LIFE CYCLE ASSESSMENT APPLIED TO THE COMPARATIVE EVALUATION OF SINGLE FAMILY HOUSES IN THE FRENCH CONTEXT

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ABSTRACT

A life cycle simulation tool has been developed and linked with thermal simulation. Inventories given in the Oekoinventare data base or collected in the European REGENER project are considered to evaluate the environmental impacts of material fabrication and other processes (energy, transport,…). An application of this tool is presented here concerning the comparison of three houses : the present construction standard in France (reference), a solar and a wooden frame house. The results of this exercise are presented and its limits are discussed. It seems still difficult to apply life cycle assessment (LCA) to the selection of materials and components. Rather, LCA can be used for the improvement of technical solutions (e.g. increasing the roof insulation in the solar house).

INTRODUCTION

The motivation for solar or bioclimatic architecture was first to save natural resources by reducing energy consumption in buildings, while providing a high level of thermal comfort. End of the 80's, energy prices decreased and energy saving was not perceived anymore as a major issue in France. Concern for broader environmental problems like global warming or ozone depletion, stricter regulations concerning waste and water management, higher concern for toxicity appeared at the beginning of the 90's. This context leads to question again the design and construction approach and to study the application of the sustainability concept in the building sector.

Sustainability includes both the satisfaction of present needs and the ability of future generations to satisfy theirs, which imposes to make a synthesis between potentially contradicting aspects. Bioclimatic architecture is an example of such a synthesis where both comfort issues (present needs) and energy efficiency (future) are addressed. This synthesis is often misunderstood, e.g. an air-conditioned sunspace was proposed in a project during a competition for "high environmental quality" in France, with the argument that a sunspace is ecological and that more comfort is achieved by air-conditioning. The building is existing, and we can check that the comfort is poor and that the energy bill is high. In most "high environmental quality" buildings, the approach has been based upon symbols rather than on the assessment of environmental impacts. Many examples show that substantial education effort is still necessary.

Compensation is often underlying environmental evaluation methods, e.g. one project may have good points on comfort and bad points on pollution, so that the global evaluation is correct. In fact according to its definition, sustainability does not mean finding such a compromise between our needs and environmental safeguards, but a synthesis allowing a long term functioning of ecosystems.

The environmental impact of a building depends on decisions taken by a large quantity of actors: owners, designers, enterprises, inhabitants, etc. An evaluation tool can help these actors to foresee the consequences of their decisions and to integrate environmental aspects into their choices, preferably by adopting prevention strategies. We propose here a contribution concerning the evaluation of quantifiable environmental impacts of buildings. The methodology is presented and illustrated by a comparative study of single family houses. The results and the limits of the present knowledge are then discussed.

1 PRESENTATION OF THE METHOD : LIFE CYCLE ASSESSMENT APPLIED TO BUILDINGS

Evaluating the environmental quality of buildings has been discussed in various seminars (e.g. [1]). We used the life cycle assessment (LCA) method [2.3] because environmental quality is the result of a global process integrating the whole life of a complex system. Occupants behaviour and interactions with the surrounding site should be taken into account, so that a specific approach must be developed for buildings [4]. LCA methods represent a rational approach, which can evolve with the progress of knowledge, and this may help various actors to agree on common strategies. The interest and potential of new technologies like renewable energy systems can be assessed by this precise approach. Another advantage is the standardisation of LCA [3], allowing a link between evaluations concerning materials and buildings.

This work has been done within the French EQUER project (Evaluation of environmental quality of buildings), gathering researchers and professional partners [5].

A general framework for applying LCA in buildings has been elaborated in the European project REGENER [4].

The different phases considered in a building life cycle are: the fabrication of components, the construction, the use of the building, the renovation and the renewal of components, the final dismantling and the treatment after use of components. The possible reuse and recycling of components is also taken into account.

We consider in the environmental assessment of a building only its influence on the outside environment. The aspects related to the inside comfort are supposed to be addressed by other existing tools. Therefore the calculation of the inside air quality, illumination and noise level as well as the thermal comfort analysis are not dealt with in this article. They are however implicitly taken into account in the definition of the "functional unit", cf. § 1.1.

The environmental impact of building components or processes (e.g. energy use, transport) can be evaluated on the basis of inventories. An inventory is a table of impact factors, indicating the quantity of each emitted or used substance with regard to the unit of the component or process. The used inventories contain impact factors on the following categories:

- the used resources (e.g. rare materials, energy),
- the emissions into air, water, ground (e.g. CO_2 into air, ammonia into water, oil into ground),
- the created waste (e.. inert, toxic, radioactive).

Data collected in the REGENER project [4], or from the Oekoinventare data base [6] has been used concerning the inventories corresponding to the different processes considered (energy, transportation, manufacturing of building materials).

The overall input and output of a whole building during its life cycle is calculated by the tool and constitutes the inventory of the building.

Beyond the product definition, LCA requires the definition of the "functional unit" considered and the system boundaries. According to ISO 14040 standard [3], the models considered for energy, transport and recycling processes should also be presented. The used method for aggregating the data of the building inventory, in order to get an environmental profile, has also to be indicated.

1.1 Definition of the functional unit

Comparing different products by LCA is meaningful only if these products fulfil the same function. A building has many functions : allowing activities, providing comfort, etc. Thus the functional unit has to be defined so that different buildings compared provide the same services, over a similar duration.

We consider as the functional unit a whole building, built in a given site and planned for a specified use (dwelling, office,...). This building is of course generally occupied and is assumed comfortable and healthy. Its comfort is defined by a given set point temperature (possibly varying in the time), for heating and if needed for air conditioning, and by sufficient illumination, ventilation and noise protection. A satisfactory indoor air quality is necessary for sanitary reasons. Also a unit of living area (one m2) can be used as functional unit under the same conditions as above which allows the comparison of different projects on an homogeneous basis.

1.2 System boundaries

The system boundaries define which fluxes (e.g. materials and energy used, emissions) are taken into consideration and if the impacts due to infrastructure (construction, maintenance,...) are assigned to the studied system in a certain proportion.

Processes could take place inside or outside a building. We take into account direct fluxes caused by external processes (e.g. energy use for transportation of materials), but the effects created by making available their infrastructure are in general negligible (e.g. the impacts corresponding to the production of a truck are negligible compared to the impact of fuel combustion over the whole service life of the truck). External processes are for example the fabrication of building components, their transport and recycling processes and waste treatment. Daily transport of occupants and urban waste processing may be included according to the purpose of the study, e.g. if different building sites are compared and the possibility of sorting domestic waste is studied.

For processes which could also be located in a building (e.g. water treatment) making their infrastructure available is taken into account. This allows a comparison between an external system and a system integrated in the building, for which the construction impact is accounted for. This approach is applied to energy production and water processing. Thus we can study local electricity production by a photovoltaic system, solar space heating, passive cooling, reuse of grey water, rain water collection, etc. An example of this approach is the production of domestic hot water which can be done either by using a solar collector or fossil fuel. All the fabrication processes of the collector are attributed to the building, as well as its maintenance and dismantling. This represents the infrastructure for the used solar energy. Therefore, to be homogeneous when comparing both systems, the infrastructure of the used energy for hot water production by fossil fuel (for fuel oil extraction, transport and refinery) has also to be taken into account.

1.3 Energy

The boundaries for the energy processes being already presented in the above paragraph, only the model of energy recovery for waste incineration will be explained here. If waste, either from building components or domestic waste, is burnt in an incinerator its intrinsic energy can be recovered and used for heat or electricity generation. We consider that the avoided impact has to be credited to the building inventory which in all cases (with energy recovery or not) will be charged with the pollution due to waste incineration. Therefore the amount of replaced fuel and its emissions, corresponding to the recovered energy, will be counted negative. Seasonal variations in heat or electricity demand may reduce the efficiency of the energy recovery and should thus be taken into account. Accounting for waste treatment allows the comparison of possible building sites, for instance one with heat recovery and another one with a combined heat and power system.

The energy loads for heating and if needed for air conditioning during a building's use phase have to be calculated. We are using the thermal simulation tool COMFIE [7], and we created links between this software and the developed environmental evaluation tool. We use simulation rather then correlation so that solar heating and passive cooling can be evaluated on a dynamic basis, accounting for energy collection, storage and distribution, and allowing the assessment of thermal comfort.

1.4 Transport

We distinguish four means of transport: truck, railway, ship and aircraft. A building component can be transported successively by different means. Building components differ much in density. We propose therefore an approach based on the load of a transport mean. According to the density of a transported good the load is either expressed by the weight or by the volume which can be transported. The inventories for a transport over 1km correspond to a full load. The part attributed to a building component is evaluated by the weight or volume ratio based on the full load.

We suppose that railway carriages, ships and aircraft only make a one way travel to deliver the goods. Therefore, they do not return empty but with other goods and hence the impacts of the return travel must not be accounted. We suppose also that a truck transports another good at least on a part of its return travel as the haulage firms limit empty tours. Due to this fact, we count only the impacts of half of the return distance.

The daily transport of the building occupants is supposed to be done by car or collective transport (e.g. bus). Average data on the use of the transport types are proposed as default values. They depend on the type of the building site (urban, suburban, rural, remote) and the distances to the next transport station, to work and to the next shopping centre.

1.5 Recycling

Recycling products reduces in general environmental impacts, particularly the use of resources and waste creation. For example, the fabrication of steel from old iron needs about half the energy used to produce steel from iron ore, according to Haberstatter [8]. The former releases as well only about half of CO_2 than the later and creates about 280 kg less waste per ton of steel. The recycling process of concrete produces granules which can be used in road construction, avoiding the use of other resources like gravel.

These two examples allow to distinguish two different recycling types for building materials. Steel is an example for a material, which after recycling can be reused for the same application. This is called closed loop recycling. On the other hand, recycled concrete can less easily be reused for the same application. The corresponding recycling process is called down-cycling or open loop recycling. It concerns materials which were degraded during their use or recycling process, or compositions where the materials can not be separated.

Reusing a building material is handled like closed loop recycling. We define as reuse a process during which a material is not transformed between two cycles, whereas it is transformed temporarily into another state during the recycling process (e.g. melted).

1.5.1 Building materials

There is a rising demand nowadays that architectonic solutions should favour the use of recycled materials for building construction, including the fabrication of building components. But they should also allow the recycling of building components at the end of their life cycle or after a building's dismantling. The recycling model should thus take both ends into consideration.

The positive effect of recycling, being considered as a negative or avoided impact, can be expressed by the material's recycling inventory I_r minus its new fabrication inventory I_n (which would be counted if there was no recycling) for the recycled part r. This positive effect occurs only once during the life cycle of a material (corresponding to one recycling run). It must therefore not be counted twice, for both fabrication and treatment after use. As recycling should be favoured at the beginning and at the end of a building's life cycle, we decided to share the avoided impact equally between these two phases. Hence, the following equations are applied for theses phases:

$$I_f = I_n + (r_f / 2) . (I_r - I_n) \tag{1}$$

$$I_t = i . I_i + d . I_d + (r_t / 2) . (I_r - I_n) \tag{2}$$

I_f represents the fabrication inventory, I_t the treatment after use inventory, I_i the incineration inventory and I_d the dumping inventory. The recycled part at the fabrication level is represented by r_f whereas r_t represents the recycled part in the treatment after use. For the later, the incinerated part is i and the dumped one is d. Equations (1) and (2) are applied for closed loop recycling processes.

In closed loops, the recycling and new fabrication inventories I_r and I_n are the same for a material's fabrication and treatment after use because the same processes are used. But these processes are not the same in open loop recycling. Nevertheless, equation (1) can be applied for the fabrication of a building material in an open loop recycling process. In this case, I_r represents the recycling inventory of a material becoming the building material after down-cycling and I_n represents the new fabrication inventory of this building material. For the treatment after use of the building material the last term of equation (2) has to be replaced because the processes involved are not the same as for fabrication. The term is replaced by $(I_r'-I_n')$ where I_r' represents the recycling process of the building material down-cycled to another material and I_n' represents the new fabrication process of a material to be replaced by the down-cycled building material.

In general, the number of cycles is limited, even in "closed" loop recycling. If n is the maximal number of recycling runs, the maximal recycling rate r_m is $n/(n+1)$. If the average recycling rate for a material of the studied building $(r_f+r_t)/2$, exceeds r_m, then pollution is displaced into another building. A penalty term is thus added to equation (1), depending on the sum of the material's incineration and dumping rates.

This term expresses the impact of the fabrication and treatment after use, related to the recycled part and distributed on the recycling runs. The above defined condition is only applied to closed loop recycling, as there is no theoretical maximal recycling rate in an open loop. The recycling rate in open loops can be limited by downwards applications (e.g. recycled PVC) or upstream production (e.g. gypsum from flue gas treatment in power plants), but we have not considered this aspect in the present step of our work.

1.5.2 Domestic waste

The model for the recycling of building materials, which shares the positive effects of recycling between fabrication and treatment after use, is not used for domestic waste. This is due to the fact that the building sector has no influence on the fabrication of the goods becoming domestic waste. Thus, we consider a fixed inventory I_f for this fabrication. But it can favour the sorting of domestic waste and hence reduce the impact of waste treatment. Therefore we decided to attribute completely the avoided impact, due to recycling, to the treatment of domestic waste. This leads for this phase to the following equation:

$$I_t = i \,.\, I_i + d \,.\, I_d + r_t \,.\, (I_r - I_n') \qquad (3)$$

I_r represents the inventory of the recycling process of domestic waste and I_n' represents the new fabrication inventory of the goods which are replaced by the recycled domestic waste.

1.6 Environmental profile

The first quantitative output of the environmental assessment is an inventory. It contains usually a large amount of data, up to a few hundreds of substances. Therefore, comparisons between products are hardly possible by using such inventories. Hence, data is usually aggregated on environmental themes in order to present the final output in the form of an environmental profile. The definition of the profile considered here (cf. table 1) is partly based on a classification method published by Heijungs et al. [9]. For some of the themes (e.g. energy or water consumption) an absolute value is calculated. On the other hand, themes like global warming or acidification can only be assessed by a potential, expressed as an equivalent quantity of a reference substance (e.g. kg CO_2 for global warming). The list of environmental themes and aggregation methods is still in evolution.

Table 1: Environmental themes considered

environmental theme	**expressed by**	**Profile name**	**unit**
energy consumption	absolute value	ENERGY	MJ
water consumption	absolute value	WATER	m3
depletion of abiotic resources	absolute value	RESOURCES	10^{-9} (1/1 billion), dimensionless, calculated by dividing used resources by known resources
waste creation	absolute value	WASTE	tons
radioactive waste creation	absolute value	RAD-WASTE	dm3
global warming	potential	GWP100	ton CO_2 equivalent
depletion of the ozone layer	potential	ODP	kg CFC-11 equivalent
acidification	potential	ACIDIFICATION	kg SO_2 equivalent
eutrophication	potential	EUTROPHICATION.	kg PO_4^{3-} equivalent
aquatic ecotoxicity	potential	ECOTOX-W	m3 of polluted water
human toxicity	potential	HUMAN-TOX	kg, human weight
photochemical oxidant formation	potential	O3-SMOG	kg C_2H_4 equivalent
malodorous air	potential	ODOUR	m3 of contaminated air (ammonia is used as a reference)

1.7 Limits of the approach

There are still many uncertainties and limits to the present state of the art of LCA. The uncertainties concern both the data (inventories) and indicators : for instance, the global warming potential (GWP) of other gases than CO_2 is known with 35% uncertainty [10]. Indicators related to human or eco-toxicity are doubtful because the location of the emissions is not considered. Air pollution inside buildings might have a much larger effect than diluted external emissions. Also, the processes occurring at the end of the building life cycle are difficult to foresee, particularly because buildings are generally long lasting (though it may be assumed that mixing materials - concrete with polystyrene or wood for instance- will make the future waste management more difficult).

The tool developed is not assessing indoor environmental quality (e.g. air quality, acoustic or visual comfort), but the related constraints have to be respected (cf. definition of the functional unit, § 1.1). Accidental risk analysis is not concerned as we assumed that this topic is accounted for in safety and work legislation. Esthetical aspects are neither included.

2 BUILDING MODEL AND SIMULATION TOOL

Our project consists in developing a simulation tool which allows the comparison of alternative designs. The simulation tool EQUER [5] is based upon a building model structured in objects, compatible with the thermal simulation tool COMFIE [7]. The functional unit considered is the whole building over a certain duration. Impacts due to the activities of occupants (e.g. home-work transportation, domestic waste production, water consumption) may be taken into account, e.g. when comparing various building sites with different home-work distances, waste collection and treatment system, water network efficiency etc.

Coupling LCA and energy calculations simplifies the use of the tool, and makes the comparison of design alternatives easier. The two models are linked according to a formalism taken from the STEP approach (standard for computer data exchange, [11]).

The main classes are the products (building materials or finishes), the components (manufactured set of products like windows, shading devices,...), the subsystems (on-site built set of products and components like walls or zones), the whole building and the building site. A zone is here meant as a thermal zone, i.e. a part of the building with an homogeneous thermal behaviour. It may include several rooms with the same occupancy schedule, orientation, internal heat gains. This thermal-oriented description can be conflicting with other evaluations (e.g. acoustic, day-lighting). A day-lighting module has been added to the thermal simulation tool. This module uses another description, based upon rooms. In order to simplify this presentation, we do not consider here comfort issues and we restrict the topic of this communication to life cycle assessment. The different phases of a building life cycle are considered (figure 1).

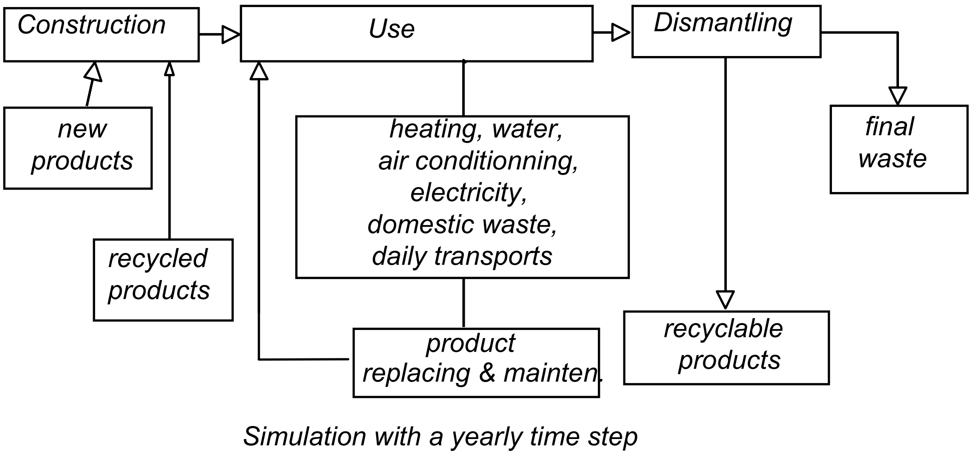

Figure 1: Principle for calculating the inventory of the whole building

The output of the software is an ecoprofile including the different CML indicators (global warming, acidification, eutrophication potentials, smog, etc.), cf. [9], plus some aggregated values like primary energy and water consumption, and generation of radioactive and other waste (cf. table 1). These indicators are given either for the different phases or for different alternatives or projects. We have used this last option in this presentation.

The limits of the methodology have been indicated in the previous paragraph. These limits induce many opportunities for improvement of this assessment methodology, e.g. by improving the indicators, by using stochastic analysis and dynamic simulation.

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3 ILLUSTRATION : COMPARATIVE STUDY OF SINGLE FAMILY HOUSES

As an illustration of the approach, we have performed a life cycle assessment of the house being selected in a solar house competition in France, organised by Observ'ER. We have compared the results to a reference corresponding to the present construction standard, and to a well insulated wooden frame house.

3.1 Description of the three houses considered

A typical house, corresponding to the present construction standard in France and named "Reference house" in the following tables and graphs, has been defined in the frame of a workshop organised by the French ministry of dwelling (Plan Construction et Architecture) and is considered here as a reference. Information from the national statistics institute (INSEE) has been used to identify the most common techniques. A typical plan has been defined by an Architect. The result is the description of a single family house with 112 sqm living area. The walls are made of concrete blocks with an internal insulation layer (8 cm polystyrene) and 1 cm gypsum plastering. The 12 cm thick gravel concrete slab lays upon 6 cm polystyrene. The upper ceiling is covered with 20 cm mineral wool, under a clay tiles roof. The PVC frame windows are double glazed (overall K-value : 3 W/sqm/K). The house is heated by a gas boiler. The ventilation is mechanical (0.6 air change per hour). The heating consumption is around 8,000 kWh/year (i.e. 70 kWh/sqm/year).

This reference house is typical from the French situation, and its thermal performance is certainly low compared to e.g. the Swedish or German standards. A comparison of houses designed according to the thermal regulation in different countries would be very interesting but should take into account investment and functioning costs in various social and climatic contexts. Such an extensive study is not addressed here.

The house selected in the competition organised by Observ'ER (named "Observ'ER house") is larger (212 sqm), and the main construction materials are stones and wood. The roof insulation is rather weak (10 cm polystyrene) and the roof area is large because the house is on a single level, which leads to a high heating load : 130 kWh/sqm/year. But a solar floor heating system with a solar fraction of 30% reduces this value to 90 kWh/sqm/year.

The third house (named "CNDB house") is proposed as a wooden frame reference by CNDB (Comité National pour le Développement du Bois). The house is more insulated than the previous one : 20 cm mineral wool in the roof and walls instead of 12 cm paper flocks in the walls and 10 cm polystyrene in the roof of the previous house. The heating load is then 35 kWh/sqm/year, the living area being 155 sqm. The other parameters (type of glazing, thermostat set point, electricity consumption, internal gains, etc.) are equivalent for the three houses. The characteristics of the three houses are summarised in table 2. The same ventilation rate, i.e. 0.6 air change per hour, the same internal gains (40 kWh/m2/year, including occupants and other heat sources) and the same temperature (19°C) is considered in the three cases.

Table 2 : Main characteristics of the three houses

Parameter	Reference house	Observ'ER house	CNDB house
Wall composition	Concrete blocks + 8 cm internal insulation (polystyrene)	wooden frame above a stone lower part, with 12 cm paper flocks insulation	Wooden frame with 20 cm mineral wool insulation
Roof composition	Clay tiles and 20 cm mineral wool	10 cm polystyrene under a vegetal terrace roof	Clay tiles and 20 cm mineral wool
Slab composition	12 cm gravel concrete slab upon 6 cm polystyrene	13 cm concrete slab upon 4 cm polystyrene	30 cm concrete slab upon 4 cm polystyrene
Glazing type	Standard double glazing	Standard double glazing	Standard double glazing

3.2 Results and interpretation

The Observ'ER house is larger and induces higher environmental impacts, e.g. twice as much CO_2 emissions than the reference house. But the quality of life in both houses is not equivalent. According to the purpose of the study (here to compare design approaches rather than living standards), it may be more relevant to consider one sqm living area as the functional unit rather than the whole house. The following comparative ecoprofile is then obtained (cf. figure 2).

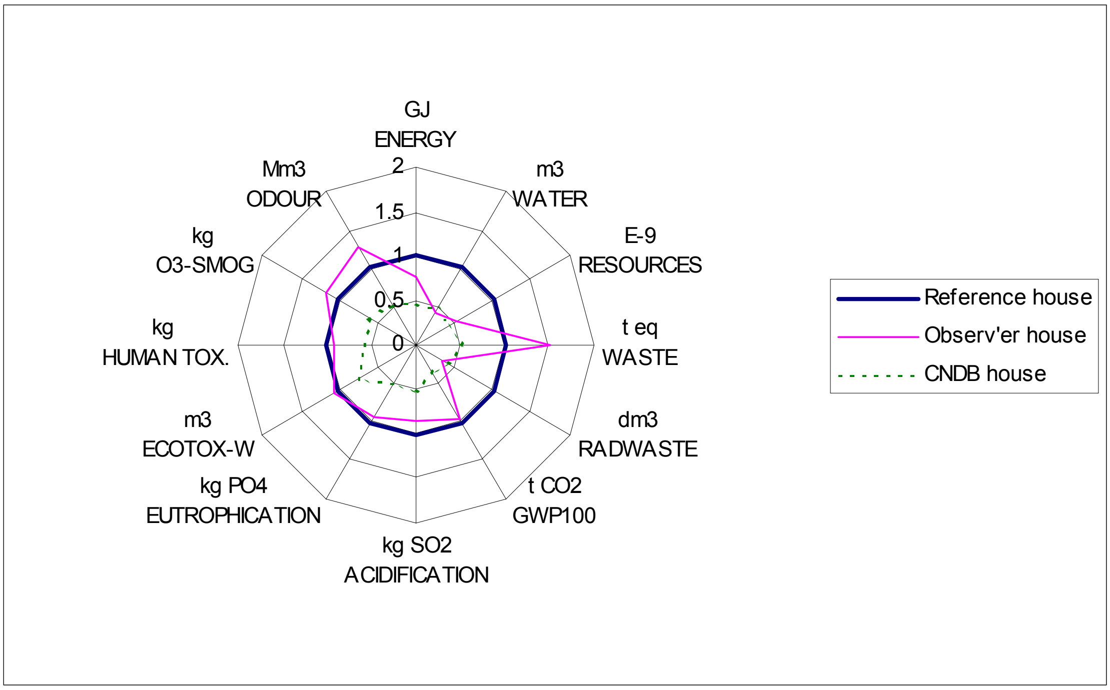

Figure 2 : Comparative ecoprofile of 1 sqm living area for the three houses

The environmental impacts estimated for the standard wooden frame house are about half the reference values. It would have been rather easy to achieve equivalent thermal insulation in the solar house, leading to a much better environmental performance.

A sensitivity study has then been performed concerning the choice of materials (wood versus concrete blocks), the type of heating energy (gas versus electricity) and the transport distance of the wood (local production with 100 km transport by truck versus 5,000 km transport by ship plus 500 km transport by truck). It is not possible to present detailed results here, and we just illustrate this comparison using the global warming indicator during construction and use phases. Assuming a 100 km transport by truck for all materials, transport-related equivalent CO_2 emissions represent only 1.5% of the total. If the wood is transported over a longer distance (5,000 km by ship and 500 km by truck) the total transport related contribution increases to 2.4% of the global life cycle CO_2 emissions, which remains limited.

End of life processes, e.g. energy recovery from wood incineration are difficult to foresee : in this illustration, all waste is supposed land-filled. A sensitivity study has been made, to assess an alternative in which the wood is incinerated. The CO_2 emissions at the end of life phase are increased by 34 tons, corresponding to a 8% increase of the total emissions. If we assume a 50% probability of landfill and incineration, the probabilistic CO_2 emissions would be around 500 tons. Such a stochastic assessment could be generalised to other uncertain parameters.

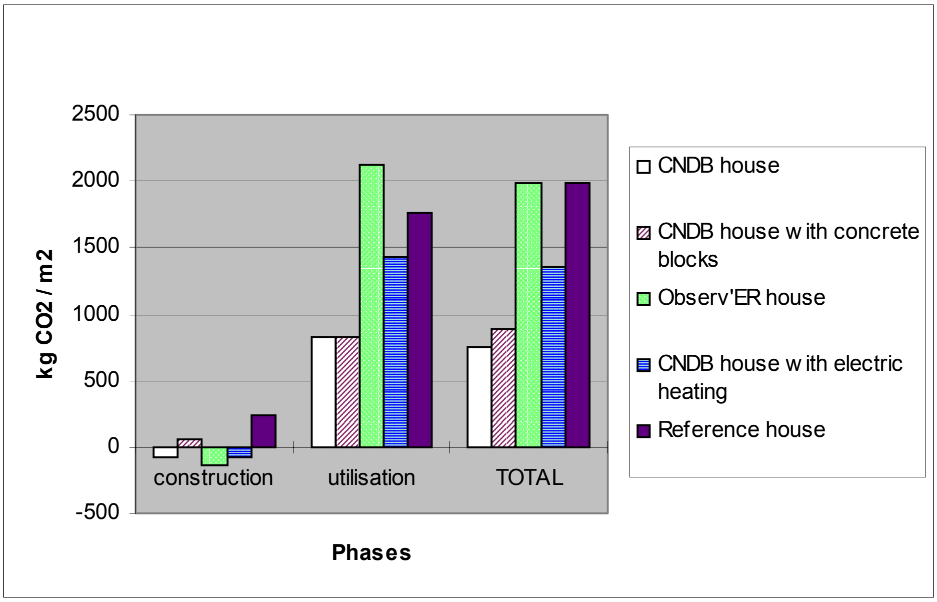

Figure 3: Sensitivity of the GWP to various parameters

The variation of CO_2 emissions between wood and concrete blocks houses represents 18% of the total emissions for the wooden house, but accounting for end of life processes may reduce this value. According to the Oekoinventare database (version 3, 1996), the production of 1 kg of wood board allows the storage of 3.49 kg CO_2. In the photosynthesis reactions, 1.85 kg CO_2 is absorbed to produce 1 kg of wood, so that is seems that several kg of wood are necessary to produce 1 kg of end product (wood boards). Sawing, transport and drying processes are accounted for. According to the same database, the land-filling of 1 kg wood produces 0.0036 kg CO_2 and its incineration 1.47 kg CO_2. The overall balance over the whole life cycle is thus not neutral. Other authors write that considering a negative global warming potential for wood is incorrect, because the wood will be sooner or later incinerated or land-filled, so that the CO_2 balance will be neutral or positive.

The sensitivity to the heating energy is also controversial, because of the uncertainty concerning the mix considered for the electricity production : we considered 41% thermal plants due to the seasonal peak demand induced by electric heating [12], but the French electricity company considers the annual mix including only 8% thermal production. It is wished that electricity companies can provide more information about their production mix, e.g. hourly values for a typical year. It can be noticed that in some countries, electricity is not recommended for heating purposes.

Another question raised is the temporal evolution of the performances, e.g. the sensitivity to a variation of insulation material conductivity. To study this aspect, we varied the conductivity of the paper flocks used in the Observ'ER house. A 25% variation of the conductivity, i.e. from 0.04 to 0.05 W/(m.K), leads to a 2.4% increase of the heating load and a 2.3% increase of the overall CO_2 emissions. A dynamic simulation could be performed, in which the performance of materials and equipment (e.g. the efficiency of the boiler) is varying each yearly time step.

4 DISCUSSION AND CONCLUSIONS

The results concerning the comparison of materials (concrete blocks versus wood) should be validated by checking the corresponding inventories (production and end of life) with the concerned manufacturers. The electricity production in France is an example where the future processes are still unknown and different scenarios can be considered (an 80 years period has been considered in this application). The same approach using probabilistic scenarios could also be used e.g. for the management of demolition waste at the end of the building life.

For some of the indicators, the contribution of the building sector could be negligible among all human activities, and the corresponding axis should be given a small weight in the comparison. This could be achieved thanks to normalisation, and such a procedure is planned. Then the user might define customised weighting factors according to preferences and priorities chosen by the actors concerned by the study. Such a procedure is not yet common among decision makers.

Despite of these limits, some conclusions might be drawn from such experimental application. A wooden frame structure allows a significant storage of CO_2 over the life of a building and reduces the waste produced at the demolition phase, but attention should be paid on thermal comfort, according to the climatic conditions : a detailed study is needed, accounting for the occupancy schedule of inhabitants. Impacts related to the transport of building products seems limited. High thermal insulation, use of renewable energy and choice of an efficient heating system remain appropriate measures to reduce the environmental impacts of buildings.

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