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# Evaluation of a building using the emergy method

F. Meillaud [a,b,*], J.-B. Gay [a], M.T. Brown [c]

[a] Solar Energy and Building Physics Laboratory, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland
[b] Institute of Microtechnology, University of Neuchâtel, Breguet 2, CH-2000 Neuchâtel, Switzerland
[c] Center for Wetlands, University of Florida, Gainesville 32611, USA

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**Abstract**

Emergy (spelled with an m) is the energy of one kind, usually solar energy, which is required to make a service or product. The yearly emergy consumption/production of a building is evaluated considering the Solar Energy Laboratory (LESO) building on the campus of the Swiss Federal Institute of Technology of Lausanne (Switzerland). This experimental building was constructed according to special environmental considerations, such as important the use of passive gains (heat emitted from solar radiations, electric appliances and building users). It is therefore characterized by a very low energy consumption, equal to 232 MJ/m$^2$ year. The LESO building is occupied by faculty and students. Undergraduate and graduate students as well as faculty represent information inputs to the system with their emergy accounting for 94.6% of the emergy inputs to the building, equal to 3.3E18 sej/year (solar emjoules per year).

"Educated students" (students who have completed a semester project, master's or PhD research in the laboratory), publications, courses and services are the main outputs of the system. The four outputs are considered as co-outputs, as such the total emergy associated to the operation of the building as a structure is entirely assigned to each of them. The evaluation established that a student leaving the LESO building has a transformity (emergy per unit energy) equal to 2.4E8 sej/J, which is about three times higher than the one which he/she had upon arrival, representing the knowledge gained through conferences and interactions with other students and professors.

Considering only energy and materials inputs, electricity was established to be the largest input to the system (2.7E16 sej/year). The total emergy of the material inflows was determined to equal 1.7E16 sej/year, paper being the largest material input (5.7E15 sej/year). The specific emergy (per mass) of some common building materials was also evaluated and compared to NRE (non-renewable energy).

Finally, the question of uncertainties related to the determination and use of average transformities and emergy per mass values is addressed, and advantages and drawbacks of the emergy method are discussed in relation to other common evaluation methodology (exergy, embodied energy, life-cycle analysis).


*Keywords:* Emergy evaluation; Building; Information production

* Corresponding author. Present address: Institute of Microtechnology, University of Neuchâtel, Breguet 2, CH-2000 Neuchâtel, Switzerland. Tel.: + 41 32 718 33 19; fax: +41 32 718 32 01.
*E-mail address:* fanny.meillaud@unine.ch (F. Meillaud).

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**Nomenclature**

| | | | |
|---|---|---|---|
| $J_{em}$ | emergy per unit time (sej/year, solar emjoules per year), Eq. (1) | $J_i$ | energy flow (J/year), Eq. (1) |
| | | $Tr_i$ | transformity (sej/J), Eq. (1) |

## 1. Introduction

### 1.1. LESO building

The experimental LESO building is three-stories containing faculty and students offices and a workshop. A photovoltaic (PV) installation is situated on the roof. The building was constructed in 1981 with different solar facades that could be individually analyzed. A homogenous south facade, replacing these units, was built in 1999 in accordance with sustainable development strategies and a drastic reduction of the use of non-renewable energy, as described in (Altherr and Gay, 2002), see Fig. 1. The LESO building energy consumption, 232 MJ/m$^2$ year, is subdivided as follows: 156 MJ/m$^2$ year for electricity and 76 MJ/m$^2$ year for heat, for a treated floor area (area that is heated and lighted) of 765 m$^2$. Seventy-five percent of the electricity consumption is associated with the presence of data-processing equipment and machines (Altherr and Gay, 2002). The PV installation covers approximately nine percent of the electricity requirements of the building. The heat consumption is very low, as gains by windows (solar gains), electric appliances and presence of people cover 75% of the total heat requirements.

### 1.2. Emergy definitions

By definition, emergy is the available energy of one kind that has been used up directly and indirectly to make a product or service (Odum, 1996). It may also be considered as a measure of the entropy that has been produced over the transformation process (Lloyd and Pagel, 1988). The term emergy was first introduced in 1987 as the "memory of energy" (Scienceman, 1987). Studies about the relationship between society and environment had then already been done for more than 10 years by H.T. Odum, (see for example Odum, 1971). A crucial concept that has occupied emergy theory during its evolution has been the notion of energy quality. Indeed, different forms of energy have different abilities to do work, and it is necessary to account for these different abilities if energies are to be estimated correctly. Some evaluations consider each flow in an "oil equivalent amount" before comparing them, whereas emergy evaluation expresses all flows using the common measure of solar energy. Emergy therefore accounts for quality differences among distinct forms of energy and allows for the inclusion of information and monetary flows to those of energy and materials.

Emergy per unit time is calculated using:

$$J_{em} = \sum (J_1 \cdot Tr_1 + J_2 \cdot Tr_2 + \cdots + J_i \cdot Tr_i) \quad (1)$$

where $J_{em}$ is the emergy per unit time, for example year, and is expressed in sej/year (solar emjoules per year), $J_i$ is an energy flow in J/year and $Tr_i$ the corresponding transformity in sej/J.

Fig. 1. View of the south facade and photovolatic installation of the LESO building.

*Unit emergy values* are calculated based on the emergy required to produce them. There are three types of unit emergy values as follows:

*Transformity* is one example of a unit emergy value and is defined as the *emergy per unit of available energy*. For example, if 4000 solar emjoules are required to generate a joule of wood, then the solar transformity of that wood is 4000 solar emjoules per joule (abbreviated sej/J). Solar energy is the largest but most dispersed energy input to the earth. *The solar transformity of the sunlight absorbed by the earth is 1.0 by definition*.

*Specific emergy* is the unit emergy value of matter defined as the emergy per mass, usually expressed as solar emergy per gram (sej/g). Solids may be evaluated best with data on emergy per unit mass; because energy is required to concentrate materials, the unit emergy value of any substance increases with concentration. Elements and compounds not abundant in nature therefore have higher emergy/mass ratios when found in concentrated form since more work was required to concentrate them, both spatially and chemically.

*Emergy per unit money* is a unit emergy value used to convert money payments into emergy units. Since money is paid to people for their services and not to the environment, the contribution to a process represented by monetary payments is the emergy that people purchase with the money. The amount of resources that money buys depends on the amount of emergy supporting the economy and the amount of money circulating. An average emergy/money ratio in solar emjoules/unit cost can be calculated by dividing the total emergy use of a state or nation by its gross economic product. It varies by country and has been shown to decrease each year. This emergy/money ratio is useful for evaluating service inputs given in money units where an average wage rate is appropriate.

To derive the unit emergy value of a resource or product, it is necessary to trace back through all the resource and energy flows that were used for its production, and express all the inputs in the amount of emergy that went into their own production process. To avoid the emergy calculation of resources and commodities every time a process is evaluated, unit emergy values established earlier are commonly used. There is no single unit emergy value for most products, but typically a range: average values are used whenever the exact origin of a resource or commodity is not known or not calculated separately. Uncertainties related to the use of average values instead of specific unit emergy has been suggested as a major shortcoming of the emergy method, and will be discussed later (see Discussion).

## 2. Method

The general methodology for emergy evaluations has been explained in numerous publications (Odum, 1996; Brown and Ulgiati, 1997; Ulgiati and Brown, 2001) and thus only a brief summary is given here. The first step of the emergy evaluation is to construct a systems diagram that is a means of organizing thinking and relationships between components and pathways of exchange and resource flow.

The diagramming starts by defining the system boundary, as well as all energy sources and system components. The boundary of the system is represented by a rectangular frame, whereas sources and systems components are drawn using systems language symbols, some of which are presented with a short description in Table 1. Sources and systems components are placed in the diagram in a hierarchical order of quality (transformity) from left to right.

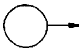
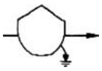
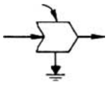
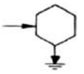
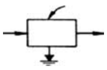
Sensors can also be added to the diagram and are represented by small rectangles on pathways or on the side of storage tanks. Their presence means that the pathway or the storage controls some other flow but does not supply the main energy. Sensors were for example added to the building structure tank in the diagram of the LESO building, presented in Fig. 2, to express that no material is actually leaving the tank, but the building structure is part of various interaction processes. Then the next step of the emergy evaluation is to construct emergy tables directly from the diagrams where each input flow becomes a row in the table to be evaluated. Finally, if simulations are part of the evaluation, equations can be written from the diagram and used to write computer simulation programs (Odum, 1994, 2002; Odum and Odum, 2000).

## 3. Results

### 3.1. Systems diagram

The systems diagram of the LESO building is presented in Fig. 2. The boundary of the system is defined as the building and PV installation. The main components of the system include the building structure (and facade), the heating system, electric appliances and equipment, the building users and PV installation. All components are placed in a hierarchical order of quality from left to right like the external sources, which are sun, water, (raw) materials, heat, electricity, appliances, equipment, furniture, services, as well as two "information sources" and a "students" one. Water source represents the water used for sanitary installation and is considered as a renewable resource (see Table 2, note 2). Hot water is accounted for as heat provided to the building by a heat pump, and is represented by the external source of heat. Apart from this external source, heat is also produced as primary flow by the electric heating system or as secondary flow by the electric appliances and building users. And, the structure also produces

Table 1
Main systems symbols and a short description of their meaning (Odum, 1996)

| | |
|---|---|
|  | *Energy circuit*: A pathway whose flow is proportional to the quantity in the storage or source upstream |
|  | *Source*: Outside source of energy delivering forces according to a program controlled from outside: a forcing function Any input that crosses the system boundary is a source, including pure energy flows, materials and information |
|  | *Tank*: A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable |
|  | *Heat sink*: Dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system |
|  | *Interaction*: Interactive intersection of two pathways coupled to produce an outflow in proportion to a function of both; control action of one flow on another; limiting factor action; work gate. The flows that are controlled enter and leave from the sides and the pathways that control the switches are drawn entering from above to the top of the symbol |
|  | *Consumer*: Unit that transforms energy quality, stores it, and feeds it back autocatalytically to improve inflow |
|  | *Box*: Miscellaneous symbol to use for whatever unit or function is labelled |

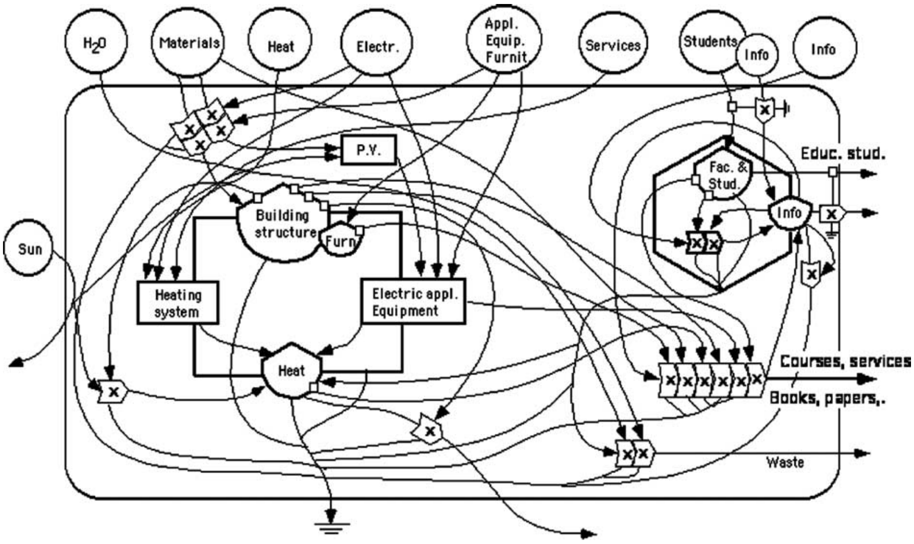



Fig. 2. Systems diagram for the LESO building.

heat by capturing solar radiations via the windows. Heat is released through two different processes: (1) the use of blinds and the opening of windows by the users, and (2) the depreciation of energy associated with any real system (entropy). Transformity of heat was established from the electricity consumption of the heat pump and its performance coefficient, as well as the transformity of electricity. This latter was established considering the Swiss electricity mix (57% of hydro-electricity and 43% of nuclear electricity).

Appliances, equipment and furniture inflows are estimated from the money paid to purchase them, as detailed data of the materials composing them was not available. Services (human labor) are also estimated the same way.

The building structure is represented as a material tank, its inflow and outflow corresponding to the necessary replacement of some materials depending on their lifetime (see Table 2). A tank of furniture is added on its side and both tanks storages are drawn together with the heating system and electric appliances to represent the "material components" of the building.

The faculty and students (as well as secretaries and technical staff) working in the building are represented

Table 2
Emergy table of inputs and outputs of the LESO building

| 1 Note | 2 Item | 3 Data units per year | 4 Unit emergy values sej/unit | 5 Solar emergy E14 sej/year | 6 Fraction of total emergy inflows % | 7 EmSwiss Francs year 2000 E4 CHF | 8 Ref.[a] |
|---|---|---|---|---|---|---|---|
| | *Renewable inputs* | | | | | | |
| 1 | Sun | 2.41E+12 J | 1.00E+00 | 0.02 | 0.0001 | 0.0004 | [a] |
| 2 | Water | 2.96E+08 J | 4.80E+04 | 0.14 | 0.0004 | 0.00 | [a] |
| | *Non renewable inputs* | | | | | | |
| | a. Materials | | | | | | |
| | a.1. Maintenance of the building | | | | | | |
| 3 | Wood | 2.79E+02 kg | 8.79E+11 | 2.45 | 0.007 | 0.042 | [b] |
| 4 | Screeds | 8.30E+02 kg | 1.72E+12 | 14.27 | 0.04 | 0.24 | [c] |
| 5 | Plaster | 8.64E+02 kg | 1.96E+12 | 16.93 | 0.05 | 0.29 | [c] |
| 6 | Iron | 3.48E+02 kg | 4.15E+12 | 14.45 | 0.04 | 0.25 | [b] |
| 7 | Aluminium | 1.35E+01 kg | 1.27E+13 | 1.71 | 0.005 | 0.03 | [b] |
| 8 | Copper | 1.43E+01 kg | 6.77E+13 | 9.65 | 0.03 | 0.16 | [d] |
| 9 | Glass | 4.83E+01 kg | 7.87E+12 | 3.80 | 0.011 | 0.06 | [b] |
| 10 | Expanded polystyrene | 2.79E+01 kg | 6.88E+12 | 1.92 | 0.006 | 0.03 | [c] |
| 11 | Natural Rubber | 1.30E+02 kg | 4.30E+12 | 5.58 | 0.02 | 0.09 | [d] |
| 12 | Painting | 1.22E+02 kg | 1.52E+13 | 18.53 | 0.05 | 0.32 | [b] |
| | a.2. Material used by faculty and students | | | | | | |
| 13 | Paper | 2.40E+03 kg | 2.38E+12 | 57.19 | 0.17 | 0.97 | [c] |
| 14 | Plastic | 7.80E+01 kg | 5.76E+12 | 4.49 | 0.01 | 0.08 | [b] |
| 15 | Metal (for the workshop) | 1.50E+02 kg | 9.28E+12 | 13.92 | 0.04 | 0.24 | [b] |
| | b. Energy | | | | | | |
| 16 | Heat (Heat Pump) | 3.74E+10 J | 4.37E+04 | 16.35 | 0.05 | 0.28 | [c] |
| 17 | Electricity | 1.44E+11 J | 1.88E+05 | 271.48 | 0.79 | 4.62 | [c] |
| | c. Goods and services | | | | | | |
| 18 | Appliances, equipment, furniture | 5.32E+03 CHF | 5.88E+11 | 31.27 | 0.09 | 0.53 | [c] |
| 19 | Services | 2.37E+05 CHF | 5.88E+11 | 1392.59 | 4.03 | 23.68 | [c] |
| | d. Students and information | | | | | | |
| 20 | Students (graduated and ungraduated) | 1.44E+10 J | 7.33E+07 | 10566.53 | 30.57 | 179.70 | [a] |
| 21 | Faculty | 3.40E+09 J | 3.43E+08 | 11648.11 | 33.70 | 198.10 | [a] |
| 22 | Secretaries et technical staff | 2.70E+09 J | 2.46E+07 | 664.91 | 1.92 | | [a] |
| 23 | External information | 8.79E+09 J | 1.12E+08 | 9805.52 | 28.37 | 166.76 | [c] |
| | *Outputs* | | | | | | |
| 24 | Educated students | 9.90E+08 J | 2.40E+08 | 2374.78 | | 40.39 | [c] |
| 25 | Publications | 7.30E+02 page | 3.39E+15 | 24763.56 | | 421.15 | [c] |
| 26 | Courses | 1.71E+02 h | 1.84E+15 | 3133.74 | | 53.29 | [c] |
| 27 | "Services" | 7.00E+04 CHF | 1.47E+13 | 10315.45 | | 175.43 | [c] |
| | *Budget* | | | | | | |
| 28 | Budget of the LESO | 2.00E+06 CHF | 5.88E+11 | 11760.00 | | 200.00 | [c] |

[a] References: [a] Odum (1996); [b] Buranakarn (1998); [c] Self-established (Meillaud, 2003) and [d] Odum (1983).

as consumers, with one tank corresponding to their population. The information tank represents the scientific knowledge of the building users. A "students" source is drawn together with an information source to characterize the students working in the building, as each of them brings previous knowledge (represented by the information source). There is also another external source of information, which symbolizes incoming information from conferences, publications, seminars, etc. The system produces information in the form of publications (books, articles, and duplicated course material), courses or services provided by professors as consultants. Furthermore, "educated" students, whose scientific knowledge and practice has been increased while they were working in the LESO, are also considered as information outflows. Faculty members, as well as secretaries and technical staff are assumed not to leave, because their turnover time is much longer on

Table 3
Comparison of common building materials using different indices

| Material | Specific emergy E12 (sej/kg) | Specific emergy over lifetime E12 (sej/kg * year) | NRE E6 (J/kg) | NRE over lifetime E6 (J/kg * year) | Emvalue (CHF/kg) | Price (CHF/kg) |
|---|---|---|---|---|---|---|
| Plaster | 1.96 | 0.10 | 5.3 | 0.27 | 3.33 | 1.22 |
| EPS | 6.88 | 0.17 | 95 | 2.38 | 11.69 | 14.67 |
| Glass wool | 9.61 | 0.12 | 80 | 1.00 | 13.75 | 12.06 (17.89) |
| Screeds | 1.72 | 0.04 | 1.4 | 0.04 | 2.93 | 0.03 |
| Cement | 1.98 (1.97) | 0.02 | 4.93 | 0.06 | 3.37 | 0.33 |

average than that of undergraduate and graduate students.

Finally, the systems diagram shows that several inputs are necessary for the process of information production besides information itself: the building structure and furniture, materials (mainly paper), heat, electric appliances, data-processing equipment and, of course, faculty and students.

### 3.2. Emergy evaluation

The emergy evaluation of inputs and outputs of the LESO building is presented in Table 2 (data for year 2000). The table was established on a yearly basis with the lifetime of the building assumed to equal 80 years. The table is made up of 8 columns: note, item, data units, unit emergy values, solar emergy, fraction of total emergy inflows, emvalue (emSwiss Francs for year 2000) and a reference column for unit emergy values. The data were collected from published literature (Altherr and Gay, 2002), as well as private communications with LESO building users. Two different kinds of external sources are supplying the system, renewable (sun and water) and non-renewable, such as materials, energy (heat, electricity), goods and services, and information. Only materials associated with the maintenance of the building are considered as inflows (spare parts for the PV installation assumed to be zero), whereas materials and energy used for the construction are included in the building structure and PV storages, and listed in a "storage table", not presented here.

The emergy of each flow, listed in column 5, was calculated by multiplying the flow in column 3 (in J, kg, CHF, etc./year) by the corresponding unit emergy value, in column 4. Column 6 represents the fraction of each flow to the total emergy inflows, and column 7 is the emvalue, calculated by dividing the solar emergy in column 5 by the solar emergy per money ratio for Switzerland, year 2000, established as 5.88E+11 sej/CHF. Emergy per unit money ratio was calculated by dividing the annual emergy value of Switzerland by the gross domestic product of year 2000 (see details in Pillet and Odum, 1987, study updated in Meillaud, 2003). Since some transformities used in this evaluation are derived from literature, the references are listed in column number 8. Most of these transformities were established for processes and data from the USA and assumed to approximate those that would be obtained using Swiss (European) data. In this way, an emergy evaluation was not required for every input, but uncertainties were introduced (see Discussion).

Table 2 shows that electricity is the highest input to the system, not including services and information. This is consequence of the important electricity consumption of the building, mainly due to the presence of data-processing machines (see Altherr and Gay, 2002). And, the transformity of electricity is also quite high, as it equals 1.9E5 sej/J. More surprising is paper as the second highest emergy input, with 57.2E14 sej/year for a consumption equal to 2.4 tons/year.

Emergies of students, faculty, secretaries and technical staff have been calculated from their energy and the transformity corresponding to their educational level (Odum, 1996). The energy of each category of building users was estimated considering their metabolic energy (assumed equal to 120 kcal/h, (Odum, 1996)) and the time spent in the building (evaluated as 70% of 8.3 h/day, 30% of the time spent outside the building at conferences, seminars, etc.). The calculation for the students' energy is presented in Table 4, as an example.

Table 4
Energy and transformity of the LESO building students

Number of students = 21 students
Energy of students = (number of students) * (metabolic energy) = (21 students) * (120 kcal/h) * (4186 J/kcal) * (8.3 h/day) * (0.7) * (235 days/year) = 1.44E+10 J/year
Transformity = 7.33E+07 seJ/J (Odum, 1996)

Table 5
Transformity of the "educated students" leaving the LESO building

| |
|---|
| Number of students = 1 student |
| Energy of students = (number of students) ∗ (metabolic energy) = (1 pers) ∗ (120 kcal/h) ∗ (4186 J/kcal) ∗(8.3 h/day) ∗ (235 days/year) = 9.90E + 08 J/year |
| Emergy of students = (number of students) ∗ ((emergy of the building inflows + (0.01) ∗ (total emergy (faculty)) + (0.1) ∗ (total emergy (students)) + (0.25) ∗(total emergy (secretaries and technical staff)) = 2.37E + 17 sej |
| Transformity = emergy/(energy of students) = 2.40E + 08 sej/J |

The transformity of the "external information" source was established the same way, by considering that students, faculty, secretaries and technical staff get new information every time they are outside the building at conferences, seminars, etc.

The transformities of the four different outputs were determined from the emergy evaluation of the entire system, by considering the outputs as co-products. When outputs from a process are evaluated as co-products it means that the emergy associated with the operation of the building as a structure was required to produce each output and, so the total emergy used in the building is assigned to each of them entirely. In contrast, the total emergy of the information inputs was divided depending on the time spent to produce each output. Indeed, if time, energy and therefore emergy are assigned to do one task, another one cannot be performed at the same time and the emergy of each output is therefore reflecting the time spent to produce it. Table 5 presents the details of calculation for the "educated students" transformity. Their energy was calculated the same way as presented in Table 4, while the emergy was established considering that 100% of the building emergy is assigned, whereas only 1% of the faculty emergy, 10% of the students' emergy, and 25% of the secretaries and technical staff emergy is assigned. These percentages correspond to the time assumed for each student to spend with the other building users; they were estimated from experience (as building user).

Following this methodology, a student leaving the LESO is shown to have a transformity around three times larger than the one he/she had upon arrival, representing the information learned through conferences and interactions with other students and professors. Also, the transformity obtained for the services is very interesting, as it is larger than the transformity of the Swiss Franc (around three times). It means that people employing professors as consultants are getting more emergy than they pay for. Finally, emergy associated with the production of publication is also very high, as time spent for research is accounted as part of the publication process.

The budget of the LESO (note 28) was considered neither as an input, nor as an output, as money is not directly used in the building. Budget accounts for wages, as well as other expenses such as insurance, amortization of the building, etc.

Specific emergy values were established for some building materials, such as expanded polystyrene (EPS), glass wool and screeds, without considering services inputs, and are compared to NRE (non-renewable energy, also referred to as embodied energy) indices. Both are presented in Table 3, with emvalue and price for each of the material. The values of emergy per mass (specific emergy) and embodied energy per mass are very different, but the hierarchy is well conserved. The difference only emerges from energy quality factor, expressed by the specific emergy or transformity applied to each input to the material production process.

When specific emergy is expressed per lifetime year, glass wool comes close to plaster, because its lifetime is four times longer (80 years instead of 20). Specific emergy may then be used as an indicator of recycle-ability of materials (Buranakarn, 1998; Brown and Buranakarn, 2003). Concerning emvalue, the higher the value, the less mass is obtained per unit cost. As a result, the more finished a material is, the higher its emvalue. This is indeed observed with EPS and glass wool having the largest emvalues. Comparison of emvalues and prices shows that the buying power of the swiss franc is higher for raw material (emvalue much higher than price).

## 4. Discussion

Emergy is an evaluation technique that can include not only environmental, but also economical and information flows. The major concern of the method is the determination of unit emergy values, which can be very fastidious and time consuming. Indeed, to derive the unit emergy value of a resource of commodity, it is necessary to consider all the resources and energy that was used to produce it, and express them in emergy. There is thus no single unit emergy value for most commodities but a range depending on the production processes. It is also very common to use unit emergy values derived from other studies, by assuming they are still valid under slightly different conditions (other place/time). This assumption, several times used in this paper (mostly for building materials), is often criticized, particularly regarding primary resources such as wind, rain, etc. Indeed, these basic flows are used in the calculation procedures of all other processes and an incorrect value of some of these values would affect all the other calculation results.

Unit emergy values may differ in both space and time, and to get a better sense of the magnitude of errors that may arise, we shall consider two important unit emergy values used in this evaluation: first the transformity of electricity with examples of values established for two different places (space difference) and, second, the emergy per unit money ratio of the Swiss Franc established for two different years (time difference). (Odum, 1996) presents different values of electricity transformity established for various places and types of electricity production processes: hydroelectricity is for example calculated for Sweden and Brazil with transformities equal to 9.4E4 sej/J and 1.7E5 sej/J respectively. Both values only differ by less than a factor of two, even if established for two systems situated in very different environments. In this study, the electricity transformity was estimated as being equal to 1.9E5 sej/J (hydro and nuclear electricity, see (Meillaud, 2003)). Regarding emergy per unit ratio of Switzerland, Pillet and Odum (1987) calculated a value of 7.2E11 sej/$, approximately 4.5E11 sej/CHF, and it was re-evaluated in (Meillaud, 2003) with a value of 5.9E11 sej/CH. Again both values only differ by a factor of 1.3. Even if no conclusion can be drawn from only two examples, they nevertheless show that errors arising from use of average transformities are usually situated in an acceptable range, and only relative: a factor of two would of course change the numerical results but not the tendencies, even if applied to every transformity.

Emergy was used for this building evaluation, because of the particular nature of the outputs: information. Indeed, emergy is defined in such a manner that every type of flow can be evaluated, contrary to other common evaluation methods, such as exergy, embodied energy or life-cycle analysis. Exergy is typically applied to energy conversion systems (for example power plants) that have a fossil fuel as the main input and electric or thermal power as output. Exergy accounts neither for goods nor services from the market, nor for information directly or indirectly required for the operation of the system. A comparison of emergy and exergy may be found in (Ulgiati, 2000).

Concerning embodied (non renewable) energy and emergy, results for building materials presented in Table 3 show that both indices give the same kind of information: the higher the specific emergy and the embodied energy per mass, the more refined the material and the more relevant the potential recycling of such material (Buranakarn, 1998). As with exergy, embodied energy can also not be used to evaluate information or monetary flows. For a complete comparison of emergy and embodied energy see (Brown and Herendeen, 1996). Concerning LCA (Life-cycle analysis), this method presents the same type of drawback about information and monetary flows as exergy or embodied energy; it may nevertheless be used as a valuable tool for energy policy, as presented in (Frankl and Gamberale, 1998).

Finally, it must be noticed that our emergy evaluation did not account directly for the impacts or effects of the emissions of co-products during the use and construction of the LESO building, but this could have been done by expanding the boundaries of analysis (see for example Buranakarn, 1998).

## 5. Conclusion

This paper presents the emergy methodology and its application to an actual and rather complex system: a building. The LESO (Solar Energy Laboratory, Swiss Federal Institute of Technology, Lausanne) is an academic building producing scientific information disseminated via publications, courses, students and services. Emergy was the most appropriate methodology to evaluate this system, because each type of flow, such as monetary or information flows could be taken into account for the evaluation. It is an advantage in comparison to other common methodologies, such as exergy, Life-Cycle Analysis (LCA) or embodied energy (NRE index) that are often used to evaluate materials flows, but not services or information. With respect to information, each of these methods would only account for the energy of the information carrier, such as computers, paper or disks. In contrast, emergy may be used to quantify information production through human metabolism and level of knowledge. The transformity of students was shown to increase three fold during their tenure as students in the LESO building. This results from their studies and the information imparted by their teachers and faculty advisors as well as interactions with other students. Moreover, publications, courses and "services" were also revealed as having high emergy contents since the "services" transformity was even larger than emergy per unit money ratio of the Swiss Franc.

The emergy evaluation of the building revealed that the most important (in emergy terms) inputs to the building were information brought by faculty and students and inputs that are obtained from outside information sources. As in most buildings the next most important inputs were human services followed by operating energies especially electricity and paper.

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