SIMULATION OF ENERGY AND MASSFLOWS OF BUILDINGS DURING THEIR LIFE CYCLE

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Abstract :
The LCA methodology [SETAC] is applied to buildings. The system limits, functional units and allocation principles are explained. Inventories have been established for 150 buildings materials and linked to the ECOINVENT database. Buildings are described on the basis of specifications which are aggregated to (cost planning)-elements. There is a catalogue of several hundred elements. Energy needs, costs and environmental impact are calculated simultaneously. Different views are possible (type of impact, life time phase, element). The life cycle is simulated through a periodic replacement model. The LCA method is actually integrated into cost planning and CAD tools.

1) INTRODUCTION

The LCA techniques have been developed in two fields:

- environmental impact assessment of products, process and services [SET93][HEI92]
- life cycle cost estimation for commodities with considerable current costs and long life time [DHIL89]

In both cases a certain number of techniques have been elaborated tending to form one coherent method. Impact assessment is extended to the whole life cycle of products and life cycle costing is extended to external costs and ecological accounting (eco audits).
The existing LCA methods must be adapted to buildings which have specific properties:

- buildings have the longest life time of industrially produced goods
- the current costs and energy use are in general much larger than the initial investment
- there are complex relations between initial and current costs
- the one-of-a-kind character of buildings makes comparisons difficult
- the design process is not linear and has many feedback, the same data are used several times with different accuracy

The adaptation of LCA techniques to buildings must take these aspects into account. It is not possible to make consistent isolated LCA for materials and for components, only buildings provide a coherent functional unit. Therefore the LCA data at different levels have to be modular, so that they can be aggregated in the design process. Buildings in turn have to be decomposed

in a systematic way allowing to use the same functional units through the life cycle.
In this contribution four technical aspects linked to LCA for buildings are discussed :
- the system limits in time and space,
- the building description
- basic data
- transformation of buildings in time
A complete description of these aspects can be found in [REG97]

2) SYSTEM LIMITS

System limits are both temporal and spatial. They can be subdivided in phases and process.

- Phases are defined in a chronological way and have temporal system limits:
  - building construction phase (from the beginning of the planning process by the client to the end of commissioning)
  - building use phase (beginning of occupation by the user to the beginning of final demolition)
  - building disposal (beginning of the final demolition to the beginning of reuse, recycling, or end of deposit.

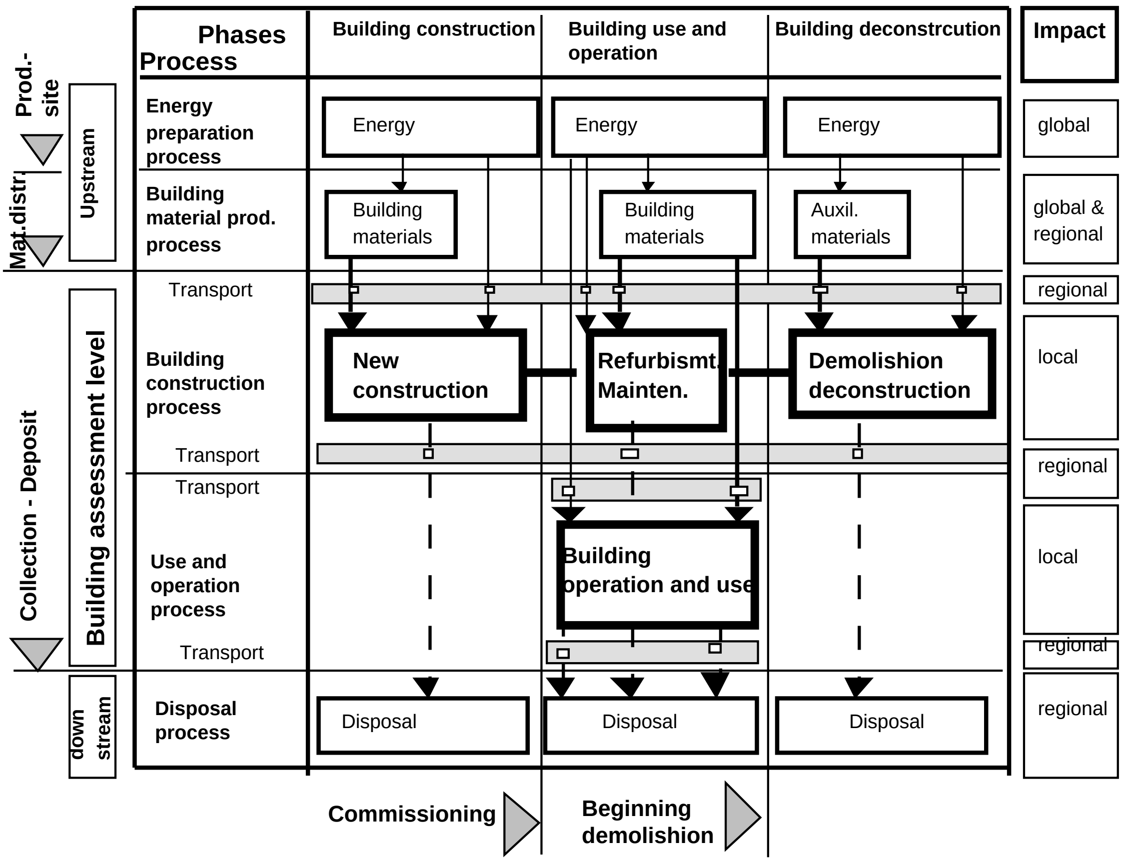

Fig. 1 : Process-phase model

- Process are defined as logical successions with spatial attributes:
  - Energy transformation process. System limits are nature (input) and the delivery of final energy or the transformation of final energy at the place of use (output).
  - Material production process (building materials and components which are produced off site). The system limits are the extraction of raw materials or the site of the production factory for inputs from other industries and the site of production or the wholesale stock as output)
  - Building Construction process (all construction processes on site as well as transport processes from whole sale stock to the building site and from the building site to the collection site for reuse, recycling or disposal). System limits are the material whole sale, the construction site (input) and the collection sites for reuse, recycling or disposal (outputs).
  - use process (all building operations and general use processes which take place at the building site). The system limits are limits of private and public property. Some transport process related to use can have other system limits.
  - disposal process (they transform building parts/waste into other products, energy or they return them into nature in various forms.) The system limits are the collection sites as input and other uses or nature as output).

3) BUILDING DESCRIPTION

According to the intention of an observer a building can be described in different ways. The hierarchical decomposition starting with the building stock and ending up with basic materials taken from nature allows to link different levels and to establish overall mass-, energy- and monetary flows. For other applications, like the simulation of the dynamic thermal behaviour (to estimate the current energy consumption) or the representation of the topology of a building, a hierarchical model is not appropriated and other models are needed. [BJÖR92[It is however possible to map these models and to share information.

- Building stock:
Reference values for resource consumption can only be determined on this level [EQK96].

- Individual Buildings:
In general the functional unit is the use type surface (e.g. m^2 of school building). All the relevant data are referred to this unit. This allows:

- to qualify and compare existing solutions
- to compose building programs and estimate the domain of future impacts.

The unit is defined by international or national standards (CEN, ISO, DIN, SIA and others)

- Macro elements:
Macro elements can be freely chosen as a combination of elements (which are fixed). This allows to compare solutions and to create special macroelements for refurbishment (e.g. a complete staircase which has to be refurbished, all kitchens etc.) [HEI95].

- Elements:
The building is decomposed into cost-elements [CRB90], [DIN95]. Each cost element has a geometrical or other functional unit (1 m^2 of exterior wall, one heat production plant etc.). All elements are described by specifications . They can define layers (e.g. the 12 cm thick insulation layer in a roof construction), distributed materials (screws) or process (drilling a hole).
At this level, many other properties can be attached. The u-value can be calculated from the composition and succession of layer information, the acoustic properties can be linked to tables with acoustic values, the fire resistance can be derived etc.

- Specifications:
Specifications contain material, mass and processes information. Process information in turn relates to machine use, direct energy use etc..
Specifications describe how a building is built. They are the most precise building description. There is many more information which can be linked to specifications like trade which executes the task, how many workers are necessary (team size), which operation has to be performed before (for scheduling) etc..

Aggregation	Building stock	Individual building	Macro-element	Element	Specify-action	Part, Process
Functional units other FU	m^2 use surface	m^2 use surface m^3 Volume	m^2 use surface	m^2 element surface heat generator	m^2 surface kg material h work	kg material h process
Properties	main function constr. year present value state	functions constr. year present value state type constr.	compositio n	composition state waste cost recyclability	compositio n type process nb.use/wa ste machines trade	defin. material, auxil.m machine type fixation mainten. mach. toxic/noise
Additional				energy	labor cost	

properties				(u-value, effic.) water resist. acoust.fire prot.	qualification	
Example	Public buildings	Elementary school	All vertical envelopes	Window	Setting up wood window fixat. PUR	Pine wood PUR foam drilling machine

Fig. 2 : Decomposition Levels

- Parts and process:

Parts can be units for which an inventory exists (e.g. a material like copper, a machine like a drilling machine). Specific information like the weight per m^2 can be derived from tables (e.g. for DIN girder profiles). There are aggregations which can be convenient for other building applications by combining information's. Information on the type of fixation (screwed or glued) will allow to appreciate the possibility to deconstruct a building etc.).

Inventories:

For all parts/processes there must be an inventory including all prior resource consumption, all emissions and transfer functions (if they exist). If there is no inventory available a temporary association with an existing inventory can be made through a mapping table.

4) BASIC DATA

- Energy relevant data

There are energy preparation process (from nature to final energy delivered at the point of use) and energy transformation process (at the point of use) They both include all inputs from nature and other process (resources) as well as all emissions produced. Some additional data like water and land consumption, noise etc. are sometimes also considered. There are two ways to obtain these data:

- from process analysis (e.g.. ECOINVENT [FRI95], GEMIS [GEM95])
- from input/output methods (e.g.. CORONAIR)

There can also be combinations of the two in the so called hybrid emission coefficients [HOH92].

The ECOINVENT are the most detailed, complete and coherent data set based on process analysis which are public. The system limits for inventories should be clearly reproducible and there should be a good data interface to allow to chose other data sets in the future. It could be interesting to compare the resulting emissions and aggregated values.

- Transport process

Transport process emissions must include the infrastructure. It is the only way to be able to compare systems.

- Down stream process

Disposal or transfer functions do exist per waste category but only for a few particular materials and technologies. Data for waste exist in ECOINVENT and in recent publications [BEW96]. There are at present research projects going on in several countries.

- Building material data

There are many literature values above all for embodied primary energy. We propose not to use these data any more. Their system limits are unclear and the data is out of date in general.

A complete new set of inventories for the most current building materials has been established together with the industry in Germany, Switzerland and Austria. It is called ÖKOINVENTARE BAUSTOFFE [ÖIB95] . The inventories are linked to the basic data of the ECOINVENT and will be linked alternatively to GEMIS. The data are public and they include approx. 250 building materials (150 basic inventories and composed materials). The following data exist:

- Definition of material (if possible CEN, DIN or SIA standard)
- Description of production process and specific system limits
- Standard inventory using material, energy, transport and emission categories of the ECOINVENT (input and output)
- List of resources and emissions calculated with an UCPTE electricity mix. (app. 450)
- Aggregated values (CML [HEI92])

At the moment only average technology (average industry data) exists.

Auxiliary materials :

These materials constitute approx. 5% of the mass flow [BUW95]. There are often no indications in the inventories because these materials are added later to give specific properties to building products (e.g. plastifier, concrete additives etc.). It is however possible through general formulations (which exist in literature) to estimate which and how much auxiliary materials could be in building product. There is a general need for inventories on this level. The issue will become crucial when the distinction between average and best technology will be made. One possibility is simply to add the auxiliary materials prorate to the current building materials on the basis of the mentioned study [BUW95] for average technology unless a producer can prove that he does not use auxiliary materials (best technology) . On the level of detailed specifications it possible to link inventories through classifications of auxiliary materials to lists of prescribed or not desirable substances on working places [GIS91]

5) Transformation of a building in time

The transformation can be described in two ways :

- simple replacement model
In most models elements are automatically replaced at the end of their nominal life time. This is problematic because the empirical knowledge about real replacement and refurbishment is low and the replacement and refurbishment depends on many technological, economical, legal, political and fashion (obsolescence) assumptions.
In this situation a basic model can be improved by adding to the actual nominal life timer values several other factors :

· technological improvement (inventories with best possible technology)
· improved recycling
· economic changes (i.e. external costs)
· new legal constraints (thermal refurbishment, no more disposal, recycling)

- refurbishment of buildings
Studies on the level of building stocks show a large convergence of maintenance and refurbishment methods:

· current maintenance (elements with life time of less than 12 years). The replacement of coatings, gaskets, paint, window glass etc. is continuous and can be taken into account on an average yearly basis.
· partial refurbishment (elements with a life between 15 and 30 years). The partial refurbishment takes place between 20 and 25 years and concerns parts of the heating, sanitary and electrical system. Coatings and windows can be part of it.
· general refurbishment (elements with life between 35 and 60 years). The partial refurbishment takes place between 40 and 60 years and concerns the heating, sanitary and electric system, windows and the roof as well as coatings. It is often accompanied by a general raise of standard and transformation of the building.

The life time of buildings is a purely conventional value. Analysing the real replacement of buildings shows that the age of the building and its state of degradation are not determining criteria [EQK96].

6) RESULTS and DISCUSSION

The software tools which have been elaborated allow to calculate simultaneously the cost, the energy consumption according to a CEN standard method [EN92], mass flows (input and output in waste categories) and up to 15 environmental impact factors [HEI92]. The results for an average apartment building are give in fig 3 .
The basic framework for combined calculation (energy, cost, environmental impact) are established. The links between professional categories and LCA data are possible [SPOLD96]. The implementation on the level of professional

tools (CAD-costplanning-energy calculation software) is under work and results are expected in two years.

The separation of inventories from valuation allows the development of new valuation methods. The main topics of the present discussion are: possibilities of global aggregation [IÖW96] [ECO95], integration of time [HOF96], evaluation of resource consumption [WUP95], appreciation of the building stock [HAS96] . The question of data quality will become more important, interesting approaches exist in [SET94[[LET96[

ECOPRO - LCA
Description of the
ifib Reference Building

Type of Building :	Appartments	
Year of construction :	1950	
Location :	Basel - CH	
Material transp. dist:	20	[km]
Dist. to disposal site :	40	[km]
Number of appartm. :	12	[]
Number of rooms :	36	[]
Number of floors :	3	[]
Num. base. floors :	1	[]
Number of staircases:	2	[]
Surface of land :	1040	[m2]
Ground surface	327	[m2]
Total surface of floors	1128	[m2]
Useful surface :	969	[m2]
Construction surface :	169	[m2]
Heated surface :	972	[m2]
Number of occupants	30	[]
Average int.temp.	20	[°]
Average ext. temp.	4,4	[°]
Degree days (12/20)	3348	[°]

Type of construction :			
		dimension	
Foundat.:	Concrete		
Ext. walls :	doubl.brick	12 and 15	[cm]
Insolation	glasswool	12	[cm]
Floors :	Concrete	18	[cm]
Roof :	wood pitch		
Roof coat.	tiles		
Int. walls :	brick	12	[cm]
	Concrete	20	[cm]
Windows	Plastic		
Glass		double insol.	

Calculated energy needs (SIA380/1) :		
Heating en.	277	[MJ/m2 a]
W.wateren.	109	[MJ/m2 a]
Electricity	100	[MJ/m2 a]
Heating en.	gas	
Electricty :	UCPTE	

Results ECOPRO: ***per m2 use surface (969 m2) for 100 year lifetime***

Criteria :	*Phase :*	Construct.	Mainten.	Demolit.	Use	Total per year	Part use p.year %
Costs	[DM]	1900,00	8000,00	0,000	2200,00	121,00	18,18
Primary energy	[GJ]	9,00	14,00	0,150	120,00	1,43	83,83
Massflow (input)	[kg]	1700,00	950,00	0,000		26,50	0,00
GWP 100	[kg CO2 Eq]	490,00	540,00	2,300	6800,00	78,32	86,82
Nutrification	[kg PO4 3 Eq]	1,20	7,40	0,003	0,00	0,09	0,03
Acidification	[kg SO2 Eq]	7,60	39,00	0,023	72,00	1,19	60,70
ODP	[kg Eq]	0,00	0,00	0,000	0,00	0,00	87,11
POcP	[kg Ethylen Eq]	1,50	6,60	0,009	6,60	0,15	44,87
Humantox	[kg hum.weigh]	17,00	58,00	0,035	140,00	2,15	65,11
Ecotox	[kg Water]	2,80	10,00	0,000	27,00	0,40	67,84
Special waste	[m3]	0,03	0,18	0,031	0,03	0,00	11,40

Fig.3 : Results of the ECOPRO method for an average appartement building

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