufficient treatment of water or of waste, for example). Such issues explain why Annex 31 covered energy issues by taking an overall approach in the environmental assessment of a project.

Although no general consensus exists among tool developers and modellers, most authors agree that the impacts related to the indoor environment are particularly important, and of increasing interest. Traditional LCA methods do not consider any impacts on the indoor environment, since these impacts are usually considered in isolation. Consequently, most LCA-oriented tools do not include indoor environment measures either, so other methods must be used for this purpose. Yet, combining energy analysis with indoor environmental quality is especially worthwhile because of the potential trade-offs and synergies.

The life span of a building or a site is another very important parameter in an environmental profile. Longer building lifetimes often reduce the impacts by extending the amortization period for large resource inputs; such as concrete foundations. Longer lifetimes also emphasize the benefits of design features which reduce operating costs. Ideally, an environmental framework would establish the scope of any impacts that may occur over the entire lifetime, for all buildings.

Unfortunately the long lifetimes of buildings impose high levels of uncertainty on the analysis, and can frustrate efforts to evaluate the costs and benefits of lifetime extensions. Over a period of 40 to 60 years it is likely a building will experience significant variations in regulatory and economic conditions, and in environmental constraints and opportunities. For a detailed discussion of factors affecting the choice of building lifetimes, refer to the Annex 31 background report entitled "Assessing Buildings for Adaptability".

5.2 The Decision-Making Framework Report

This report explains why the design and development of effective environmental assessment tools has to take place within the context of a decision-making framework. It clarifies how and when specific participants become involved in key decisions at each stage in a building's life-cycle. The report also defines the scope of each decision, and types of evaluation criteria and decision-support tools that may be useful.

Decisions taken at the inception of a project often have a large, if indirect, influence on its performance over the entire life-cycle. For example, the orientation of a building can have a profound effect on overall energy consumption.

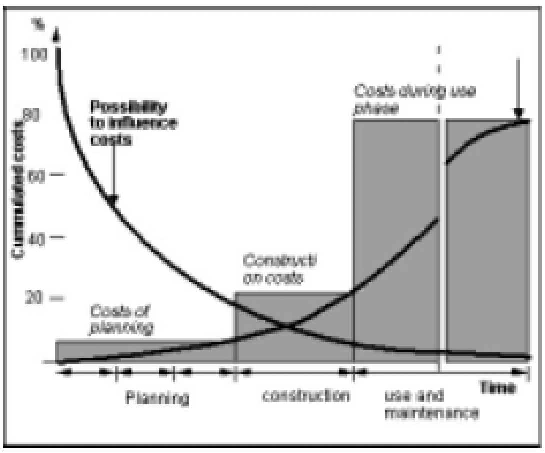

Figure 6: Impact of time on cost and influence

Other decisions taken at the planning stage can affect maintenance requirements and demolition costs. Simulation models and tools can be used to analyse these issues by evaluating different scenarios over the building or stock's lifetime. This process can be used throughout the design and the life cycle stages for a building, as listed below:

- Preliminary study (basic information, study of feasibility, determination of purpose)
- Design process (development of concepts, design phase, preparation of approval)
- Preparation of working documents (specifications, tenders)
- Execution (organisation of construction site, construction, control/inspection, documentation)
- Use (utilisation, maintenance)
- Deconstruction or demolition (design of deconstruction, preparation of deconstruction, deconstruction, disposal/recycling)

Table 1 presents a more detailed example of such a generic process.

Step	**Description**
Identifying the problem	- recognise the problem
	- engender 'awareness' of the problem
Describing the problem	- analysis and description of the starting point
	- analysis and description of requirements
Determine tasks	- establish programme of requirements
	- state economical, ecological boundary conditions
	- evaluate *guidelines* possibly
	- establish *evaluation criteria*
	- establish *limits and target values*
	- arrange solution of problem
Establish prerequisites	- choose *calculation methods and tools*
	- choose evaluation *methods and tools*
	- evaluate *information sources (databanks)*
	- evaluate *case studies, benchmarks, precedents*
Generating alternatives	- generate alternatives
	- describe technical parameters
	- generate balances
	- use *calculation methods and tools*
Evaluating alternatives	- evaluate technical, economical and ecological performance
	- use *evaluation methods, indicators and tools*
Pre-selection stage 1	- establish whether solutions are legally 'permissible'
	- use (technical) *limits/thresholds*
	- use *exclusion criteria*
Pre-selection stage 2 (*)	- compare 'advantages' of solutions
	- use technical/economical/ecological *target values*
	- use *recommendation criteria*
Decision-making	- select alternatives (to follow up)/stop (no decision**)
	- use multi-criteria *decision methods*
	- use *decision-making aids*
Special cases:	
Preparation of specifications	- specify important building measures
	- prepare technical, legal, and organisational documents
Execution	- judge performance
Verification	- measure, monitor and compare performance relative to limits and target values

(*) The pre-selection stage 2 is intended to reduce the amount of possible solutions after the initial pre-selection. Stage 2 selects the more advantageous solutions from the technically possible and permissible solutions selected in Stage 1. The aim is to reduce the quantity of final alternative solutions to a manageable amount.

(**) Breaking off the decision-making process due to inadequage solutions is usually accompanied by the identification of a new problem and leads to a new decision-making cycle on the same or a higher level.

Table 1: A Description of Decision-Making and Preparatory Process

Surveys by Annex 31 researchers identified that most countries have some form of standard, or make recommendations, for the design process for buildings. These are often created to make the costs of the design process more transparent. For example, the standard design protocol used in Switzerland (SIA, 1996), identifies the percentage of the total fee that can be charged at each stage of a design. A standardised design process of this kind can be a valuable guide when preparing a decision-making framework at a conceptual level.

Improving the Role Played by Key Personnel

A wide range of individuals are involved in building projects and they come from different disciplines. They have different concerns, choice criteria, and priorities. The term ‘environment’ carries different meanings to each of them– and is often restricted to only the types of impacts historically related to their respective disciplines. This broad variety of perspectives, and the predominance of non-environmental criteria in decision-making, presents a major barrier to the development of green buildings.

Nevertheless, each participant in a building design process has his or her own scope for decision-making, and may become involved in decisions at a number of stages in the process. Decision support tools must reflect this complexity, and recognise that each person is unlikely to derive the same results when using similar tools. Also, specific tools are needed to support good decision-making at the most appropriate stage of a project. Annex 31 identified that participants involved in design need the following:

- Decision aid and assessment tools
- Tools for raising awareness, and for educational purposes
- Design aid tools (catalogues of solutions or of products)
- Tools with which to carefully consider the environment at the local scale
- Tools to aid the participants in making the right decision at the right time, but without making the decisions for them.
- Tools which speak their language, which are transparent, are easy to use and are appropriate.

They need quick, effective, affordable tools adapted to their needs and culture. These tools also must adapt to the different levels of decisions involving tool application, including:

- The person who initiates an approach to the assessment of the environmental quality of a project (example: a local political entity),
- The person who selects the most suitable tool (example: an environment consultant),
- The people who provide the necessary input data (examples: the architect, the engineering firms, the manufacturers),
- The person who implements the assessment tool (example: an engineering firm),
- The person who interprets the results of the assessment (example: the engineering firm with relation to the building owner),
- The person who takes the final decisions (example: the building owner or the contracting authority).

Building owners are typically very sensitive to issues of cost, affordability, and quality of life. Environmental concerns are often treated as if they are achieved at the expense of these concerns. However, the recent emphasis on sustainable development in urban areas has repeatedly emphasized the potential for true synergy when an integrated design process is adopted. By simultaneously addressing the three spheres of sustainability, - economy, social welfare and environment – it is possible to improve all three. While the larger issues of sustainable design were beyond the scope of Annex 31, ultimately they are unavoidable. Only by achieving synergy across a broad range of goals is it possible to have significant success in reducing the energy-related environmental impacts of buildings.

Figure 7: The three spheres of sustainability

It is important to reposition the environmental quality of a building in a broader overall context. This means that each technical or architectural green solution has to be systematically compared to a range of criteria (environmental, technical, financial, social) as part of an integrated, multi-criteria approach. Ideally the entire design team should be educated and made aware of environmental issues, the use of assessment tools, and environmental management procedures. The design team for a building project should include people who are knowledgeable about use of assessment tools.

The overview of the decision-making process in Annex 31 emphasized the need for purpose-built tools that can assess solutions throughout the project life-cycle. Such tools need to be quick, effective and low-cost, adapted to the individual's needs and culture. Each of the interested parties has special needs that need to be addressed, as discussed below:

For owners and financial controllers, it is important to be able to translate improved performance from green buildings into opportunities for financial incentives, increased productivity, enhanced marketing opportunities, innovative financing schemes, improved technical guarantees, and reduced liability and risk. Life cycle cost thinking is fundamental to such an approach. Environmental methods or tools can be used to help building owners translate general environmental goals into tangible goals, and set priorities.

For architects, decision-support tools must be adapted to the day-to-day realities of work processes. Tools must accommodate fast-paced, visual decisions, and allow for rapid iterations. Environmental criteria need to become another layer of information, integrated into a multi-criteria analysis.

For engineers, access to objective and detailed information on appropriate tools is the greatest need. Engineers also need 'just-in-time' training, and regular feedback on actual performance of existing green buildings.

For contractors, the major issue is managing the changes and developing new standards for specific applications. Results from decision-support tools need to be transparent, and closely tied to information on best practices.

The best way to address the multi-disciplinary nature of the design process, and to integrate the environmental elements with other functions, is to use an integrated design process (IDP). This involves a design team working together with a wider range of technical experts, local stakeholders and partners than would normally be the case. It brings them together at the early stages of a project and uses their expertise to influence fundamental design decisions. Although IDP involves more extensive decision-making at the early stage, the additional time taken is usually recovered later in the project. In addition to improving co-ordination between disciplines, it allows for effective, controlled input from the public and to improved designs.

In this context, the use of relevant environmental assessment tools should lead to better knowledge of environmental impacts related to buildings, and to an improved dialogue between all parties involved in a building project. Tools must provide precise answers to questions on the environmental impact of buildings during their life-cycle, and satisfy the environmental objectives mentioned in the brief.

They should contribute to a rationale for choosing environment-friendly solutions, and emphasise the importance of life cycle environmental impacts during the critical early design phases.

5.3 The Types of Tools Report

Tools are the interface between the environmental framework and the decision-making framework. They inform the decision-making process by helping individuals understand consequences of different choices. In this way assessment tools ultimately serve to improve environmental performance.

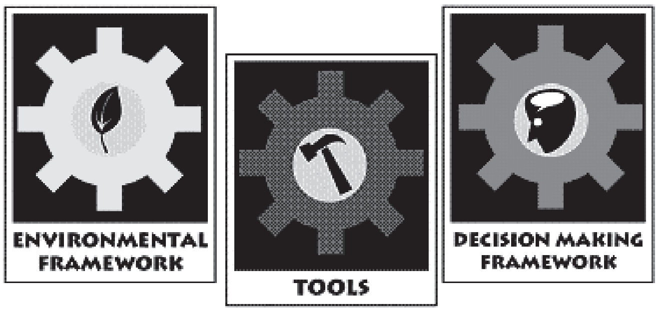

Figure 8: Tools are the interface between the environment and the decision-maker

To be effective, a tool must be tailored to the planning phase, the knowledge base of the user, and the concerns of the actors – including 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 users' needs and knowledge. This report describes the categories of tools, and their information requirements. The report also identifies key features that make tools effective.

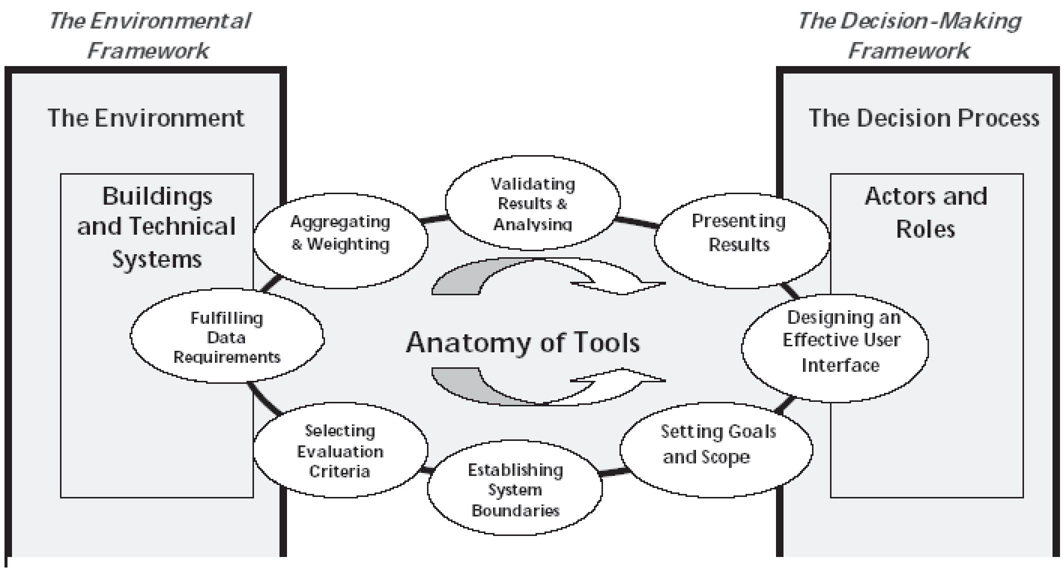

Figure 9: An anatomy of tools in relation to the environment and the decision-making process

LCA Tools for Buildings and Building Stocks

LCA tools help to unravel the relationships between building specifications and potential environmental impacts. They explicitly address one or more stages in the life cycle. They help users collect and analyse data on the energy and material flows. They translate design and management choices into meaningful statements about environmental effects and impacts. Because of the complex interrelations between life cycle states, resource flows and environmental consequences, all LCA tools are based on computer models and databases. Hence these tools employ interfaces that increase potential for interaction between the user, the model and the associated databases.

Interactive software is widely available for designers who wish to optimise aspects of building performance, such as ventilation or heating. These simulation models may be educational and predictive models, although some are also designed as decision-support for planners, engineers and designers. They also may be required or embedded into LCA tools. Unlike LCA tools, however, 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 scale.

LCA tools specifically address one or more stages in the life-cycle of a building. As many of the most important decisions are made during the preliminary study and design phase, it may be appropriate at this point to use a comprehensive LCA tool (i.e. a single tool addressing all stages), or a series of LCA tools that can be integrated for decision support purposes. LCA tools can then be applied to each stage in the life cycle, as follows:

- Embodied energy

LCA methods are especially helpful for assessing embodied energy and environmental impacts, since the tools can conveniently analyse the extensive product assessment data generated by other sectors. In view of the extensive data processing involved, tools are essential when assessing the energy and mass flow involved in both the manufacture of building products and the provision of technical services like heating.

- Assessing construction and erection of the building

The construction phase is often overlooked but can have a significant environmental impact. Transportation of materials and workers is also a potentially important source, as is worker health and safety. A rigorous assessment must include a description of all building products and services employed (including supporting materials, waste and the proportional usage of temporary materials, e.g. shuttering) as well as of the transport costs and construction processes. The accounting process is complete when the building is approved for occupancy. As ever, analysis methods and their accuracy depend to a large extent on the availability of accurate information about the construction process.

- Assessing the occupancy phase of a building

The assessment of environmental impacts associated with the occupancy phase are based on a range of assumptions (scenarios) and calculation methods. The process involves inventories of energy usage and/or the amount of end-energy and energy carrier necessary to run the building when in use, including heating / cooling, water heating, lighting, ventilation, lifts and other technical services and auxiliary energy usage.

Scenarios forecast the type and duration of usage, the user requirements and standards of thermal comfort, location of the building, climate, and intensity of use. Such assumptions are usually calculated according to predetermined default values and calculation methods. In the interests of better understanding and flexibility of use it is better to calculate energy usage by its function and the manner in which it is supplied rather than to aggregate it.

- Urban systems during the use-phase

Analysing the energy usage and environmental pollution created by a building’s demand on urban systems can be an especially challenging - and yet important - function for LCA Tools. Of particular concern is the location of large housing schemes, and their impact on the use of public and private transport. Other issues which affect energy use in this context include: energy demand for cooking, household appliances etc.; energy demand for technical services; water requirements and the amount of waste water and sewage produced; the type and volume of rubbish; and the transport of goods.

- Maintenance and refurbishment activity

Cleaning, servicing, maintenance and refurbishment work are needed to maintain the usefulness of a building during its lifetime. The resulting energy and mass flow can be determined as part of a life-cycle analysis. The data can be significant, for example, cleaning costs can exceed energy costs in some facilities.

Planning tools often contain detailed information concerning new and refurbished elements. These can be linked with maintenance schedules and used as a basis for calculating the energy and mass flow which result from the cleaning and maintenance of the building. Values are typically given both as a total for the expected duration of the use-phase, or for each year in which cleaning or maintenance have occurred during the lifetime of the building.

- Decommissioning and disposal of buildings

A significant amount of energy is used during the demolition and disposal of a building. The energy and mass flow involved in the demolition, removal and possibly also the disposal processes should be assessed. However, the extended life of buildings makes predictions of this kind rather imprecise and they are approximations rather than accurate assessments – the longer the lifetime of a building the less exact the prediction.

The outputs from LCA tools can include raw and/or evaluated information regarding the energy and mass flow involved in the demolition, decommissioning and disposal of a building. In addition, a declaration of re-use and recycling potential is possible. An alternative definition for the end of a particular life-cycle as opposed to the demolition of the building, could be the re-use or conversion of the building for a new activity. The resulting energy and mass flows can then be assigned to any subsequent life cycle, rather than the existing one.

Passive Tools

Passive tools support decisions without demanding much interaction from the user, and typically lack the degree of customisation and computer support provided by LCA tools and simulation models. Passive tools tend to contribute static information to a process, rather than performing calculations, or altering designs. Depending on their type and purpose, passive tools:

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

Passive tools come in various guises: regulations and conventions; guidelines; checklists; case-studies and examples of best practice; building or energy passport documentation; product labelling and descriptions, are just some of the examples discussed in this report. The advantages and drawbacks are reviewed in each case.

All Tools are Not Equal

Unfortunately, the application of the various methods and tools that are available for the environmental assessment of buildings will lead to results that are often not directly comparable. Differences are most often a result of the system boundaries – what is included and excluded from the analysis – which have been established for the building, or stock, and the environment. Other common reasons for variations in the results obtained include:

- the actions of the intended user, his or her role in the decision making process, and the way in which choices are framed
- how the cause and effect chains are constructed in the model
- data sources, quality and format

- how results are aggregated and presented

Key Features of Effective Tools

Decision support tools should integrate any environmental criteria into the existing design process. This is a challenge. Architects and others involved in the building design process must already juggle many conflicting criteria to arrive at a satisfactory solution, be it for new buildings or for renovation. When assessment tools are introduced, they always take up economic resources, time, knowledge, and require access to specialised information. It is essential therefore that decision-support tools minimise complexity and costs. In this context, tools must:

- address those factors that have the most deleterious effect on the environment
- be readily adaptable to specific buildings and locations
- be capable of ranking results rapidly, so that trivial issues can be eliminated
- be transparent in their assumptions

5.4 The LCA Methods for Buildings Report

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. The LCA method entails 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. This report shows how to apply the basic LCA method to building products, single buildings and groups of buildings. The report then examines typical problem areas encountered when LCA methods are used for buildings, and recommendations are made as how best to adapt the LCA method and overcome specific problems.

Figure 10 illustrates the flow of materials from nature, to nature, through the course of a building's life. The type of impacts generally considered include those on resource use, human health and on the ecological consequences associated with the input and output flows of the analysed system.

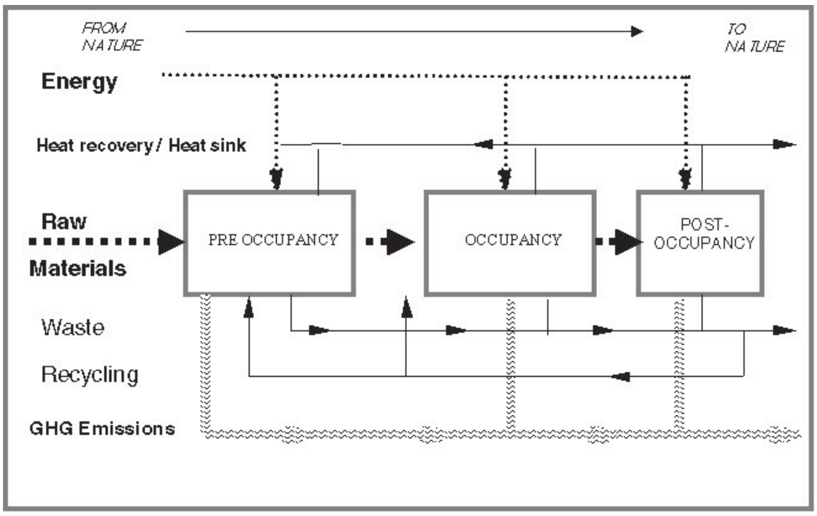

Figure 10: Life cycle assessment for buildings

The LCA method is not the only approach to analysing the impact of material goods on their environment, but it is probably the most comprehensive.

Six LCA issues are examined in detail in this report and they are summarised below:

- Setting Boundaries for Building Assessments
- Accounting for Local Impacts
- Use and Maintenance Scenarios and Assessing for Building Adaptability
- The Allocation Problem
- Accounting for Building-Related Transportation
- Analysing Groups of Buildings (Stock Aggregation)

Setting System Boundaries

System boundaries define what is included, and excluded, as part of LCA. Boundaries can be established in all areas but, ultimately, they must relate closely to the intended use of the tool, (this is explained in more detail within the Annex 31 report on Decision-Making Frameworks). System boundaries also need to reflect a reasonable compromise between the validity of the results and the practicability of obtaining them.

Setting system boundaries for buildings is critical to achieving valid and comparable results. A system boundary has the effect of limiting specific resource flows and emissions included in the assessment. These flows and emissions are the sources of impacts, and through cause and effect chains they ultimately establish the LCA results. Indeed, comparative studies implementing different LCA tools, show that most of the variations observed in the results come from differences within the limits of the system - differences that were not always clear at the outset.

Areas which pose particular problems for the LCA analysis of buildings include: occupant behaviour in the use phase; transportation inputs; and the processes (and related flows) linked to the building (in particular the water supply, sewage, and solid waste processing). These issues illustrate the fact that, when in use, a building is a kind of active "process" and is only one dependant element within a broader and more complex urban system.

Accounting for Local Impacts

Buildings can be difficult subjects for LCA because many of the environmental impacts associated with them are specific to their locality. Site-specific environmental impacts fall into four main categories:

- neighbourhood impacts (e.g. micro-climate, glare, solar access, wind patterns);
- indoor environment (e.g. Indoor Air Quality and Indoor Environmental Quality);
- local ecology (e.g. ecologically sensitive areas, connected green spaces,); and
- local infrastructure (e.g. carrying capacity of transportation system, water supply).

Traditional LCA does not address local impacts of this type. Instead, all the loadings are aggregated, and thus impacts can only be calculated at the regional or global scale. In order to adapt LCA to buildings, the site-specific impacts must be either excluded from the assessment (by boundary setting), or separately inventoried and classified.

Modelling of site performance is becoming much more common. However, this is usually restricted to indoor environmental quality, and to natural ventilation and lighting potential. The interaction between a building and the local environment, in terms of noise, glare and other factors, is much more difficult to model and typically beyond the capacity of LCA practitioners.

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 the community by contributing to the industrial ecology and by functioning as part of the neighbourhood infrastructure (– generating power, treating wastes, collecting water and so on). Understanding such interactions is a necessary step in assessing lifecycle environmental impacts for a specific building design. Since models and tools are currently unable to predict most of these site-specific impacts, LCA methods cannot adapt to meet such needs. The best alternative may be to combine LCA with more passive and qualitative evaluation tools.

Use and Maintenance Scenarios and Assessing Building Adaptability

Unlike most other products, buildings are occupied for long periods of time and their 'use' phase can have a more significant impact on the environment than all other phases combined. The issue for LCA applications is how best to characterise the use phase. Scenarios are needed to define the role of occupant behaviour. In addition, other scenarios are needed to indicate how the building itself will be kept in order and modified – maintenance cycles, repair and replacement schedules, renovation and refurbishment of interior spaces by occupants. Assumptions about the efficiency with which the building will adapt to changing expectations, changing uses, and the introduction of new technologies will have a direct bearing on the building's performance and longevity (Many buildings are vacated or demolished long before the end of their useful life due to a lack of adaptability.) Evaluating a range of usage scenarios is thus critical when assessing the true long term performance of a given design or product or system.

The Allocation Problem

The LCA method should ensure that individual products and services receive their fair share of the overall environmental loading that is being estimated. To this end some form of allocation procedure may be needed, and this usually occurs in one of two situations:

1 The process in question delivers more than one useful product - a so-called "multi functional process". Most processes included within typical LCA system boundaries contribute to the production of more than one product. Under such conditions, allocation procedures are required to determine which inputs and outputs of the multi-functional system are attributable to the one product or service under assessment. For example, information may be available on the overall energy required in a factory producing metal products for the automobile industry and also a particular line of metal products used in buildings.

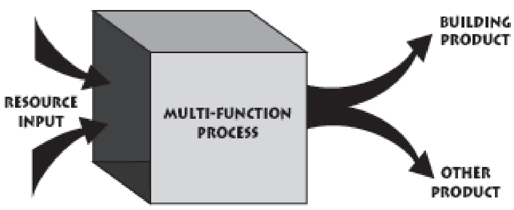

Figure 11: Simultaneous shared process

However, there may be no records that discriminate between the amounts of energy required for the auto products and the building products. One of the many ways to allocate the energy would be to apportion the total energy use to each product on the basis of weight. Whatever allocation procedure is used, the object is to ensure that products receive their fair share of the environmental interventions originating from the shared processes.

2 The process in question is part of a 'recycling loop'. In other words, the multifunction process delivers more than one useful product, succeeding each other over time. For example, the metal produced by the metal factory may contain 50 per cent recycled scrap iron, with correspondingly fewer environmental loadings than if new iron was used. Similarly, once metal has been used in a house, it may be destined for re-use in another building, and then returned to the scrap iron pile for recycling into auto parts. Allocation procedures are needed to fairly

allocate the environmental loads from mining, transportation, industrial processes, and so on, amongst these successive products.

Accounting for Building-Related Transportation

Transportation is a process that needs to be inventoried at each stage in a building's life cycle. Typically, the loadings from transportation are calculated separately from other processes. The energy used for all of this transportation can be very significant. Often transportation impacts are the most variable input for a product, and serve to differentiate the higher and lower impact options. While energy consumption in the building sector is falling, due to advances in energy efficient design and new technologies, transport energy is predicted to rise by 4% per annum.
In the UK, as with all other developed and urbanised countries, the car is the dominant mode of transport. Figure 12 highlights the contribution of UK's transport to global warming and shows that road transport accounts for 80 per cent of the total carbon produced by transport. The Confederation of British Industry (CBI) has put the cost of congestion to the British economy at approximately £15 billion (EUR 22.5 billion) every year.

Transport to and from a building can cause environmental impacts as large as those incurred operating the building itself. Hence, the transport related environmental consequences of location, and the potential for savings, are substantial and some account must be made for them in an assessment.

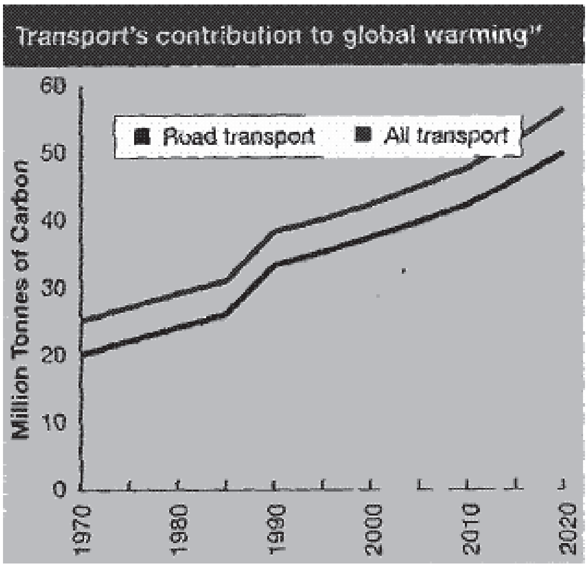

Figure 12: The contribution of UK's transport to global warming

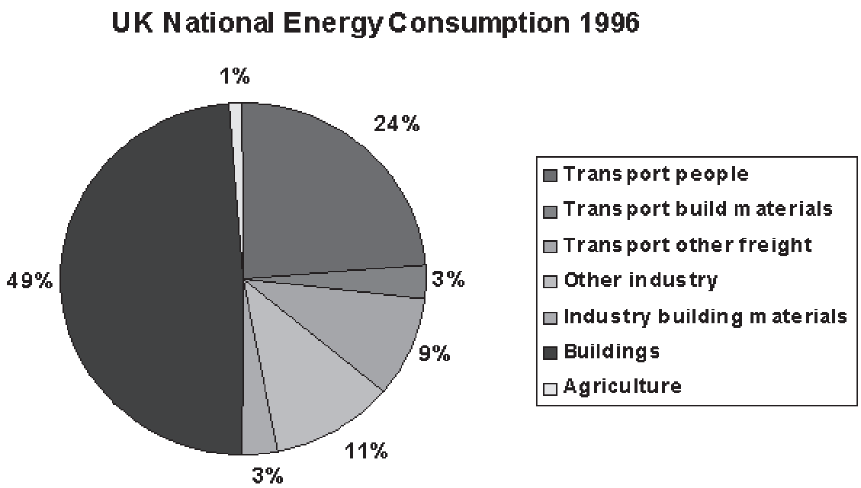

Figure 13: Energy consumption in the UK

However, a major difficulty with LCA for buildings is in determining how best to account for transportation during the use phase. Occupant behaviour is difficult to predict, and transportation scenarios are complex. Types and amounts of occupant transportation are dependant upon many factors unrelated to building design or occupancy. It is also difficult to correlate design and management decisions with quantifiable changes in the amounts of occupant transportation. Again, much depends on the system boundaries and objective of the study if transportation is included in LCA for buildings.

Analysing Groups of Buildings (Stock Aggregation)

Stock aggregation refers to the process of evaluating the performance of a building stock using LCA results from components of the stock. For example, total energy use by a stock of buildings can be estimated by adding up the energy estimates for all the individual buildings within the stock. Or for less effort, a subset of representative buildings can be analysed using LCA methods, and the results then factored in proportion to the total number of such buildings in the stock.

As stock aggregation usually begins with the analysis of individual buildings, it is referred to as a 'bottom up' approach. Any performance issues that can be analysed and assessed at the 'bottom' – for an individual building or specific technology - can then be aggregated upwards and used to evaluate the performance of a building stock.

Stock aggregation is often the best method available for analysing stock performance for several reasons:

1. Energy and resource flows are a function of dynamic relationships between a building's shell, and its equipment, systems and operations. By first using dynamic computer models at the building or end use level, and then aggregating upwards, one can observe, analyse and resolve energy use and environmental performance with greater accuracy.

2. Much of the energy and environmental impact associated with buildings is related to the full life cycle of buildings – including material production and demolition. Only by aggregating data based on LCA methods is it possible to estimate accurately the impacts of the stock.

3. The detailed and precise structure of a bottom-up database can help to identify any sensitive variables that may be especially important to the overall performance of the buildings, or stock. By changing such variables, it becomes possible to forecast the results of specific scenarios, and to prepare substantive arguments for particular building designs and policies.

The scale of stock aggregation can vary, from a small housing stock within a single project, all the way to aggregation of national building stocks for residential, commercial, and institutional sectors. The base data and the results can be nested from neighbourhood, to community, to regional and national level - while preserving the same data structure and detail. Partial stocks can be aggregated, consisting of sets of private or publicly owned buildings.

Stock aggregation can be used to estimate performance of building stocks in the future, if assumptions are made about the growth and turnover rates within a stock, and the adoption rates for new technologies. Forecasts for energy, water and land use, and for generation of solid and liquid wastes, can be compared with the current and planned capacity limits for the surrounding infrastructure. Environmental loadings originating from the stock can be compared with the capacity of the local ecology to absorb them.

Stock aggregation methods are of particular value to energy analysts, building scientists, statisticians and practically anyone involved with planning urban development and promoting environmentally friendly technologies. Table 2 provides examples of user groups and typical queries suitable for stock aggregation methods.

Classes of Users and Responsibilities	**Example Query**
Policy Analysts	
- Local Agenda 21 - Regional Growth - National - European Union - International Energy Agency	*"What kinds of building technologies are needed in order to meet greenhouse gas emission targets?"*
Planners	
- Site Development - Infrastructure investment - Technology Promotion and Development	*"What is the potential for a district energy system?"*
Private Sector	
- Large Corporation - Specialty Businesses	*"What is the expected market size for window replacements?"*
Utilities	
- Electric/Gas - Water/Sanitary - Telecommunications	*"What is the expected peak demand for houses in the planned neighbourhood?"*

Table 2: User groups and example applications

6. Background Reports

6.1 Context and Methods for Tool Designers

The art of tool design is evolving in concert with the sophistication of users, the availability of improved information technology and increased market demand for green buildings. This report provides an overview of the most important issues currently facing tool developers. Many of the critical assumptions about building lifetimes, energy flows and occupant behaviour are addressed.

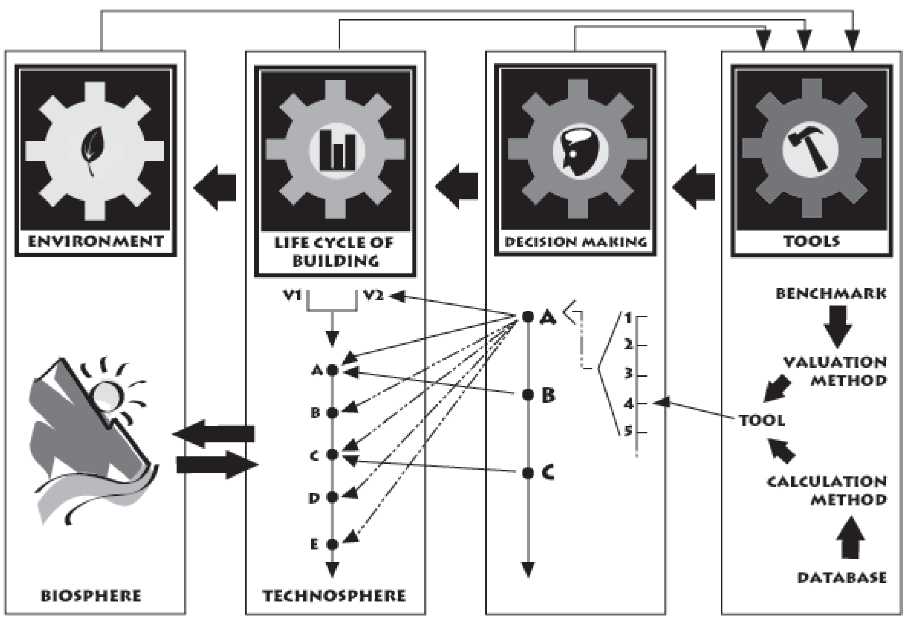

Figure 14: Decision-making relating the to environment and tools

The needs and motivations of users are analysed, and examples are given for how tool developers can best present results.

Assessing the environmental performance of buildings involves a number of critical assumptions concerning the anticipated life, maintenance, demolition or deconstruction phases of a building. The nature and scope of these assumptions must be clear to the user: tool developers must justify them and make them explicit. Also, given the sensitivity of the results to the set of assumptions used, some form of sensitivity analysis should be undertaken. Environmental tools must inform the user of any uncertainties and assumptions that have been made, in order to be able to interpret accurately the assessment results.

Developers of methods and tools should concentrate on the information requirements of their target audience. The developer should analyse the working methods and decision-making processes of the intended users. Tools must be designed to be easily understood by users and decision-makers. They must provide meaningful results that reveal causal relationships between sources and impacts. Key decision-makers and other non-technical audiences are likely to want concise information presented in plain language. Others, who may be more accustomed to using assessment tools, will be able to deal with more detailed and technical information.

This study has also identified a number of other areas where there is a need for progress in tool development. In particular, setting system boundaries is more difficult and critical than it appears at first sight, and tool designers must be more explicit when they describe boundaries they have set, and must justify their choices. Tool developers should inform users about the validation procedures and results. They should also:

- try to avoid redundancy,
- maximise the objectivity of outputs,
- include the most significant environmental impacts attributed to the building sector,
- focus on those outputs which are amenable to improvement by the user (generally the building designer).

The decision-maker should be able to identify the sources responsible for the environmental effects. The decision-maker should also be aware of any uncertainties, and the tool developers should find adequate means to present them. In general, current tools do not present uncertainties well.

Assessment methods are particularly valuable at the inception of a building project, when information is scarce, or can be very imprecise. Ideally, an assessment tool should be able to accommodate increasingly detailed levels of data which become available as the project progresses. To this end, it may be advantageous for tool designers to establish new 'simplified' models from current detailed models. These could then be used by decision-makers at the outset of a project. More importantly, assessment tools should provide some form of cost analysis in addition to the environmental results, as cost is a key factor in decision-making.

All of the assessment tools currently available require a competent person to interpret the results they produce. Simply presenting this information to the target audience without some form of dialogue or discussion is of little value. It will leave them with little understanding of the results, their implications, and of any decisions that have been made.

6.2 Comparative Applications - A Comparison of Different Tool Results on Similar Residential and Commercial Buildings

This report describes the results of an Annex 31 research project in which the environmental impact of both a single dwelling and an office building was assessed with tools from participating countries. The tools used in the IEA ECBCS Annex 31 study are described in Table 3. All of these tools are 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.

Country*		Tool	Energy Calculation
Australia	r	LCA-based tool	-
Canada	r	Optimize	HOT 2000
Denmark	r	SBI tool	BV95
Germany	o	Ecopro	-
England	o	BREEAM'98 for offices	Esicheck
Finland	o	BEE 1.0	-
France	r	EQUER	COMFIE
	r	TEAM for buildings	Th-C and DEL2 methods
Japan	r,o	BRI-LCA	-
Netherlands	r	Eco-Quantum	Energy Performance Calculation
Norway	r	LCA-based tool	-
USA	r	BEES 1.0	Energy 10
Sweden	r	EcoEffect	-
Switzerland	r	E2000 Oeko bau Standard	-

Table 3: Tools in application in Annex 31. The energy calculation programme is mentioned if applied.
***r -** signifies a residential building**: o** signifies an office building*)*

This research identifies similarities and differences between tools and gives an evaluation of their performance. It shows how tools work, and how they lead designers, consultants and researchers to produce more environmentally conscious buildings.

Each tool was use to calculate the environmental impact of the reference buildings. This was carried out in three stages, using common input data:

1. Excluding the energy-in-use phase for the buildings
2. Including energy-in-use and adapting the buildings to the local climate
3. Including energy-in-use and improving the environmental performance of the buildings

Differences in outputs occurred between the tools used. The source and quality of data, system boundaries, data allocation and weighting factors and environmental profiles had a significant impact on the results and the scope for comparing the quality of the tools. Unfortunately the accuracy, or the validity, of the results could not be fully verified because there was no datum against which to compare them. Nevertheless, all of the tools produced similar results: they showed that energy consumption during the use phase was responsible for 75-95 per cent of the environmental impact of buildings during their life-cycle.

Reducing energy use produces the greatest environmental benefits; but for highly energy-efficient buildings, reducing the environmental impact of building materials assumes greater importance. Another important conclusion from this study is that it is possible to improve the energy consumption of a building without increasing its embodied energy. A further finding is that the life-cycle embodied energy of a building is likely to be of greater significance than the initial embodied energy.

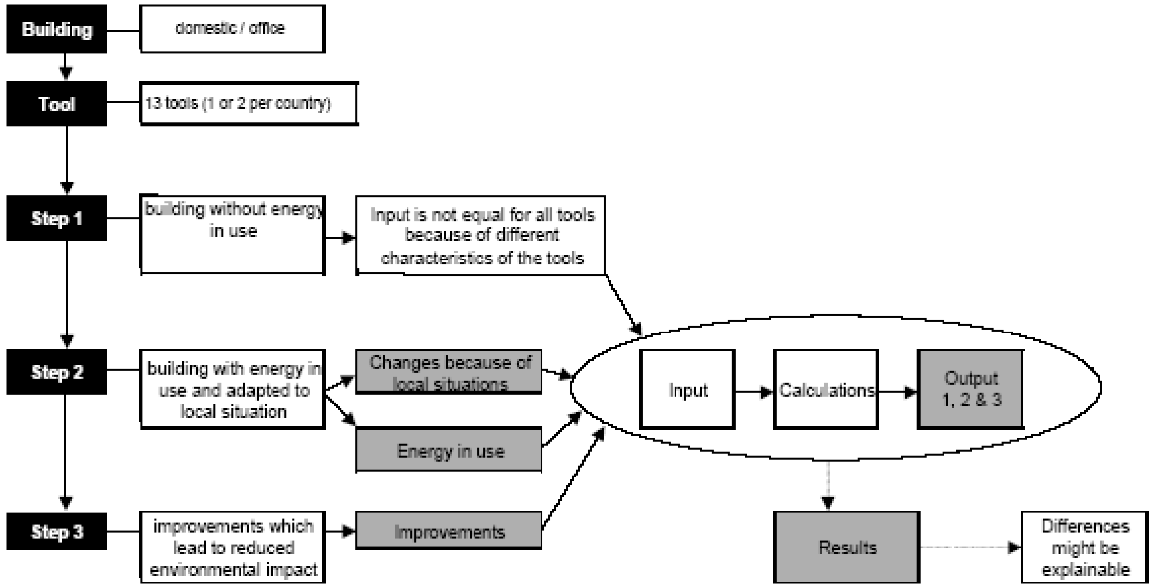

Figure 15: Plan of action for the comparative assessment

The results also support the view that the transparency of an assessment tool is one of its most important characteristics. The people who use them need to be able understand the background details of tools before they can draw appropriate conclusions from the results they produce. Uncertainty analysis and variability analysis are also very important for the interpretation of the performance of the tools. However, they rarely feature in the current generation of tools, or are not apparent to the user when they do.

This study demonstrates that current thinking about environmental assessment is converging towards LCA methods, and that these can be used for certain types of impacts such as the impacts of materials. However, LCA is not appropriate for considerations such as comfort, or health and, although such aspects were not addressed in Annex 31, they are an important part of a sustainability assessment of a building.

6.3 Case Studies of How Tools Affect Decision-Making

The aim of this report was to explore how life-cycle assessment tools influence the design and environmental performance of buildings. Six countries were asked to submit case studies of building projects where the intention had been to use assessment tools to create a more efficient and environmentally friendly building or buildings stock. Each case study includes information on the site and project; the energy and environmental features; and the assessment tool and results.
The case studies all demonstrated that the application of life-cycle assessment tools resulted in significant environmental improvements. Using an assessment process during the design phase created a positive impact on the built environment and, in most instances, the users. Where stock aggregation tools were used to measure environmental impact on a community-wide scale, the outcome was also considered to be successful.

6.4 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, amongst other things, on the aggregation level chosen, such as at the product, building or stock level. The type of general data needed for each category of tool is described in the Annex 31 core report Types of Tools.

This report contains a more detailed examination of data requirements and sources. Most LCA tools provide a database with generic inventory data, and some with building-oriented data. These data have to be checked for their quality and relevance to ensure that an appropriate fit is found between the data inputs and the case under study. Passive tools, such as checklists and guidelines, tend to be more self-contained and so no external data may be required other than the building's specifications. It is important to verify that the assumptions built into such tools are based on relevant data of sufficient quality.

An LCA study should be sufficiently transparent to enable different practitioners to draw similar conclusions - providing the assumptions and assessment method are acceptable. This report recommends the following for developers of tools and databases:

1. LCA software tools, including databases, should follow the requirements of the SPOLD (Society for the Promotion of LCA) format in order to cope with comprehensive sets of data.

2. Since most LCA tools allow users to modify or implement new impact assessment methods, they should allow users to implement their own data quality indicator system, since no standard protocol currently exists for this.

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 need for artificial lighting), indoor air quality, hygro-thermal comfort, and so forth.

4. Taking into account the high degree of variability of inventory data in many cases, developers should calculate value intervals or conduct any other uncertainty or sensitivity analysis in a way that is readily understood.

5. Developers should use existing conceptual models and publish data models to assist the development of software interfaces that can be used to perform complementary studies: energy consumption during building occupancy being one example.

6.5 Assessing Buildings for Adaptability

Adaptability refers to the capacity of buildings to accommodate substantial change. The concept of adaptability can be broken down into three areas which will be familiar to most designers: flexibility; convertibility; and expandability. It is closely related to, but different from, two other design strategies that attempt to enhance long-term environmental performance of buildings, namely durability and design for disassembly.

A building that is adaptable will be utilized more efficiently, and stay in service longer, than one that is not. The extension of its useful life may, in turn, translate into improved environmental performance over its life-cycle. This report examines all aspects of adaptability in buildings, from principles to strategies, to specific features. Evaluation methods and potential benefits are also discussed.
Increasingly, the world faces resource scarcities and ecological crises, and the adaptability of buildings is a matter of growing concern. The current building stock represents the largest financial, physical and cultural asset in the industrialised world. So, a sustainable society will only be achieved if this resource is managed appropriately. 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.

A building that cannot be altered in response to changing circumstances is at risk of becoming underused and prematurely obsolete. This is usually the case whenever a building cannot accommodate new, more efficient, technologies or working practices. If adaptability is to be used to overcome such problems at the design stage there must be some means of distinguishing those features of a new building that will significantly increase its capacity for change. This may prove difficult in the short term as few of today's buildings have been designed specifically for adaptability, and those that were, have not been in use for any length of time. A further problem is the difficulty involved in accurately predicting future requirements for buildings.

In today's marketplace, the adaptability of a building will typically be subordinated to the short-term goal of maximising the return on capital expenditures, and to satisfying the functional and comfort needs of occupants. There are two ways to overcome these constraints: incentives to promote adaptability might be incorporated into any new public policy which is directed at sustainable urban development; or businesses could commit to the basic principles of sustainability, and adjust their behavior accordingly.

If adaptability is to be embraced in public or private policy, it may be necessary to relate adaptability to the basic principles of sustainable development, such as stewardship and intergenerational equity. From this perspective, the responsibility of the designer or developer must be to meet the client's needs and expectations without compromising those of future building owners and users. A design team that is committed to sustainable, environmentally-sound building needs to take the extra effort to identify opportunities for enhancing adaptability, and to estimate the related cost and environmental advantages.

Key Priniciples of Adaptability

- Independence

Integrate systems within a building such that parts can be removed or upgraded without affecting the performance of the 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; maximise the durability of materials where long lifetimes are required, such as structural components and cladding

- Record keeping

Ensure information on building components and systems is readily available, and will remain so in the future

There is great uncertainty about the next 50 years and what they will bring, which militates against designing for adaptability. There are, however, some steps that can be taken by designers:

- accommodating changes that can be expected to occur in the shorter term
- applying 'common sense' practices that have been shown to promote adaptability
- incorporating 'adaptability' features that can be justified on other grounds
- adopting features that enhance adaptability at little or no additional cost

6.6 Sensitivity and Uncertainty

Sensitivity and uncertainty analysis can be used at many stages throughout the assessment of energy related environmental impacts of buildings. The key purpose of sensitivity analysis is to identify and focus on key data and assumptions that have the most influence on a result – thereby simplifying data collection and analysis without compromising the results. A parallel to sensitivity analysis is uncertainty analysis.

Experience shows that uncertainty related to a LCA inventory can be significant, and must be considered when performing comparative LCAs. This report describes how to undertake sensitivity and uncertainty analysis, and includes examples of how such exercises can improve decisions.
Sensitivity analysis can be used throughout an assessment to achieve the following:

- test the assumptions and data used for LCAs
- identify the key parameters affecting the embodied energy of a component or building
- test the extent to which parameters are important to the life cycle of a building, such as maintenance or replacement rates
- determine which materials require accurate data for the compilation of transport energy and which do not. This determines which materials are sensitive to location
- determine the importance of the life cycle energy use of a building compared with its energy-in-use consumption

When used skillfully, sensitivity analyses 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 merits further investigation.

For example, a sensitivity analysis of energy use during the lifespan of Swedish buildings “from cradle to grave” shows that the occupational phase, excluding renovation, is responsible for about 85 per cent of total energy use, while construction is responsible for 10 to 15 percent of the total.

Renovation during the occupation phase is responsible for about 5 per cent, while deconstruction in most cases has an insignificant influence on total energy use. This indicates that the greatest potential for energy savings occur when buildings are in use and so, if the objective is to measure energy consumption, this should take place during the use phase of the lifecycle. Detailed sensitivity analyses can reveal which parameters to focus on to reduce other environmental impacts, or to obtain representative measurements.

Uncertainty analyses can have significant implications for LCAs. They are particularly important when performing comparative LCAs. A judgement based soley on mean values, with no confidence interval, may not result in an appropriate choice of a component or process.

Although it is widely recognised that uncertainty is an essential part of LCA it is rarely considered in practice. The main reason for this being that there is no international concensus on how uncertainty should be treated or which method should be used to calculate it. However, most LCA-inventory tools today have some means of handling uncertainty or sensitivity analysis. The biggest problem seems to be a lack of data and, regardless of which method is eventually chosen, more data will have to be available than is the case at present if uncertainty analyses are to be adopted.

6.7 Stock Aggregation

Stock aggregation refers to a process in which the performance of buildings is evaluated using components or archetypes from the stock under investigation. One way to estimate the energy consumption of a stock of buildings is by adding up, or aggregating, the energy used by each individual building within the stock. Alternatively, and for much less effort, a subset of representative buildings can be analyzed, and the results then factored in proportion to the total number of such buildings in the stock.

This report explains why aggregation is frequently the best method of assessing large numbers of buildings. Examples are given which show how stock aggregation can assist in policy development at the local and regional scale. The method is also shown to offer significant benefits for designers, planners, businesses in the building sector, and utilities, including:

- it can be used to identify trends, and create profiles, forecasts, and benchmarks of performance.

- it can assist designers of individual buildings to understand how their design choices might affect – or be affected by - the overall stock performance
- it can provide planners and policy-makers at varying scales with a richer, more powerful database on building costs, energy and resource use, and environmental effects.

Stock aggregation methods appear especially appropriate for use by utilities who, for example, may wish to gain a better understanding of their customer base, and for use by communities. Where a database is available at the community level, then stock aggregation can provide the basis for new and powerful planning methods, including urban environmental management systems, and urban forecasting information systems.

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

Stock aggregation is best used in combination with top-down models. These can be used to predict the impact of prices and regulations on supply and demand. Stock aggregation is clearly a useful application for many of the new assessment methods and tools now available for evaluating the environmental performance of a building. With the aid of stock aggregation, the same tools can be used at a local and national level. However, at present no commercially available tools exist specifically for stock aggregation purposes.

7. Directory of Tools

Many countries now have a variety of tools which have been tailored for use by specific users, and which fill particular analytical needs. Annex 31 surveyed these tools, and has used the survey to create a directory of tools, accessible on the project CD-ROM and web site. The purpose of this directory was to provide a quick overview of the tools that are currently available, or that are soon to be released. Each tool is described in terms of its functions, audience, users, software application and technical support, data requirements, strengths, availability and contact information.

Assigning tools to categories makes it easier for potential users to identify tools most appropriate for their needs. Annex 31 Tools were categorised as follows:

- Energy Modeling software
- Environmental LCA Tools for Buildings and Building Stocks
- Environmental Assessment Frameworks and Rating Systems
- Environmental Guidelines or Checklists for Design and Management of Buildings
- Environmental Product Declarations, Catalogues, Reference Information, Certifications and Labels

The Annex 31 survey was designed to complement the United States Department of Energy (US DOE) Building Energy Software Tools Directory: *www.eere.energy.gov/buildings/tools_directory*

The US DOE Directory includes descriptions of interactive software tools for evaluating energy efficiency, renewable energy and sustainability in buildings. Other types of tools, including LCA Tools, Assessment Frameworks, Rating Systems, Guidelines, Catalogues, Checklists and so on are described in this Annex 31 report. Both the Annex 31 site, and the US DOE site, use a similar format for organising and describing tools.

8. Glossary

A glossary of selected terms was designed for Annex 31 to standardise the many specialised terms used for describing the environmental performance of buildings, in a number of languages. The glossary emerged as a result of ongoing communications difficulties experienced within Annex 31.

Academics and researchers in 14 countries used different English terms interchangeably. Varying translations compounded this problem. The solution was to carefully review the use of all terminology, with special reference to terms used in international standards, and then to translate a standard set of English terms into the other languages commonly used within the Annex.

9. Conclusions

As the need to reduce the environmental impact of buildings becomes more pressing, energy and life cycle assessment tools will become increasingly important resources. Annex 31 presents a comprehensive overview of the theory behind them, and provides a wealth of information on the development of building assessment tools and their use. Some of the main conclusions are discussed below, but readers are encouraged to access the complete series of reports which are available on the Annex 31 CD-ROM or at *www.annex31.com*.

Assessing the environmental performance of buildings involves a number of critical assumptions concerning their anticipated life, maintenance, demolition or deconstruction. A major finding of Annex 31 is that the nature and scope of these assumptions must be made clear: tool developers must justify them and make them explicit. Transparency is an essential feature of assessment tools because the people who use them need to be able understand the background assumptions of tools before they can draw appropriate conclusions from the results they produce. Uncertainty analysis and variability analysis are also very important for the interpretation of the performance of assessment tools. Yet they rarely feature in the current generation of tools, or are not apparent to the user when they do. For environmental tools to be effective they must not only inform the user of any assumptions that have been made, but must also be amenable to some form of sensitivity analysis.

Developers of methods and tools should also concentrate on the information requirements of their target audience. The developer should analyse the working methods and decision-making processes of the intended users. Tools must be designed to be easily understood by users and decision-makers. They must provide meaningful results that reveal causal relationships between sources and impacts. Key decision-makers and other non-technical audiences are likely to want concise information presented in plain language. Others, who may be more accustomed to using assessment tools, will be able to deal with more detailed and technical information.

Each participant in a building design process has his or her own scope for decision-making, and may become involved in decisions at more than one stage in the process. Decision support tools must reflect this complexity, and recognise that each person is unlikely to derive the same results when using similar tools. Also, specific tools are needed to support good decision-making at the most appropriate stage of a project – the early design phase – where decisions can have the largest impact on a building's performance. Annex 31 identified that participants involved in design may need the following:

- Decision aid and assessment tools
- Tools for raising awareness, and for educational purposes
- Design aid tools (catalogues of solutions or of products)
- Tools with which to carefully consider the environment at the local scale
- Tools to aid the participants in making the right decision at the right time, but without making the decisions for them
- Tools which speak their language, which are transparent, are easy to use and are appropriate

Assessment methods are particularly valuable at the inception of a building project, when information can be scarce, or very imprecise. Ideally, an assessment tool should be able to accommodate the increasingly detailed levels of data which become available as the project progresses. But it may be advantageous for tool designers to establish new 'simplified' models from current detailed models for use by decision-makers at the outset of a project. In addition, tool designers should always provide users with some form of cost analysis in addition to the environmental assessment, as cost is a key factor in decision-making.

Decision support tools should integrate any environmental criteria into the existing design process. This is a challenge as architects and others involved in the building design process already have many conflicting issues to resolve. When assessment tools are introduced, they always take up more economic resources, time and knowledge, and require access to specialised information. It is essential therefore that decision-support tools minimise complexity and costs. In this context, tools must:

- address those factors that have the most deleterious effect on the environment
- be readily adaptable to specific buildings and locations
- be capable of ranking results rapidly, so that trivial issues can be eliminated
- be transparent in their assumptions

Current thinking about environmental assessment is converging towards LCA methods, and Annex 31 identified that while these can be very effective for certain types of impacts, they are less so for others. Areas which pose particular problems for LCA include the impact of building occupants, transportation, and other processes linked to the use of a building, such as water supply, sewage, and solid waste processing.

Unlike many other products, buildings are occupied for long periods of time and their 'use' phase can have a more significant impact on the environment than all other phases combined. So a major issue for LCA applications is how best to characterise this phase. Scenarios are needed to define the role of occupant behaviour. In addition, other scenarios are needed to indicate how the building itself will be kept in order and modified - its maintenance cycles, repair and replacement schedules, renovation and refurbishment of interior spaces by occupants.

Assumptions about the efficiency with which the building will adapt to changing expectations, changing uses, and the introduction of new technologies will also have a direct bearing on the building's performance and longevity. Evaluating a range of usage scenarios is thus critical when assessing the true long term performance of a given design or product or system.

Annex 31 has shown that stock aggregation can be used to estimate the performance of building stocks in the future, if assumptions are made about the growth and turnover rates within a stock, and the adoption rates for new technologies. Forecasts for energy, water and land use, and for generation of solid and liquid wastes, can be compared with the current and planned capacity limits for the surrounding infrastructure. Environmental loadings originating from the stock can be compared with the capacity of the local ecology to absorb them. Stock aggregation also allows policy makers to formulate regulations and incentives to achieve specific targets, and can also be used to identify priorities for research and development.
Transport to and from a building can cause environmental impacts as large as those incurred operating the building itself. Hence, the transport related environmental consequences of location, and the potential for energy savings, are substantial and some account must be made for them when the boundaries for an assessment are set. Similarly, the life span of a building or a site is a very important parameter in an environmental profile. Longer building lifetimes often reduce the environmental impacts by extending the amortization period for large components. They can also favour design features which reduce operating costs. Ideally, an environmental framework would establish the scope of any impacts that may occur over the entire lifetime, for all buildings. However, the long lifetimes of buildings impose high levels of uncertainty on the analysis, and can frustrate efforts to evaluate the costs and benefits of lifetime extensions.

Nevertheless, building stock is the largest financial and physical asset in the industrialised world. This resource will have to be managed appropriately if society is to move towards greater sustainability. Urban areas everywhere are experiencing problems related to poor use of buildings and the high flows of energy and materials associated with it. Annex 31 has identified that designing buildings for adaptability is important in this context, but if adaptability is to be used to overcome such problems at the design stage there must be some means of distinguishing those features of a new building that will significantly increase its capacity to adapt to change.

The LCA methodology is not appropriate for considerations such as health or productivity and, although such aspects were not addressed in Annex 31, they are an important part of a sustainability assessment of a building. Traditional LCA methods do not consider any impacts on the indoor environment, since these impacts are usually considered in isolation. Consequently, most LCA-oriented tools do not include indoor environmental impacts either, so other methods must be used for this purpose. Combining energy analysis with indoor environmental quality assessments can be especially worthwhile because of the potential trade-offs and synergies. By the same token, energy efficiency measures may make conditions worse for building occupants or others: usually when not implemented properly or when users are not well enough informed. This is why Annex 31 covered energy issues by taking an overall approach in the environmental assessment of a project.

The LCA method typically employs rules for cutting off the analysis at appropriate boundaries. Where one draws these boundaries when assessing the energy-related impact of one, or several buildings, was part of Annex 31's deliberations. A key finding of Annex 31 is that setting system boundaries is more difficult and critical than it appears at first sight. Tool designers must be explicit when they describe boundaries they have set, and must justify their choices. Boundaries must relate closely to the intended use of the tool and reflect a reasonable compromise between the validity of the results and the practicability of obtaining them. Setting system boundaries for buildings is critical to achieving valid and comparable results: comparative studies of the performance of different LCA tools in this Annex showed that most of the variations observed in the results came from differences within the limits of the respective systems - and that these were not always clear at the outset.

In order to improve the environmental performance of buildings and building stocks, tools should provide enough information on the impact of buildings to satisfy the environmental objectives. They should assist in the selection of environment-friendly solutions, and influence key decisions from the inception of a project onwards. Ultimately the use of environmental assessment tools in this way should lead to:

- a greater awareness of the environmental impact of the built environment
- more emphasis on life cycle impacts during the initial design stages
- the identification of solutions that are sympathetic to the environment
- improved communication between the parties involved in a building project

10. Acknowledgements and Key Contacts

Annex 31 has benefited from participation by many agencies and individuals from the member countries. Names and contact information are listed in the Links to Annex 31 Participants and Agencies section. Authors of research reports are noted on the first page of each original research report available in the reference materials. Each of the participants in Annex 31 contributed valuable material to the final reports, 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), with funding from Canada Mortgage and Housing Corporation (CMHC).

Agencies

The table below provides a list of Agencies that have sponsored participants, and provided financial support for Annex 31.

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www.tce.rmit.edu.au/iea
www.uni-weimar.de/ANNEX31

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12. References

Principal Annex 31 Project Reports *(available at www.annex31.com)*

Core reports:

- Environmental Framework
- Decision Making Framework
- Tools
- LCA for Buildings

Background Reports:

- Context and Methods for Tool Designers
- Comparative Applications - A Comparison of Different Tool Results on Similar Residential and Commercial Buildings.
- Case Studies of How Tools Affect Decision Making
- Data Needs and Sources
- Assessing Buildings for Adaptability
- Sensitivity and Uncertainty
- Stock Aggregation

The International Energy Agency (IEA) Energy Conservation in Buildings and Community Systems Programme (ECBCS)

The International Energy Agency (IEA) was established as an autonomous body within the Organisation for Economic Co-operation and Development (OECD) in 1974, with the purpose of strengthening co-operation in the vital area of energy policy. As one element of this programme, member countries take part in various energy research, development and demonstration activities. The Energy Conservation in Buildings and Community Systems Programme has sponsored various research annexes associated with energy prediction, monitoring and energy efficiency measures in both new and existing buildings. The results have provided much valuable information about the state of the art of building analysis and have led to further IEA sponsored research.