EVALUATION OF THE SOLAR EXPERIMENTAL LESO BUILDING USING THE EMERGY METHOD

By

FANNY MEILLAUD

February, 2003

UF Professor: Mark T. Brown, Center For Wetlands, University of Florida

EPFL Professor: Jean-Bernard Gay, Solar Energy and Building Physics Laboratory (LESO), EPFL

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

A THESIS PRESENTED TO THE SWISS FEDERAL INSTITUTE OF TECHNOLOGY (EPFL) FOR THE DEGREE OF PHYSICS ENGINEER

ACKNOWLEDGMENTS

I would like to thank Dr. Mark T. Brown at The Center for Wetlands, University of Florida (UF), United States, for his advice and academic support, which made it possible for me to undertake this project under his supervision and have this formidable experience. I am also very grateful to late Dr. Howard T. Odum who first encouraged me to come to UF.

I am also very thankful to my Professor at the Swiss Federal Institute of Technology, Jean-Bernard Gay for his constant support and help, and to Professor Jean-Louis Scartezzini, Director of the LESO.

I greatly appreciated the academic support provided by Dr. R. Raymond Issa and Dr. Charles J. Kibert and their interest in my project.

Finally, I would like to thank all the students at the Center for Wetlands for their marvelous welcome and would like to particularly thank Lynn V. McIndoo and Kori Jacobs, for their help and great friendship.

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Abstract

The objective of this thesis is to perform an emergy (with an m) evaluation of the LESO building (Solar Energy and Building Physics Laboratory), situated on the campus of the Swiss Federal Institute of Technology (EPFL) in Lausanne, Switzerland. The building is three-stories containing faculty and students offices and a workshop. The building was constructed in 1981 with a south-facing facade composed of multiple units, to allow simultaneous measurements using different materials and configurations. In 1999, a homogenous facade, with a low NRE (Non-renewable Energy) index replaced the multiple elements. The LESO building was chosen for this study, because much data is available about material and energy flows, as well as costs.

What is an emergy evaluation? Emergy may be defined as "the quantity of energy of one kind used up directly and indirectly to make a product or service" (Odum, 1996). The kind of energy considered is solar energy and all the flows and processes are then evaluated using this common unit of measure. The monetary flows, as well as the information flows, may also be quantified. The inclusion of monetary and informational flow is crucial in this study, as the output of the LESO building is the production of scientific knowledge through publications, courses, formation of scientists and services (as consultants). The quality of each type of energy is expressed by the transformity, defined as the emergy per unit useful energy.

The first step of the evaluation was to do a model of the building and draw a diagram with the external sources of energy and main components of the building represented with the appropriate systems language. Then, all the storages and flows of energy, material or services were listed in a table, along with their transformity, and emergies were calculated. Most of the transformities used in this thesis were available from previous studies or calculated. The transformity of the Swiss Franc was updated, following a model available for the emergy evaluation of the United States.

The emergy content of each type of information produced by the building was established considering the entire system. The corresponding transformities are extremely large as information is among the highest quality type of energy. It was assessed that the transformity, expressed as solar joules per joules of metabolic energy of a student leaving the building was approximately three times bigger than its initial value, the student's education level getting higher.

Simulations of the information produced by the building during its lifetime, estimated as 80 years, were performed. Different scenarios and the influence of various parameters on the rate of information production were examined. The external information source was assumed to have a constant growth of one percent per year.

The model showed, among other results, that the number of faculty members and students had to grow too to assure a competitive information production. And the influence of the building on the information production was revealed assuming that the maintenance abruptly stopped after 40 years.

Résumé

L'objectif de ce diplôme est de réaliser une évaluation émergétique (avec un m) du bâtiment du LESO (Laboratoire d'Energie Solaire et de Physique du Bâtiment), situé sur le campus de l'Ecole Polytechnique Fédérale de Lausanne (EPFL), en Suisse. C'est un bâtiment de trois étages contenant des bureaux pour le corps enseignant et les étudiants, et un atelier. Le bâtiment a été construit en 1981 avec une façade sud composée de multiples unités, pour permettre des mesures simultanées en utilisant différents matériaux et configurations. En 1999, une façade homogène, avec un faible indice d'énergie grise, a remplacé les éléments multiples. Le bâtiment du LESO a été choisi pour cette étude, car beaucoup de données sont disponibles au sujet des flux de matériaux et d'énergie, ainsi que des coûts.

Qu'est qu'une évaluation émergétique? L'émergie peut être définie comme la quantité d'énergie d'un certain type, utilisée directement et indirectement pour produire un bien, service ou flux d'énergie (Odum, 1996). Le type d'énergie considéré est l'énergie solaire et tous les flux et processus sont alors évalués en utilisant cette unité de mesure commune. Les flux monétaires, tout comme les flux d'information, peuvent donc également être comptabilisés.

L'intégration des flux monétaires et flux d'information est cruciale dans cette étude, étant donne que le rôle du bâtiment du LESO est la production de connaissance scientifique au travers de publications, cours, formation d'étudiants et services rendus en tant que consultants. La qualité de chaque type d'énergie ou flux est exprimée par sa transformité, définie comme l'émergie par unité d'énergie disponible.

La première étape de cette évaluation émergétique était la réalisation d'un modèle du bâtiment dessiné sous forme de diagramme avec les sources extérieures d'énergie et les composants principaux du bâtiment représenté avec le langage systémique approprié. Ensuite, tous les réservoirs et flux d'énergie, matériel ou services ont été répertoriés dans une table, avec leur transformité, et les émergies correspondantes calculées. La plupart des transformités utilisés dans ce diplôme étaient disponibles, car préalablement établies dans le cadre d'autres études. Néanmoins certaines transformités ont du être calculées dans le cadre de ce diplôme.

La transformité du franc suisse a été mise à jour, suivant le modèle utilisé pour l'évaluation émergétique des Etats-Unis.

Le contenu émergétique de chaque type de flux d'information produit par le bâtiment a été établi en considérant le système entier. Les valeurs de transformité obtenues sont extrêmement élevées, l'information faisant partie des types d'énergie de très haute qualité. Il a été déterminé que la transformité d'un étudiant quittant le LESO, exprimée en tant que joules solaires par joule d'énergie métabolique, était approximativement trois fois plus grande que sa valeur initiale,le niveau d'éducation de l'étudiant étant alors plus élevé. Plusieurs simulations de l'information produite par le bâtiment ont été effectuées, considérant la durée de vie de ce dernier, estimée à 80 ans. Pour cela, un second diagramme a été dessiné, le bâtiment étant alors agrégé. Différents scénarios et l'influence de certains paramètres sur le taux de production d'information ont été examinés, en supposant que la croissance de la source extérieure d'information était égale à un pour cent par année. Le modèle a montré, entre autres, que le nombre de professeurs et d'étudiants doit alors également croître si une production concurrentielle d'information veut être atteinte.

CHAPTER 1
INTRODUCTION

1.1. LESO building and sustainable development

The LESO building (Solar Energy and Building Physics Laboratory) is particularly interesting, since its construction in 1981 was influenced by special considerations, such as (Altherr, 2002):

(a) Allowing in situ measurement and evaluation of solar and/or high insulating facades,

(b) Showing what could be done in an office building for the best use of passive gains and daylight,

(c) Offering a working space to the staff of the laboratory

The building was first constructed with a south facade composed of multiple elements: up to nine different facade units could be measured simultaneously. In 1999, a unique homogenous facade replaced all these elements. The materials for the new facade were chosen in accordance with sustainable development strategies and a drastic reduction of the use of non-renewable energy (Altherr, 2002). A picture of the south facade and the PV installation is presented below in Figure 1-1.

The LESO building is characterized by a very low energy demand: 232 MJ/m^2/yr for the year 2000, corresponding to a consumption of 156 MJ/m^2/yr of electricity and 76 MJ//m^2/yr of heat, for an energetic reference surface of 765 m^2. A very high proportion of the electricity consumption, seventy-five percent, is associated with the presence of data-processing equipment and machines. 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 seventy-five percent of the total heat requirements.

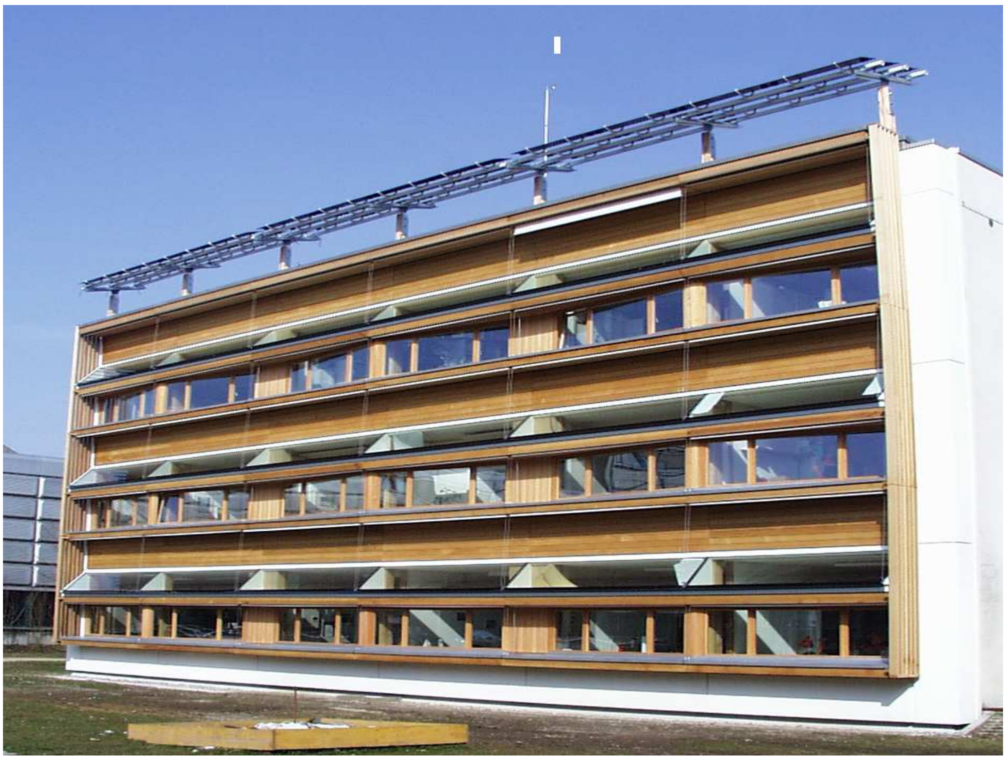


Figure 1-1. View of the south facade and the PV installation of the LESO building

The emergy evaluation not only considers the present consumption of energy of the LESO building, but also the energy required for its construction. Indeed, buildings are infrastructures that demand large amounts of material and energy for each step of their lifetime and, according to the OFEN (Swiss Federal Office of Energy.),

> "Buildings account for around sixty percent of total Swiss energy (heating fuels and electricity)(…). About 50 percent of total energy demand is for residential, service sector and industrial buildings, while some 10 percent is required for the manufacture of building materials and products. The buildings sector, through conversions, renovations and new constructions, is also largely responsible for using up resources, while generating waste and polluting our environment. There are good reasons therefore for introducing the concept of sustainability in the construction industry."

The concept of sustainability has been expressed for some years now by the "NRE index" (Non-renewable Energy), also called "embodied energy". It represents the energy used up through all the processes of fabrication of a material. This index, together with GWP (Global Warming Potential) and AP (Acidification Potential) indexes, allows architects to choose and propose building materials according to their "environmental qualities" and not only to their performance.

1.2. Emergy analysis

The notion of emergy was first introduced in 1983 by H. T. Odum who developed the field of Systems Ecology to study the relationship between society and the environment. Emergy is defined as "the available energy of one kind that has been used up directly and indirectly to make a product or service" (Odum, 1996). The kind of energy often considered is solar energy. Emergy is sometimes also referred to as "Energy memory"(Scienceman, 1987). An emergy analysis allows the inclusion of energy, materials, and monetary flows, by expressing all flows using the common measure of solar energy. As all flows are expressed in the same form, the problem of comparing energies of different qualities is averted. Moreover, this method allows flows of services and information to be considered which is important, since their respective transformities are really high.

Emergy is calculated using:

$$Em = \sum_i J_i * Tr_i$$

where Em is emergy expressed in sej, J_i an energy flow in J/yr and Tr_i the corresponding transformity in sej/J.

Transformity, defined as the emergy per unit available energy is equal to:

$$\mathrm{Tr} = \mathrm{Em/J}$$

Transformities represent different energy qualities which increase hierarchically. For example, the transformity of the sun is by definition 1 sej/J and is the lowest quality energy flow, whereas monetary and information flows are among the highest.

At each stage of energy transformation, a certain amount of available energy is lost by depreciation (second law of thermodynamics) but the quality improves as further processes are involved. A higher quality source can produce feedbacks to improve the quality of other energy or material flows, such as the use of electricity to make products from raw materials.

Sometimes, especially for materials, it is more convenient to express the transformity in units of emergy per gram or kilogram (sej/g, sej/kg). Transformities can also be expressed as emergy per unit currency (sej/$, sej/CHF) for monetary flows.

1.3. Other Methods

Two other methods for assessing energy and materials inputs of different processes include embodied Life-Cycle Analysis and Exergy. A summary of these methods is provided below. The results they provide are quite different from those obtained from an emergy evaluation; the differences are presented for each method.

1.3.1 Life-Cycle Analysis (LCA)

LCA is defined as "a systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle"(Life-cycle Assessment - Principles and Guidelines, 1995). LCA is composed of three stages: the life-cycle inventory, the impact analysis and the improvement analysis. The life-cycle inventory corresponds to the quantification of raw material, energy inputs and environmental releases associated with a system.

LCA is fundamentally different from the emergy evaluation, as it is focused on the evaluation of impacts and emissions, whereas emergy focuses on the quantification of the energy available to do useful work. Emissions and impacts are not part of the emergy evaluation, as no available energy, and therefore no emergy, is associated to them.

1.3.2 Exergy

The exergy analysis is based on the combination of the first and second law of thermodynamic with the introduction of the concepts of enthalpy and entropy. Exergy describes the change in the quality of energy that accompanies its conversion from one form to another and is typically applied to individual processes or technologies.

Exergy corresponds to the maximum amount of work that can be extracted from a given flow. Exergy efficiency is therefore a good indicator of the real performances of a system, in opposition of the results only based on the first law of thermodynamics. Indeed, efficiency based on the second law of thermodynamics accounts not only for energy quantity, but also energy quality (Simpson & Kay, 1989).

One drawback of the exergy method is that it does not account for human labor (services), information and environment.

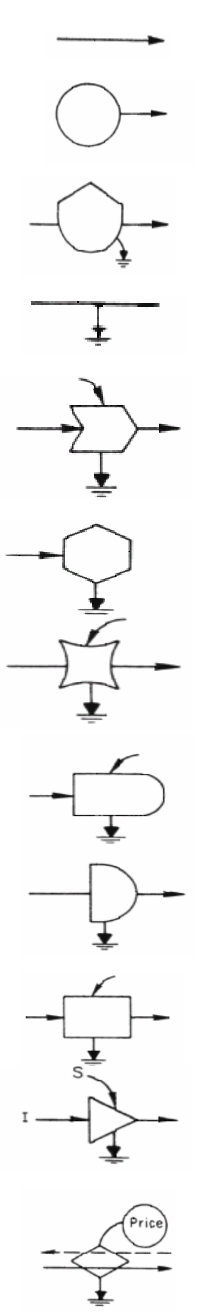
CHAPTER 2

METHODOLOGY

This chapter presents the methodology associated with the emergy analysis.

2.1 System Diagram

The evaluation starts by defining the system boundary, as well as all energy sources and system component. A diagram is then drawn using energy language symbols, which are illustrated with a short description in the figure 2-1 below:



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.

Switching action: A symbol that indicates one or more switching actions.

Producer: Unit that collects and transforms low-quality energy under control interactions of high-quality flows.

Self-limiting energy receiver: A unit that has a self –limiting output when input drives are high because there is a limiting constant quality of material reaction on a circular pathway within.

Box: Miscellaneous symbol to use for whatever unit or function is labelled.

Constant-gain amplifier : A unit that delivers an output in proportion to the input I but changed by a constant factor as long as the energy source S is sufficient.

Transaction : A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line). Price is shown as an external source

Figure 2-1. Main system symbols and a short description of their meaning (Odum, 1994 & Odum, 1996)

Sensors are also part of the language. They are represented by a small rectangle on a pathway or on the side of a storage tank. The presence of a sensor 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 material tank in the diagram of the LESO building, to express the fact that some material (corresponding mainly to the windows) was contributing to solar gains through interaction with the solar flow, but not leaving the tank.

A rectangular frame represents the boundary of the system and all the external sources are arranged around it, in a hierarchical order of quality (transformity) from left to right. The sun is thus the first source placed on the left. Then the components are drawn inside the frame, following the same hierarchical order from left to right. Finally, the symbols are connected through pathways representing flow of energy, material or money.

2.2 Emergy evaluation table

Once the diagram is drawn, an emergy evaluation table is created. Each flow crossing the system boundary is an entry in the table. Flows are usually expressed on a yearly basis. The table is constructed as follows (Odum, 1996):

1	**2**	**3**	**4**	**5**	**6**
Footnote	Item	Data (j/yr, g/yr, CHF/yr)	Transformity (sej/J, sej/g, sej/CHF)	Solar emergy (sej)	Emvalue (Em$/yr)

Column one is a list of line item numbers indicating the source of raw data and detail calculations with a footnote.

Column two is a name of the evaluated item identified on the accompanying system diagram.

Column three contains the value of the flow or storage in raw units: joules grams, or Swiss Francs. The data are collected from industry, from published literature or statistical reports. All data are shown on an annual basis. Calculations and references are shown in each footnote.

Column four is the transformity, expressed in sej/J for energy, sej/g, for mass or sej/CHF (Swiss Franc) for money. Data in column three is multiplied by solar transformity in column four to obtain solar emergy values (sej/yr) in column five.

Column five is solar emergy values of each evaluated flow or storage. These values are calculated by multiplying input resource data in column three by solar transformity values in column four.

Colum six is Emvalue. Emvalues are calculated by dividing the solar emergy in column five by the solar emergy per money ratio for a specific year and country. The solar emergy per money ratio is calculated by dividing the annual solar emergy value of the country by the Gross Domestic Product (GDP) of that year.

2.3. Transformities

Many transformities are available from previous studies. The primary reference used for this emergy analysis of the LESO building is a Ph. D. Dissertation comparing recycling and reuse of building materials (Buranakarn, 1998). Most of the values established by Buranakarn were based upon processes and data from the USA or Canada; nevertheless it is assumed that they may approximate those one would obtain using Swiss (European) data. In this way, an emergy evaluation was not required for every input evaluated. Any uncertainty related to the use of these transformities, will be discussed in Chapter Four.

In addition to those previously calculated, new transformities of products were determined as part of this study; they are presented in Tables 3-3 to 3-6 and a list of all the transformities used in this thesis is given in Table A-1. The transformities were calculated from the processes of fabrication and all the related inputs. An example of a transformity calculation is presented Figure 2-2.

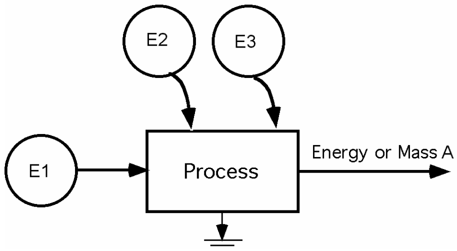


Figure 2-2. Model for calculation of transformity

$E_1 + E_2 + E_3$ are inputs to the process of fabrication, such as energy, material or money, and A is the output (material or energy). The emergy of each input is calculated by multiplying the value of the flow by the corresponding transformity. Consequently, all the intermediate transformities must be available from previous studies or calculated.

The transformity of the output A is then obtained by:

$$Transformity\, A\,(sej/J \; or \; sej/g) = \frac{Emergy\, E_1 + Emergy\, E_2 + Emergy\, E_3}{Energy\, A}$$

where Emergy and Energy have units of sej and J (or kg), respectively. The same kind of calculation is used to obtain the transformity of a currency: the system considered is in that case a country and the transformity is calculated by dividing the annual solar emergy value of the country by the Gross National Product (GNP) for a specific year.

2.4. Equations

Once the diagram of the system is drawn, the corresponding equations can be written. First the equations are written considering energy and/or material flows (which are usually expressed in kg/unit time), but equations may then also be written using emergy flows, each flow being multiplied by its transformity.

An example of an interaction is presented in Figure 2-3 where S represents a storage and A, B and C are energy or material sources. Each source is interacting with inflow J to produce J_1. As for diagrams, the sources are placed in quality hierarchy from left to right. A heat sink is always associated to the interaction symbol to express the second law of thermodynamics.

The interaction symbol may represent different functions, such as a multiplication or division; therefore the corresponding mathematic symbols (x, ÷) are usually added to the interaction symbol for accuracy.

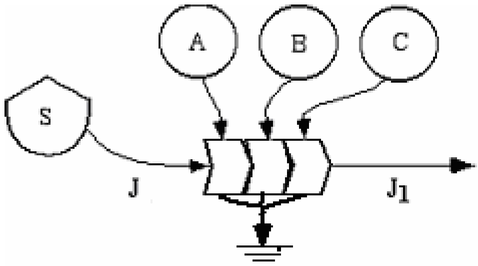


Figure 2-3. Interaction between four different flows

The multiplicative interaction is a frequent example: its output is proportional to the product of all inputs, which means that the process ends if one of the flows becomes zero.

In that case, the outflow would be expressed by the relation: $J_1 = k_1 \times S \times A \times B \times C$ where k1 is a coefficient and S, A, B and C are defined as above. Coefficients are introduced to express the proportionality between the inputs and output of an interaction. They are generally constant and unitless, unless some inputs are not expressed in the same unit as the others (for example joules of fuels and kg of raw material, if the interaction represents a production process).

The interaction can also be additive or subtractive, but the symbols "+" or "–" cannot be used, as they were defined for positive, respectively negative multiplier (Odum, 1994). If a "+" is added to an interaction symbol, it means that the outflow is equal to $J_1 = k_1 \times A \times (1 + k_2 \times B)$ with A and B the inflows, and thus does not equal $J_1 = k_1 \times (A + B)$. The equations for the different components of the diagram (such as tanks, boxes, etc.) are obtained considering the conservation of energy (or emergy). See section 3-4 for examples of equations.

CHAPTER 3
RESULTS

3.1. Systems diagram

A systems diagram of the LESO building is presented in Figure 3-1.

The boundary of the system was defined as the building and the PV installation and represented by a rectangular frame. All external sources were then placed in a hierarchical order of quality (transformity) from left to right on the outside of the frame.

The main components of the system include the building structure (including the facade), heating system, electric appliances and equipment and the PV installation. The faculty and students of the building are represented as consumers, with one tank corresponding to their population. This tank also includes the secretaries and technical staff. The information storage represents the scientific knowledge utilized to produce information, but as the users are entering and leaving the building every day, their knowledge is considered as a flow and not a storage in the emergy table.

The educated students flow represents students graduating. Faculty members are assumed not to leave (their turnover time is longer than that of undergraduate and graduate students). The external source of information symbolizes incoming information from conferences, publications, seminars, etc.

The building structure is represented as a material storage, its inflow and outflow corresponding to the necessary replacement of some materials depending on their lifetime (see section 3.2 for further details). Some materials are also consumed by the users, primarily paper, plastic and metal. A furniture tank is added on the side of the building structure tank. They are drawn together with the heating system and electric appliances to represent the material components of the building and placed in a hierarchical order from left to right.

Sensors are drawn on the side of the building structure and furniture tank to express that there is no actual material outflow, only interactions with other flows, such as the sun to produce heat. Similarly, a sensor on the faculty and students tank represents the production of information, rather than a physical outflow coming from the tank.

The PV installation also includes a material storage, but as it is also acting as a producer of energy, it is represented by a rectangle, called a miscellaneous box.

Heat is considered as an external source, because it is provided to the building as hot water from a heat pump. But, apart from this external source, heat is also produced as a direct flow by the heating system (radiators and electric heater) or secondary flow (by the electric appliances and people). The structure produces heat by capturing solar radiation 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 (second law of thermodynamics). Heat is of course also considered as a storage.

Some inflows, such as appliances, equipment and furniture are estimated from the money paid to get them, because detailed data of the materials composing them are not available. Services (human labor) are also estimated in the same way.

In fact, there are two separate processes of information production, the other one being drawn as part of the consumer component of the system. It represents the reinforcement of knowledge through contact with information coming from outside of the building (at conferences, seminars, etc). A quadratic drain is drawn on the side of the information tank to express that the brain only absorbs a small fraction of the total exposed information (in the long-term memory). Loss of information is part of the interaction too, as only a fraction of the new information is kept and used.

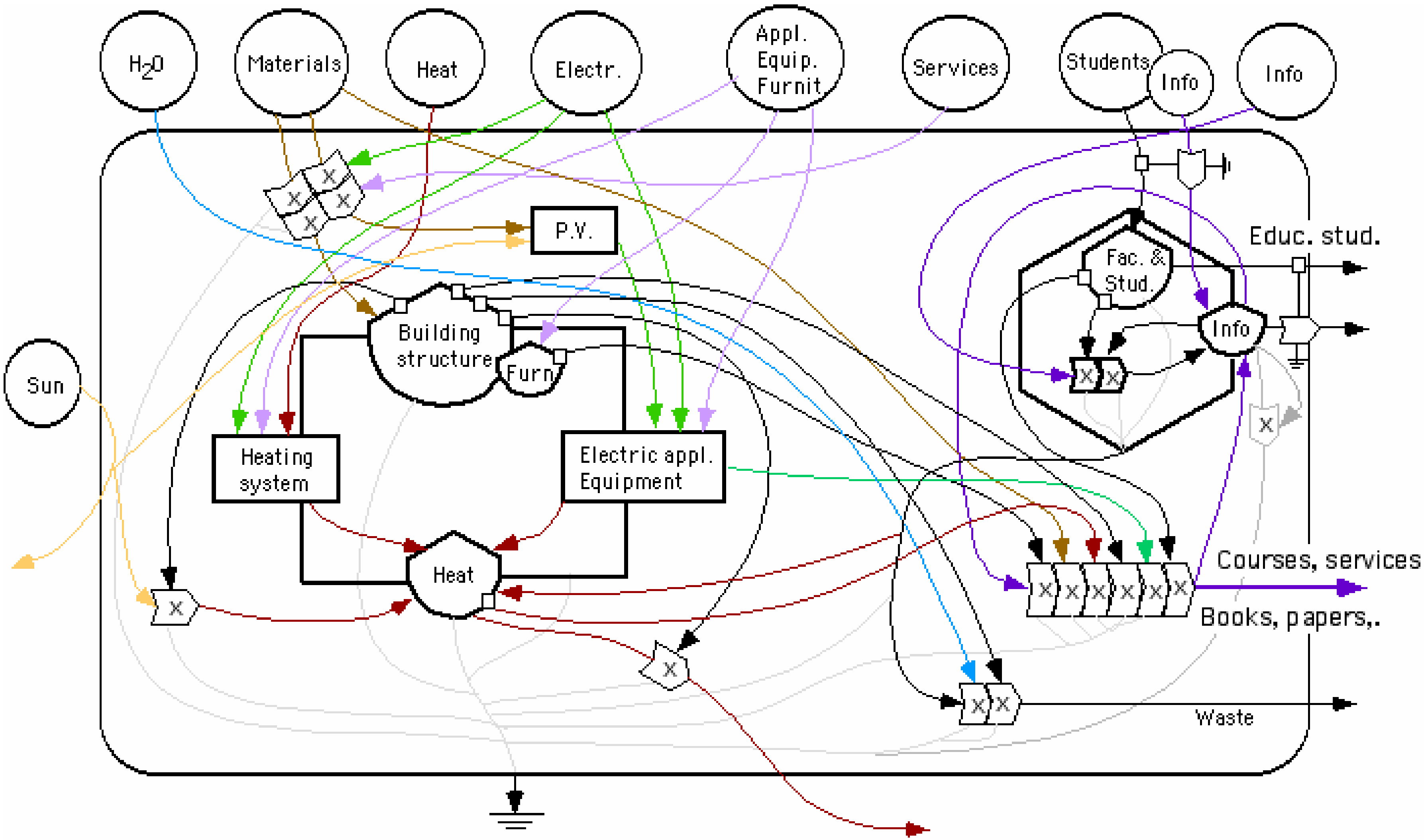


Figure 3-1. Systems diagram for the LESO building

The feedback from the information storage accounts for the previous information necessary to understand the new information and reinforce it.

Several inputs are necessary for the process of information production ("packaging"): the building structure and furniture, materials (mainly paper), heat, electric appliances and data-processing equipment. For simplification, a single material flow that includes plastic and metal was used even if they are not direct inputs to the information production, such as paper.

The outputs of the building are waste (and heat released) and information. Waste is produced through interaction between the building structure (sanitary installations) and water inflow. Information is produced as publications (books, articles, and duplicated course material), courses, or services provided by professors as consultants to a third party. Furthermore, graduating students, whose scientific knowledge and practice has been increased while they were working in the LESO, are also considered as information outflows

3.2. Emergy evaluation of the LESO building

The emergy evaluation of inflows and outflows of the LESO building is presented in Table 3-1, whereas Table 3-2 corresponds to the emergy evaluation of the building storages.

Table 3-1 is established on a yearly basis; the lifetime of the building is assumed to equal 80 years. The emergy of each flow is calculated using the corresponding transformity. Once the emergy is determined, its fraction to the total emergy of inflows, respectively storages, is calculated. Last column of Tables 3-1 and 3-2 indicates the emvalue of each inflow, obtained by dividing their emergy by the emergy per money ratio for Switzerland in 2000, 5.88E+11 sej/CHF (see Table C-1). For this calculation, a ratio of 1.6 CHF/$ is considered.

Table A-1, in the Appendix, presents all the transformities used in this study with their references. Transformities of plaster, expanded polystyrene, glass wool and screeds were established in this thesis and are presented in Tables 3-3 to 3-6. The details of calculation and references for each table presented in this chapter are situated in the footnotes, in Appendices B-1 to B-6.

3.2.1 Emergy evaluation of inflows and outflows

Two different kinds of external sources are supplying the system, renewable (sun and water) and non-renewable as materials, energy or information (knowledge). The flow of water represents the consumption of water for the sanitary installation. Hot water is considered as heat and therefore accounted for as non-renewable energy. Only materials associated with the maintenance of the building (spare parts for the PV installation assumed to be zero) are considered as inflow to the building and PV installation. Materials, as well as energy/fuels used for the construction are included in the building structure and PV storages.

The quantity of each material necessary for replacement is calculated by multiplying the initial quantity used for the construction by the number of necessary replacements (considering the material and building lifetime). The mass thus obtained is then divided by the lifetime of the building to obtain a yearly-based flow.

As already mentioned in section 3-1, the emergies of electric appliances, equipment, and furniture are established from their economic value and the transformity of the Swiss Franc, as detailed data about their material composition are not available. The emergy thus primarily accounts for human services and energy provided during the processes of production, the raw material being often underestimated (because emergy from the environment is then not accounted for). But, products like computers require so much human labor that this kind of approximation is justified.

The information (scientific knowledge) is generated by the system as four different "products", students, publications (books, articles and duplicated course materials), courses and services, and the assumption is made that the emergy consumed by the building as a structure is assigned to each product, whereas the emergy of the information inflows is split, depending upon the time spent. See Chapter Four for more details.

The budget (wages) is not considered as an input because the money is not used inside the building, and it is not an output either as it is not produced by the building. It is therefore considered as an extra category and not accounted for.

3.2.2. Emergy evaluation of storages

The system is composed of three different storages (information is considered as an inflow): the building structure, PV installation and heat. The building structure and PV storages include the materials, as well as fuels and services related to the construction of the building, respectively PV installation. The heat storage represents the heat produced by the electric appliances and the people working in the building.

More than sixty percent of the total emergy of storages is represented by the materials of the building structure. Concrete and cement alone represent approximately 55% of total emergy, mainly because of the quantities used.

The heat storage is defined as the heat produced by the people and electric appliances, as the rest of the heat consumed must be provided from external sources (heat source or sun).

3.3. Emergy evaluation of some building materials

Transformity of plaster, expanded polystyrene, glass wool and screeds were established in this study by considering the different inputs to their processes of fabrication and an emergy table was developed for each of them. Their transformity was obtained by summing the emergy of each input and dividing the total emergy by the quantity of material produced. The transformities thus assessed are discussed in section 3.3.5 by comparison with the NRE (Non-renewable energy) values of these materials. Each of theses transformities corresponds to the "services" non-included products. The emvalues of each of these materials and their inputs are calculated in the last column of each table

3.3.1 Emergy evaluation of plaster

The emergy table of plaster production is presented in Table 3-3. The emergy of the raw material, limestone, represents 98.53% of total emergy, its high transformity being related to the great amount of emergy associated with the geological processes necessary to its formation. The transformity of plaster thus obtained is equal to 1.96E +12 sej/kg and its emvalue is 3.33 CHF/kg.

3.3.2 Emergy evaluation of expanded polystyrene

The emergy table of expanded polystyrene is presented in Table 3-4. As the transformities of raw polystyrene, pentan and "organic fireproof material" were not available, assumptions were made: the transformity used for polystyrene corresponds to plastic, whereas the transformity used for pentan and organic fireproof material corresponds to refined oil. These statements were made because of the organic origin of these products. As the transformity of refined oil is only known as sej/J, the energetic content of each product had to considered too (see Table B-4 in Appendix for more details).

Table 3-1
Emergy evaluation of the inflows and outflows of the LESO building

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

TOTAL EMERGY

A	Total emergy of inflows (for one yr) =	3.46E+18 sej	(1.88E+17 sej building inflows, 3.27E+ 18 sej information inflows)
B	Total emergy of storages =	3.18E+18 sej	
C.	Total emergy (inflows & storages) for one yr =	6.64E+18 sej	
D	Fraction emergy inflows/total emergy =	52.08 %	
E	Fraction emergy storages/total emergy =	47.92 %	

1) Emergy estimated from the electricity produced by the PV installation
2) Emergy estimated from the electricity consumption of the heat pump
3) Estimated from metabolic energy and time spent at conferences, seminars, etc (30% of 5.4 hrs/day)
4) Estimation : the emergy of each output is the sum of the emergy of the bldg inflows + fraction of information inflows according to time spent
5) This flow represents the students leaving the LESO, assumption : one student

Table 3-2
Emergy evaluation of the storages of the LESO building

Note	Item	Raw Units	Transformity (sej/unit)	Solar Emergy (E16sej)	Fraction of total stored emergy %	EmSwiss Francs (E4 2000 CHF)
STORAGES						
1	**BUILDING STRUCTURE :**					
	Materials :					
	Concrete	7.01E+05 kg	1.44E+12	100.94	31.75	171.67
	Cement	3.68E+05 kg	1.98E+12	72.86	22.92	123.92
	Gravel	2.44E+04 kg	1.68E+12	4.10	1.29	6.97
	Screeds	6.64E+04 kg	1.72E+12	11.42	3.59	19.42
	Plaster	2.30E+04 kg	1.96E+12	4.51	1.42	7.67
	Wood	2.23E+04 kg	8.79E+11	1.96	0.62	3.33
	Iron	2.79E+04 kg	4.15E+12	11.58	3.64	19.69
	Aluminium	1.08E+03 kg	1.27E+13	1.37	0.43	2.33
	Copper	1.14E+03 kg	6.77E+13	7.72	2.43	13.13
	Glass	1.93E+03 kg	7.87E+12	1.52	0.48	2.58
	Glass wool	3.30E+03 kg	9.61E+12	3.17	1.00	5.39
	Expanded polystyrene	2.23E+03 kg	6.88E+12	1.53	0.48	2.61
	Natural rubber	3.46E+03 kg	4.30E+12	1.49	0.47	2.53
	Painting	3.25E+03 kg	1.52E+13	4.94	1.55	8.40
	Fuels/energy :					
	Fuels for construction	1.18E+10 J	1.11E+05	0.13	0.04	0.22
	Electricity for construction	2.36E+10 J	1.88E+05	0.44	0.14	0.75
	Services :					
	Labor for construction	1.47E+06 CHF	5.88E+11	86.44	27.18	147.00
2	**PV INSTALLATION :**					
	Materials :					
	Wood	1.62E+02 kg	1.44E+12	0.02	0.01	0.04
	Iron	1.26E+03 kg	4.15E+12	0.52	0.16	0.89
	Copper	4.50E+01 kg	6.77E+13	0.30	0.10	0.52
	Silicon	3.28E+02 kg	7.43E+12	0.24	0.08	0.41
	Fuels/energy :					
	Electricity for construction	1.20E+09 J	1.88E+05	0.02	0.01	0.04
	Services :					
	Labor for construction	1.20E+04 CHF	5.88E+11	0.71	0.22	1.20
3	**HEAT**	4.71E+09 J	4.37E+04	0.02	0.01	0.04

Table 3-3
Emergy evaluation of plaster production 1994 (CH)
Source of raw data : H. Zentner-Gipsunion AG (1994)

Note	Item	Raw Units (per year)	Transformity (sej/unit)	Solar Emergy (E12 sej/yr)	Fraction of total emergy %	EmSwiss Francs (2000 CHF)
1	Limestone	1.15E+03 kg	1.68E+12	1932.0	98.53	3285.71
2	Transport (28t Truck)	1.70E-01 t-km	6.61E+11	0.1	0.01	0.19
3	Natural gas	1.62E+07 J	5.88E+04	1.0	0.05	1.62
4	Extra light oil	1.55E+07 J	8.90E+04	1.4	0.07	2.35
5	Heavy oil	1.10E+07 J	8.90E+04	1.0	0.05	1.67
6	Electricity	1.35E+08 J	1.88E+05	25.4	1.29	43.16
7	Annual yield (without services)	1.00E+03 kg	1.96E+12	1960.8		3334.71

Table 3-4
Emergy evaluation of EPS (expanded polystyrene) production 1994 (CH)
Source of raw data : Oekologische Bewertung von Wärmedämmsystemen-Sarnafil (1994)

Note	Item	Raw Units (per year)	Transformity (sej/unit)	Solar Emergy (E12 sej/yr)	Fraction of total emergy %	EmSwiss Francs (2000 CHF)
1	Polystyrene	1.00E+03 kg	5.76E+12	5760.0	83.78	9795.92
2	Pentan	2.80E+09 J	1.11E+05	310.7	4.52	528.33
3	Organic fireproof material	4.42E+08 J	1.11E+05	49.1	0.71	83.42
4	Plastic	6.00E+00 kg	5.76E+12	34.6	0.50	58.78
5	Transport (28t Truck)	5.25E-01 t-km	6.61E+11	0.3	0.01	0.59
6	Extra light oil	1.38E+08 J	8.90E+04	12.3	0.18	20.89
7	Heavy oil	2.72E+09 J	8.90E+04	242.4	3.53	412.20
8	Electricity	2.48E+09 J	1.88E+05	466.2	6.78	792.93
9	Annual yield (without services)	1.00E+03 kg	6.88E+12	6875.5		11693.05

The transformity of expanded polystyrene thus assessed is equal to 6.88E +12 sej/J and its emvalue is 11.69 CHF/kg.

3.3.3 Emergy evaluation of glass wool

The emergy evaluation of glass wool is presented in Table 3-5. As mentioned for expanded polystyrene, the chemicals inputs (phenol and ureeformol) are evaluated using transformity of refined oil. The transformity of glass wool is equal to 9.61E +12 sej/J and its emvalue is 16.35 CHF/kg.

Table 3-5
Emergy evaluation of glass wool production 1997 (CH)
Source of raw data : ISOVER (1997)

Note	Item	Raw Units (per year)	Transformity (sej/unit)	Solar Emergy (E12 sej/yr)	Fraction of total emergy %	EmSwiss Francs (2000 CHF)
1	Quartz sand	3.25E+02 kg	1.68E+09	0.5	0.01	0.93
2	Recycled glass	6.75E+02 kg	2.13E+12	1437.8	14.96	2445.15
3	Phenol	5.88E+08 J	1.11E+05	65.3	0.68	111.07
4	Ureeformol	1.48E+08 J	1.11E+05	16.4	0.17	27.91
5	Transport	3.40E-01 t-km	6.61E+11	0.2	0.00	0.38
6	Extra light oil	1.04E+08 J	8.90E+04	9.3	0.10	15.80
7	Electricity	4.30E+10 J	1.88E+05	8084.0	84.09	13748.30
8	Annual yield (without services)	1.00E+03 kg	9.61E+12	9613.5		16349.54

3.3.4 Emergy evaluation of screeds

The emergy evaluation of screeds is presented in Table 3-6. The transformity of screeds obtained is equal to 1.72 E +12 sej/J and its emvalue is 2.93 CHF/kg.

Table 3-6
Emergy evaluation of screeds production 1995 (CH)
Source of raw data : SIA D0123 "Hochbaukonstruktionen nach ökologischen Gesichtspunkten (1995)

Note	Item	Raw Units (per year)	Transformity (sej/unit)	Solar Emergy (E14 sej/yr)	Fraction of total emergy %	EmSwiss Francs (2000 CHF)
1	Sand	8.60E+02 kg	1.68E+12	14.45	83.90	2457.14
2	Portland cement	1.40E+02 kg	1.98E+12	2.77	16.10	471.43
3	Annual yield (without services)	1.00E+03	1.72E+12	17.22		2928.57

3.3.5 Comparison of emergy results to embodied energy

The transformities established for plaster, expanded polystyrene (EPS), glass wool and screeds are presented in Table 3-7 along with the embodied energy (also called NRE for Non-renewable Energy), the emvalue and the actual price to show the buying power of the currency.

The value obtained by Buranakarn for cement is added for comparison. The value in brackets represents the transformity of the product not including services. The transformity of screeds is the lowest and is very close to cement as expected. It is also the lowest NRE value, as well as emvalue and price. The values of embodied energy per mass and emergy per mass are very different, but the hierarchy is well conserved. The exception is expanded polystyrene with a higher NRE value than glass wool, but a smaller transformity. The transformity of glass wool and EPS were the most difficult to establish as their process require inputs for which no transformity was available (such as pentan or phenol) and some assumptions were therefore made. When transformity is expressed per year of lifetime, it is interesting to note that glass wool comes close to plaster, because its lifetime is four times longer (80 years instead of 20).

The larger emvalue it is, the more mass is obtained per dollar. As a result, the more finished a material is, the lower its emvalue. Indeed, as price is directly related to human labor, the materials with the lowest emvalue are often the ones with large inputs of human services to their process. This is observed as EPS and glass wool have the largest emvalue. As their actual prices are also very high it means that the buying power of the Swiss Francs for these products is smaller.

Table 3-7
Comparison of some materials using different indices

Material	Transformity E12 [sej/kg]	Transf over lifetime E12 [sej/kg*yr]	NRE E6 [J/kg]	NRE over lifetime E6 [J/kg*yr]	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	0.10	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

3.4. Simulation of the production of information

In order to test the information production model, simulations were made for different conditions, using an aggregated system.

3.4.1. Systems diagram of information production (aggregated diagram)

As the primary output of the LESO building is information (scientific knowledge), its production was simulated, using different scenarios, during 80 years (building lifetime). The building was aggregated as a storage because it doesn't vary much during this period (except if maintenance stops). A new diagram was therefore drawn and is presented in Figure 3-2. On the time scale considered, faculty and students are considered as a storage of information rather than inflows.

3.4.2. Equations

Table 3-7 presents the equations for the diagram shown in Figure 3-2.

An equation is written for each system component (storage) of the system and initial conditions are used to calculate each coefficient (Table 3-8). Some assumptions were required for determining theses conditions. First, the storage of information at steady state and the external information source has a constant growth per year, set at one percent. The values of the storages are arbitrarily chosen as 100 for both the building and the information storages. The proportion of new information coming into the storage is assumed to be 5% of the information storage. This means that J_2 - J_1 = 5. J_5 is considered as a quadratic drain to express the fact that we "lose" information (i.e. forget) in proportion to the square of the information presented to us. Indeed, the quantity of information that our brain conserves in long-term memory is small compared to the amount of information we are exposed to. The value of the flow is presumed to be 4% of the information storage. The number of students coming into the building each year is directly related to their turnover time: 4 years for a graduate student, and one year for an undergraduate. The turnover time of the faculty member is assumed to be 20 yrs. J_5 is set to be equal to 15, this value being estimated from the proportion of emergy of nine students compared to the one of the entire group of building users.

Ten percent of the information produced by the building is used as a feedback and finally, the value of J_3 is fixed by the steady-state conditions.

A short description of each flow is presented in Table 3-9

Sensors are placed on the side of the building because it is needed to produce information, but no actual outflow is really used (except paper). It was decided to add an interaction between the flow of incoming students and the building storage to convey that fewer students will use the building if it is degraded and can no longer sustain. The doted line and production symbol represent the necessary environmental inputs to the system, which are not considered as part of the process for simplification

Once the coefficients were established, a simulation was run for the entire lifetime of the building. Different scenarios were studied in relation to the building, using a fixed growth of the external information source (1% per year).

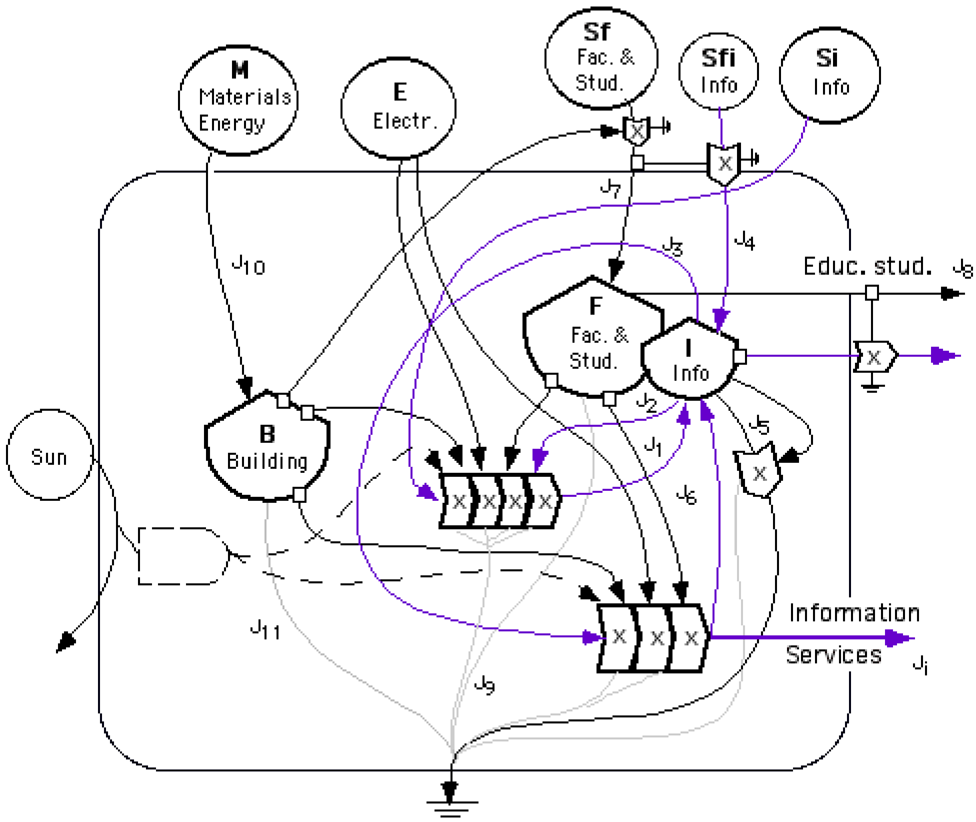


Figure 3-2. Aggregated diagram for production of information

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Table 3-8 Equations for the model of information production

Equations :

dI/dt = J1 + J4 + J6 - J2 - J3 - J5

dF/dt = J8 - J9 - J10

dB/dt = J11 - J12 - J13 - J14

Flows :

J1 = k1*B*E*F*I*Si	J5 = k5*I^2	J9 = k9*F
J2 = k2*B*E*F*I*Si	J6 = k6*B*E*I	J10 = k10*M
J3 = k3*B*E*I	J7 = k7*Sf*B	J11 = k11*B
J4 = k4*J7*Sfi	J8 = k8*Sf	Ji = ki*E*B*F

Table 3-9 Initial conditions and coefficients for simulation

Initial conditions :

Io = 100	J1o = 7.00E+00	
Bo = 100	J2o = 2.00E+00	J9o = 0.00E+00
Fo = 25	J3o = 1.80E+01	J10o = 1.50E+00
Eo = 50	J4o = 1.50E+01	J11o = 1.50E+00
Sfo=Sf = 30	J5o = 4.00E+00	Jio = 2.00E+01
Sfio = Sfi = 75	J6o = 2.00E+00	
Sio = 50	J7o = 9.00E+00	
Mo = 50	J8o = 9.00E+00	

Coefficients:

k1 = J1o/(Bo*Eo*Fo*Io*Si) =	1.12E-08	k7 = J7o/Sfo*Bo =	3.00E-03
k2 = J2o/(Bo*Eo*Fo*Io*Si) =	3.20E-09	k8 = J8o/Fo =	3.60E-01
k3 = J3o/(Bo*Eo*Io) =	3.60E-05	k9 = J9o/Fo =	0.00E+00
k4 = J4o/(J7o*Sfio) =	2.22E-02	k10 = J10o/Mo =	7.50E-02
k5 = J5o/(Io*Io) =	4.00E-04	k11 = J11o/B =	1.50E-02
k6 = J6o/(Bo*Eo*Io) =	4.00E-06	ki = Jio/(Io*Bo*Eo*Fo) =	1.60E-06

Table 3-10. Short description of the flows

J1	Fraction of new information actually conserved (in long term memory)
J2	Fraction of previous knowledge used as feedfack to reinforce the new information flow
J3	Knowledge that will be transformed ("packaging process") to be generated as information outflow
J4	Previous knowledge of the students
J5	Quadratic drain representing the information we forget (short-term memory)
J6	Feedback from the production process to the information storage (each time an article is published, part of the students/faculty will probably read it)
J7	Graduate or undergraduate students coming in the LESO building
J8	Graduate students leaving the building
J9	This flow = zero, as there is no depreciation associated to the people themselves
J10	Maintenance of the buildings (materials, energy, etc)
J11	Depreciation of the building (used materials)

3.4.3 Simulation

Different scenarios are considered using the simulation model to study the influence of the building on the information produced. The constant parameter is the growth of the external source of information assumed to be 1% per year. The results are presented in Figure 3-3 to 3-6. Each time, the actual behavior is shown together with a curve representing the result that would be obtained if the information production (or storage) had the same rate of change as the external information source.

3.4.1. Constant building storage

In that first simulation, the building storage is set at steady state during its lifetime, using a constant maintenance. The faculty and students storage is also assumed to be constant, with 9 students coming and 9 leaving each year.

For a rate of change of the external source of information set at 1.0% per year, the growth of the information storage shows a mean growth of approximately 0.5% per year, as shown in Figure 3-3. The production of information follows approximately the same rate of change, as shown in Figure 3-4.

These results show that the growth rate of knowledge of the people working in the building cannot catch up with that of external source. This result is intuitive because the external information available is produced by different sources, some producing information faster than others. Indeed, especially with respect to scientific information, spectacular rates of growth may be observed depending on the general public interest for it. One such current example may be the field of biotechnology. The results obtained also show that the interactions between building users result in positive feedbacks that produce more information each year.

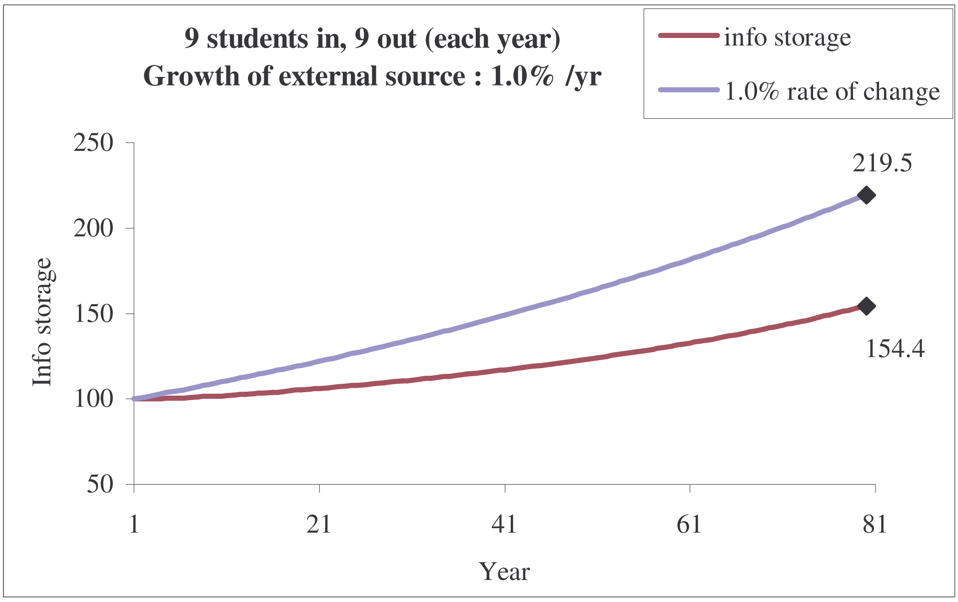

Figure 3-3. Information storage for a growth of external info source equal to 1% /yr

Noticing the fact that the information stored and produced are both growing slower than the external source, it was decided to find out what other conditions would allow the information to be produced at the same rate as the external source, with the building still at steady state.

The first two parameters that were changed are the number of persons working in the building, i.e. the value of the faculty and student tank, and the consumption of electricity. First, only the faculty and student storage was modified and assigned different rates of constant growth in order to find out for which one the information produced would match the external growth of one percent per year.

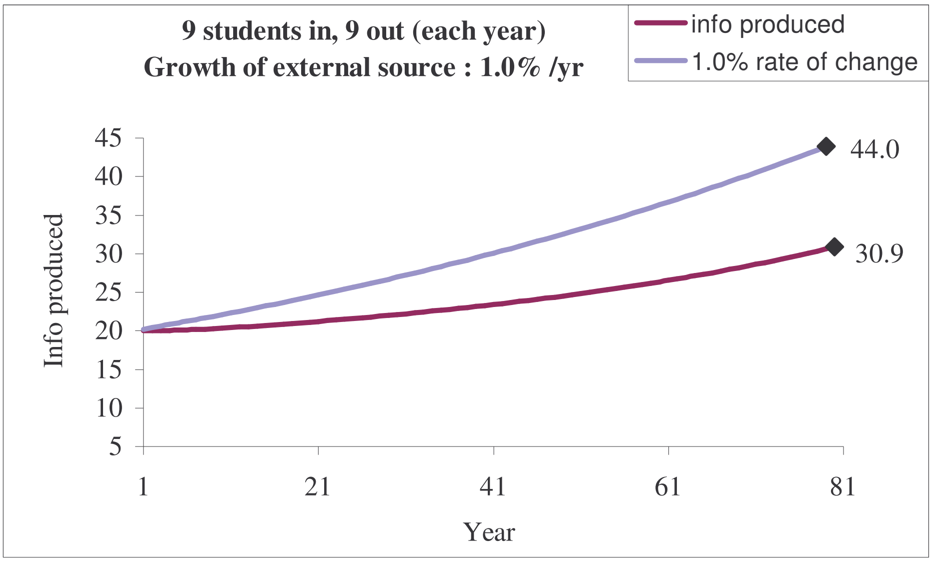

Figure 3-4. Information produced for a growth of external. info source equal to 1% /yr

As shown in figure 3-5, the growth of the faculty and students must be at least 0.25% to produce the same amount of information during at the end of its lifetime. If the rate of change is fixed to be higher than 0.25%, the increase of information produced will overcome the one of the external source. It would then represent a fast source of information because of the growth of the number of people working or studying in that field. One example is the systems communication department at the EPFL (Swiss Federal Institute of Technology) which development has been very fast since its creation, the number of research projects performed directly related to the number of students and professors. It is very interesting to note that the increase of the number of persons doesn't need to be more than a quarter of the external production growth to be competitive as a source of information. As part of this information produced is services, the number of faculty members and students would be expected to have a higher influence on the production process than on the internal information process. It is exactly what is observed, as shown in figure 3-6.

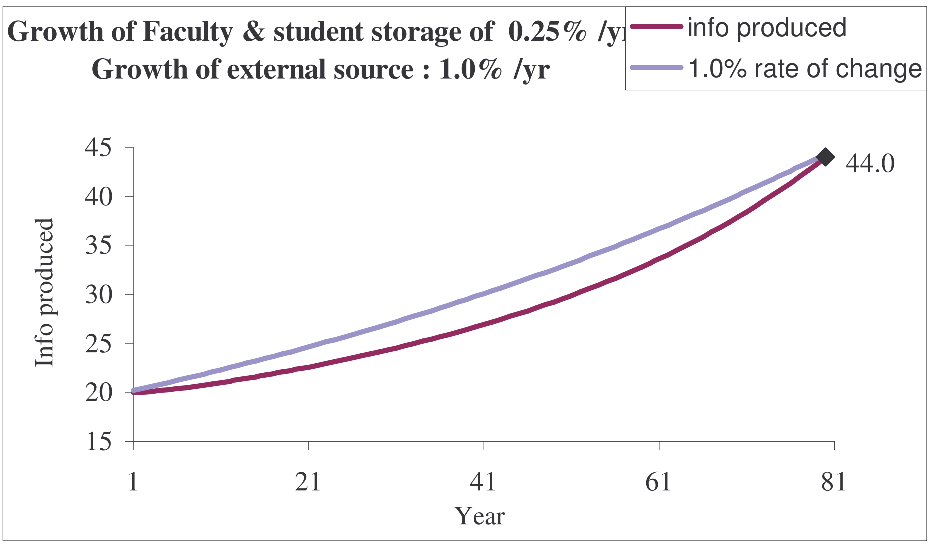

Figure 3-5. Information produced for a growth of faculty & student storage of 0.25% /yr

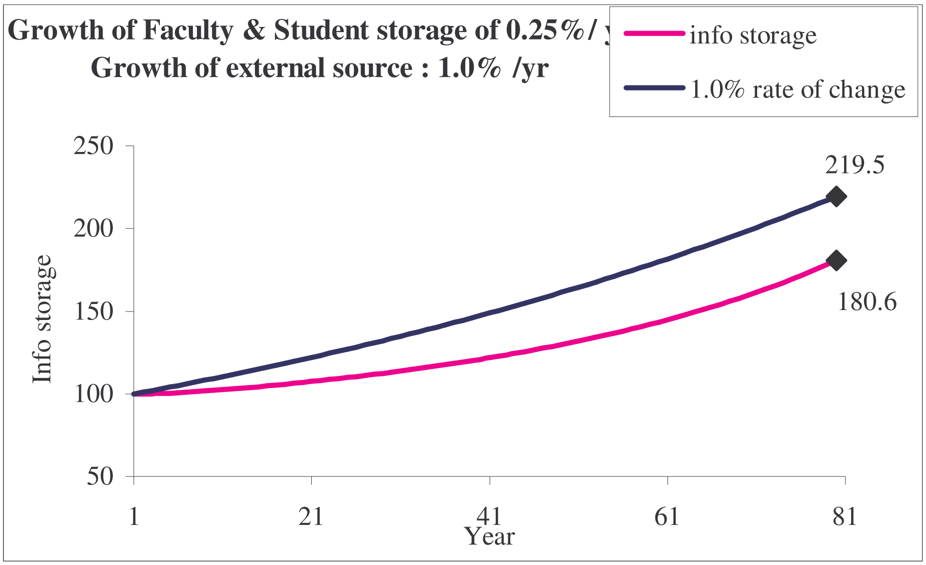

Figure 3-6. Information storage for a growth of faculty & student storage of 0.25% /yr

Nevertheless, it is improbable that the faculty and student storage growth is not accompanied by a growth of electricity consumption. Therefore, both were set at the same constant rate of change and again the minimal value allowing a competitive production was sought. This value was determined to be 0.17% as shown in Figure 3-7.

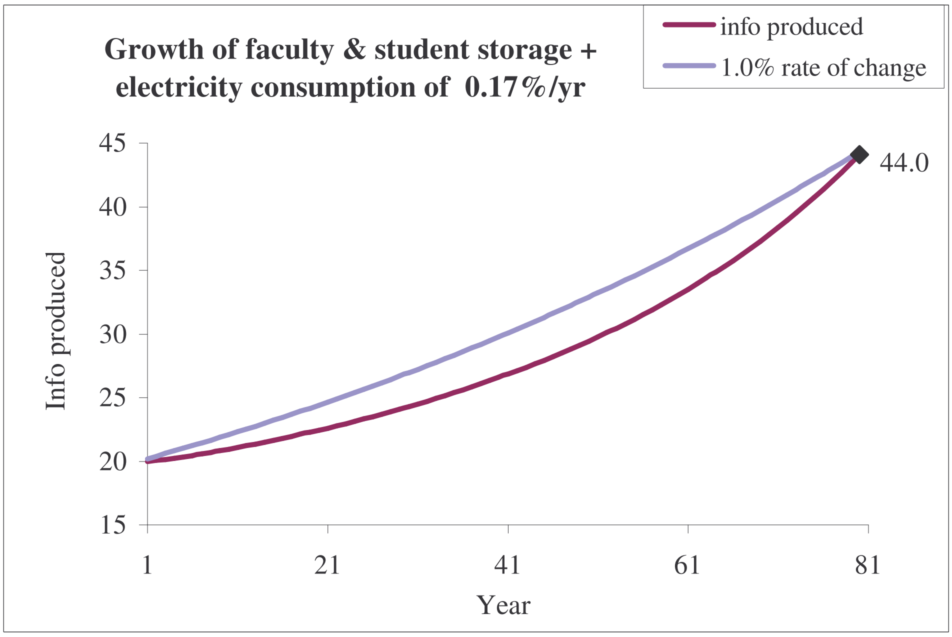

Figure 3-7. Information storage for a growth of faculty & student storage, as well as electricity consumption of 0.17% /yr

Such a result would be expected, as it corresponds to the possibility of each supplementary student or professor to use a computer and therefore produce more information than if only acting as a supplementary "brain" without the possibility to export his knowledge.

The last parameter studied with the building at steady state is the value of the inflow to the information storage provided by the external source. Instead of being set at 5% of the storage value, different values were used, which required that other inflows and outflows be modified to keep the storage at steady state. If the value is set to be at least 8% of the storage value the production becomes competitive. This means that the proportion of new information learned each year should represent 16% of the external source instead of 10% percent as we had assumed.

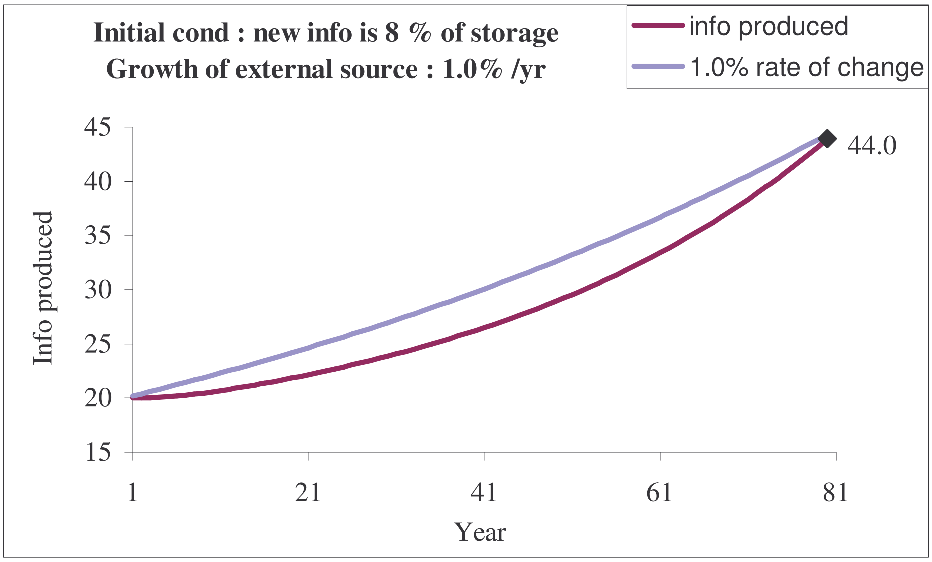

Figure 3-8. Information produced for new information inflow equal to 8% of storage

3.4.2. Variable building storage

The effect of the building as a parameter of information production was studied with one scenario, corresponding to the abrupt interruption of the maintenance after 40 years (half of the building lifetime). As expected the information produced decreases rapidly, along with the number of students coming (and leaving) the building. This effect is shown in Figure 3-9.

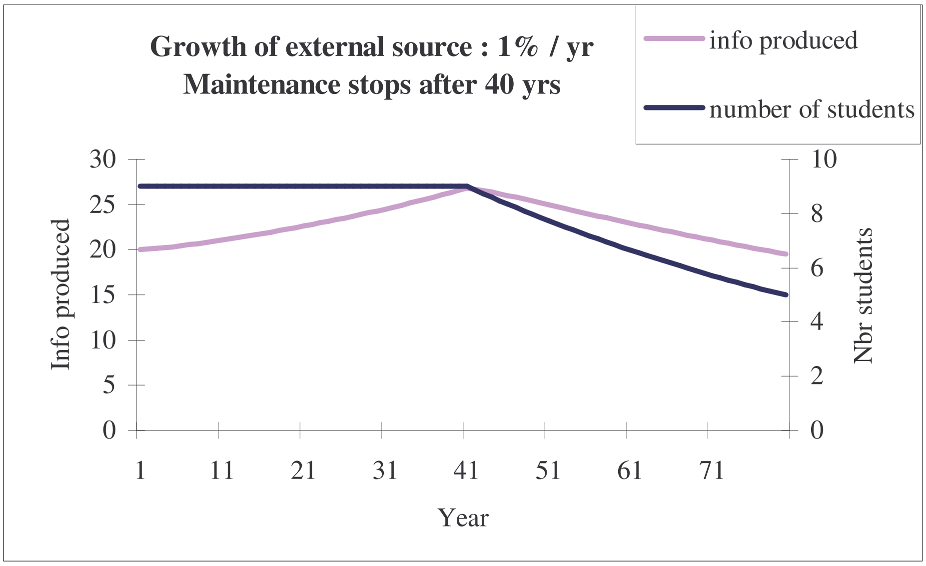

Figure 3-9. Information produced and number of students if maintenance stops after 40 yrs

CHAPTER 4
DISCUSSION

4.1. Emergy evaluation of the LESO building

4.1.1. Emergy evaluation method

The goal of this study was to use the emergy methodology to evaluate the LESO building and its inputs and outputs. As the LESO is an academic building, its output is scientific information disseminated via publications, or services to third parties as consultants. The building also generates information as knowledge through courses taught by the professors and assistants and through students who graduate and leave the building with a higher level of education. Therefore, emergy was the most appropriate methodology for this to studying this system. Indeed, other common methodologies, such as exergy, Life-Cycle Analysis (LCA) or embodied energy (NRE index) could be used to express materials inflows, but not services and information. With respect to information, each of them accounts only 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 a person is calculated from the total emergy inputs to its country and the number of persons with the same level of education. The transformity is thus inversely proportional to the number of person in each category, the higher the level of education, the fewer people and then higher transformity. As transformity is a measure of quality and ability to produce feedback, this kind of result is as expected.

4.1.2 Emergy inflows and outflows of the LESO building

The inputs to the LESO building system can be divided into two major categories, the inputs related to the building as a structure and the information inputs represented by the knowledge of the building users. Considering all inputs, the emergy of the information inflows represents 94.6% of all inputs; 4.1% is covered by the emergy related to the flows of goods and services, whereas inputs to the building structure only represent 5.4%. The emergy of the building structure is mainly accounted for in the emergy storages.

4.1.2.1 Building inputs

The material, as well as goods (appliances, equipment, furniture) and service flows, only represent the emergy related to the maintenance of the building. They are therefore small compared to the total amount of material, energy, and services that are required to construct the building. Plaster and painting are the highest emergy building material inputs, mainly because of their short lifetime (20 yrs), which implies more replacements. The importance of considering the lifetime of any material and not only its emergy per mass was already discussed in section 3.3.5. There are two subcategories of material inflows depending on their use by the building as spare parts or by the people working in the building. It is assumed that no material is required for the maintenance of the PV installation. Paper is a high input with its emergy representing 17.3% of total inflows, and 35.1% of all material inflows. The total emergy of the material inflows is only 1.68 E16 sej/yr, which is less than the emergy associated to the electricity consumption. Electricity is the highest input of the system, not including services and information. This is consequence of the combination of two factors: first the consumption of the building is particularly important (70% of the total consumption of energy) due to the presence of data-processing machines. And, the transformity of electricity is also quite high, as its value is 1.88 E5 sej/J. This value was estimated from electricity sources in Switzerland, which consist mainly of hydro (56%) and nuclear (43%).

What is more surprising is that paper is the second highest emergy input, with 57.19 E14 sej/yr for a consumption equal to 2.4 tons/year. More than forty percent of this quantity is used for publications and courses.

4.1.2.2 Information inputs

As the LESO is an academic building, the knowledge of the people working in it represents a very high input. It was decided to account for the knowledge of the users as an input rather than a storage, because people come and go every day and employ part of their knowledge in proportion to the time spent in the building. This means that emergy from knowledge is being divided according to the time spent for each activity throughout the day. All the students coming in the building are assumed to have the same transformity, corresponding to that of a college education. As 75% percent of the students are at the graduate level, this assumption is adequate.

The values of transformities considered were established for the United States and their use implies the assumption that approximately the same fraction of people occupy each category and each person gets the same amount of emergy for its county. This assumption is again suitable, as both the United States and Switzerland have the same type of education system and a very close emergy per person value.

4.1.2.3. Outputs

The four different outputs considered for the buildings are educated students, publications, courses and "services'. The emergy associated to the operation of the building as a structure is required to produce each output, so it was 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 spend to produce it.

The emergy associated with the production of publications is therefore very high, because time spent for research was accounted as part of the publication process. Time granted by professors to students was estimated as one hour per professor per week. Secretaries and technical staff were assigned one fourth of their emergy to each output.

A student leaving the LESO has a transformity around three times larger than the one he had upon arrival, representing the information learned through conferences and interactions with other students and professors. The knowledge gained through classes is not included as classes are either not taught by professors from the LESO and therefore not part of the system, or already accounted for in the courses category. The transformity obtained for the services is very interesting, as it is 25 times larger than the transformity of the Swiss Franc. It means that people employing professors as consultants are getting 25 time more emergy than they pay for.

Another category of information products that should have been accounted for are e-mails. The time spent to write and read them is not negligible, but it was assumed that their content has often more to do with private or administrative subjects rather than useful scientific information and they were therefore not accounted.

4.1.3. Emergy storages of the building

Two different kinds of storages are part of the system: two material storages and one storage of heat. The material storages associated to the building and the PV installation include the materials as well as the emergy of the energy and service inputs to the construction. The heat storage is assumed to be equal to the heat released by the people and electric appliances. The transformity of this "type" of heat is assumed to be equal to the one produced by the heat pump, as both heat have the same quality (even if the heat pump is producing hot water). The transformity of the heat was established considering the heat consumption of the LESO and the performance coefficient of the heat pump. The value thus assessed is equal to 4..37 E4 sej/J, which is coherent as it the transformity of fuels are the same order of magnitude (8.90 E4 sej/J for oil).

In contrast to the results obtained considering the inflows, the building materials and particularly cement and concrete represent the majority of the total emergy. The transfomities of concrete and cement are among the smallest, but the quantities involved are relatively large, so the emergy ends up being 31.8%, respectively 23.0% of total emergy of storages.

4.2 Emergy evaluation of some building materials

The transformities of plaster, expanded polystyrene, glass wool and screeds were established in this thesis as they were not previously available. The transformities determined do not include services. It would have been interesting to establish the transformities with services included for comparison but data from (Buranakarn, 1998) show that the services have a small effect on the transformity value, especially with unfinished products such as cement or concrete, since most of the emergy comes from the environment. The proportion of services to a process can be roughly evaluated by comparing the emvalue to the actual price of a product. Indeed, the price is often a good indicator of the human labor necessary to manufacture a product. A detailed comparison was done in section 3.3.5

4.3. Production of information

The results of the simulation were already presented in detail in Section 3.5 and will not be discussed further in this Chapter. Nevertheless, it must be indicated that the interesting results obtained show the extent to which the emergy evaluation method and corresponding systems diagram may be applied to represent a quite complex system.

4.4 Conclusion

This study presents the emergy methodology and its application to a rather complicate system: a building. Some issues are related to the use of transformities as for example the necessity to consider each system as part of the global biosphere system, as every input is related to the energy of the sun. Some compromises must therefore be made about the use of transformities, as every subsystem cannot be evaluated each time. But, the emergy method is unique as transformities are available for each type of flow, as for example information, each type of energy placed among a quality hierarchy. Moreover, the systems diagram methodology was very useful to present a simple but accurate model of the LESO building and its production of information.

APPENDIX A

LIST OF TRANSFORMITIES

Table A-1 List of Transformities used and calculated in this dissertation

Item	Transformity [sej/kg] with services	[sej/kg] without services	[sej/J] with services	[sej/J] without services	[sej/CHF]	Reference sources
Materials						
Limestone	1.68E+12					(Odum, 1996, p.50,updated with Odum, 2000, Folio #1)
Sand	1.68E+12					(Odum, 1996, p.50,updated with Odum, 2000, Folio #1)
Quartz Sand	1.68E+12					(Odum, 1996, p.50,updated with Odum, 2000, Folio #1)
Water			4.80E+04	4.80E+04		(Odum, 1996, p.120)
Fuels and Energy						
Coal			6.69E+04			(Odum, 1996, p.308,updated with Odum, 2000, Folio #1)
Oil			8.90E+04			(Odum, 1996, p.308,updated with Odum, 2000, Folio #1)
Refined oil			1.11E+05			(Odum, 1996, p.308,updated with Odum, 2000, Folio #1)
Natural gas			5.88E+04			(Odum, 1996, p.308,updated with Odum, 2000, Folio #1)
Electricity			1.88E+05			(Estimation, this study, Table C-1)
Heat			4.37E+04			(Estimation, this study, Table 3-1)
Transportation						
Trucks	6.61E+11 sej/tonne-kilometer					(Buranakarn, 1998, Table E-1, p. 236)
Products						
Aluminium (sheet, convent.), 1997	1.27E+12					(Buranakarn, 1998, Table 3-6, p. 60)
Cement without fly ash (conventional), 1995	1.97E+12					(Buranakarn, 1998, Table 3-1, p. 38)
Ready-mixed concrete (conventional), 1996	1.44E+12					(Buranakarn, 1998, Table 3-2, p. 42)
Expanded polystyrene, 1994		6.88E+12				
Float glass (conventional), 1997	7.87E+12					(Buranakarn, 1998, Table D-4, p. 219)
Glass wool, 1997		9.61E+12				(This study, Table 3-4)
Iron, 1996	2.83E+12					(Buranakarn, 1998, Table C-3, p. 177)
Hardwood Plywood	1.44E+12					(Buranakarn, 1998, Table C-16, p. 203)
Lumbers	8.79E+11					(Buranakarn, 1998, Table 3-9, p. 69)
Paper	2.38E+12					(Estimation, this study, Table 3-1)
Plaster, 1994		1.96E+12				(This study, Table 3-3)
Plastics (Europe), 1993	5.76E+12					(Buranakarn, 1998, Table C-11, p. 193)
Screeds, 1995		1.72E+12				(This study, Table 3-6)
Silicon	7.34E+12					(Estimation, this study, Table 3-2)
Steel (conventional), 1996	4.10E+12					(Buranakarn, 1998, Table 3-4, p. 52)
Economy						
Swiss Franc	5.88E+11 sej/CHF					
Information						
School Education				2.46E+07		(Odum, 1996, p.232)
College graduate				7.33E+07		(Odum, 1996, p.232)
Post College eduaction				3.43E+08		(Odum, 1996, p.232)

APPENDIX B

FOOTNOTES TO EMERGY EVALUATION TABLES

Table B-1 Footnotes to Table 3-1 Emergy evaluation of the inflows and outflows of the LESO building

Footnotes to Table 3-1

RENEWABLE RESOURCES

1 SOLAR ENERGY :

BUILDING :

South facade =	2.16E+02	m^2	
East facade =	1.08E+02	m^2	
West facade =	1.08E+02	m^2	
North facade =	1.20E+02	m^2	
Roof =	2.09E+02	m^2	
Vertical South irradiation =	3.08E+09	J/m^2 yr	(PVSyst 3.21, albedo taken as 20% included))
Vertical East irradiation =	2.60E+09	J/m^2 yr	(PVSyst 3.21, albedo taken as 20% included))
Vertical West irradiation =	2.52E+09	J/m^2 yr	(PVSyst 3.21, albedo taken as 20% included))
Vertical East irradiation =	1.50E+09	J/m^2 yr	(PVSyst 3.21, albedo taken as 20% included))
Horizontal global irradiation =	4.25E+09	J/m^2 yr	(PVSyst 3.21, albedo taken as 20% included))
Energy(J) =	Sum {(area)*(avg insolation)}		
=	(____m^2)*(____J/m^2 yr)		
=	2.29E+12	J/yr	

PV INSTALLATION :

Net collectors surface =	2.60E+01	m^2	
Global irradiation in the collect. plane =	4.88E+09	J/m^2 yr	(PVSyst 3.21, albedo taken as 20% included))
Energy(J) =	(Net surface)*(Irradiation)		
=	1.27E+11	J/yr	
Total solar energy =	Irradiation of building + irrad. PV inst		
=	2.41E+12	J/yr	
Transformity =	1.00E+00	sej/J	Definition

2 WATER :

Avg consumption =	6.00E+01	m^3/yr	
Energy (J) =	(Avg consumption)*(1000kg/m^3)*(4.94E+03J/kg)		
=	2.96E+08	J/yr	
=	2.96E+08	J/yr	
Transformity =	4.80E+04	sej/J	(Odum, 1996, Table 7-6, p.120)

NON RENEWABLE OUTSIDE SOURCES

a. MATERIALS

a 1. Replacement for the building

3 WOOD :

Quantity for used for the building =	2.23E+04	kg	
Number of replacement	1	(Lifetime : 50 yrs)	
Lifetime of the building =	80	yr	
Mass (kg) =	{(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)		
=	2.79E+02	kg/yr	
Transformity =	8.79E+11	sej/kg	(Estimated equal to transformity of lumbers, Buranakarn, 1998, Table 3-9 , p. 69)

4 SCREEDS :

Quntity used for the building =	6.64E+04	kg	
Number of replacement	1	(Lifetime : 40 yrs)	
Mass (kg) =	{(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)		
=	8.30E+02	kg/yr	
Transformity =	1.72E+12	sej/kg	(This study, Table 3-6)

5 PLASTER :

Quntity used for the building =	2.30E+04 kg		
Number of replacement	3 (Lifetime : 20 yrs)		
Mass (kg) =	{(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)		
=	8.64E+02 kg/yr		
Transformity =	1.96E+12 sej/kg		(This study, Table 3-3)

6 IRON :

Quantity for used for the building =	2.79E+04 kg		
Number of replacement	1 (Lifetime : 60 yrs)		
Mass (kg) =	{(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)		
=	3.48E+02 kg/yr		
Transformity =	4.15E+12 sej/kg		(Transformity of steel, conventional, Buranakarn, 1998, Table 3-4, p.52)

7 ALUMINIUM :

Quntity used for the building =	1.08E+03 kg		
Number of replacement	1 (Lifetime : 40 yrs)		
Mass (kg) =	{(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)		
=	1.35E+01 kg/m^2 yr		
Transformity =	1.27E+13 sej/kg		(Transformity of aluminium, conventional, Buranakarn, 1998, Table 3-6, p.60)

8 COPPER :

Quantity for used for the building =	1.14E+03 kg		
Number of replacement	1 (Lifetime : 60 yrs)		
Mass (kg) =	{(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)		
=	1.43E+01 kg/yr		
Transformity =	6.77E+13 sej/kg		(Odum et al., 1987, p.159)

9 GLASS :

Quntity used for the building =	1.93E+03 kg		
Number of replacement	2 (Lifetime : 30 yrs)		
Mass (kg) =	{(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)		
=	4.83E+01 kg/yr		
Transformity =	7.87E+12 sej/kg		(Transformity of float glass, conventional, Buranakarn, 1998, Table 3-14, p.85)

10 EXPANDED POLYSTYRENE :

Quntity used for the building =	2.23E+03 kg		
Number of replacement	1 (Lifetime : 40 yrs)		
Mass (kg) =	{(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)		
=	2.79E+01 kg/yr		
Transformity =	6.88E+12 sej/kg		(This study, Table 3-4)

11 NATURAL RUBBER :

Quntity used for the building =	3.46E+03 kg		
Number of replacement	3 (Lifetime : 20 yrs)		
Mass (kg) =	{(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)		
=	1.30E+02 kg/yr		
Transformity =	4.30E+12 sej/kg		(Odum et al., 1987, p.159)

Table B-1.— Continued

12 PAINTING :

Quntity used for the building = 3.25E+03 kg
Number of replacement 3 (Lifetime : 20 yrs)
Mass (kg) = {(Quantity used)*(Number of replacements)}/(Lifetime of the bldg)
= 1.22E+02 kg/yr
Transformity = 1.52E+13 sej/kg (Buranakarn, 1998, Table C-14, p.199)

TOTAL MASS :

Total Mass of material used = 2.68E+03 kg/yr
Transformity (weighed) = 3.34E+12 sej/kg

a 2. Material used by the faculty & students

17 PAPER:

Paper consumed (publ., courses,..) = 2.40E+03 kg/yr
Transformity = 2.38E+12 sej/kg (Estimated from 1.42E+5 sej/J, Keller, 1992, p.116 considering energy content of paper = 4 kcal/g)

18 PLASTIC :

Plastic consumed = 7.80E+01 kg/yr
Transformity = 5.76E+12 sej/kg (Buranakarn, 1998, Table C-11, p.193)

19 METAL (for the workshop) :

		Transformity	
Aluminium consumed =	9.00E+01 kg/yr	1.27E+13 sej/kg	(Buranakarn, 1998, Table 3-6, p.60)
Iron consumed =	6.00E+01 kg/yr	4.15E+12 sej/kg	(Buranakarn, 1998, Table C-3, p.177)
Total mass =	1.50E+02 kg/yr		
Transformity (weighed) =	9.28E+12 sej/kg		

TOTAL MASS :

Total Mass of material used = 2.63E+03 kg/yr
Transformity (weighed) = 2.87E+12 sej/kg

b. ENERGY

21 HEAT :

Heat consumed (hot water) by the bldg = 3.74E+10 J/yr (The heat is produced is a heat pump (HP))
Performance coefficient of the HP = 4.30E+00
Electricity consumed by the HP = Heat produced/perf.coefficient
= 8.70E+09 J/yr
Transformity of electricity = 1.88E+05 sej/J (Estimation based on origin of elect. in Switzerland : ~ 57% hydro, ~ 43% nuclear and Odum, 1996, Table C.1, p.305, updated)
Emergy of heat = Electricity consumed*Transformity =
= 1.64E+15 sej/yr
Transformity of heat = (Emergy)/(Qtty of heat produced) =
= 4.37E+04 sej/J

22 ELECTRICITY :

Electricity consumed by appl., equip. = 1.22E+11 J/yr
Electricity consumed by heaters = 2.23E+10 J/yr
Electricity consumed for maint. of the bldg = 1.57E+09 (Estimated equal to 2 MJ/m^2 yr, J-B Gay)
Total electricity consumed = 1.44E+11 J/yr
Transformity = 1.88E+05 sej/J (Estimation based on origin of elect. in Switzerland : ~ 57% hydro, ~ 43% nuclear and Odum, 1996, Table C.1, p.305, updated)

c. GOODS and SERVICES

23 APPL., EQUIP., FURNITURE :

Cost of heating system = 6.00E+03 CHF
Cost of electric appliances = 7.45E+04 CHF
Cost of equipment = 1.50E+05 CHF
Cost of furniture = 1.45E+05 CHF
Cost of sanitary inst. = 5.00E+04 CHF
Total costs = 4.26E+05 CHF
Lifetime of the building = 8.00E+01 yr
Costs = (Total costs)/(Lifetime of the building)
= 5.32E+03 CHF/yr
Transformity = 5.88E+11 sej/CHF (This study, Table C-1)

Table B-1.— Continued

24 SERVICES :			
Maintenance and amortiz. of the building =	1.94E+05 CHF/yr	Amortization estimated as 5.5% of total constr. costs, maintenance as 1.5%	
Maintenance of the heating system =	3.00E+02 CHF/yr	Estimated as 5% of price	
Maintenance of the el. appliances =	3.73E+03 CHF/yr	Estimated as 5% of price	
Maintenance of the equipment =	3.00E+04 CHF/yr	Estimated as 20% of price	
Maintenance of the furniture =	7.25E+03 CHF/yr	Estimated as 5% of price	
Maintenance of the sanitary inst. =	1.00E+03 CHF/yr	Estimated as 2% of price	
Maintenance of the PV installation =	9.60E+02 CHF/yr	Estimated as 2% of total construction costs	
Total labor =	2.37E+05 CHF/yr		
Transformity =	5.88E+11 sej/CHF		(This study, Table C-1)
d. PEOPLE & INFORMATION			
25 STUDENTS (ungrad & grad) :			
Number of students =	2.08E+01 person		
Energy of students =	(Nbr of students)*(Metabolic energy) =		
=	(2.08E+1 pers)*(120 Kcal/hr)*(4186 J/Kcal)*(5.4h/day)*(0.7)*(365 days/yr)		
=	1.44E+10 J/yr	(Estimation : 30% of time is spent outside of the bldg : conf, seminars, etc)	
Transformity =	7.33E+07 sej/J		(Transformity of college grad., Odum, 1996, p.232)
26 FACULTY :			
Faculty members =	4.90E+00 person		
Energy of students =	(Nbr of faculty members)*(Metabolic energy) =		
=	(4.90E+0 pers)*(120 Kcal/hr)*(4186 J/Kcal)*(5.4h/day)*(0.7)*(365 days/yr)		
=	3.40E+09 J/yr		
Transformity =	3.43E+08 sej/J		(Transformity of post college educated, Odum, 1996, p.232)
27 SECRETARIES & TECHN. STAFF :			
Number of secretaries & tech. staff =	3.90E+00 person		
Energy of students =	(Nbr of secret. & techn. staff)*(Metabolic energy) =		
=	(3.90E+0 pers)*(120 Kcal/hr)*(4186 J/Kcal)*(5.4h/day)*(0.7)*(365 days/yr)		
=	2.70E+09 J/yr		
Transformity =	2.46E+07 sej/J		(Transformity of school education, Odum, 1996, p.232)
28 EXTERNAL INFORMATION :			
Students (ungrad & grad) :			
Number of students =	2.08E+01 person		
Energy of students =	(Nbr of students)*(Metabolic energy) =		
=	(2.08E+1pers)*(120 Kcal/hr)*(4186 J/Kcal)*(5.4h/day)*(0.3)*(365 days/yr)		
=	6.18E+09 J/yr		
Transformity =	7.33E+07 sej/J		(Transformity of college grad., Odum, 1996, p.232)
Faculty :			
Faculty members =	4.90E+00 person		
Energy of students =	(Nbr of faculty members)*(Metabolic energy) =		
=	(4.90E+0 pers)*(120 Kcal/hr)*(4186 J/Kcal)*(5.4h/day)*(0.3)*(365 days/yr)		
=	1.46E+09 J/yr		
Transformity =	3.43E+08 sej/J		(Transformity of post college educated, Odum, 1996, p.232)
Secretaries & Techn. staff :			
Number of secretaries & tech. staff =	3.90E+00 person		
Energy of students =	(Nbr of secret. & techn. staff)*(Metabolic energy) =		
=	(3.90E+0 pers)*(120 Kcal/hr)*(4186 J/Kcal)*(5.4h/day)*(0.3)*(365 days/yr)		
=	1.16E+09 J/yr		
Transformity =	2.46E+07 sej/J		(Transformity of school education, Odum, 1996)
Total emergy of external info =	Sum ((Total energy for each categ.)*(Transf.))		
=	9.81E+17 sej/yr		
Total energy =	8.79E+09 J/yr		
Transformity (weighed) =	1.12E+08 sej/J		

Table B-1.— Continued

e. OUTPUT

Total emergy of building inflows = 1.88E+17 sej

Total emergy of information inflows = 3.27E+18 sej

29 EDUCATED STUDENTS :

Students leaving the LESO = 1.00E+00 person
Energy of students = (Nbr of students)*(Metabolic energy) =
= (1 pers)*(120 Kcal/hr)*(4186 J/Kcal)*(5.4h/day)*(365 days/yr)
= 9.90E+08 J/yr
Emergy of students = Nbr stud.*((Emergy of the bldg inflows) + ((0.2h/28h)*(Total Emergy(fac.))+ (2h/28h)*(19.8/20.8)*(Total Emerg
(7h/28h)*(Total Emergy(secret. & techn staff.))) = **(Total emergy includes emergy ext. info)**
= 2.37E+17 sej
Transformity = Emergy/(energy ofstudents) =
= **2.40E+08 sej/J**

30 PUBLICATIONS :

Publications prod.(books, papers,..) = 1.14E+03 kg/yr
= 7.30E+02 page/yr
Emergy of publications = (Emergy of the bldg inflows) + ((13.8h/28h)*Emergy(faculty)+ (26.8h/28h)*Emergy(stud.)) +
(7h/28h)*Emergy(secret. & techn staff.)) =
= 2.48E+18 sej
Transformity = Emergy/(mass paper or nbr pages) =
= **2.18E+15 sej/kg**
= **3.39E+15 sej/page**

31 COURSES :

Nbr of hours taught by Prof. from LESO = 1.71E+02 hr
Emergy of courses = (Emergy of the bldg inflows) + (((171h*2)/1380h)/4.9)*(Total Emergy(fac.))+
(1.1h/28h)*(Total Emergy(stud.))) + (7h/28h)*Emergy(secret. & techn staff.)) =
= 3.13E+17 sej
Transformity = Emergy/nbr hours =
= **1.84E+15 sej/hour**

32 "SERVICES" :

"Services" (as consultants) = 7.00E+04 CHF/yr
Emergy = (Emergy of the bldg inflows) + (13.8h/28h)*(Total Emergy(fac.))+ (7h/28h)*Emergy(secret. & techn staff.)) =
= 1.03E+18 sej
Transformity = Emergy/money received
= **1.47E+13 sej/CHF**

f. BUDGET

33 Budget of the LESO = 2.00E+06 CHF/yr
Transformity = 5.88E+11 sej/CHF (This study, Table C-1)

Table B-2 Footnotes to Table 3-2 Emergy Evaluation of the Storages of the LESO building

Footnotes to Table 3-2

1 BUILDING STRUCTURE :

MATERIALS :			
CONCRETE : Qtty used for constr. =	7.01E+05	kg	
Transformity =	1.44E+12	sej/kg	(Ready-mixed concrete (conventional), Buranakarn, 1998, Table 3-2 , p. 42)
CEMENT : Qtty used for the constr. =	3.68E+05	kg	
Transformity =	1.98E+12	sej/kg	(Conventional cement, Buranakarn, 1998, Table 3-1 , p. 38)
GRAVEL : Qtty used for the constr. =	2.44E+04	kg	
Transformity =	1.68E+12	sej/kg	(Odum, 1996, Table C-4, p. 310, updated with Odum, 2001, Folio #1)
SCREEDS : Qtty used for constr. =	6.64E+04	kg	
Transformity =	1.72E+12	sej/kg	(This study, Table 3-6)
PLASTER : Qtty used for constr. =	2.30E+04	kg	
Transformity =	1.96E+12	sej/kg	(This study, Table 3-3)
WOOD : Qtty used for constr. =	2.23E+04	kg	
Transformity =	8.79E+11	sej/kg	(Estimated equal to transformity of lumbers, Buranakarn, 1998, Table 3-9 , p. 6
IRON : Qtty used for constr. =	2.79E+04	kg	
Transformity =	4.15E+12	sej/kg	(Transformity of steel, conventional, Buranakarn, 1998, Table 3-4, p.52)
ALUMINIUM : Qtty used for constr. =	1.08E+03	kg	
Transformity =	1.27E+13	sej/kg	(Transformity of aluminium, conventional, Buranakarn, 1998, Table 3-6, p.60)
COPPER : Qtty used for constr. =	1.14E+03	kg	
Transformity =	6.77E+13	sej/kg	(Odum et al., 1987, p.159)
GLASS : Qtty used for constr. =	1.93E+03	kg	
Transformity =	7.87E+12	sej/kg	(Transformity of float glass, conventional, Buranakarn, 1998, Table 3-14, p.85)
GLASS WOOL : Qtty used for constr. =	3.30E+03	kg	
Transformity =	9.61E+12	sej/kg	(This study, Table 3-5)
EXP. POLYST. : Qtty used for constr. =	2.23E+03	kg	
Transformity =	6.88E+12	sej/kg	(This study, Table 3-4)
NAT. RUBBER : Qtty used for constr. =	3.46E+03	kg	
Transformity =	4.30E+12	sej/kg	(Odum et al., 1987, p.159)
PAINTING : Qtty used for constr. =	3.25E+03	kg	
Transformity =	1.52E+13	sej/kg	(Buranakarn, 1998, Table C-14, p.199)
FUELS/ ENERGY:			
Fuels for the constr of the bldg =	1.18E+10	J	(Estimated as 15 MJ/m^2 (J.-B. Gay))
Transformity =	1.11E+05	sej/J	(Odum, 1996, Table C.2, p.308, updated using Odum, 2001, Folio #1)
Electricity for constr. of the bldg =	2.36E+10	J	(Estimated equal to 30 MJ/m^2, Triaudes bldg, CH (J.-B Gay))
Transformity =	1.88E+05	sej/J	(Estimation based on origin of elect. in Switzerland : ~ 57% hydro, ~ 43% nuclear and Odum, 1996, Table C.1, p.305, updated)
SERVICES :			
Labor for construction of the bldg.=	1.47E+06	CHF/yr	
Transformity =	5.88E+11	sej/CHF	(This study, Table C-1)
TOTAL MASS :			
Total Mass of material =	1.25E+06	kg	
Transformity (weighed) =	2.53E+12	sej/kg	

2 PV INSTALLATION :

MATERIALS :			
WOOD :			
Quantity used for the PV inst. =	1.62E+02	kg	
Transformity =	1.44E+12	sej/kg	(Hardwood plywood, Buranakarn, 1998, Table C-16 , p. 203)
IRON :			
Quantity used for the PV inst. =	1.26E+03	kg	
Transformity =	4.15E+12	sej/kg	(Transformity of steel, conventional, Buranakarn, 1998, Table 3-4, p.52)
COPPER :			
Quantity used for the PV inst. =	4.50E+01	kg	
Transformity =	6.77E+13	sej/kg	(Odum et al., 1987, p.159)
SILICON :			
Energy of the PV inst. =	1.19E+10	J/yr	
Transformity (sej/J) =	2.04E+05	sej/J	
Emergy of the Si collectors =	(Energy)*(Transformity) =		
=	2.43E+15	sej/yr	

Table B-3 Footnotes to Table 3-3 Emergy Evaluation Plaster Production, 1994

Footnotes to Table 3-3

1 LIMESTONE :			
Consumption =	1.15E+03	kg	
Transformity =	1.68E+12	sej/kg	(Odum, 1996, Table 3.5, p. 46, updated using Odum, 2000, Folio #1)
2 TRANSPORT :			
Transport =	1.70E-01	t-km	
Transformity =	6.61E+11	sej/t-km	(Buranakarn, 1998, Table E-1, p.234))
3 NATURAL GAS :			
Consumption =	1.62E+07	J	
Transformity =	5.88E+04	sej/J	(Romitelli, 2000, p. 53-69)
4 EXTRA LIGHT OIL :			
Consumption =	3.65E-04	t	
Energy =	(3.65E-04 t)*(4.26E10 J/t)		
=	1.55E+07	J	
Transformity =	8.90E+04	sej/J	(Odum, 1996, Table C.2, p. 308, updated using Odum, 2000, Folio #1)
5 HEAVY OIL :			
Consumption =	2.67E-04	t	
Energy =	(2.67E-04 t)*(4.12E10 J/t)		
=	1.10E+07	J	
Transformity =	8.90E+04	sej/J	(Odum, 1996, Table C.2, p. 308, updated using Odum, 2000, Folio #1)
6 ELECTRICITY :			
Consumption =	1.35E+08	J	
Transformity =	1.88E+05	sej/J	(Estimation based on origin of elect. in Switzerland : ~ 57% hydro, ~ 43% nuclear and Odum, 1996, Table C.1, p.305, updated)
7 ANNUAL YIELD :			
Production of plaster =	1.00E+03	kg	
Total emergy =	Sum emergy of each input		
=	1.96E+15	sej	
Transformity of plaster =	Total emergy/production		
=	**1.96E+12**	**sej/kg**	

Table B-4 Footnotes to Table 3-4 Emergy Evaluation of EPS Production, 1994

Table B-5 Footnotes to Table 3-5 Emergy Evaluation of glass wool Production, 1997

Footnotes to Table 3-5

1 QUARTZ SILICA :				
Consumption =	3.25E+02	kg		
Transformity =	1.68E+09	sej/kg	(Odum, 1998, Table 3-5, p.46, updated using Odum, 2000, Folio #1)	
2 RECYCLED GLASS :				
Consumption =	6.75E+02	kg		
Transformity =	2.13E+12	sej/kg	(Buranakarn, 1998, Table C-11, p.193)	
3 PHENOL :				
Volume =	1.30E+01	l		
Density =	1.07E+00	kg/l	(Deutsche Gesellschaft für Technische Zusammenarbeit, GTZ)	
Consumption =	Volume * density			
=	1.39E+01	kg		
Energetic content =	4.23E+07	J/kg	(Estimated equals to benzene energetic content, Jenny, 1995)	
Consumption (J) =	(Consumption (kg))* (Energetic content)			
=	5.88E+08	J		
Transformity =	1.11E+05	sej/J	(Transformity of refined oil, Odum, 1996, Table C.2, p. 308, updated using Odum, 2000, Folio #1)	
4 UREEFORMOL :				
Consumption =	8.40E+00	kg		
Energetic content =	1.76E+07	J/kg	(Haukoos, 1995)	
Consumption (J) =	(Consumption (kg))* (Energetic content)			
=	1.48E+08	J		
Transformity =	1.11E+05	sej/J	(Transformity of refined oil, Odum, 1996, Table C.2, p. 308, updated using Odum, 2000, Folio #1)	
5 TRANSPORT :				
	3.40E-01	t-km		
Transformity =	6.61E+11	sej/T-km	(Buranakarn, 1998, Table E-1, p.234)	
6 EXTRA LIGHT OIL				
Consumption =	2.45E-03	t		
Energy =	(2.45E-03 t)*(4.26E+10 J/t)			
=	1.04E+08	J		
Transformity =	8.90E+04	sej/J	(Odum, 1996, Table C.2, p. 308, updated using Odum, 2000, Folio #1)	
7 ELECTRICITY				
Consumption =	4.30E+10	J		
Transformity =	1.88E+05	sej/J	(Estimation based on origin of elect. in Switzerland : ~ 57% hydro, ~ 43% nuclear and Odum, 1996, Table C.1, p.305, updated)	
8 ANNUAL YIELD :				
Production of glass wool =	1.00E+03	kg		
Total emergy =	Sum emergy of each input			
=	9.61E+15	sej		
Transformity of glass wool =	Total emergy/production			
=	**9.61E+12**	**sej/kg**		

Table B-6 Footnotes to Table 3-6 Emergy Evaluation of screeds production, 1995

Footnotes to Table3-6

1 SAND :

Consumption =	8.60E+02 kg	
Transformity =	1.68E+12 sej/kg	(Odum, 1996, Table 3.5, updated using Odum, 2000, Folio #1)

2 PORTLAND CEMENT :

Consumption =	1.40E+02 kg	
Transformity =	1.98E+12 sej/kg	(Buranakarn, 1998, Table 3-1, p.38))

3 ANNUAL YIELD :

Production of screeds =	1.00E+03 kg
Total emergy =	Sum emergy of each input
=	1.72E+15 sej
Transformity of screeds =	Total emergy/production
=	**1.72E+12 sej/kg**

APPENDIX C
EMERGY EVALUATION OF SWITZERLAND

Table C-1. EMERGY Evaluation of Resource Basis for Switzerland (2000)

Not	Item	Raw Units	Transformity* (sej/unit)	Solar Emergy (E20 sej/yr)	EmDollars (E9 1994 US$)
RENEWABLE RESOURCES:		**Switzerland**			
1	Sunlight	1.25E+20 J	1.00E+00	1.25	0.08
2	Rain, chemical	9.89E+16 J	3.05E+04	30.18	1.82
3	Rain, geopotential	3.54E+17 J	4.70E+04	166.32	10.02
4	Wind, kinetic energy	6.24E+16 J	2.45E+03	1.53	0.09
5	Rivers, chemical	6.36E+16 J	4.55E+04	28.94	1.74
6	Rivers, geopotential	1.14E+17 J	4.70E+04	53.64	3.23
7	Earth Cycle	9.07E+16 J	5.80E+04	52.61	3.17
INDIGENOUS RENEWABLE ENERGY:					
8	Hydroelectricity	1.36E+17 J	1.76E+05	239.36	14.42
9	Agriculture Production	4.49E+16 J	3.36E+05	150.86	9.09
10	Livestock Production	1.59E+15 J	3.36E+06	53.42	3.22
11	Fisheries Production	6.94E+12 J	3.36E+06	0.23	0.01
12	Fuelwood Production	1.49E+16 J	2.21E+04	3.29	0.20
13	Forest Extraction	5.55E+16 J	2.21E+04	12.27	0.74
NONRENEWABLE SOURCES FROM WITHIN SYSTEM:					
14	Natural Gas	0.00E+00 J	5.88E+04	0.00	0.00
15	Oil	0.00E+00 J	8.90E+04	0.00	0.00
16	Coal	0.00E+00 J	6.69E+04	0.00	0.00
17	Calcium Carbonate	4.29E+12 g	1.68E+09	72.07	4.34
18	Metals	0.00E+00 g	1.68E+09	0.00	0.00
19	Top Soil	4.29E+15 J	7.40E+04	3.17	0.19
IMPORTS AND OUTSIDE SOURCES:					
20	Oil derived products	6.34E+17 J	1.11E+05	703.74	42.39
21	Nuclear fuel elements	2.72E+17 J	-	180.00	10.84
22	Metals	3.91E+12 g	1.68E+09	65.69	3.96
23	Minerals	1.02E+13 g	1.00E+09	102.00	6.14
24	Food & ag. products	6.65E+16 J	3.36E+05	223.44	13.46
25	Livestock, meat, fish	3.90E+14 J	3.36E+06	13.10	0.79
26	Plastics and rubber	1.88E+16 J	1.77E+05	33.28	2.00
27	Chemicals	4.36E+12 g	1.48E+10	645.28	38.87
28	Wood, paper,textiles	3.95E+16 J	6.94E+04	27.41	1.65
29	Mech.& trans equip.	1.59E+12 g	6.70E+09	106.53	6.42
30	Service in imports	4.08E+09 $	1.66E+12	67.73	4.08
31	Tourism	8.66E+09 $	1.66E+12	143.76	8.66
EXPORTS:					
32	Food & ag. products	5.11E+16 J	3.36E+05	171.70	10.34
33	Livestock, meat, fish	0.00E+00 J	3.36E+06	0.00	0.00
34	Wood, paper,textiles	3.33E+16 J	6.94E+04	23.11	1.39
35	Oil derived products	5.22E+16 J	8.90E+04	46.46	2.80
36	Metals	2.38E+12 g	1.68E+09	39.98	2.41
37	Minerals	1.05E+12 g	1.68E+09	17.64	1.06
38	Chemicals	1.73E+12 g	1.48E+10	256.04	15.42
39	Mech. & trans equip.	1.11E+12 g	6.70E+09	74.37	4.48
40	Plastics and rubber	1.46E+16 g	1.77E+05	25.84	1.56
41	Service in exports	1.78E+10 $	1.66E+12	295.48	17.80
42	Tourism	7.33E+09 $	1.66E+12	121.68	7.33

* Transformity based on total renewable emergy flow of 15.83E24 sej/yr, (Odum, 2000, Folio #1)

Table C-2. Footnotes to Table C-1

RENEWABLE RESOURCES:

1 SOLAR ENERGY:

Land Area = 4.13E+10 m^2 — OFS
Insolation = 1.03E+02 Kcal/cm^2/yr — Meteonorm
Albedo = 0.30 (% given as decimal) — Estimate
Energy(J) = (area incl shelf)(avg insolation)(1-albedo)
= (____m^2)*(____Kcal/cm^2/y)*(E+04cm^2/m^2)*
(1-0.30)*(4186J/kcal)
= 1.25E+20 J/yr
Transformity = 1.00E+00 sej/J — Definition

2 RAIN, CHEMICAL POTENTIAL ENERGY:

Land Area = 4.13E+10 m^2
Rain (land) = 1.47 m/yr — BWW
Evapotrans rate = 33.00 % — Atlas hydr. de la Suisse,1992
Energy (J) = (area)(Evapotrans)(rainfall)(Gibbs no.)
= (____m^2)*(____m)*(1000kg/m^3)*(4.94E+03J/kg)
= 9.89E+16 J/yr
Transformity = 3.05E+04 sej/J — (Odum, 2000, Folio #1)

3 RAIN, GEOPOTENTIAL ENERGY:

Area = 4.13E+10 m^2
Rainfall = 1.47 m
Avg. Elev = 888.00 m — OFS
Runoff rate = 67.00 % (percent, given as a decimal)
Energy(J) = (area)(% runoff)(rainfall)(avg elevation)(gravity)
= (____m^2)*(____m)*(1000kg/m^3)*(____m)*(9.8m/s^2)
= 3.54E+17 J/yr
Transformity = 4.70E+04 sej/J — (Odum, 2000, Folio #1)

4 WIND ENERGY:

Area = 4.13E+10 m^2
Density of Air = 1.30E+00 kg/m^3
Avg. annual wind velocity = 2.00E+00 mps — estimate
Geostrophic wind = 3.33E+00 mps — observed winds are about 0.6 of geostrophic winds
Drag. Coeff. = 1.00E-03 — (Miller, 1964 quoted by Kraus, 1972)
Energy (J) = (area)(air density)(drag coefficient)(velocity^3)
= (_____m^2)(1.3 kg/m^3)(1.00 E-3)(______mps)(3.14 E7 s/yr)
Energy(J) = 6.24E+16 J/yr
Transformity = 2.45E+03 sej/J — (Odum, 2000, Folio #1)

5 RIVERS, CHEMICAL ENERGY:

Rivers flowing into Switzerland :
Mean volume flow = 1.31E+10 m^3/yr
Density = 1.00E+06 g/m^3
Energy(J) = (mean volume flow)(density)(Gibbs energy)
= (___m^3/yr)(1 E06 g/m^3)(4.854 J/g)
Energy(J) = 6.36E+16 J/yr
Transformity = 4.55E+04 sej/J — (Estimation runoff = 67%)

6 RIVERS, POTENTIAL ENERGY:

Rivers flowing into Switzerland :
Mean volume flow = 1.31E+10 m^3/yr
Avg Elev. = 8.88E+02 m — height of source-egress estimated equal to avg elevation
Density = 1.00E+03 kg/m^3
Energy(J) = (mean volume flow)(avg elev.)(density)(gravity)
Total energy (J) = 1.14E+17 J/yr
Transformity = 4.70E+04 sej/J — (Odum, 2000, Folio #1)

7 EARTH CYCLE			
	Land Area =	4.13E+10 m^2	
	Heat flow =	2.20E+06 J/m^2	B. Matthey
	Energy (J) =	(4.13E+10)(2.2E+06)	
	=	9.07E+16 J/yr	
	Transformity =	5.80E+04 sej/J	(Odum, 2000, Folio #2)
INDIGENOUS RENEWABLE ENERGY			
8 HYDROELECTRICITY:			
	Kilowatt Hrs/yr =	3.79E+10 kWh/yr	T 8.2.4.1, 2000
	Energy(J) =	(3.79 E+10kWh/yr)*(3.6 E+06 J/kWh)	
	=	1.36E+17 J/yr	
	Transformity =	1.76E+05 sej/J	(Etimation from Odum,1996)
9 AGRICULTURAL PRODUCTION:			
	Production =	3.35E+06 MT	T 7.3.3.1.1, 2000
	Energy(J) =	(3.35 E+06 MT)*(1E06 g/MT)*(80%)*(4.0 Cal/g)*(4186 J/Cal)	
	=	4.49E+16 J/yr	
	Transformity =	3.36E+05 sej/J	(Brown, 1996, 105-130)
10 LIVESTOCK PRODUCTION:			
	Livestock Production =	3.80E+05 MT	T 3.3.1.1, 2000
	Energy(J) =	(3.8E+05 MT)*(1E+06 g/MT)*(20%)*(5 Cal/g)*(4186 J/Cal)	
	=	1.59E+15 J/yr	
	Transformity =	3.36E+06 sej/J	(Brown, 1996, 105-130)
11 FISHERIES PRODUCTION:			
	Fish Catch =	1.66E+03 MT	T 7.3.9.2, 2000
	Energy(J) =	(1.66E+03 MT)*(1E+06 g/MT)*(5 Cal/g)*(20%)*(4186 J/Cal)	
	=	6.94E+12 J/yr	
	Transformity =	3.36E+06 sej/J	(Brown, 1996, 105-130)
12 FUELWOOD PRODUCTION:			
	Fuelwood Prod =	2.48E+06 m^3	X 01.07, p.342, 2000
	Energy(J) =	(2.48E6 m^3)(0.5E6g/m^3)(3.6 Cal/g)(80%)(4186 J/Cal)	
	=	1.49E+16 J/yr	
	Transformity =	2.21E+04 sej/J	(Romitelli, 2000, 53-69)
13 FOREST EXTRACTION			
	Harvest =	9.20E+06 m^3	X 01.07, p.342, 2000
	Energy(J) =	(9.2E+06 m^3)(0.5E+06 g/m^3)(80%)(3.6 Cal/g)(4186 J/Cal)	
	=	5.55E+16 J/yr	
	Transformity =	2.21E+04 sej/J	(Romitelli, 2000, 53-69)
NONRENEWABLE RESOURCE USE FROM WITHIN SWITZERLAND			
14 NATURAL GAS		0.00E+00	
	Consumption =	0.00E+00 ft^3/yr	
	Energy(J) =	(0.0 ft^3/yr)*(1.055E+6 Joules/ft^3)	
	=	0.00E+00 J/yr	
	Transformity =	5.88E+04 sej/J	(Romitelli, 2000, 53-69)
15 OIL			
	Consumption =	0.00E+00 barrels	
	Energy(J) =	(5.7 E06 b)*(6.1 E9 Joules/barrel)	
	=	0.00E+00 J/yr	
	Transformity =	8.90E+04 sej/J	(Odum, 1996, Accounting)

Table C-2. – Continued

16 COAL

Consumption = 0.00E+00 MT/yr
Energy(J) = (0.0 Mt/yr)*(2.9E+10 J/Mt)
= 0.00E+00 J/yr
Transformity = 6.69E+04 sej/J (Odum, 1996, Accounting)

17 CALCIUM CARBONATE

Consumption = 4.29E+06 MT/yr CEM, 2001
Mass(g) = (4.29 E6 MT/yr)*(1E6 g/MT)
= 4.29E+12 g/yr
Transformity = 1.68E+09 sej/g (Odum, 1996, Accounting)

18 METALS (Au,Ag,Pb,Cu,Zn,Fe,Mn,Mo)

Production = 0.00E+00 MT/yr
Consumption = 0.00E+00
Mass(g) = (0 MT)*(1E6 g/MT)
= 0.00E+00 g/yr
Transformity = 1.68E+09 sej/g (Odum, 1996, Accounting)

19 TOPSOIL:

Soil loss = 1.53E+02 $g/m^2/yr$ Prof. Védy
Energy(J) = (153 $g/m^2/yr$)*(4.13 E10 m^2)*(0.03 organic)
*(5.4 Kcal/g)(4186 J/Kcal)
= 4.29E+15 J/yr
Transformity = 7.40E+04 sej/J (Brown, 2001, Folio #3)

IMPORTS OF OUTSIDE ENERGY SOURCES:

20 OIL DERIVED PRODUCTS

Imports = 6.34E+05 TJ T 8.2.1.1, 2000
Energy (J) = (6.34 E5 TJ/yr)*(1 E12 J/TJ)
= 6.34E+17 J/yr
Transformity = 1.11E+05 sej/J (Odum, 1996, Accounting)

21 NUCLEAR FUEL ELEMENTS T 8.2.1.1, 2000

Imports = 2.72E+05 TJ
The emergy is evaluated from the electricity produced by this amount of fuels
Nuclear electricity = 8.98E+04 TJ
Energy (J) = (8.98 E4 TJ/yr)*(1 E12 J/TJ)
= 8.98E+16
Transf. of electr. (sej/J) = 2.00E+05 sej/J
Emergy of nuclear elect. (sej) = 1.80E+22 sej/yr

22 METALS

Imports = 3.91E+06 MT/yr Swiss Customs
Mass (g) = (3.91E+06)*(1E6 g/MT)
= 3.91E+12 g/yr
Transformity = 1.68E+09 sej/g (Odum, 1996, Accounting)

23 MINERALS :

Imports = 1.02E+07 MT/yr Swiss Customs
Mass (g) = (1.02E7 MT/yr)*(1E+6 g/MT)
= 1.02E+13 g/yr
Transformity = 1.68E+09 sej/g (Odum, 1996, Accounting)

24 FOOD and AGRICULTURAL PRODUCTS

Imports = 5.67E+06 MT/yr — Swiss Customs
Energy (J) = (5.67E6 MT/yr)*(1E6g/MT)*(3.5 Kcal/g)*(4186 J/Kcal)*(80%)
= 6.65E+16 J/yr
Transformity = 3.36E+05 sej/J — (Brown, 1996, 105-130)

25 LIVESTOCK, MEAT, FISH

Imports = 8.47E+04 MT/yr — Swiss Customs
Energy (J) = (8.47E4 MT/yr)*(1E6 g/MT)*(5 Kcal/g)
(4186 J/Kcal)(.22 protein)
= 3.90E+14 J/yr
Transformity = 3.36E+06 sej/J — (Brown, 1996, 105-130)

26 PLASTICS & RUBBER (LEATHER)

Imports = 6.25E+05 MT/yr — Swiss Customs
Energy(J) = (6.25E5 MT/yr)*(1000 Kg/MT)*(30.0E6 J/kg)
= 1.88E+16 J/yr
Transformity = 1.77E+05 sej/J — (Buranakarn, 1998, Table C-11)

27 CHEMICALS

Imports = 4.36E+06 MT/yr — Swiss Customs
Mass (g) = (4.36 E6 MT/ yr)*(1E6g/MT)
= 4.36E+12 g/yr
Transformity = 1.48E+10 sej/J — (Brandt-Williams, 2001, Folio #4)

28 WOOD, PAPER, TEXTILES, (LEATHER)

Imports = 2.63E+06 MT/yr — Swiss Customs
Energy(J) = 2.63 E6 MT/yr)*(1e6g/MT)*(15e3J/g)
= 3.95E+16 J/yr
Transformity = 6.94E+04 sej/J — (Doherty, 1995)

29 MACHINERY, TRANSPORTATION, EQUIPMENT

Imports = 1.59E+06 MT/yr
Mass (g) = (1.59 E9 MT/yr)*(1E6g/MT) — Swiss Customs
= 1.59E+12 g/yr
Transformity = 6.70E+09 sej/J — (Brown, 2001, Folio #3)

30 IMPORTED SERVICES:

Dollar Value = 4.08E+09 $US — T 4.2.2, 2000
Transformity = 1.66E+12 sej/$US

31 TOURISM :

Dollar Value = 8.66E+09 $US — X 01.10, p.427, 2000
Transformity = 1.66E+12 sej/$US

EXPORTS OF ENERGY, MATERIALS AND SERVICES

32 FOOD and AGRICULTURAL PRODUCTS

Exports: 4.36E+06 MT/yr — Swiss Customs
Energy(J) = (4.36E6 MT)*(1E+06 g/MT)*(80%)*(3.5 Cal/g)*(4186 J/Cal)
= 5.11E+16 J/yr
Transformity = 3.36E+05 sej/J — (Brown, 1996, 105-130)

33 LIVESTOCK, MEAT, FISH

Exports = 0.00E+00 MT/yr — T 7.3.3.3.2, 2000
Energy (J) = 0 MT)(1E+06 g/MT)(5 Cal/g)(4187 J/Cal)(.22 prot)
= 0.00E+00 J/yr
Transformity = 3.36E+06 sej/J — (Brown, 1996, 105-130)

34 WOOD, PAPER, TEXTILES,LEATHER

Exports =	2.21E+06 MT/yr	Swiss Customs
Energy (J) =	(2.21E6 Mt)(1.0E+06 g/Mt)(3.6 Cal/g)(4186 J/Cal)	
=	3.33E+16 J/yr	
Transformity =	6.94E+04 sej/J	

35 OIL DERIVED PRODUCTS

Exports =	1.21E+06 MT/yr	Swiss Customs
Energy (J) =	(1.21E6 MT/yr)*(4.3E10 J/MT)	
=	5.22E+16 J/yr	
Transformity =	8.90E+04 sej/J	(Odum, 1996, Accounting)

36 METALS

Exports =	2.38E+06 MT/yr	Swiss Customs
Mass (g) =	(2.38E6 MT)*(1E6 g/MT)	
=	2.38E+12 g/yr	
Transformity =	1.68E+09 sej/g	(Odum, 1996, Accounting)

37 MINERALS

Exports =	1.05E+06 MT/yr	Swiss Customs
Mass (g) =	(1.05E+6 Mt)(1.0E+06 g/Mt)	
=	1.05E+12 g/yr	
Transformity =	1.68E+09 sej/g	(Odum, 1996, Accounting)

38 CHEMICALS :

Exports =	1.73E+06 MT/yr	Swiss Customs
Mass (g) =	1.73E6 MT)*(1E6 g/MT)	
=	1.73E+12 g/yr	
Transformity =	1.48E+10 sej/J	(Brandt-Williams, 2001, Folio #4)

39 MACHINERY, TRANSPORTATION, EQUIPMENT

Exports =	1.11E+06 MT/yr	
Mass (g) =	(1.11 E6 MT/yr)*(1E6g/MT)	Swiss Customs
=	1.11E+12 g/yr	
Transformity =	6.70E+09 sej/J	(Brown, 2001, Folio #3)

40 PLASTICS & RUBBER

Exports =	4.87E+05 MT/yr	Swiss Customs
Energy(J) =	(4.87E5 MT/yr)*(1000 Kg/MT)*(30.0E6J/kg)	
=	1.46E+16 g/yr	
Transformity =	1.77E+05 sej/J	(Buranakarn, 1998, table C-11)

41 SERVICES IN EXPORTS:

Dollar Value =	1.78E+10 $US	T 4.2.2, 2000
Transformity =	1.66E+12 sej/$US	

42 TOURISM

Dollar Value =	7.33E+09 $US	X01.10, p.426, 2000
Transformity =	1.66E+12 sej/$US	

Table C-3 Summary of Flows in Switzerland

Variab	Item	Solar Emergy (E20 sej/y)	Dollars
R	Renewable sources (rain, rivers)	279.07	
N	Nonrenewable resources from within Switzerland	91.04	
N0	Dispersed Rural Source	18.97	
N1	Concentrated Use	72.07	
N2	Exported without Use	360.12	
F	Imported Fuels and Minerals	1051.43	
G	Imported Goods	1049.04	
I	Dollars Paid for Imports		4.08E+09
P2I	Emergy of Services in Imported Goods & Fuels	67.73	
E	Dollars Received for Exports		1.78E+10
P1E	Emergy Value of Goods and Service Exports	950.62	
x	Gross National Product		2.70E+11
P2	World emergy/$ ratio, used in imports	1.66E+12	
P1	Switzerland Emergy/$ ratio	9.40E+11	

Table C-4. Indices using emergy for overview of Switzerland. (2000)

Item	Name of Index	Expression	Quantity
1	Renewable emergy flow	R	2.79E+22
2	Flow from indigenous nonrenewable reserves	N	9.10E+21
3	Flow of imported emergy	F+G+P2I	2.17E+23
4	Total emergy inflows	R+N+F+G+P2I	2.54E+23
5	Total emergy used, U	N0+N1+R+F+G+P2I	2.54E+23
6	Total exported emergy	P1E	9.51E+22
7	Fraction emergy use derived from home sources	(NO+N1+R)/U	0.15
8	Imports minus exports	(F+G+P2I)-(N2+B+P1E)	8.57E+22
9	Export to Imports	(N2+P1E)/(F+G+P2I)	0.60
10	Fraction used, locally renewable	R/U	0.11
11	Fraction of use purchased	(F+G+P2I)/U	0.85
12	Fraction imported service	P2I/U	0.03
13	Fraction of use that is free	(R+N0)/U	0.12
14	Ratio of concentrated to rural	(F+G+P2I+N1)/(R+N0)	7.52
15	Use per unit area	U/(area)	6.15E+12
16	Use per person	U/population	3.52E+16
17	Renewable carrying capacity at present living standard	(R/U) (population)	7.92E+05
18	Developed carrying capacity at same living standard	7(R/U)(population)	5.54E+06
19	Ratio of use to GNP, emergy/dollar ratio	P1=U/GNP	9.40E+11
20	Ratio of electricity to use	(el)/U	11%
21	Fuel use per person	fuel/population	1.23E+16

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