REGENER

European methodology for the evaluation of

Environmental impact of buildings

- Life cycle assessment -

EUROPEAN COMMISSION, DIRECTORATE GENERAL XII FOR SCIENCE, RESEARCH AND DEVELOPMENT

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Abstract

The European commitments regarding the environment constitute new driving forces for technical innovation. The building sector, being the first energy consuming sector in Europe, is most concerned by this trend, which gives new chances for renewable energies and energy saving technologies. The REGENER project provides a common methodology for the evaluation of environmental impacts of buildings, based on « life cycle analysis ». This method allows a precise comparison of design alternatives, showing the possible environmental benefit of energy efficient techniques and providing arguments for their implementation by decision makers. First prototypes of tools have been developed in order to help architects to account for environmental performance in their design. A data base on building materials has been collected. Advice has been formulated for the use of life cycle analysis by target groups (policy makers, clients, architects, contractors and manufacturers). First example applications have been performed, e.g. for the « high environmental quality highschools » programme of Greater Paris Area. A set of brochures has been elaborated for the promotion of various R.E. techniques in this region, after a multi-criteria selection where environmental performance complemented the classical technico-economical assessment.

keywords

renewable energies, building, environment, life cycle analysis, design

1 OBJECTIVES

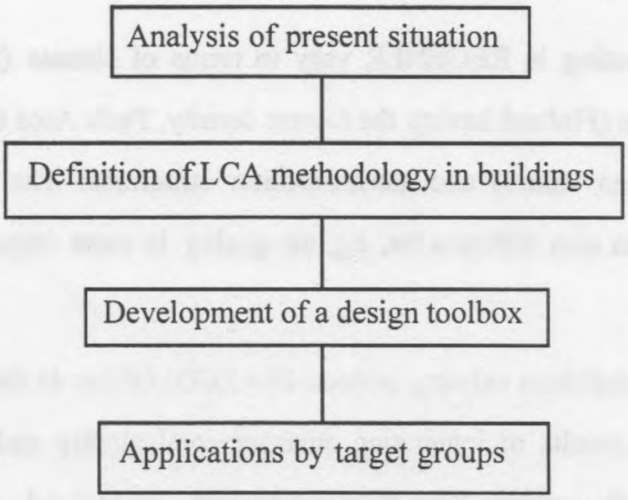
The research part of the project aimed to define a common methodology for the application of life cycle analysis (LCA) in the building sector, to collect data on building materials and to derive tools helping architects to integrate environmental performance objectives in their design.

The planned application part consisted in working with regional or local administrations in order to contribute to the improvement of environmental quality, particularly by the development of renewable energies (RE) in the building sector.

This complementarity between research and application aims to orientate research efforts according to the needs of target groups, and to disseminate more efficiently the results and final products among professionals.

2 METHODOLOGY

The project has been organized in four tasks, according to the following scheme.



Analysis of present situation, through questionnaires sent to decision makers, helped to identify the needs for life cycle analysis tools in the building sector and thus to orientate the research activities (tasks 2 and 3).

The common theoretical basis defined in task 2 for the application of LCA to buildings has been used for the improvement of various design tools, developed according to national specificities of design practice.

Guidelines for the application of LCA have been elaborated for the different target groups in the building sector. They are complemented by example applications of the design tools considered in task 3 (sensitivity studies, simplified software).

3 RESULTS

3.1 Analysis of present situation

Previous local experiences concerning environmental assessment and planning or renewable energy applications were first analysed in the regions of the Regener partners. A lack of knowledge has been identified concerning environmental assessment. The needs of decision makers have been reviewed in order to direct the development of appropriate LCA tools so that they can be efficiently integrated in the regional/ local planning processes to assist local authorities.

3.1.1. Assessment of previous plans

The regions participating in REGENER vary in terms of climate (from Italy to Finland), density of population (Finland having the lowest density, Paris Area the greatest, Umbria and the Netherlands mean values) and administration structures. The relative importance of environmental criteria also differs a lot, e.g. air quality is more important in urban districts than in remote areas.

Information is collected from existing projects like ECOLONIA in the Netherlands, for which the process and the results of integrating environmental quality and energy saving into the urban plan and building design have been considered. In Finland, several case studies are analysed : 20,000 summer residences equipped with off-grid photovoltaic systems; ORIVESI communal heating system where solar heating is experienced; the PUUHA project aiming to assess the economical interest of producing wood fuel from the forests of the Mikkeli Region.

A new tool for energy policy simulation, at the regional and town level, was recently implemented within the Ten-year Energy and Environmental Plan of the UMBRIA Region. It consists of an energy and environment policy simulator (TEP model). The residential building stock is classified according to the building type and technology, leading to a comprehensive sectoral energy demand/supply model for each of the 92 towns of Umbria. The model provides the energy conservation and substitution potentials, taking into account investment costs, local resources and environmental benefits. An environmental data base is used to compare alternative energy policies (conservation or substitution) according to the estimated potential reduction of environmental impact.

A study, performed for the GREATER PARIS Area, combines an economical evaluation with environmental and social criteria. Several typical existing projects are analysed. A review of bibliographical sources and local data bases allowed to list around 150 large scale systems. Private initiatives, often smaller, are not considered. Most systems are demonstration projects, aiming at the pomotion and test of new technologies, particularly the active collector systems in the 80's.

In these local experiences, only qualitative or simplified tools have been used for environmental assessment and the need for a more precise approach, able to better justify the decisions taken, was identified. LCA could correspond to this objective, provided that the tools developed are adapted to the decision process.

3.1.2 Analysis of the planning process and decision structure

The regional decision structures have been examined in Ile de France, Ecolonia and Umbria. Regions may promote techniques on a collective level (e.g. geothermics, wood fuel supply) but on the building level, the selection of technologies should be left open to the designers' choices. Regional administration should rather define targets concerning environmental criteria, like CO_2 emissions or equivalent contribution to air pollution, etc.

Environmental assessment of building projects can be of a very different character, depending on the design stage and the amount of available information. A whole series of tools to assist designers and clients have been developed. One of the shortcomings of these tools is that they are not integrated in the "planning" process. A more comprehensive assessment should ideally follow the principles of a **life cycle approach**.

In order to have a better view of the opinion of decision makers in the different regions involved in REGENER, a questionnaire was proposed.

Questionnaire for the analysis of decision processes

The questionnaire was organised in six sections corresponding to the process phases.

In all sections the following questions were formulated:

- what happened in the Region at this level ?
- how was it structured ?
- who played the major decisional and organisational role ?
- how could this phase be improved by applying LCA approaches ?

The following table summarizes possible uses of LCA along the decision process.

LCA methods within decisional process structures

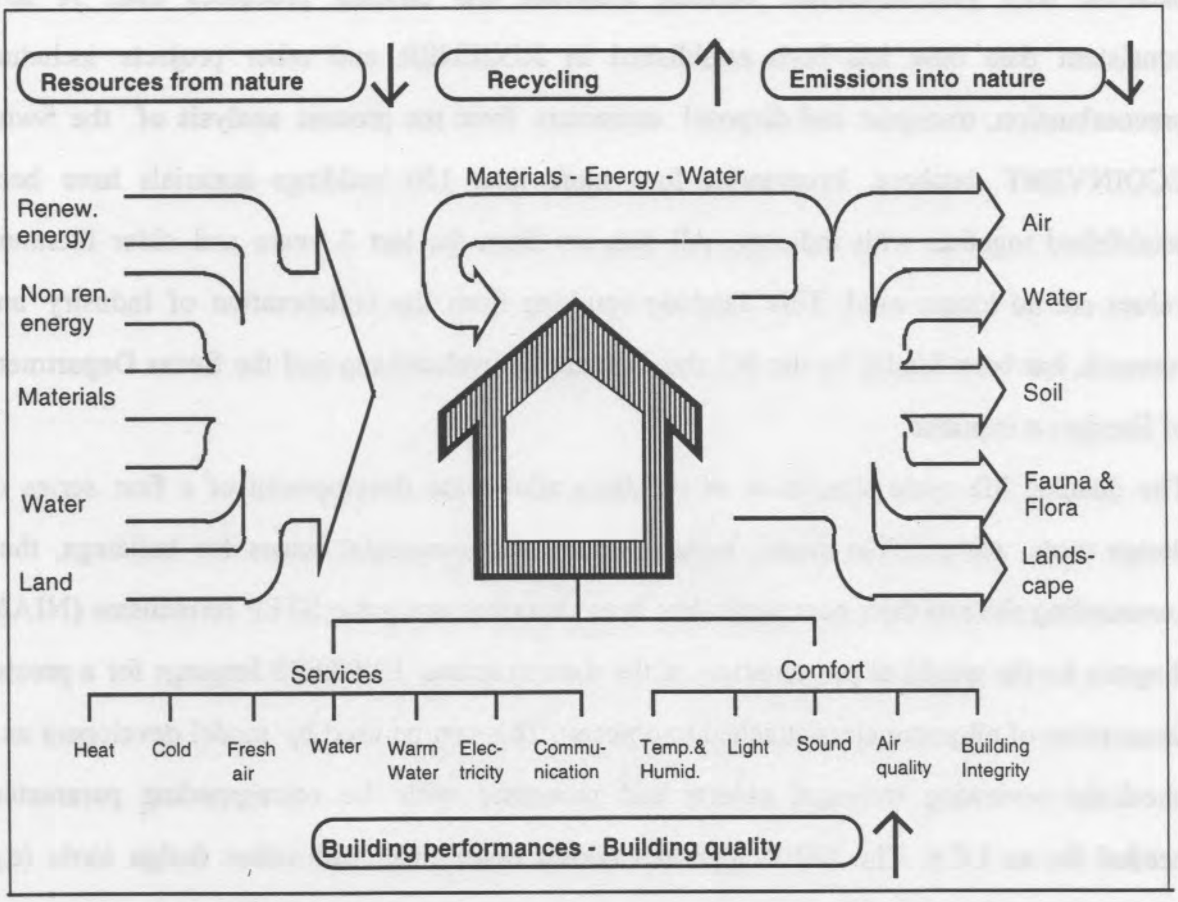
Process Phase	Ile-de-France	Ecolonia	Umbria Region
GOALS	identify relevant indicators for targets, difficult application	set targets referring to national statistics - limited role	set reference target of ecological impact - difficult application
POLICIES	set technico-economically realistic targets	set targets - limited role	defining mandatory schemes for a local application
PROGRAM	choose a site, improve performance specification, suggesting several alternatives to the designers	evaluating the design and comparing the alternatives - more general demands instead of very specific lists	implementing mandatory schemes (local authorities) - guidelines for LCA at the settlement scale
DESIGN	assessment of technical solutions, with multi-objective basis	real optimisation if LCA is limited to evaluation within the design process	design tool that enables the professional to evaluate design alternatives
SPECIFICATION	provide a serious and objective environmental assessment of the technologies used for specific solutions	help to specify materials with the lowest impact, not only by comparing products	specify building materials and assessment of their application in different design conditions
BUILDING	reduce on site impacts (e.g. management of construction waste)	limited role - calculation of the environmental impact should be part of the costs evaluation	assessment of the conformity between declared impact and actual impact

The above listed potential uses of LCA has been considered by the tool developers involved in the following tasks.

3.2 LCA methodology for buildings

The overall objectives in the building sector are to minimize the resource consumption and the emissions and to maximize the overall performances and quality of a building (comfort, reliability, function, form etc.). The inventory of mass and energy flows during the life cycle of a product is one generally accepted basis for the environmental impact evaluation.

The method of Life cycle assessment (LCA) has been developed by scientific associations like SETAC and has been widely accepted by industry and standardization boards (ISO). The complete LCA method has 5 steps : the definition of the objectives of the study, the inventory (quantification of mass and energy balances of the system), the classification (quantification of environmental indicators e.g. global warming potential), the evaluation (comparison of results with a reference) and the improvement (identification of the possibilities of reducing impacts).



LCA, which was mainly developed for industrial products with current life times of weeks and months had to be adapted to the building industry. Buildings are produced as one-of-a-kind products, their lifetime may be up to hundreds of years, they include a large and still growing number of materials, and their design process is complex, involving many actors with often contradicting targets. The system limits in time and in space have been defined and models for the simulation of the life cycle (maintenance, refurbishment) have been developed. Specific functional units (adapted to the different steps in planning from design brief through the design and construction process to facility management) have been defined.

The main effect-oriented evaluation methods (based on emissions) were taken from the current methods developed inside the SETAC group by CML and others. Additional methods had to be added to take into account resource consumption.

One of the principal shortcomings of all of the existing methods is the lack of a coherent database with precombustion, building materials and building processes data. A new consistent data base has been established in REGENER and other projects including precombustion, transport and disposal emissions from the process analysis of the Swiss ECOINVENT database. Inventories for more than 150 buildings materials have been established together with industry. All data are from the last 3 years and older literature values are no longer used. This database resulting from the collaboration of industry and research, has been funded by the EC, the German Umweltstiftung and the Swiss Department of Energy; it is public.

The detailed life cycle simulation of buildings allows the development of a first series of design tools. An example model, including many environmental issues for buildings, their surrounding site and their occupants, has been described using the STEP formalisms (NIAM diagram for the graphical presentation of the data structure, EXPRESS language for a precise description of all parameters attached to objects). This can be used by model developers as a check-list reviewing technical objects and processes with the corresponding parameters needed for an LCA. The STEP approach allows easier links with other design tools (e.g. CAD, other technical evaluations), as suggested in the previous COMBINE project.

The evolution of environmental assessment e.g. in ISO groups (TC 207 SC5) leads to more precise indicators. For instance, human toxicity is now evaluated by 4 themes : carcinogenic subtances, airborne and waterborne heavy metals, winter smog and summer smog.

Integration of life cycle assessment in the design process provides a more scientific basis in the construction field. There are however still many open questions for research : do multicriteria methods allow one to handle the complexity of several evaluation criteria, how to appreciate the impact on the local environment (town and regional planning), indoor air pollution (sick building syndrome) , worker protection, user protection during refurbishment. This research effort will only be successful if it is based on a close collaboration of industry, research institutions and designers.

3.3 Integration of environmental assessment in building design

When developing tools for assessing the environmental impact of buildings, it has to be taken into consideration when and where during the planning process which of these design tools will have to be used. Design tools are considered to be instruments intended as aids in the planning process. In order to be as effective as possible they must relate to the problems confronting the actors involved and to the way in which external knowledge and information is used to tackle these problems.

3.3.1 Development of a design toolbox

In this REGENER report a design toolbox is discussed that tries to take into account the different roles in the building process, the different phases in the building process and the distinction in the decision-making process and the design process. It is also tried to classify different types of environmental aspects by analyzing existing tools for sustainable building.

The design process of buildings is not linear. Design tools for LCA must be tailored to the main steps in the decision process. One question in the design brief is: do we need a new building or can we transform an existing building. In the building design the questions are how does a design alternative relate to functional performance, costs, energy consumption and environmental impáct. In the construction stage the optimal choice of building materials and building processes in relation to the ecotoxicological and humantoxilogical requirements are critical. At the same time the fuctional unit varies from very general m2 use surface to detailled building specification (e.g. 1 m3 of concrete).

Existing tools, theories on designing and decision making, and consulting practice have been analysed in order to study the relations between phases and actors in the planning process and to derive a general scheme for design tools.

On the basis of the inquiry into a toolbox for design tools on sustainable building it is suggested to distinguish three categories of environmental aspects and to make an assessment in every category. These assessments will occur in every phase of the building process. In the inquiry a subdivision of the building process in three phases is proposed. Ambitions can be formulated in performance standards. Also informative and implicit instruments should exist because performance standards alone are not sufficient to guarantee a good result. As most important roles in the building process a distinction is suggested in designing and decision-making.

Existing instruments should be adapted to the structure of this typology of tools and coordination between the tools for different phases, different environmental aspects and different roles is required.

3.3.2 Input parameters

A next step is to determine input needed for assessing the environmental inpact of a building and to make a distinction in input needed in every phase of the building process.

In order to give advice to building designers one would prefer to use environmental analysis tools at every project step (site selection, owner's brief, sketch, first project and detailed project). This complex process can be seen as a succession of input - evaluation - output phases. The parameters taken into account in the input step vary from a very simple description at early stages towards the most detailed model at the end. Therefore attention has been given to the importance of each parameter and its availability at the relevant design step.

3.3.3 Output and visualization

Output of three methods of environmental assessment of buildings is presented. The methods differ in the determination of local system limits, national conditions of building practice, and performance specification. The methods discussed are ECOPT/ECOPRO/ECOREAL, developed at IFIB (Germany), EQUER, developed by Ecole des Mines de Paris (France) and ECO-QUANTUM, developed by IVAM and W/E consultants (The Netherlands).

3.3.4 Comparison of approaches

Eventually, a reference building has been compared, applying three different methods and comparing the results obtained.

3.4 Applications by target groups

One of the specificities of the building sector is the large number of actors involved : policy makers, urban planners, clients, architects, engineers, manufacturers, contractors, occupants etc. We formulated guidelines and presented example applications according to these different target groups.

3.4.1 Policy makers

Life cycle analysis can help policy makers to quantify the contribution of the different economic sectors to the global environmental burden in a region, and to evaluate target values according to technico-economic constraints. In the building sector, such application would consist first to study typical buildings and quantify their environmental impact. In a second step, relevant technical alternatives (respecting socio-economic boundary conditions) could be compared to the reference and the environmental benefit obtained could lead to define target values (e.g. 10% reduction of CO2 emissions).

An example application concerned the development of RE in Greater Paris Area. A new agency has been created (ARENE, Regional Agency for Environment and Renewable Energies), and it was useful to assess previous activities in order to plan further development. A multicriteria assessment, where environmental criteria complemented technico-economic issues, lead to the selection of R.E. technologies appropriate in the regional context. A set of brochures has been elaborated for these technologies.

3.4.2 Municipalities

A software - CEADS, developed by JCEM (University of Colorado) - has been applied in a theoretical case study in order to present the possibilities of the tool concerning a performance assessment of R.E. technologies at a community level. A set of buildings (including different types) and infrastructure can be defined, integrating various R.E. or energy efficient elements (PV systems, active and passive solar, biomass, wind energy, waste incineration, cogeneration). The environmental benefit, compared to a reference case, is evaluated according to a set of criteria : reduced energy demand of the community, reduced emissions (Nox, SO2, CO2, particulates). R.E. can contribute to improve air quality in cities, provided they do not induce higher transportation needs.

3.4.3 Clients

Environmental objectives can be integrated in a building programme. This has been experimented e.g. for a highschool near Paris, where the competing teams had to fullfill a comprehensive set of requirements. In such a process, LCA can help to precise objectives according to a regional or local environmental policy, and to check if the proposed projects match these objectives. It would lead to replace, when possible, technical requirements by performance objectives. The choice of a technical solution by a client (e.g. wood fuel or geothermal heating in a highschool) can also be derived from a precise study, performed in a first step before the competition.

3.4.4 Architects and designers

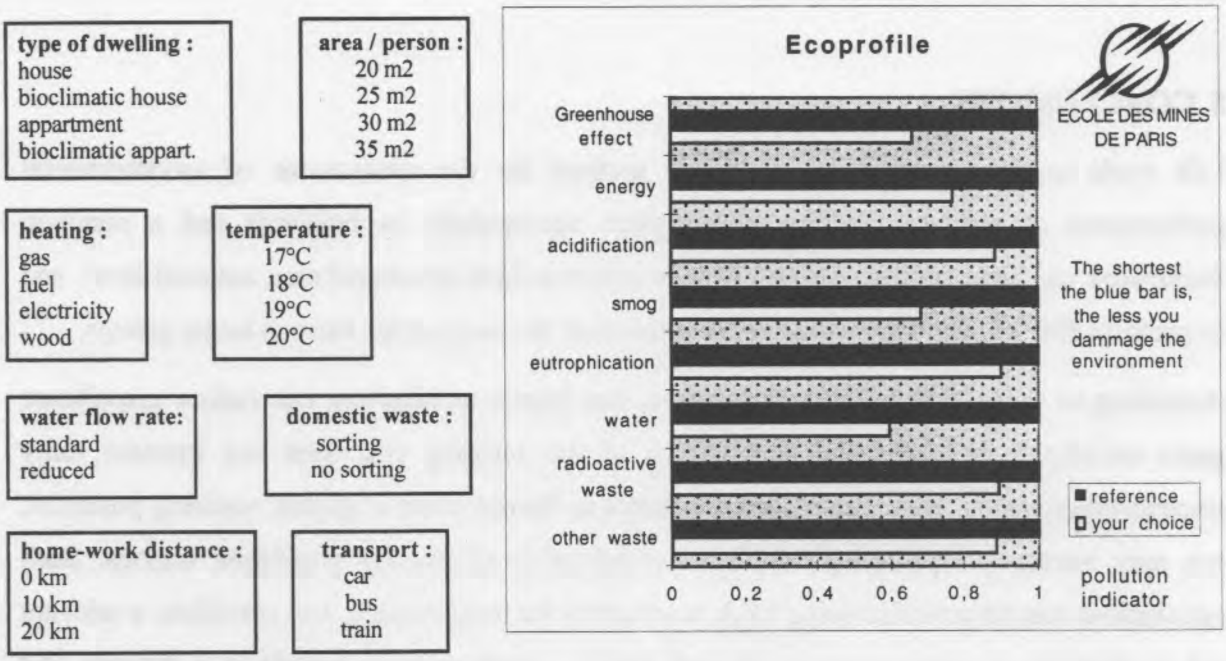
Example LCA based tools have been presented in task 3 : ECOPRO -developed by IFIB, University of Karlsruhe-, EQUER - authors : Ecole des Mines- and ECOQUANTUM -co-authors : W/E Sustainable Building-. They allow a comparison of alternative designs, once a first sketch has been drawn. A few sensitivity studies are presented, illustrating the environmental benefit of bioclimatic architecture in two cases : educational buildings and dwelling. The design process of a real project, called Educatorium, a multi-functional university building in Utrecht, The Netherlands has been considered as a case study to illustrate the added value of LCA based design tools in the future.

3.4.5 Manufacturers

LCA could orientate the development of innovative products according to environmental objectives. A product should be assessed accounting for all steps of its life duration, from its manufacturing to its disposal, through its implementation and use (including maintenance). Thus, LCA of buildings can provide manufacturers with useful information on products, accouting for their possible interaction with the rest of the envelope.

3.6 Occupants

According to first sensitivity studies, the performance of buildings results with a rather equal importance from design and occupants behaviour. It is thus essential to inform occupants about environmental consequences of their choices. A simple software, ECOPROFILE, has been developed for an exhibition at La Villette museum in Paris (« EcoLogis »). Visitors can click on choices on the left side of the screen, and an environmental profile is displayed on the right side by comparison with standard values. After an international architecture competition, an ecological house was built and an LCA has been performed. Compared to a standard house of the same size, the greenhouse gas emission is reduced by 20%.



4 EXPLOITATION PLANS AND ANTICIPATED BENEFITS

The common methodology defined in REGENER for the application of LCA in the building sector allows improvement of tools developed on a local level for the assessment of environmental quality of buildings. The link between these research activities and regional applications ensures adaptation of the tools to professional needs.

The « high environmental quality highschools program » of Greater Paris Area is a direct application of the knowledge developed. This program constitutes a good opportunity to demonstrate various R.E. and energy efficient techniques, with a justification based upon both economic and environmental arguments.

LCA tools provide a precise evaluation, which can convince decision makers of the interest of renewable energy concepts (e.g. bioclimatic architecture, solar water heating,...). Regional administrations can act as building clients and the integration of environmental objectives in their programs is an essential driving force for the development of R.E. techniques. Regions also provide advice towards the community level. ARENE for instance edited brochures presenting various R.E. techniques integrated in community equipment (office or educational buildings, social dwelling, sport equipment like swimming pools, etc.). Regional administrations constitute an efficient information mean to disseminate knowledge from research to practice.

The « EcoLogis » exhibition will be replicated in other cities in France, showing the interest of bioclimatic architecture and other « green technologies ».

The tools developed according to the REGENER methodology are being tested and progressively integrated in professional practice, e.g. DUMEZ (major contractor in France) is beginning to use EQUER in experimental projects.

5 CONCLUSIONS

Life cycle analysis constitutes a precise method for the assessment of environmental performance of products. It has been applied successfully to buildings and a common framework has been defined. This allowed to improve tools developed on a national level, and to perform first applications showing the interest of the method for various target groups.

According to these first application studies, bioclimatic architecture can reduce greenhouse gases emissions, provided that the choice of the building site does not increase daily transportation needs. Wood fuel also contributes to the reduction of global warming potential, but may increase air pollution which is not advisable in densely populated regions. Such conclusions can be provided using LCA, accounting for local context, and constitute a relevant aid to planning at community or regional levels : environmental benefit is a rational and efficient argument for the implementation of renewable energy technologies by decision makers.

At the building level, LCA can be integrated in the design practice and complements energy analysis tools developed in past European projects. Energy consumption has not the same environmental impact for heating (mainly fossile fuels), cooling (mainly summer electricity), daylighting and transportation, and thus kWhs should not simply be added. Balancing energy related impacts with impacts due to fabrication of materials, possibly water consumption, domestic waste management and transportation constitutes a more global approach, according to the concept of sustainable development. LCA provides such global balances, and allows comparison of alternative designs. It will contribute to convince clients and architects of the interest of some R.E. techniques, according to the function of the building project and local context, leading thus to the promotion of appropriate technologies.

The building sector being the first energy consumer in Europe, the penetration of R.E. in this sector is essential in order to fullfill commitments concerning the reduction of greenhouse gases emissions or the improvement of air quality in cities. The software developed according to the REGENER methodology constitute operational tools for the implementation of such environmental policies.

6 REFERENCES

Kohler N. Life cycle costs of buildings. European Forum on Building and Environment, University of British Columbia, Vancouver, Canada, march 1991

Cole R., Cooper I., Kohler N., Lützkendorf T. and Smith P., "Buildings and the Environment", Proceedings of the International Research Workshop, Cambridge, sept. 1992

Kohler N. Life cycle models of buildings. EuropIA'95. Lyon 1995.

HAB Weimar / Ifib / ETHZ-LES : Baustoffökoinventare. Ifib - Karslruhe 1996 (LCA Inventories of 160 building materials)

Peuportier B., Development of a design tool for architects, International research workshop « Buildings and the Environment », Cambridge, september 1992

REGENER, Regional planning for the development of renewable energies, APAS contractors seminar, Venice, novembre 1995

Polster B., Peuportier B., Blanc Sommereux I., Diaz Pedregal P., Gobin C. and Durand E., Evaluation of the environmental quality of buildings - a step towards a more environmentally conscious design, Solar Energy vol. 57 n°3, 1996

Boonstra C., Method Environmental Preference for Building Materials, First CIB Conference on Building and Environment, 1994

David Anink, Chiel Boonstra, John Mak; Handbook of Sustainable Building, An Environmental Preference Method for Choosing Materials in Construction and Refurbishment, ISBN 1-873936-38-9, James&James Science Publishers, London, May 1996