ANNEX 31

ENVIRONMENTAL FRAMEWORK

Annex 31

Energy-Related Environmental Impact of Buildings

November 2001

CONTENTS

ENVIRONMENTAL FRAMEWORK

An *environmental framework* is the foundation to any analysis of the energy-related environmental impact of buildings. The environmental framework provides a consistent and comprehensive system for describing the physical interactions arising throughout the life cycle of buildings.

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

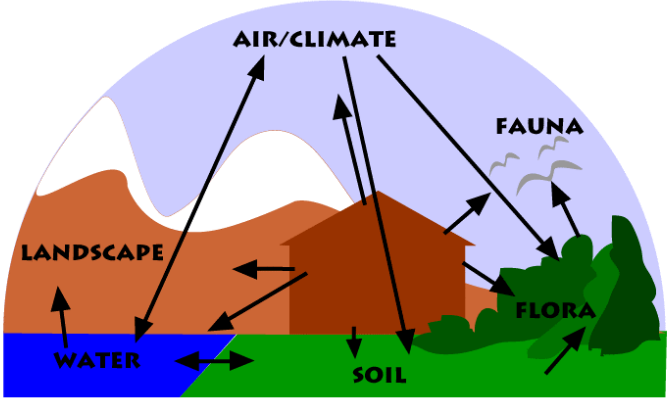

Figure 1: Technical systems are contained within the environment

Technical systems like buildings are a subset of the environmental framework. Technical systems are part of the 'technosphere', which includes all processes and artefacts designed or created by people. All the resources used by technical systems – as inputs or outputs - are derived from the natural environment, and ultimately return to nature.

Importance of Buildings in the Environmental Framework

From the perspective of environmental impact, the most significant technical system is the building, and its associated infrastructure (systems including potable water, waste water, solid waste, transportation, communications and energy. Throughout their existence, from construction to demolition, buildings affect both their external environment and their indoor environment. The types of impacts are varied, and occur on different spatial scales (planetary, regional, and local). Some impacts are related to others, and the chain of effects can be long and complex.

Figure 2 is a schematic of the building life cycle and the associated environmental loadings and impacts.

Figure 2 shows one interpretation of the life cycle of a building, from component production at the left to demolition at the right. Although during the second stage, design, there are no physical mass and energy flows - the essence of the quantitative assessment - it is the critical stage from an assessment viewpoint. It is the phase during which design options can be considered. Naturally, the use/operation phase predominates, not only on a time scale but also on an energy-use scale. Typically, 85%

of impacts occur during this phase, but this is highly dependent, of course, on whether a building stands for 20 or 200 years.

Figure 2 shows the first links to the environment as *Environmental Loadings* and the ultimate link to the environment as *Environmental Impacts*. This distinction is important and is expanded on in the "Environmental Effects and Impacts" section below.

LCA Method Provides a Foundation for Assessing Buildings

Life Cycle Assessment (LCA) is a method for assessing the impact of buildings by accounting for potential environmental loadings and impacts at varying stages in the life cycle. LCA is potentially a rigorous accounting process for reconciling physical interactions between buildings and other elements of the environmental framework. In LCA the flows of energy and materials are counted at each stage in the life cycle, and are then summed.

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.

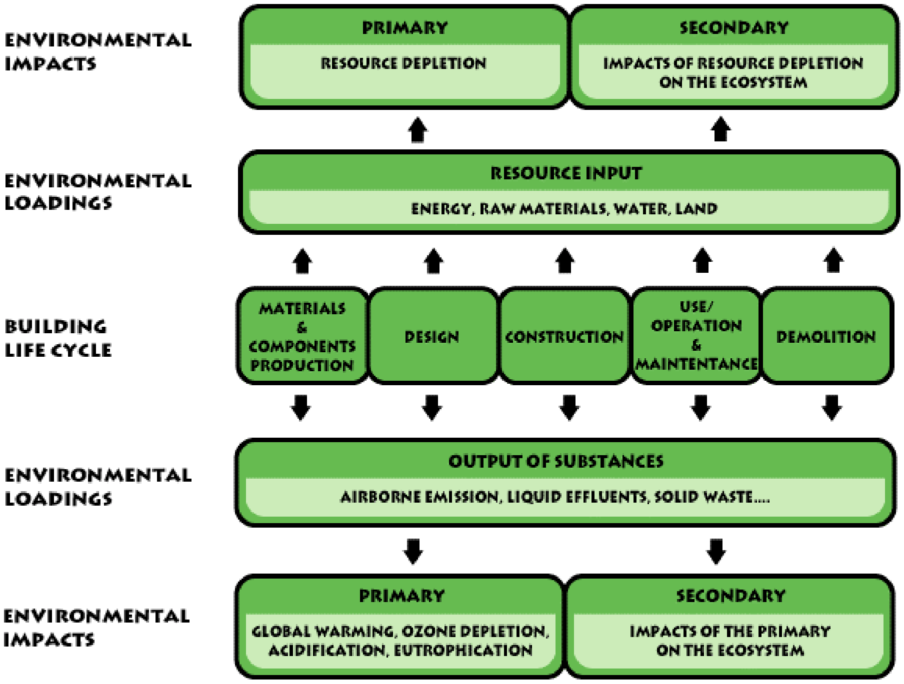

Figure 2: Building life cycle and environmental loadings and impacts

Because buildings and building stocks have such long lifetimes, they are ideally sited to the LCA method. Only by considering resource flows at each stage in a building's lifecycle 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.

Energy as the Key Parameter

Energy is the single most important parameter for consideration 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% of air emissions, and are central to the most serious global environmental impacts and hazards, including climate change, acid deposition, smog and particulates.

Just as solar energy is at the base of the food chain, the energy sources available to man are at the base of the supply chain for materials and resource flows into and throughout buildings and other parts of the technosphere. Energy is also vital for the operation of buildings in most climates. Operational energy in buildings typically accounts for about half of the energy consumed by developed countries. Transport energy typically accounts for about a third of the energy. This includes a 5% component for the transport of construction materials. A further 5% of energy is used to manufacture construction materials totalling 10% attributable to the embodied energy of the materials.

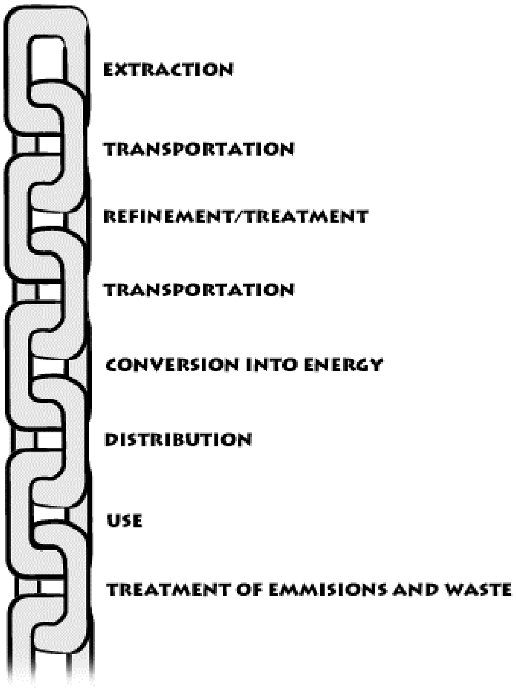

Figure 3: Links in typical energy chain

The sources of the energy consumed vary substantially for their environmental implications. Renewable energy sources can have substantially lower environmental impacts and should be much more sustainable long-term if not indefinitely. These include:

- ❑ Hydro and tidal electricity power stations
- ❑ Solar energy systems e.g. Photovoltaics
- ❑ Biomass systems which harvest sunshine and CO_2 as combustible fuels
- ❑ Geothermal systems
- ❑ Wind turbine electricity generators

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

Unit Processes and Related Flows

From the perspective of an LCA method, buildings are seen as a combination of **unit processes** that create or maintain the building products and services.

Process tree and system boundaries

Linking together all required production processes leads to a graphic illustration of flows, the so-called 'process tree'. A process tree is useful as a means of displaying system boundaries – and thus clarifying what processes are included in any particular analysis. A complete process tree will include all the processes and activities required to deliver ancillary products or materials occurring during the production of a building product (or a set of products). The process tree can also define to what extent the assessment might include flows related to use and maintenance of infrastructure.

Unit process

A production chain displayed in the process tree consists of a set of distinct activities. The activities can be further divided into a number of processes. These processes may be subdivided into 'unit processes' consisting of one distinct basic activity. Structuring the technical system into clearly and coherently defined unit processes enables visualisation of the system boundaries, and helps to avoid omissions and double

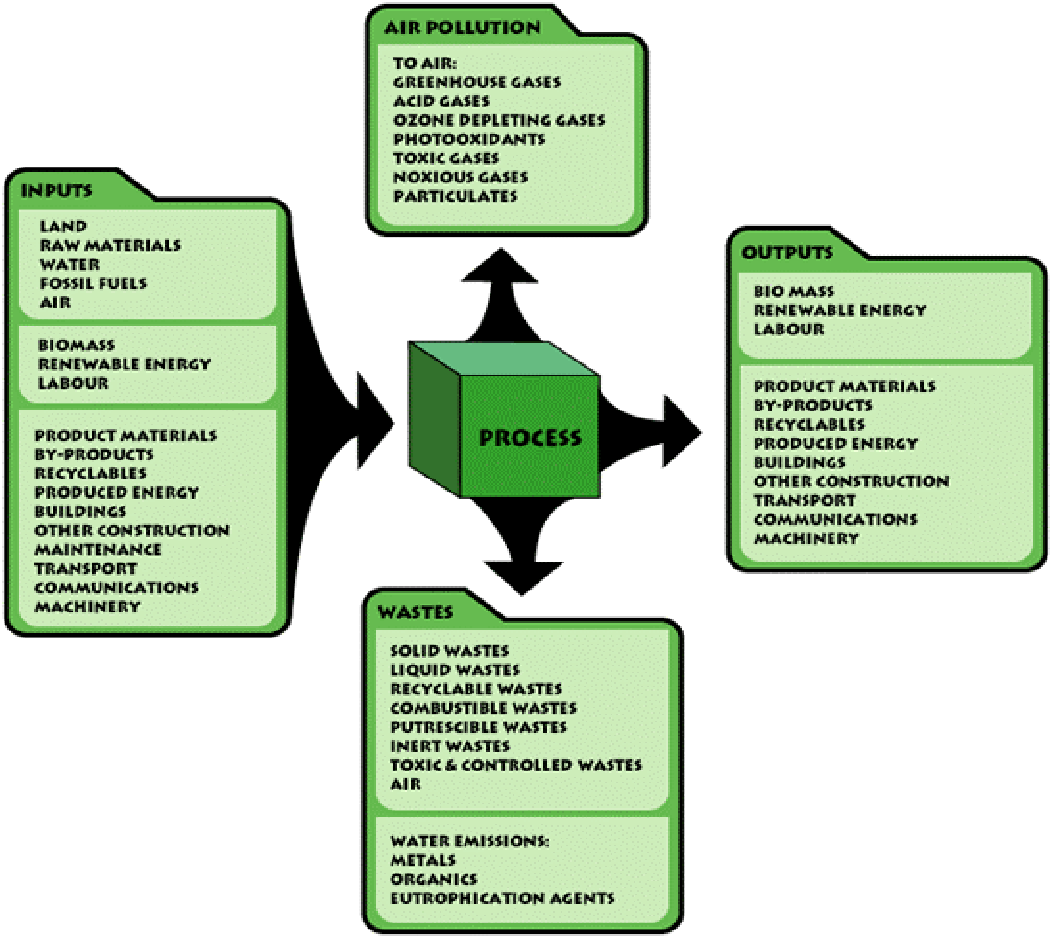

Figure 4: Potential stream of inputs, outputs, and wastes associated with each unit process

accounting errors. Each unit process has associated with it a stream of inputs, outputs, and wastes to air water and land. Figure 4 shows a generic flow diagram for a unit process.

Processes work in Combination

Many of the resources needed for any particular process are obtained from another industry, or as a by-product or recycled waste. A process diagram similar to figure 4 can be compiled for each of the upstream processes that feed into the unit process. Basically the outputs of one process become the inputs to the next. By combining processes, it should always be possible to trace the effects of an output back to the point of winning the raw materials or energy from the earth, air, water or the sun. When processes are combined, they can be treated collectively as a single 'meta' process with the same collection of inputs and outputs.

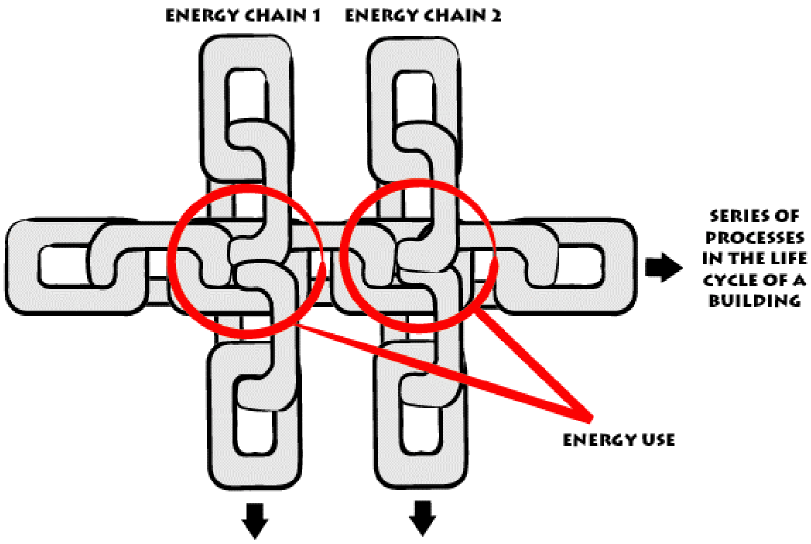

Figure 5: Energy chain processes crossing the building process chain

Chains and Cross-Chains

The life cycle of a building can be described as a series of processes that link together to form a chain. The inputs into each link of the primary 'building' process chain are themselves part of secondary chains that 'cross' the primary chains. For example, each process using energy connects to the upstream and downstream energy process chain. Figure 5 illustrates how such secondary energy chains repeatedly cross the building process chain over its life cycle. The concept of cross chains may be applied to the other infrastructures systems and flows connected to buildings (water, storm water, materials).

Adding Up The Process Chain

All the unit processes identified in a building's process chain can be qualified, then quantified. In this way the LCA method can be used to account for energy and mass flows, as long as databases are available for use in quantifying each of the unit processes. Often a difficulty arises when a unit process includes co-products, or wastes that are effectively recycled or re-used. A decision must be made on how to allocate the environmental loadings between the co-products or subsequent users. This issue is especially troublesome for LCA assessment of buildings, because of the their complexity, and because of their long life. Refer to the Annex 31 Report on LCA Methods for Buildings for a detailed discussion of allocation issues and techniques.

Difficulties with LCA Inventories for Buildings

The task of adding up the process chains is referred to as an LCA inventory. The central difficulty with completing inventories is the inaccessibility of data and the variations in data quality. Other difficulties arise when following process chains that are long and complex, such as the process chains for electricity supply systems (This is an example of a cross chain mentioned earlier). Each of these difficulties is addressed below.

Accessing Data for LCA inventories

Approaches to accessing and qualifying data vary greatly by country, tool and task. For building LCA it is usually possible to use generalised data for materials and products. A survey of sources, and recommendations for how to access and evaluate data quality, can be found in the Annex 31 report on **Data Needs and Sources**.

Inventory Challenges for Electrical Energy

Process chains for electricity are highly complex in most urban centres. Some electricity supply sources can respond rapidly to changes in demand, whilst others can only respond slowly. The mix of fuel sources therefore changes throughout the day, with the slow response sources meeting base loads and the rapid response sources filling in peak demands. The primary energy sources used for generating electricity are time sensitive, changing over the day and even from one season to the next, in response to the shifting loads and peak demands. Renewable energy sources are sometimes mixed with fossil fuels. The location of generation facilities may be centralized, or neighbourhood-based or even integrated with buildings.

Each region can have a different mix of primary energy sources for their electricity grid. The result can be a significant variation in the relative importance in the indirect (upstream) energy-related environmental loadings. Table 1 shows an example of how total energy and greenhouse gas emissions vary for the same house, located in different regions of Canada. In each case the house is a 140 m2 single-family bungalow with a full concrete basement, using natural gas for space and water heating. The life span is 40 years, and the lifecycle emissions from electrical generation have been calculated based on the current primary energy mix for the three regions (BC, Alberta, and Ontario). The different electricity mixes create very different results - the percentage of total emissions produced on the building site ranging from 48% to 73%.

Category	Lifecycle Energy (GJ)	GHG Emissions (Tonnes of CO2 equiv.)	% of Total Life Cycle Emissions		
PRE-OCCUPANCY STAGE *(Initial Embodied Energy and Construction Energy)*					
			Van.	Cal.	Tor.
Initial Embodied Energy (Extraction, Transportation of Resources, Fabrication of Commodities, Distribution and Warehousing, Land clearing of site)	271.5	4.350	4.2	1.8	3.1
Construction of Dwelling & Transportation of Workers	2.4	.038	.04	.02	.03
Sub total	***273.9***	***4.388***	***4.24***	***1.82***	***3.13***

OCCUPANCY STAGE

(Operating Energy, Recurring Embodied Energy, and Full Fuel Cycle Energy over 40 year life span)

							Van.	Cal.	Tor.
o Repair, replacement and renovation activities (Recurring Embodied Energy	183.6			2.940			2.8	1.2	2.1
o	Van.	Cal.	Tor.	Van.	Cal.	Tor.			
o Direct emissions generated on-site	1512	2368	1936	75.2	118	96.2	72.6	48.1	69.5
o Electricity Consumed On Site	1231	1243	1238						
o Electricity emissions (primary energy)				6.65	96.0	16.1	6.4	39.1	11.6
o Full fuel cycle upstream emissions natural gas	106	166	136	17.3	27.1	22.1	16.7	11.0	16.0
Sub total				***99.2***	***241***	***134***	***95.7***	***98.2***	***97.1***

POST- OCCUPANCY STAGE

							Van.	Cal.	Tor.
Demolition, Disposal, and Recycling	1.9			.030			***.03***	***.01***	***.02***

TOTAL LIFE CYCLE EMISSIONS

				Van.	Cal.	Tor.	Van.	Cal.	Tor.
Total for Life Cycle				***104***	***245***	***138***	***100***	***100***	***100***

VAN - VANCOUVER, CAL - CALGARY, TOR - TORONTO

Table 1: Lifecycle Energy and GHG Emissions for Identical Houses in Three Regions[1]

For these reasons the current models of electricity supply are not able to represent properly the complexity of the existing situation. This accounting problem is exacerbated when projecting life cycle impacts for

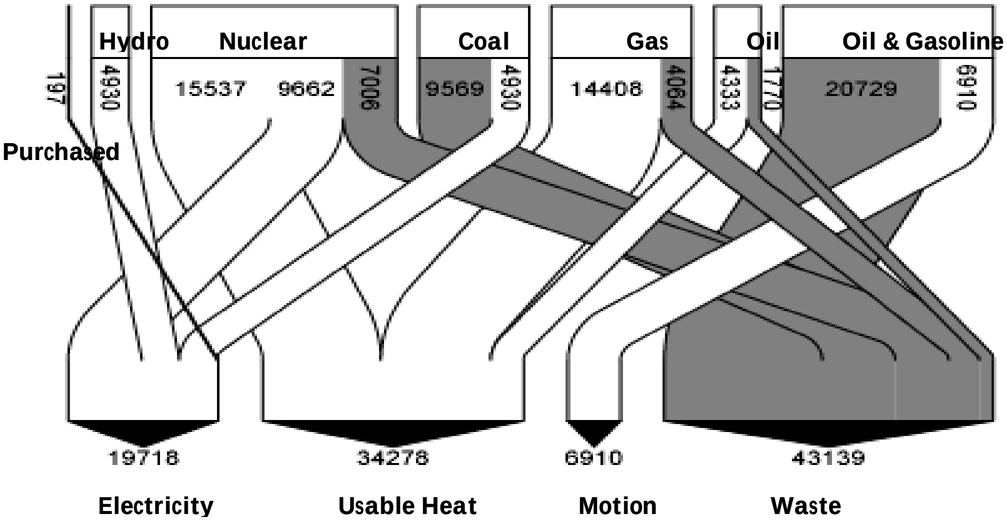

Figure 6: Sankey diagram showing primary and secondary energy mix for City of Toronto

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[1] Sheltair Group Inc. **Residential Sector Climate Change Foundation Paper**, 1999, for the National Climate Change Secretariat, Canada

buildings over periods of up to 100 years. Over a period of 10, 30 or 50 years it is likely that the energy chains connected to electricity will be radically altered, with significant implications for the calculated life cycle impacts of buildings. Longterm scenarios become highly problematic.

The problem of changing energy chains is not so sharp with other energy sources (e.g. natural gas), although the related chains may evolve with improved emission controls and greater integration of infrastructure and buildings.

Regardless of the type of energy source, the inventory of energy flows requires data on both the quantity of the energy and the qualitative values that affect the chains that are involved, including:

- the instant in the day and in the year (for electricity)
- the place of production, and
- the expected usage (thermal, electrical)

Environmental Loads, Effects and Impacts

A building process chain includes a series of physical transformations. Each transformation leads to further transformations, in an increasingly indirect chain of reactions. Following the sequence, and interpreting the results from different perspectives, is part of assessing the full costs and benefits associated with one building process or another.

The sequence of transformations is typically analysed in two stages:

1. Environmental **loads** are to be understood as direct interventions with the environment in forms of emissions to air, soil and water, generation of noise, vibration, odour, nuisance and general pollution, the use of natural resources, and so on.
2. Environmental **effects** - or effect potentials – refer to the primary response by the surrounding environmental system. Determining environmental effects is dependant on where in the cause and effect chains the analysis of environmental effects is performed. Commonly, environmental assessment of buildings considers such primary effects such as global warming potential (GWP), acidification potential (AP), ozone depletion potential (ODP), and nutrification potential (NP). Note that such effects are not yet complicated by cascade reactions within the exterior environment.

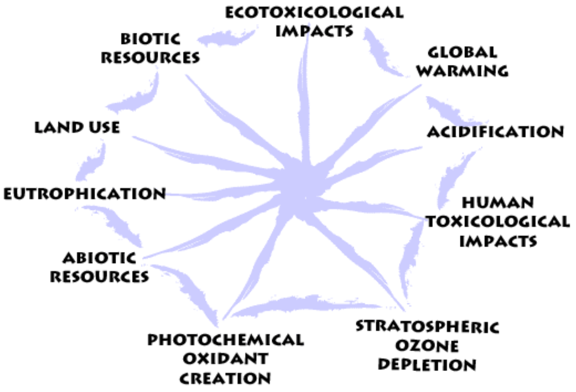


Figure 7: Typical impacts considered by LCA

Environmental impacts occur as the result of environmental effects. An impact involves an apparent loss or gain to society or to a specific individual or group of concern. The loss or gain is normative or value-based, and may involve changes to such assets as climate, human health, resource availability and genetic resources. The definition and relative valuation of such assets can vary. Figure 7 illustrates the typical impacts considered within LCA.

Potential impacts / actual impacts within LCA

An 'actual' environmental impact could be defined as the consequences for human health, for the well being of flora and fauna or for the future availability of natural resources attributable to the input and output streams of a system. 'Potential' impacts do not assess any consequences (mortality for example) but only gives an indication of hazard. A parallel can be made with the Risk Assessment (RA) approach. The distinction between potential and actual impacts is of the same order as with the notions of 'hazard' and 'risk'.

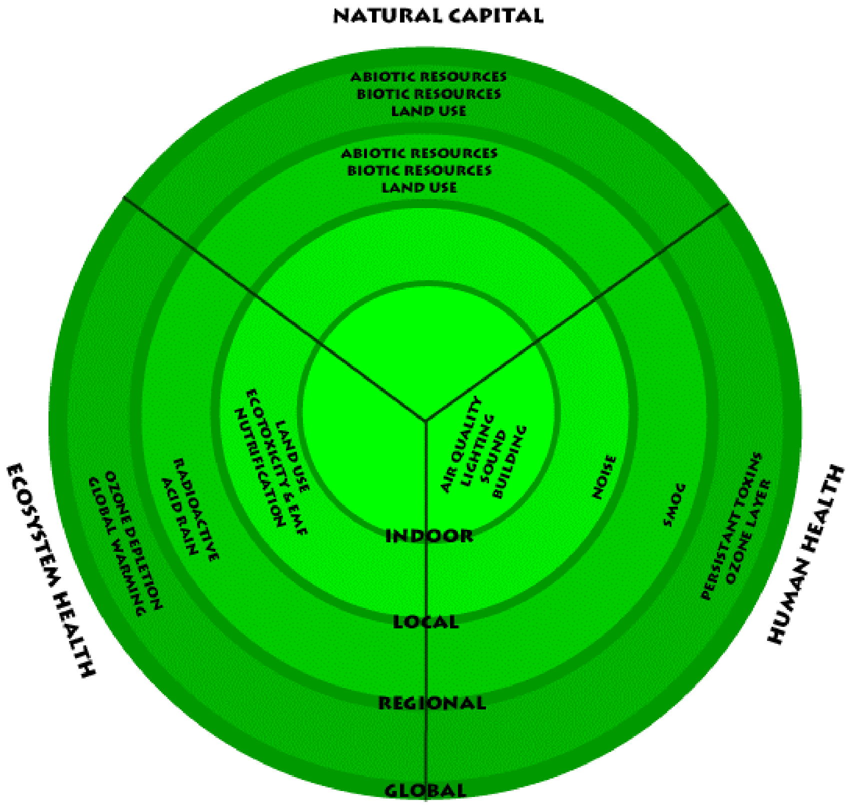


Figure 8: Receptor and Scales

Geographic variations

Geographic variation is a factor to consider when accounting for environmental loads. Typically three geographic scales are used: **local**, **regional** and **global**. The Local scale may be further subdivided into the site, and the adjacent sites and neighbourhood. Depending on the goal and scope of the study, focus might be restricted on one of these scales, intentionally ignoring impacts occurring on the other scales. In some cases, environmental effects become relevant at certain scales. For example, the global warming potential is defined on global scale. The impacts of global warming may be felt at local scale, but the effect is always global.

Receptor capacity

The relevance and the impact potential of environmental loads vary not only with the quantity and quality of the environmental load, but also with the receptor and the initial state of the receptor. Accounting for local and regional environmental impacts often necessitates consideration of the local or regional capacity of the receptor of environmental loads.

Likewise, the natural state of the receptor may differ between regions. For example, the emission of natriumchlorine to water may be of little concern in coastal areas with salt-water receptors; however the potential effects are much more significant if the receptor is a fresh water aquifers. Because buildings become a continuous source of loads in their local environments, the local receptor capacity is much more relevant than is the case with most other types of industrial products consumed in the marketplace.

Specialised LCA Methods required for Buildings

Because traditional LCA methods focus almost exclusively on the global and regional impacts, and ignore local scale and indoor receptors, they are not adapted for use with building systems. The long time frames under consideration also require that the loads and effect inventories cannot easily be lumped together over the whole life cycle. For these and other reasons, LCA methods must be adapted if they are to be used for assessing buildings. Such adaptations are examined in the Annex 31 Report on **LCA Methods for Buildings.**

Links Between Building Processes and Impacts of Concern

Complexity of the causal chains

Between the sources of loads, and the impacts on groups of concern, lies a complex web of the casual chains. The links of these chains are comprised of the sources (or unit processes), the loadings, the effects and finally the impacts. Identifying and accounting for so many complex chains presents a major challenge when assessing the energy-related environmental impact of buildings. Tools are needed to help overcome such difficulties. However even with the most sophisticated tools it is not possible to conduct a comprehensive assessment of a building. Instead the process must involve narrowing the focus of assessment to the most significant issues. This is referred to as boundary setting.

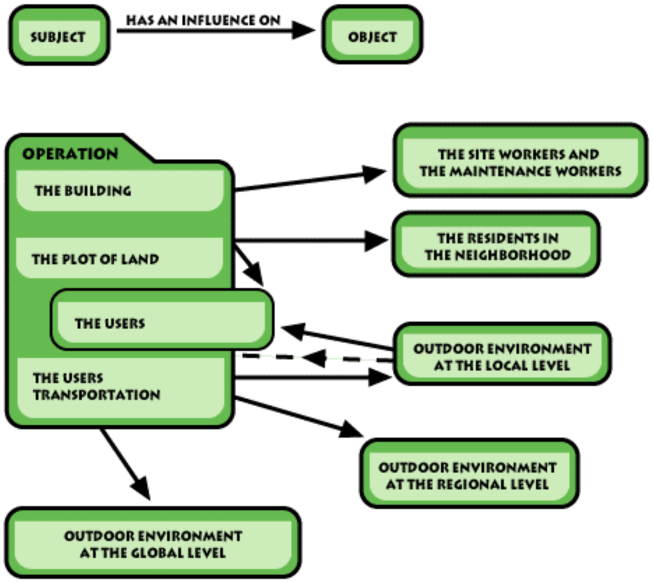


Figure 9 Full Scope of Relationships

Figure 9 illustrates the full scope of sources (subjects) and receptors (objects) that can be considered when undertaking an assessment. This type of schematic is useful when first setting boundaries on the assessment process.

Cause and Effect Chains

Each chain in such a web is comprised of a similar series of links as shown in figure 10.

Source	***Loading***	***Effect***	***1st order impact***	***2nd order impact***	***Other impact***
Fuel combustion in a domestic heating boiler	CO_2 emission	Increase of the greenhouse effect	Global warming & climate change	Sea level raise & ecological damage	Property loss and dislocation of families
Traffic of commuter vehicles on a motorway	Acoustic pressure level on the building façade	Indoor noise level	Discomfort, tiredness of the occupants	Absenteeism, increase of health problems and expenses	Decreased economic efficiency

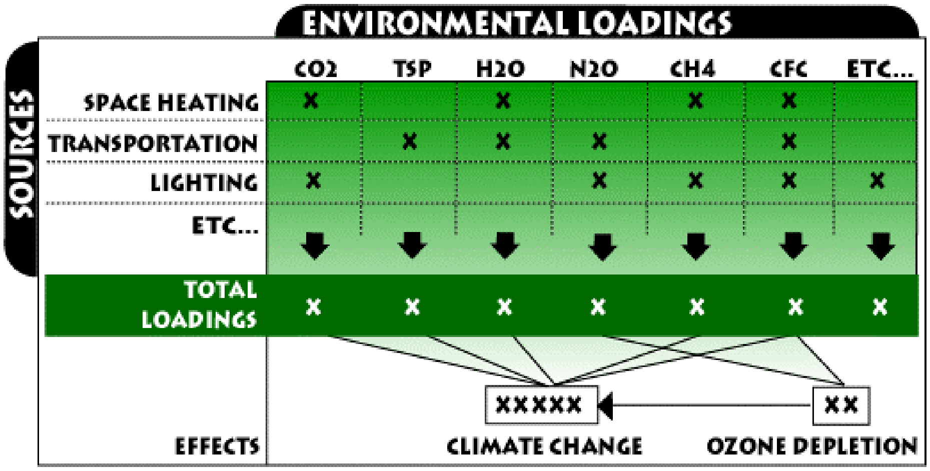
Figure 10: Examples of cause and effect chains for buildings

A Matrix of Loadings and Effects

Generally, the complexity of the cause and effect chains is greater than shown. In reality:

- ☐ a source can generate several loadings, each with their own effects.
- ☐ different combinations of loadings have different effects.
- ☐ combinations can include loadings from different sources; and
- ☐ some effects can impact the sources in a feedback loop, and generate increased loadings.

Confused? Figure 11 illustrates the complex branching and looping that can occur as sources cascade through the environment. Such a matrix of sources and loadings constitutes an essential framework for completing an environmental assessment of buildings. The matrix can be based on quantitative and or qualitative data. The sources and loadings need to be defined appropriately for the building sector. The matrix then becomes a transparent model for tracing impacts and effects back to their respective sources.



	CO2	TSP	H2O	N2O	CH4	CFC	ETC...
SPACE HEATING	X		X		X	X	
TRANSPORTATION		X	X	X		X	
LIGHTING	X			X	X	X	X
ETC...	⬇	⬇	⬇	⬇	⬇	⬇	⬇
TOTAL LOADINGS	X	X	X	X	X	X	X

Allocation of loadings between co-products and Multiple services

It is not always clear how to allocate loadings from a specific source. One problem occurs when the outputs from a process include several products. Another problem occurs when the products contain recycled wastes from other (past) products. Still more problems are encountered when products are used repeatedly for different purposes, and cascade through the system. Under such conditions it becomes difficult to determine what percentage of the loadings are to be allocated to the building process under assessment.

Allocation processes are conceptually complex, and may require arbitrary decision. What is key is to standardize the allocation methods to avoid calculation errors like double counting. Some of the most typical techniques used to standardize allocation include:

- ☐ Expanding the system boundary and measuring the inputs and outputs from any combined processes
- ☐ Allocation by physical causality – usually mass
- ☐ Allocation by calorific content of the product stream
- ☐ Allocation by monetary value of the product stream

For buildings, a wide variety of situations arise and it is not appropriate to use a single allocation method universally. More discussion of allocation methods for buildings can be found in the Annex 31 Report on **LCA Methods for Buildings**.

THE TECHNOSPHERE

The technosphere is a term to describe the built or adapted environment created by humans. As mentioned earlier, the Technosphere is always a subset of the Environmental Framework. From a modelling perspective, the technosphere (or built environment) marks the beginning of the energy and mass cycles resulting from human intervention.

The technosphere exists as a dependant subset of nature's more or less closed natural cycles, and thus always exerts an influence on natural flows. Technical systems are functional combinations of products and processes that are designed and built to serve human needs. The level of influence exerted by these 'artificially produced' energy and mass flows depends on the degree that technical systems interfere with the historical dimensions of the biosphere.

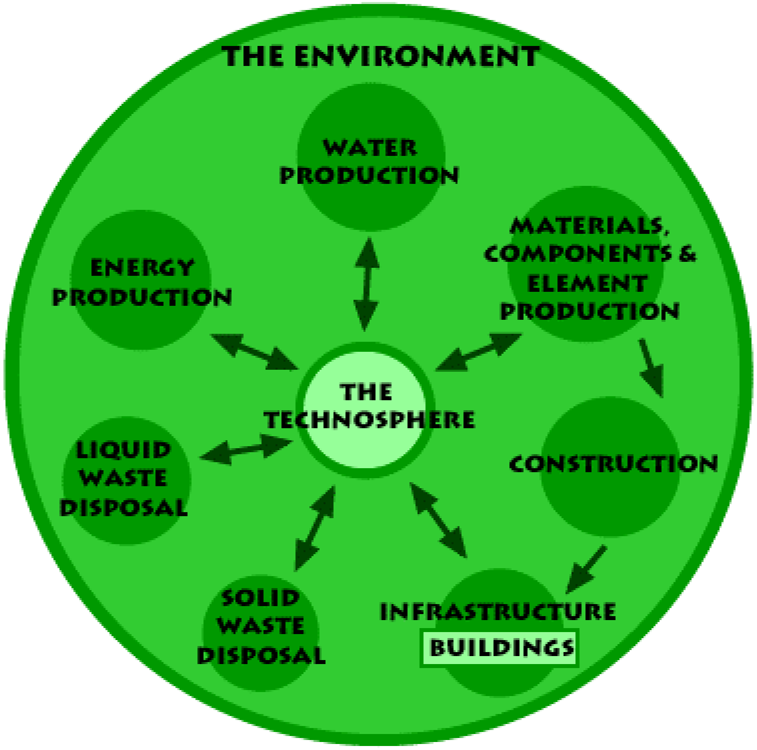


Figure 12: The Technosphere - the built environment created by humans

Functional Units

Elements of the technosphere that defined in specific quantifiable terms, and subjected to analysis, are referred to as **functional units**. A whole building over its lifespan can be a functional unit. Or the functional unit might be the building over the occupancy phase. Or more commonly the functional unit will be a single meter square of the building floor area over a typical year. Sometimes it makes sense to use the occupant as the functional unit, instead of the building area. The choices for functional units are many, and always involve tradeoffs.

Basically the purpose of subdividing the technosphere into functional units is to simplify the modelling process. By setting clear boundaries for the analysis, individuals can focus on those elements over which they have the greatest influence or concern. As long as the functional units are classified and defined in standardized ways, it becomes possible to fairly compare their performance.

The method used for analysing functional units can vary depending upon the processes, products, activities, services and geographic scale defined for the building. Typically a building is subdivided into elements (or components), and then into processes and products, and finally into materials. For some purposes it is also useful to analyse the building in terms of rooms, or services provided.

Figure 13 illustrates the technosphere as the simplified life cycle of an individual building. The following stages are linked together to form the life cycle building process chain:

v1	production of energy (preliminary stage)
v2	manufacture of basic materials (preliminary stage)
a	erection of the building/construction
b	maintenance measures
c	repair/renovation
d	maintenance measures
e	modernisation/conversion

During each of these life cycle stages the building process interacts with the environment. The interactions can be described in terms of mass and energy flows. These flows are loadings on the receiving environment, creating cause and effect chains and impacts of concern. By aggregating the loadings at each stage, it is possible to use Figure 13 as a guide to completing a bottom-up, life cycle inventory for the building process, in accordance with LCA methods.

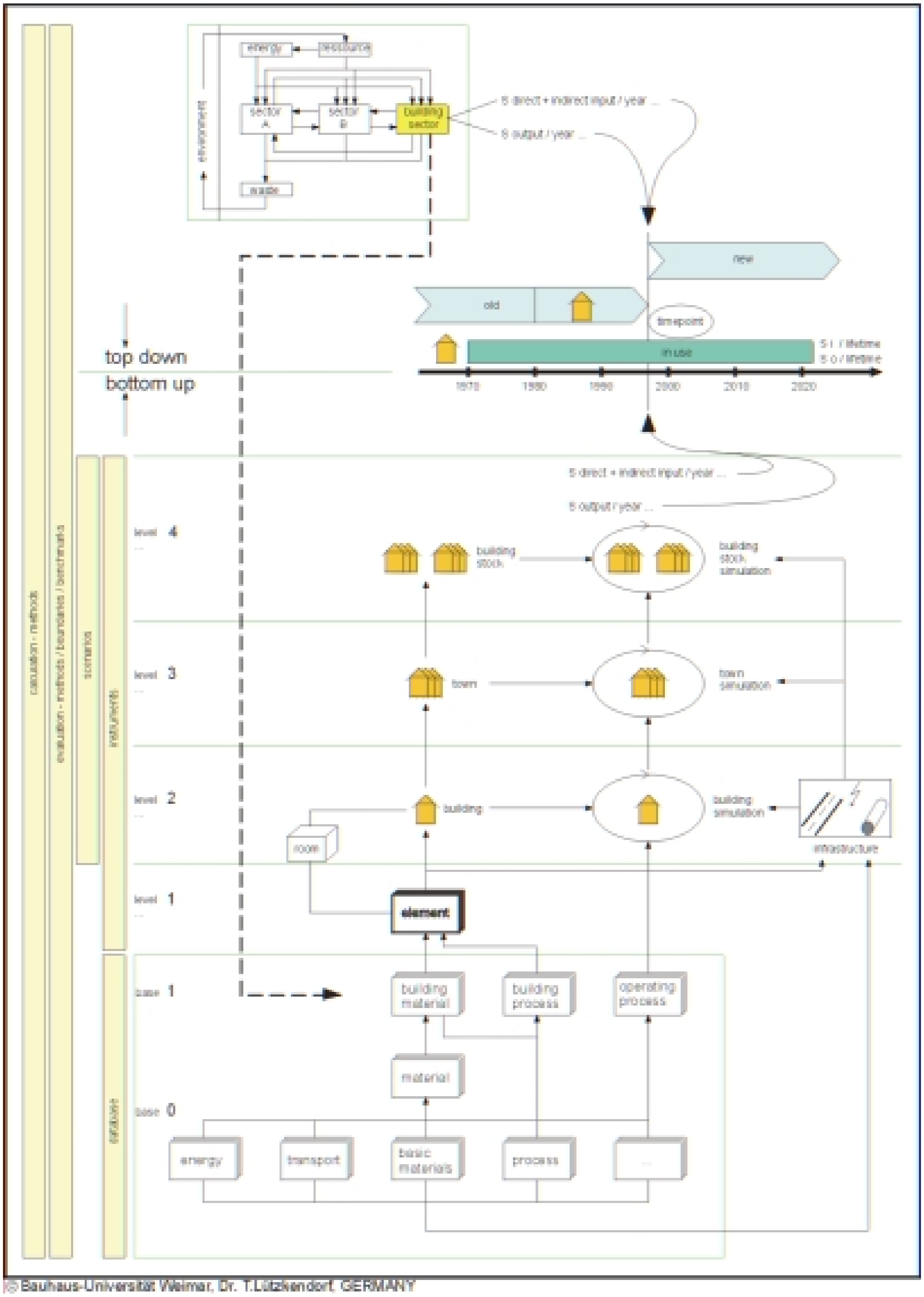


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Figure 13: Technosphere as the simplified life cycle of an individual building

Base Data on Energy and Raw Material Processing

At the lowest part of the figure (Base 0) basic data are required to inventory the energy and material flows. Such data is derived from the Databases (left margin of diagram) typically organized according to:

- ☐ energy use and energy demand
- ☐ transport services
- ☐ production of basic materials
- ☐ disposal processes.

These basic data are cross-linked with other chains. The LCA method typically employs rules for cutting off the analysis at sensible boundaries. For example it is usually not worth the time to attempt to account for the energy used by human bodies, or for the energy and materials used by the machines that make machines. Such cut-off criteria are well described in SETAC publications[2]. Basically, to keep the work manageable, the analyst should make a preliminary and crude assessment of likely impacts, and then exclude those processes that have a very trivial effect or impact (the Pareto principle).

Building Products

The next stage in the inventory process (Base 1) involves the creation of products and services used primarily by the building sector, including:

- ☐ building products, including specific building materials and assembled systems such as heating appliances;
- ☐ construction processes, such as energy for the operation of machinery during erection, maintenance, and demolition work;
- ☐ services for the supply of energy, including space heating, warm water, and lighting;
- ☐ urban services for supply and disposal (e.g. water and waste water); and
- ☐ property management services, including cleaning.

One of the major difficulties in analysing buildings at this level is the transcription of measurements expressed in builders' units (ml, m^3, sheets, items. etc) into units of mass particularly in the case of complex materials such as windows or roof assemblies. For example, the quantities contained in design blueprints and specifications are not easily translated into the units used by databases on material energy and waste intensity. A reliable interface between the databases and estimates/ measurements/ plans is necessary.

Building Elements

Elements are the components of a constructed building, for instance 1 m² of outer wall, or 1 window installed or 1 operable heating plant. Elements in the sense of structural members represent the embodied materials and building products as well as the associated building processes (construction work).

When simulating the energy flow for the life cycle of buildings it is essential to collect data on each element, such as:

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[2] For example, refer to **A Technical Framework for Life-Cycle Assessment**, 1994, Society of Environmental Toxicology and Chemistry

- ❑ the K-value of the outer walls
- ❑ the source of energy, annual efficiency, and emission coefficients for heating plants.

When simulating the flows of energy and materials for maintenance of elements over the life cycle, other data may be required. For example,

- ❑ the element description can contain data on service life and maintenance expenditure; or
- ❑ elements are separately described depending upon their use in new construction and rehabilitation.

The Building and its Rooms

Single buildings (Level 2) may be described by as a collection of elements, or as rooms. The assessment can begin by accounting for the energy and materials used specifically for construction of the element or room, inclusive of all previous energy-related and material stages. An additional assessment can then be undertaken to estimate loadings and costs incurred during the occupancy period.

In order to model the building operation during occupancy assumptions are required regarding usage, maintenance, management and so on. These assumptions represent 'scenarios' for the occupancy period. The types of energy and material expenditures considered in such occupancy scenarios may vary. For example cooking of food may be considered in one scenario, the use of office equipment may not. Scenarios should be defined in ways that reflect the areas of concern and influence for decision-makers.

From Buildings to Towns and Stocks

Issues related to the impact of town and combining or aggregating buildings at appropriate scales, from the block to the estate, neighbourhood, city or region, can address settlement planning. Aggregation of buildings may involve expanding the scope of building elements to include portions of the urban infrastructure. It is especially useful to combine stocks and their associated infrastructure when making decisions about regional and national management of resources. Combining individual building assessments to create an aggregate assessment for the stock is referred to as a bottom-up method. This is described in more detail in the Annex 31 Report on **LCA for Buildings**.

Figure 14: Scale of analysis

Establishing System Boundaries

The maximum system boundaries are illustrated in figure 15. These boundaries are defined as broadly as possible, and consideration is given even to the marginal changes in urban infrastructure. However most building design teams will choose to ignore the effects on urban infrastructure, since they are currently difficult to predict and value. The main system boundary for the decision choices is usually the property limit; and the direct effects of occupants on the surrounding area.

The effects generated by occupants of a building can be divided into three main categories: outside of the property limit (e.g. transportation), inside of the property due to the use of the building and also inside the property due to individual activities of humans (such as reproduction). For each assessment, a choice must be made about which of these elements should be included in the system boundary. Figure 15 illustrates a common "example" of system boundary setting that excludes the urban infrastructure, transportation and the effects of occupants.

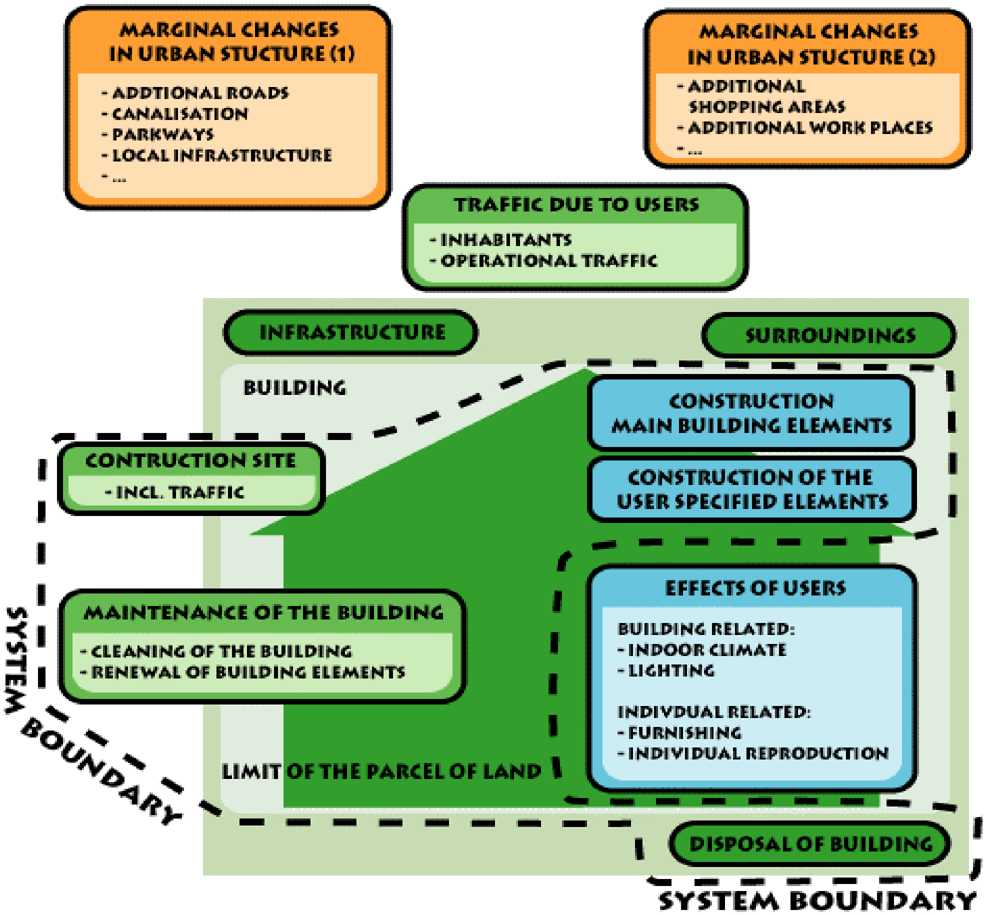

Figure 15: Example of system boundary setting

For the boundaries upstream and downstream in the energy and transport chain, we have further circumstances:

- where only immediate impacts considered; no transport or fuel chain analysis; mainly useful when considering design decisions that have an impact on operating energy demand with fixed energy sources,
- when fuel consumption related to transport of materials and energy forms included; essential when assessing "embodied impacts", or
- when both transport and fuel chains are included; the full picture.

The Building as a Functional Unit

While construction projects are the usual object of environmental assessments, this normally translates into the building and possibly the plot of land upon which it is located. That contains it, considered over a part or all of its life-cycle (depending on the objectives of the study, which may target the renovation phase, or may on the contrary involve the entire life-cycle, for instance). In some cases, the object of the assessment may be larger, covering an entire district or town, and including not only buildings but also infrastructures. However, most of the tools catalogued at present correspond to the former configuration.

Building as a Product, Process and Place

A building can be defined differently, depending upon the scope of analysis. In general, a building can be defined as:

1. **a "product"**, or more exactly a complex assembly of products, which is manufactured, used and disposed of. Moreover, 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".** It is therefore 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 lifecycle, such as site workers, maintenance staff and neighbours.

Lifecycle Energy Transformations

For simplicity, consider the functional object to be a single building. A building's life cycle, in the sense of the life cycle analysis, includes a number of phases that are presented in the first column of the Table 2. The corresponding uses of energy are listed in the second column.

As Table 2 demonstrates, no event occurs in the building's lifecycle without an energy exchange. The sources of energy used by any building over the lifecycle are extremely varied, and the forms of energy may be heat, force or light. In general, the main functions of energy over a building's life cycle are:

- To transform and to treat materials, including water, food, air, wood, metals, masonry and so on;
- To transport materials, products, goods, fluids, people, energy, and information;
- To control climates, particularly within the building, thermally, visually and otherwise; and
- To supply services to occupants by operating household appliances, entertainment systems and so on.

Phases in the building life cycle		***Functions of energy***
Extraction of raw materials		Energy for extracting raw materials
Possible transportation		Energy for transporting products
Manufacture of materials and products		Energy for manufacturing the materials and products
Transportation		Energy for transporting products
Manufacture of complex components (multi-materials, multi-products)		Energy for manufacturing complex components
Transportation to the building site		Energy for transporting products
Construction on the building site		Energy for handling, assembling, transforming, ...
Removal of waste from the building site and treatment of this waste		Energy for treating and transporting materials
Building's use phase (loops)	Operation and maintenance	Operating energy to create a comfortable environment (thermal, visual) Operating energy to supply services within the building Energy for routing, making available (upstream), treating and removing (downstream) the operating flows (water, energy, waste, merchandise, information data) Energy for the maintenance operations
	Transportation of users	Energy to transport occupants within site, and commuting to essential services off-site.
	Replacement of elements at various frequencies	Energy to disassemble, transport, treat or eliminate the elements to be replaced Energy to manufacture, transport, incorporate the new elements
	Refurbishment	Energy for the multiple operations linked to refurbishment
Demolition / deconstruction		Energy to demolish or dismantle the building
Transportation / removal of waste		Energy to transport / remove the waste
Treatment of waste (re-use, recycling, storage, elimination of final waste and associated		Energy to treat or process the waste (sorting, purifying, recycling, making inert, storing)

transportation)	
Reconditioning of the site	Energy to recondition the site (various operations possible)

Table 2: The building life cycle and the functions of energy

Energy consumption is very different from one phase to another. As we can see, transportation often comes into play and the overall contribution of transportation is substantial. Obviously, energy consumption during the building use phase is also substantial.

The transport of users falls more within an approach on an urban scale, for the analysis of sites, for instance, than an approach on the scale of an individual building. However, there is currently no consensus between tool developers whether or not to take the transport of users into account in building environmental assessment tools. This brings us back to the question of the choice of limits for the system. It should be noted that, when user transportation is taken into account, it has a significant influence on the environmental impacts.

Energy analysis tools may intentionally choose to ignore specific sources of energy, and specific energy transformations. Such boundaries may be warranted because quantities are negligible, or because of uncertainties, or because the sources are of little interest to the target audiences. Figure 15 illustrates how energy use breaks down for a single-family house, and emphasises the very significant differences in relative energy use[3].

The future is likely to include buildings as 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.

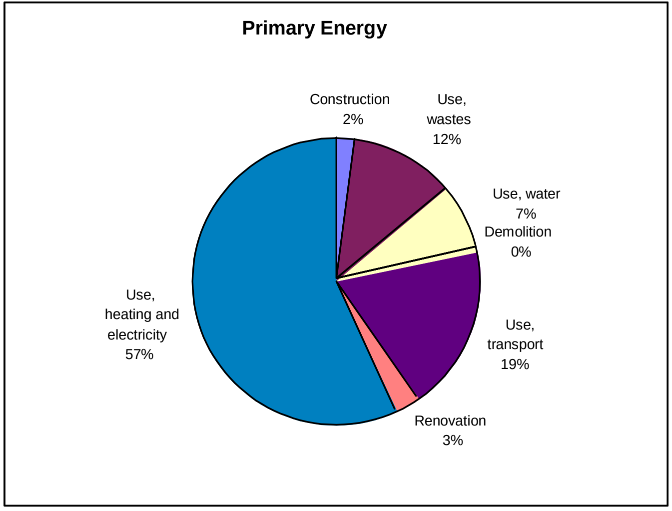

Figure 15: Energy use breakdown for single-family house

To provide software input data concerning the composition of the building (nature and quantity of materials), exact plans and a precise, detailed descriptions are required, consistent with the geometric data. The nature of the materials and the conversion of quantities into units of mass must be unambiguous. This is not often the case, as a substantial amount of work is required. Moreover, it is not desirable to provide developers with aggregate quantities of materials, as no link to the geometric data is provided, leading to uncertainties in calculating the energy performance of the building and in the possible study of variants.

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[3] EQUER results provided by Ecole des Mines of Paris

Options for Reducing Energy Loads of Buildings

1. Reduce building growth rate
   - ☐ Reduce the need for new dwelling and work spaces
   - ☐ Reduce the size of new buildings
   - ☐ Improve the use of presently under-utilized spaces (e.g. warehouses, basements)
   - ☐ Encourage densification

2. Reduce initial and recurring embodied energy

3. Change occupant behaviour

4. Reduce operating energy - systems approach
   - ☐ Space conditioning (heating, cooling, ventilation)
   - ☐ Building envelope
   - ☐ Windows
   - ☐ Controls
   - ☐ Water heating
   - ☐ Lighting
   - ☐ Appliances and other equipment (including outdoor equipment)
   - ☐ Promote alternative energy supply systems
   - ☐ Active solar hot water heaters
   - ☐ Active and passive solar space heating & cooling
   - ☐ Photovoltaics
   - ☐ Wind turbines (building cluster or community level)
   - ☐ Co-generation and shared energy systems
   - ☐ Fuel cells

The Importance of Non-Energy-Related Impacts

Energy saving in buildings leads to a relative higher environmental impact of other factors, like the choice of materials. The work in Annex 31 was oriented in the beginning to energy (because energy is the key parameter in environmental impact of buildings), but, finally, includes the effect of the other sources upon the environment. On the other hand energy saving can result in the aggravation of an impact related to a source of another nature (mostly when not conducted properly or when users are not well enough informed: discomfort, health problems, impact related to insufficient treatment of water or of waste, for example). This is why we certainly need to cover, in detail, the questions of energy by taking an overall approach in the environmental assessment of a project.

Infrastructures and Energy Chains

In addition to energy consumption in buildings, energy is also used to construct and in some cases operate other aspects of infrastructure. Energy is embodied in the services and products delivered by all urban systems. Consider the energy in energy, the energy in water, and so on. A complete list is provided in Table 3.

Infrastructure and Energy Processes	*Possible Units*
o Energy supply utilities	
o Electricity generation, storage and distribution	kWh delivered
o Gas extraction, processing, storage and distribution	kWh delivered
o Oil extraction, refining, storage and distribution	kWh delivered
o Solid fuel extraction and delivery	kWh delivered
o Water supply utilities	m^3 delivered

o Sewage disposal utilities	m^3 delivered m^3 generated
o Communications Transport infrastructure including: o Roads, Car Parks, Paths o Railways o Airports o Infrastructure Telecommunications	pass.km km, pass.km and t.km

Table 3: List of infrastructure energy processes

The impacts from these processes arise from the land use taken up, the transport and use of materials used to construct, operate and maintain the facilities, the energy, water, waste and other utilities used to operate the facilities over their productive lives and the disposal of any associated wastes. These need to be determined and allocated to a unit of the service provided. Some possible units are suggested.

Full Fuel Cycle Analysis

The energy process chains vary according to the type of energy (fuel, electricity, renewable energy,) and the technology. A standard process list for an energy industry listed below:

- Extraction
- Transportation
- Refinement/treatment
- Transportation
- Conversion into energy
- Distribution
- Use
- Treatment of emissions and waste

Sometimes a building may contain a major part of the energy infrastructure that is habitually located outside the building. For example, this is the case whenever the building contains a system of co-generation or of solar panels. If we wish to make a comparison between two building projects, one containing in itself an energy production system, the other calling upon an outside infrastructure, the system then needs to be properly delimited, making sure that the comparative analysis is coherent.

There are a number of ways of including energy chains in the system to be studied. We can adopt a "marginal" approach (we only take into account the effects of an additional production of energy), or an "average" approach (infrastructure considered overall). According to the starting goals, and the geographical scale that we include, we are led to choose one or the other. In every case, it is necessary to justify the assumptions and select the input data sets accordingly.

These two last remarks may also be applied to other types of infrastructure than energy, for instance water supply of sewage utilities.

The site

The site represents the plot of land that receives the building and its immediate surroundings, with all their characteristics or parameters. It should be noted that the site is both a source of impact (through its characteristics) and a receiver of impacts (local impacts).

The environmental performance of a building project is strongly dependent on the site, in terms of climate, outdoor environment, landscape, ecosystems, technical infrastructures, and transportation. The choice of a certain site, instead of another one, has environmental consequences, and thus it is important to understand the interface between the building and the site.

When a building project is assessed from an environmental point of view, site characteristics can be characterised as either environmental opportunities or constraints. Site factors that may be considered include:

- ☐ Local technical networks (water, energy, waste, transportation...)
- ☐ Access to services (shops, schools...)
- ☐ Ecology of the site (fauna, flora, soil, risks...)
- ☐ Neighbours' environment (noise, wind, sun...)
- ☐ Users' potential comfort on the plot
- ☐ Architectural quality and landscape.

Outdoor/Indoor Environmental Issues

Indoor environmental quality refers to all aspects of the indoor environment that affect health and well being of occupants. These include air quality but also light, thermal comfort, acoustic, vibration and other aspects of the indoor environment. Some authors (ATEQUE, France) refer to 'users' environment' - a term that is a little broader than indoor environment and includes the users' comfort and health on the plot of land.

As a place to live, buildings can have a major impact on individual health and comfort. Although no general consensus exists among tool developers and modellers, most authors agree that the impacts related to the indoor environment are especially important, and of increasing interest.

Traditional LCA methods do not consider the impacts on indoor environment, since impacts are viewed in isolation from location and medium. The inventory parameters (mass and energy balances) are not expressed under concentrations type data. Moreover they are summed over the various phases of the life cycle without any consideration of location. Consequently most LCA-oriented tools do not include indoor environment. Other methods must be used for this purpose.

Combining energy analysis with indoor environmental quality is especially worthwhile because of the potential trade-offs and synergies. Some methods of energy conservation can improve indoor environmental quality, and others may sacrifice indoor environment. It is best to view both kinds of impacts simultaneously.

About the ranking or the prioritisation of impacts, some attempts have been made for ranking outdoor environmental issues (e.g. EPA Science Advisory Board, USA, 1990). But it appears difficult to rank outdoor and indoor issues in the same assessment.

Life Span

The life span of a building or a site is a very important parameter in the final environmental profile. Depending upon functional units, longer building lifetimes often reduce the impacts by extending the amortization period for large resource inputs, like concrete foundations. Longer lifetimes also emphasize the benefits of design features that reduce operating costs. Ideally the environmental framework would establish the scope of impacts that may occur over the entire lifetime, for all buildings. Unfortunately the long lifetimes of buildings impose high levels of uncertainty to 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 the building will experience significant variations in regulatory and economic conditions, and in the 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**.