LIFE CYCLE ASSESSMENT APPLIED TO URBAN SETTLEMENTS AND URBAN MORPHOLOGY STUDIES

HERFRAY G., VORGER E., PEUPORTIER B.

CEP, MINES ParisTech, 5 rue Léon Blum, 91120 PALAISEAU, FRANCE

ABSTRACT

Life Cycle Assessment (LCA) is increasingly used to improve the environmental performance of products, and its application in the building sector seems promising. Several tools have been developed and compared in the frame of the European Thematic Network PRESCO (Practical recommendations for sustainable construction). An LCA model has been developed for Settlements, in order to help the decision making process during their design or renovation.

The system considered includes buildings, public spaces (streets, parks…) and networks (drinking water, sewage, district heating). All phases of the life cycle are modelled: fabrication of products, transport, construction, operation, renovation, dismantling and waste treatment with possible recycling. This model allows an evaluation of different impact indicators (e.g. resource depletion, energy and water consumption, global warming, waste generation, toxicity…), and the comparison between different design alternatives to be performed. The aim is to assess the influence of buildings and urban morphology on the environmental impacts of a settlement project.

The operation phase is long lasting, so that processes like heating/cooling play an important role in the global environmental balance. Decisions made at the level of the settlement (orientation of streets, compactness and urban density) have a large impact on heating/cooling loads. Therefore the LCA tool is linked to thermal simulation. Some development is on-going regarding dynamic-LCA aspects, particularly accounting for the temporal evolution of the electricity production mix. This communication presents an application of the model on case studies inspired by Quartier Vauban in Freiburg. The aim is to define a best practice reference to which other projects can be compared.

INTRODUCTION

Buildings and urban settlements are complex systems. Knowledge is still missing regarding the links between decisions, particularly design choices, and environmental impacts. Such knowledge and derived tools is needed by professionals in order to progress in their practice of eco-design.

This communication presents a model developed at the settlement's scale, on a cradle to grave basis, in order to compare design alternatives on an environmental point of view, addressing impacts from a regional to a global scale. When evaluating a project using such a model, it is useful to compare performances using a benchmark. In order to identify best practice references, the model has been applied to case studies inspired from Quartier Vauban in Freiburg.

METHOD

As we consider here that in the case of a settlement, most impacts are related to the production of energy, water, materials etc, which occurs out of the settlement, Life Cycle Assessment (LCA) has been used rather than impact evaluation focussing a local system. Impacts can occur on a global scale, like in the case of climate change, or the depletion of the ozone layer, at a regional scale, with the acidification or eutrophication problems, or at a local scale, as with smog or waste production. We choose here to use the LCA methodology, in order to get the most comprehensive information about the consequences of settlement on the environment. This methodology permits the calculation of various indicators, e.g. damage-oriented, regarding the human health, the biodiversity or resource depletion.

LCA is a standardized assessment methodology [1], permitting the study of a system from its production to its end of life. LCA is composed of four main steps: after the definition of the goal and the scope of the study, the system is clearly defined (principally its functional unit and boundaries) and the hypothesis of the study specified, then the inventory analysis is performed. This inventory is an account of all substances taken and emitted in the environment, during the whole life cycle of the system. From this account, indicators corresponding to impacts are calculated. All those steps are directly linked with an interpretation phase, which may imply a new definition of the system or the goal and scope of the study (for example if a lack of data appears during the inventory phase).

The model developed for the settlements' study take into account four stages in the life cycle: construction, operation, renovation and dismantling of the settlement [2][3]. The calculation of the inventory is based on two different aspects: first on the production, the renovation and the elimination of what is included in a physical boundary, then on the assessment of all that is included in the flows boundary defined in our model, which include transport, water, energy, materials and settlement's components and waste. The settlement is composed of different types of buildings, open spaces, networks and optional district heating production infrastructure. Because energy consumption represents a large part of the environmental burden, heating and cooling loads are evaluated for the different buildings using a dynamic multi-zonal simulation [4]. A graphical interface simplifies data input, making possible to study a large number of buildings within the time constraints of professional practice.

PRESENTATION OF THE CASE STUDY

The model presented above has been applied on two settlements inspired from the eco-district Vauban in Freiburg (Germany) [5]. The first one named "low energy neighbourhood" (LEN) is representative of the major part of the whole eco-district. The second one, named "plus-energy neighbourhood" (PEN) is similar to the Solar-City designed by Rolph Disch, but adapted in order to harmonize the number of inhabitants in the two cases.

Both include dwellings, a tertiary building, an elementary school and a parking lot of four levels including a supermarket in its ground floor and a photovoltaic system on the roof.

In order to use these models as references for a comparison with projects in Greater Paris area, the two settlements are contextualized in the model, e.g. using climatic data for Paris and the French electricity mix.

The surfaces of the open-spaces and the number of buildings of the plus-energy neighbourhood represented above have been adapted so that the two settlements include the same number of inhabitants.

Plus-energy neighbourhood (PEN) (Architect Rolf Disch)	**Low-energy neighbourhood (LEN) (Quartier Vauban)**

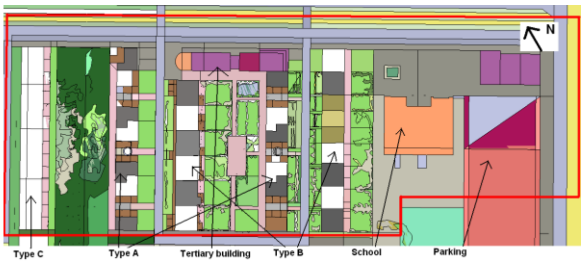

Figure 1 : overview of the two settlements

Settlements characteristics	**PEN**	**LEN**
Settlement area	39,000 m²	24,000 m²
Built area	7,000 m²	6,000 m²
Area of street and pavement	9,000 m²	9,000 m²
Area of green spaces and garden	23,000 m²	9,000 m²
Number of inhabitants	394	394
Average area of the dwellings	138 m²	87 m²
Number of employees – offices	100	100
Number of employees - school	10	10
Number of employees - supermarket	15	15
Number of pupils - school	110	110

Table 1: Characteristics of both settlements

Building models include different thermal zones according to their orientation and function (dwelling, offices…). The functions are modelled using weekly and hourly scenarios regarding occupancy (in number of occupants per zone or per m²), ventilation (in m3 per hour, taking into account the infiltrations), internal gains (W/m²), heating and cooling set points (°C). Building characteristics are indicated in Table 2.

Thermal performances	Plus-energy neighbourhood	Low-energy neighbourhood
Glazing, U in W/(m².K)	0,70 (triple glazing)	0,87 (triple glazing)
Outer walls, U in W/(m².K)	0,12 (exterior insulation)	0,16 (exterior insulation)
Ground floor slab, U in W/(m².K)	0,16	0,16
Roof, U in W/(m².K)	0,11	0,11
Thermal bridges around the slab W/(m.K)	0,05	0,10
Average heating load of the buildings	17 kWh/m².year	23 kWh/m².year

Table 2: Thermal performances of the building

We also define the cold and hot water consumption in litter per day per person, as well as the characteristics of the public spaces (type, composition, surface, needs of lighting and water, imperviousness), and of the heating, drinking water and sewage networks (length, composition, maintenance…).
Because the objective is to compare urban and architectural choices, aspects related primarily to occupants' behaviour, e.g. domestic waste sorting, choice of home-work transport mode etc. are not accounted for, but they are included in the model.
Buildings are heated by district heating, the source being a cogeneration plant using 20% of natural gas and 80% of wood with an efficiency of 26% for electric production and 61% for heat production. The domestic hot water is produced 50% by this plant and 50% by solar panels (410 m² of south oriented collectors for both settlements). The French electricity production mix is considered (78% nuclear, 14% hydroelectric or renewable, 4% gas and 4% coal) with 9% losses in the network. 5 440 m² of photovoltaic panels are integrated on roofs for the plus-energy neighbourhood and 1 650 m² for the low-energy neighbourhood.
The life cycle assessment is performed considering a 80 years life span, but this parameter can be varied in sensitivity studies. Demolition waste is considered treated as inert waste, except metals that are recycled. Impact indicators are normalized in equivalent inhabitants-year, using French references (e.g. 8.7 t eq. CO_2 emissions per person and per year).

RESULTS

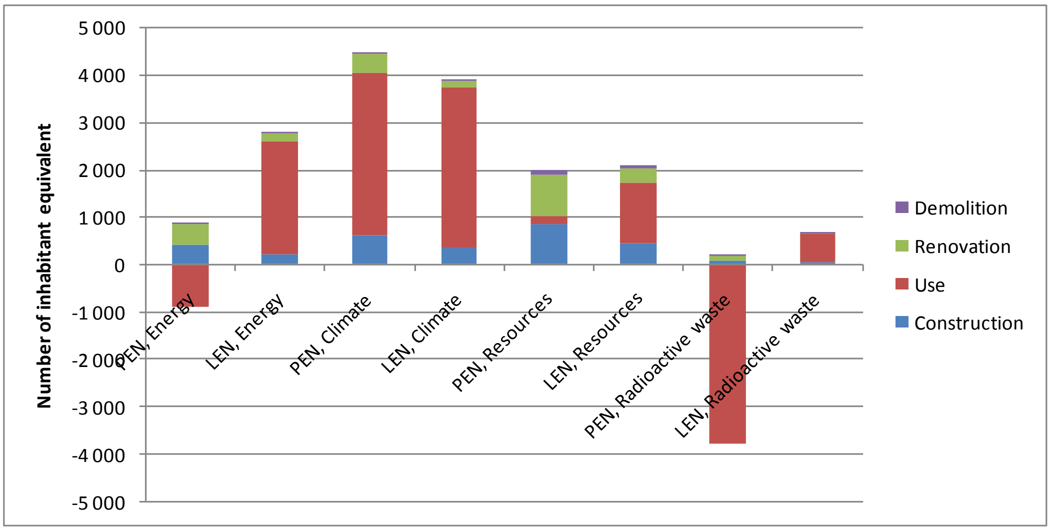

Figure 2: Comparative total life cycle impacts on four indicators

The histogram above presents the results of the LCA for the two settlements, on four indicators (of the twelve existing), decomposed into four life cycle phases.
The first indicator is the primary energy consumption. More energy is consumed in the PEN for construction and renovation, due to the fabrication of PV modules, but the renewable electricity production (combined with solar hot water and co-generation systems) compensates this consumption so that the overall performance is higher than for the LEN (see Table 3).

	PEN		**LEN**	
	Use phase	**Life cycle**	**Use Phase**	**Life cycle**
Photovoltaic	-100%	-85%	-29%	-25%
Cogeneration	-9%	-8%	-10%	-9%
Thermal solar	-8%	-7%	-9%	-8%
Total	-117%	-100%	-47%	-42%

Table 3: primary energy balance compared to a reference without photovoltaic, cogeneration and thermal solar

The trend is similar regarding resource depletion, but PV production does not allow a zero impact to be achieved. In this indicator, the use of gas has a large effect than the uranium saved by renewable electricity production. The balance would probably be different if probable instead of ultimate reserves are considered in the impact assessment, and further research is still needed on such topics.

The French electric mix consists in 78% of nuclear power. Avoiding a standard production, the electricity produced by the cogeneration and the photovoltaic systems reduce heavily the generation of radioactive waste.
The climate change indicator (t CO2 equiv) presents an impact 15% higher for the PEN than for the LEN. The difference appears principally during the phases of construction, renovation and demolition, due to the fabrication of photovoltaic panels, whereas the impacts of the use phase are very close for the two settlements. This result can be explained by the electric mix, which includes only 4% of gas and 4% of coal thermal plants. Therefore solar electricity production doesn't influence significantly the greenhouse effect indicator (-8% for the PEN and -2% for the LEN).
On the other hand, the impact is higher for the PEN because the dwelling area per occupant is higher in this settlement. In fact, by m² of heated surface, the impact on greenhouse effect is lower by 18% for the PEN than for the LEN.

DISCUSSION

Comparing the energy performance of different urban forms leads to different conclusions, e.g. regarding appropriate glazing ratio and solar exposure. One main reason for such variability is related to assumptions regarding occupant's behaviour, particularly the management of solar protection and window opening. Applying LCA extends the problematic, accounting for the use of materials and addressing various environmental impacts. For instance compactness may reduce material quantities, which may displace the optimum evaluated using only energy assessment. But environmental performance is greatly influenced by occupants' behaviour. Standard scenarios have been used in the present study, but sensitivity analysis would be useful to complement the comparison of alternatives.

Comparing urban morphologies requires harmonization of the functional unit considered. This is complex for a settlement including various types of buildings (dwellings, tertiary buildings, shops…), infrastructures (parking loan, roads…), of different size, capacities, characteristics... It is therefore difficult to define a universal benchmark and best practice reference that can be used to assess the performance of projects, e.g. for labelling purposes. Perspectives for methodological improvement are discussed e.g. in the frame of the European LORE-LCA research coordination action, aiming at identifying good practice and knowledge gaps regarding the application of LCA in the building sector. For instance, some elements are neglected when modelling large systems like urban districts, inducing the question of the validity of such cut off rules.

CONCLUSION

Sustainability is on the agenda of most organisations, and particularly cities. Accounting for environmental issues in the building and urban sectors is presently based upon rather subjective approaches. Yet the severity and planetary extent, long duration and possible irreversibility of environmental impacts like global warming, nuclear risk, dispersion of toxic substances, biodiversity loss and resource depletion, justifies more precise tools to be used in the decision making process. Developing such tools therefore corresponds to the needs of professionals, and can be based upon experience gained in the industry, using methods like LCA. The example comparison presented here illustrates the possibility to compare alternatives on a multi-criteria basis, showing advantages and draw-backs of the different solutions. Further activities are planned to improve the methodology and perform sensitivity studies, e.g. regarding life span and occupants' behaviour.

ACKNOWLEDGEMENTS

CEP takes part in the European research coordination action LORE LCA (Low Resource consumption buildings and constructions by use of LCA in design and decision making) coordinated by SINTEF (Norway). Some work is also performed with the help of national projects (ANR) and a Chair "Eco-design of buildings and infrastructure" has been created by ParisTech with the support of VINCI.

REFERENCES

1. International Organization for Standardization (ISO): Environmental Management – Life Cycle Assessment - Principles and framework. European standard EN ISO 14040, Geneva, 2006.
2. Herfray, G., Peuportier, B., « Life Cycle Assessment applied to urban settlements », Sustainable Building 2010 international conference, Revitalization and Rehabilitation of Districts, Madrid, Spain, 2010.
3. Popovici, E.: "Contribution to the life cycle assessment of settlements", thèse de l'école des Mines de Paris, 204 p., 2006.
4. Peuportier B. and Blanc Sommereux I., Simulation tool with its expert interface for the thermal design of multizone buildings, International Journal of Solar Energy, vol. 8 pp 109-120, 1990.
5. Heinze1 M. and Voss K., Goal: zero energy building, Exemplary Experience Based on the Solar Estate *Solarsiedlung Freiburg am Schlierberg,* Journal of green building, Vol 4 n°4, 2009.