PERGAMON

Building and Environment ■■■ (■■■■) ■■■–■■■

BUILDING AND ENVIRONMENT

www.elsevier.com/locate/buildenv

Life cycle assessment of energy and environmental implications of the implementation of conservation technologies in school buildings in Mendoza—Argentina

A.P. Arena *, C. de Rosa

LAHV, INCIHUSA, Cricyt (CONICET), Avenue Ruiz Leal s/n Parque Gral, San Martín, 5500 Mendoza, Argentina

Received 25 May 2000; received in revised form 15 February 2001; accepted 21 February 2002

Abstract

The energy and environmental implications of applying different conservative technologies in school buildings in arid Andean regions of Mendoza—Argentina have been assessed in this work using life cycle assessment. The case studied is a school building which has recently been built in Lavalle, a county in northern Mendoza's province. The obtained results show that almost all the environmental effects investigated are improved when the conservative technologies are implemented, except for the photochemical ozone formation potential. The use of wood in an uncontrolled combustion as the energetic source for brick baking has been identified as the responsible process of that unintended negative effect. © 2002 Published by Elsevier Science Ltd.

Keywords: ■; ■; ■

1. Introduction

Nowadays, there is a growing concern about the environmental problems caused by anthropogenic activities, and many actions are being taken in different fields and sectors in order to mitigate those undesirable outcomes of the productive systems which sustain modern way of life. It can be stated that there is a shifting from a passive "concerned" phase towards an active one, which requires new tools and methods and a new way of thinking for the design, analysis, management and optimization of those systems. In this new phase the environmental dimension must be included during the planning and design stages in a systematic way, and the availability of these tools to the involved actors in these stages should be assured.

The influence of the building sector over the environmental damage is not irrelevant, as it will be shown in the next paragraph. In general terms, the factors which influence the energetic aspects in a building are:

- The effect of shape and orientation of a building over its heating and cooling loads.
- The influence of the building envelope over the solar gain, day-lighting, natural ventilation and natural cooling.
- The management of the building by its users on the strategies of energy savings and environmental control.

The largest part of these effects are produced during the operative phase of the building's life, and the right time to reduce them is acting during the design and construction of the building, that is, the previous phase.

The designer has a great degree of control over those factors, and must be conscious of and able to gauge the impacts that his/her decisions have on the energetic and environmental context of the society. In fact, when he/she does not include energy and environmental efficient technologies in his project, the owner and the whole society loses an important chance of diminishing those effects for the whole life of the building, which is usually a very long time (e.g. 50, 100 years), while an environmentally sensible designer can achieve, with the right knowledge and tools, a significant reduction of the environmental impacts of the sector.

The actions that can be taken in order to diminish the energy consumption, highlight the use of renewable resources, making a rational use of energy, and the adoption of less energy-intensive materials. Besides, in order to achieve a reduction in the environmental effects produced during the

* Corresponding author. Fax: +54-261-428-7370.
E-mail address: aparena@lab.cricyt.edu.ar (A.P. Arena).

0360-1323/02/$ - see front matter © 2002 Published by Elsevier Science Ltd.
PII: S0360-1323(02)00056-2

operation phase, it is necessary to adopt technologies which require the manufacture of new materials and components which consume less energy and release fewer emissions. To assess the real implications of the implementation of these technologies information regarding materials, components and processes used in the building sector, together with sound methods and tools which include all stages of the building's lifetime are needed. With these tools it is possible to assess and compare the environmental impact of these "environmentally conscious" buildings (usually called green-buildings) with the traditional ones over their whole life cycle.

The aim of this study was to perform a comparison of traditional and energy-conservative technologies applied in school buildings of Andean arid regions in Mendoza (Argentina), using life cycle analysis (LCA) as a tool. As a necessary step to accomplish this aim other objectives were reached, like collecting environmental data for building materials and components, adapting a foreign software tool to the local conditions, and solving methodological problems which came up when applying LCA to this case.

2. The environmental impact of the building sector

It is usual for the common people to blame mainly the industrial sector for the negative effects of the human activities on the natural environment, due to the big amounts of resources consumed and emissions released in a small area, while the building sector "disguises" the magnitude of its effect owing to its extended spatial distribution. However, the building sector has a significant influence over the total natural resource consumption and on the emissions released, with their associated environmental impact (resource depletion, global warming, acid rain, waste accumulation, etc.). In fact, a large share of the total final energy consumption in a country is due to the residential sector, its magnitude depending on the climatic, socio-cultural and economic conditions of the considered country. In Europe, the building sector accounts for 28–45% of the total energy consumption, depending on the country, from which approximately 2/3 is originated in residential buildings. In Great Britain, almost half of the energy consumption and of the CO_2 emissions is due to this sector [1]. In USA the energy consumption for heating, ventilation, air conditioning and lighting accounts for nearly 40% of the total fossil fuel consumed [2]. In Argentina the domestic sector occupies the third place among the biggest consumers, with a share of 22% [3], while Mendoza is the second biggest energy consumer, accounting for a share of about 26% of the total consumption. However, maybe the most interesting data is that in Mendoza in the last 16 years the energy consumed in the building sector has experienced an increase close to 100%, mainly due to the penetration of the natural gas distribution network in the province and secondly to the vegetative growth of the population. In terms of *per capita* net consumption, the domestic consumption went from 146 to 230 Koe/person, which represent an increase of 56.9% in that period [4].

Among the gases which contribute to the green-house effect (global environmental impact), the main component released by the processes linked to the building sector is the CO_2. In 1970 the building sector accounted for 12.3% of the total CO_2 emissions in Argentina, occupying the fourth place in the country's ranking. Twenty years later, the building sector occupied the second place among the biggest contributors to the GWP [5].

Regarding the resources consumption, according to data from the Worldwatch Institute the construction of buildings consumes 40% of the stone, sand and gravel, 25% of the virgin wood, 40% of the energy and 16% of the water used globally every year in the world [6]. In addition, the sector produces also a huge amount of wastes (local/regional environmental impact), considering those produced during the material extraction, component manufacture, construction, refurbishment, demolition, etc. In USA, that amount is comparable with the municipal solid wastes collected in the same period [7]. In order to reduce that amount of wastes it is necessary to consider the use of durable materials and components designed for being recycled/reused after their useful life.

3. Life cycle assessment (LCA). The method

LCA is an environmental management tool used to assess the environmental impacts of a product or process from the "cradle to the grave", that is through every step of its life, from extraction of raw materials, production of building materials and components, construction, operation onto demolition and disposal. It examines the contribution the product or process has to global and regional environmental issues, such as global warming, ozone depletion and energy use.

The general concept and principles of the LCA are not new. In the 1970s the idea was used in order to analyze the life cycle of fuels and for tracking energy flows in industrial systems, and life cycle costs methods have been used for several years in economic studies. However, only in the last decade the LCA has been used as a tool for assessing the environmental impact of each stage which composes the life cycle of a productive process. In 1990 in a Society of Environmental Toxicology and Chemistry (SETAC) meeting, the name "life cycle assessment" was coined and the general principles and guidelines started to be developed. The SETAC definition of LCA says [8]: "is an objective procedure for evaluating the energetic and environmental loads corresponding to a process or activity, which is performed identifying the materials and energy used and the wastes released in the natural environment. The evaluation is performed for the whole life cycle of the process or activity, including the extraction and treatment of raw materials, the fabrication, transport,

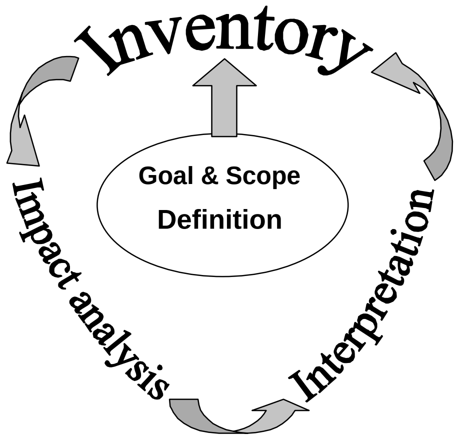

Fig. 1. LCA phases.

distribution, use, recycling, reuse and final disposal". Today the methodology is being standardized by ISO under the 14040 series, and this process will help wide spreading the application of LCA in different fields and the exchange of studies and results among different groups and countries. According to the ISO/FDIS standard in LCA [9]:

LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by

- compiling an inventory of relevant inputs and outputs of a system,
- evaluating the potential environmental impacts associated with those inputs and outputs, and
- interpreting the results of the inventory and impact phases in relation to the objectives of the study.

LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health, and ecological consequences.

LCA has been accepted in the scientific community as the only legitimate method to assessing and comparing materials, products and services from the environmental viewpoint.

The key phases of LCA are: goal/scope definition, inventory analysis, impact assessment and interpretation. In brief, the meaning of these stages are (see Fig. 1):

- *Goal/scope definition*: Includes the definition of the purpose of the study, the functional unit (that is, the unit to which all data and calculations are referred), and of the system boundaries (e.g. which processes and operations would be included, and which ones would be excluded from the study).
- *Inventory*: Includes data collection and calculation procedures to quantify relevant inputs and outputs of a product system. These inputs and outputs may include the use of resources and releases to air, water and land associated with the system. The main advantage of the LCA inventory process lies in being able to by-pointing the "hottest" portions of the systems where the largest reductions in environmental loadings can be made.
- *Impact assessment*: The process for estimating and characterizing the effects of the environmental burdens identified in the inventory stage.
- *Interpretation*: A systematic procedure to evaluate information from the conclusions of the previous phases, checking that the requirements of the application as described in the goal and scope of the study are met.

The LCA method is well structured for industrial systems, following the SETAC or the ISO 14040 guidelines. In order to apply the method for the building sector, it is necessary to understand the main differences between the industrial and the building systems. Among them, the useful life of products (much longer for the building than for industrial products), the number of identical products (very few for the buildings sector, thousands for the industrial systems) and the units used in each system are of the main influence.

3.1. The existing data

Traditionally, materials selection in the building sector has been concerned with such features as strength, thermal properties, weight, cost, aesthetical aspect, etc., but recently environmental concerns have been introduced into the list of properties to consider during the planning and design stage. In the building sector, this aspect has a remarkable relevance due to the bulk of materials involved and to the long lasting of the buildings. In addition, the materials chosen will influence its processing, use and end life strategy.

Due to the complexity of the systems involved, the energetic and environmental evaluation of all materials and components involved in the construction of a building is a cumbersome task, and a great international effort is being carried on in order to calculate and collect environmental data on building materials. There is a number of databases which provide data about several materials, most of them responding to production systems of developed countries and usually included in software packages which help carrying all the necessary calculus.

3.2. The use of life cycle assessment in developing countries

There is a growing interest in developing countries in environmental issues and in environmental management systems (EMS). The importance given to LCA in these countries is due to the possibility of improving processes and products, for implementation of an EMS, or to gain foreign markets. The ISO program for developing countries (ISO

DEVPRO) looks to assist them in order to achieve sustainable development conditions through the application of the ISO 14000 standards. However, there is a number of difficulties for using LCA in these countries. Among them the lack of expertise, high costs, complexity and lack of local data are of outmost importance, being the last one the most costly aspect of an LCA.

In the case of Argentina, only few (if any) data are available, and usually not in the required format. Because of this, a big amount of work is required in order to collect all the information needed before starting the specific calculations involved in an LCA study. In spite of this, due to low sensibility of many of the energy and material flows, usually the accuracy degree required is not very high, and some data coming from other countries or regions can be used when the local ones are not available. This is certainly not a general rule, and must be applied with great care. In fact, sometimes the technologies adopted in different countries are very different from the local ones, reflecting different development or local conditions, and therefore the resulting data are not "importable". One relevant aspect to be considered when foreign data are to be used is the energy source used for the production of the studied material or component. When the environmental loads associated with the energy consumption are to be assessed, the energy source must be known (or the energy mix of the country in the case of electrical energy), otherwise the extrapolation will not be representative. An example of this problem is the brick production in Mendoza (Argentina). In this province, a great portion of the total brick production is made in a handicraft fashion, using wood as fuel instead of fossil fuels and industrialized systems as in developed countries. In this case using the inventory of brick production in a foreign country will not be representative of the real impact of local brick production.

Regarding the lack of expertise, a great effort will be needed in order to bridge the gap with developed countries. Simplified methods can be a good way to start, because they are less resource consuming (time, money, personnel) and they are less complex than a complete LCA. Two different approaches can be followed in order to perform a simplified LCA: the screening cradle-to-grave and the expandable gate-to-gate [10]. The first approach seeks to have a reduced look at the life cycle of the system, in order to identify the critical processes in which to concentrate the analysis. The second one focuses on the processes which take place in the analyzed system (a gate-to-gate assessment), with the possibility of considering the upstream and the downstream processes in a further step. This approach changes the limits of the analyzed system, but is very helpful when data are not available, because the data belonging to the studied company are usually easier to collect. Both simplified methods apply the life cycle concept, and quick conclusions can be obtained without spending too much money and time. As stated farther on in the goal definition and scope section, a simplified version of LCA has been used here for assessing the benefits of the application of conservative technologies in the school building.

4. The case study

4.1. Aim

The LCA method is used here for comparing different building technologies which have been applied in a rural school building for obtaining thermal comfort with minimum fossil energy consumption. The comparison is made between one room of this school (which is called the "conservative" case) with a functionally identical one but built following the traditional technologies applied in the region (the "traditional" case).

Besides, the LCA is to be performed in the present study in order to identify in the building studied possible design opportunities for:

- reduction of energy consumption during the operation phase of the building;
- reduction of emissions with negative impact in the environment during the operation phase;
- reduction of the use of materials which produce negative effects during their production; and
- reduction of energy use and environmental impact during the whole life cycle of the building.

4.2. Description of the conservative building

The case studied is the school building No. 4-041, "ALICIA MOREAU DE JUSTO", which has recently been built in Lavalle, a small town in northern Mendoza's province. A complete description of the building school can be found in [11]. The design of the building was commissioned by the School Board of Mendoza to the Human Environment and Housing Laboratory, R& D Unit belonging to the National Scientific and Technological Research Council of Argentina (CONICET).

Lavalle is located at 32.75S, 68.07W, alt. 600 m.o.s.l., with a climate featuring 980 heating DD (base 16°C), 270 cooling DD (base 23°C), mean annual global horizontal radiation: 18.4 MJ/m^2, global mean annual external horizontal illuminance 65800 lx (solar noon). The aim of the project is to obtain maximum thermal and visual comfort with a minimum fossil energy consumption, using local available technologies and trying to maximize the use of local specialized manpower and reducing the global costs where possible without affecting the building durability and quality.

The main constructive components are: metal sloping roofs, horizontal concrete roofs, both insulated with expanded polystyrene ($K = 0.50\ W/m^2\ K$); external walls: double brick layer with thermal insulation in between (see

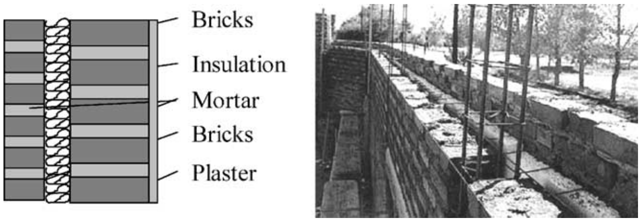

Fig. 2. The insulated external walls: section (left) and picture during their construction (right).

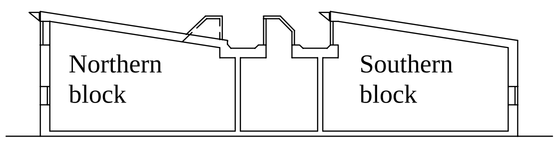

Fig. 3. Section of the classrooms block.

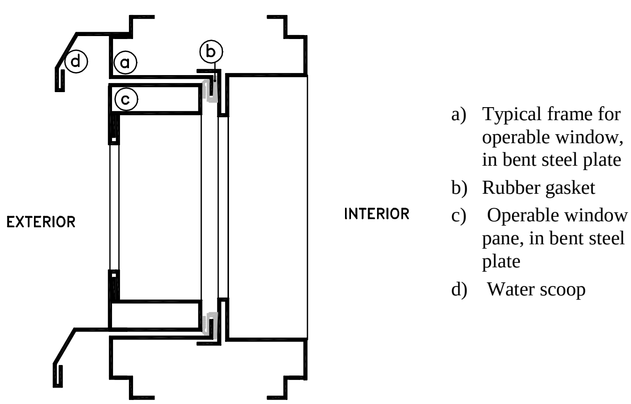

Fig. 4. Details of the conservative window.

Fig. 2), ($K = 0.55$ W/m^2 K); foundations: uninsulated ($K = 0.70$ W/m^2 K).

The building is made up of three functional blocks, from which only the classroom block has been considered for this study (see Fig. 3). These spaces have been designed as to obtain solar gain from north facing upper clerestory windows in both blocks. Cross ventilation in the northern rooms is assisted by upper windows (wind catchers) placed on the roofs.

Fixed external overhang allow for full solar access of collector windows from May 6 to August 6 and complete shadow from November 6 to February 6 (for each season this means 45 days before and 45 days after the winter and summer solstices, respectively). Conservative double glazed windows with rubber gasketting has been installed ($K = 2.73$ W/m^2 K) (see Fig. 4 for details). Internal diffuser devices homogenize the luminous flux and avoid the direct radiation incidence on the work surface. An hybrid ground cooling system has been installed experimentally for summer conditioning of three north oriented school rooms.

4.3. Goal definition and scope

The study was conducted choosing a representative segment of the building, keeping in mind the evaluation of the conservative technologies. Only locally available technologies were taken into consideration. The environmental aspects included in the study account only for external effects, therefore neither indoor nor human effects like noise, odor and work environment have been taken into account.

It is assumed that the decision of building the school in a given place is taken, so the factors associated to the people transportation during the operation phase are not included in the study. Considering the alternatives to improve energy conservation features in traditional school buildings, it was decided to focus the study only on the vertical components of the building envelope, i.e. exterior walls and windows. Besides being responsible for the largest share of heat losses, air infiltration included, they require more significant constructive improvements over the conventional envelope components. The improvement of roofs, either lightweight or heavy, can easily be achieved by only thickening the insulation layer, already present in the local conventional structures. The small benefit obtained by insulating perimetral foundations, indicates that it is not worth the effort.

A simplified LCA method has been applied. Starting with the processes involved and the components used during the construction of the school building, the upstream processes, components and materials have been included.

Since the interest of the study was not to analyze the productive processes of components, transportation systems or the infrastructure which supports the building sector, no secondary effects have been taken into account. The only exception to this rule are the energy flows, which have been analyzed not only in magnitude, but also in their efficiency of production, transformation, and transportation to the place where they are consumed. Last, since there is at present no organized structure for recycling or reusing the materials coming from building demolition, this phase was not included. Thus, from the downstream processes only those related with the operation phase have been taken into consideration.

The environmental aspects which are addressed in the present study are:

- global warming,
- acid rain,
- photo-smog,
- resource consumption,
- eutrophization, and
- toxicity

For all calculations regarding the inventory, impact assessment and normalization phases the SBID database has been used, from the Danish Building Research Institute. In Petersen [12] details about the SBID model can be found.

The utilized data account, if possible, for present technologies used in Argentina. When these data were not available foreign values were used, taking into account the local energy mix for calculating the environmental effects associated with the energy consumption. Average data have been used except when the supplier was known and its data were available.

For comparing the technologies two intermediate rooms have been taken into account, one from the northern block and the other from the southern one. Only the conservative technologies designed for reducing the heating energy consumption have been considered, leaving aside those related with day lighting or passive cooling. According to this criteria, the chosen pairs for comparison are:

- efficient external walls vs. traditional external walls; and
- double glazing windows with rubber gasket vs. traditional single glazing windows (without gasketing).

The energy saving that these technologies are expected to yield are:

Walls:

1. A reduction in the energy losses by heat conduction through the external walls by the added insulation.

Windows:

2. A reduction in the energy losses by heat conduction through the windows by the additional glass layer, and the created air space between the two layers.
3. A reduction in the energy losses by air infiltration through the windows by adding a rubber gasket in the windows frame.

The functional unit, i.e. the basis for comparison, was defined taken into consideration that the compared technologies have the same area, and that the school rooms are completely equivalent in both cases. Because of this, instead of taking as a functional unit one square meter of floor area or one square meter of window or external wall (as usual), the whole area of the considered technology has been taken into account. Following this criteria, the functional unit can be defined as "the environmental impact of the implementation of a given technology in the school building (together with all the additional materials required), including the reduction of heat losses over its operative lifetime". This definition allows for reaching the scope of the study, but the results will not be comparable with others coming from different studies.

4.4. Energy and environmental analysis—results

According to the previously stated criteria for the analysis, only the constructive differences between the studied technologies have been taken into account. Consequently, for the conservative case only those materials that have been used in addition to the traditional case are included (that is glass, bricks, rubber gaskets, mortar, etc.). For the traditional school only the amount of natural gas consumed in addition to the conservative case over the considered life span (50 years) was considered.

Table 1
Annual and global savings obtained by adopting efficient technologies

Annual energy savings		
Savings during use phase	5307.5	MJ/year
Specific savings during phase use	49.8	MJ/year m^2 floor
Bottled gas	2.5	45 kg bottles/year
Natural gas	136.3	m^3/year
Kerosene	164.7	1 *l*/year
Global energy savings (50 years lifetime)		
Savings during use phase	265374.5	MJ
Specific savings during use phase	4980.7	MJ/m^2 floor
Bottled gas	125.8	45 kg bottles
Natural gas	6812.8	m^3
Kerosene	8236.3	1 *l*

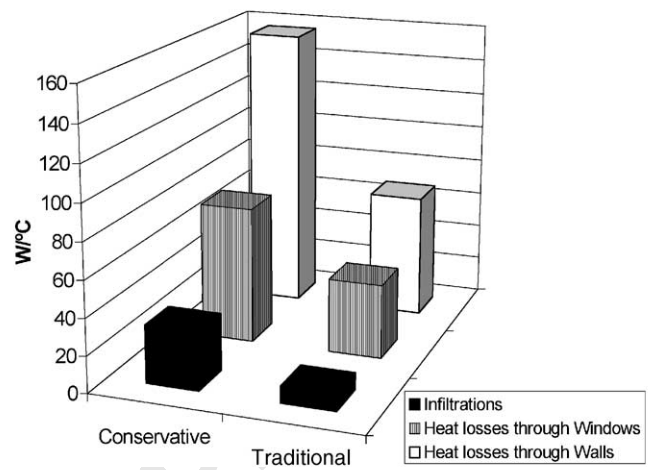

Fig. 5. Energy losses (W/°C) for the traditional and conservative buildings.

One aspect to remark is that a central strategy adopted in the Moreau school was the design and placing of the windows acting as solar collectors, which is a beneficial effect over the energy consumption that has not been considered here due to the difficulty in finding a traditional reference for comparisons. In fact, while it is clear that the traditional school buildings in the region have no double glazing or gaskets in their windows, or external insulated walls, at the moment this work was carried out there were no elements as to establish in an unambiguous way a traditional criteria of windows patterns, orientation and distribution.

The energy saving calculations have been performed according to the LANL method [13]. The obtained results are presented in Table 1. The energy savings have been reported in MJ, and also in amounts of different fuels used in the region.

The energy losses in W/°C for each considered element in both the traditional and the conservative cases are presented in Fig. 5, where the effect of each technology on

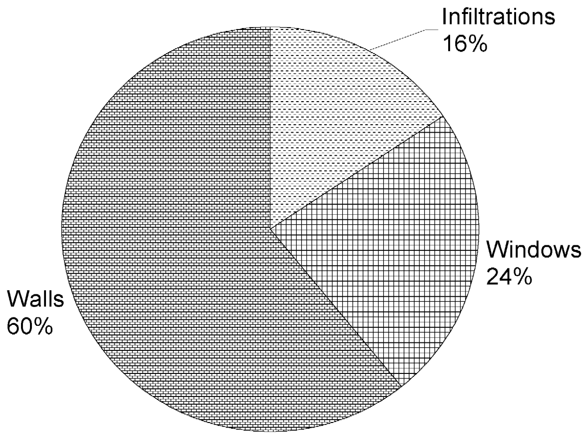

Fig. 6. Energy savings (%) produced by each conservative technology in the conservative building.

the energy losses can be observed. The relative energy savings for each energy conservation measure are reported in Fig. 6. It is shown that using insulated external walls produces 60% of the total energy savings; double glazing amounts for 24% and the remaining 16% is saved by the reduction in infiltrations.

In order to get these savings, it is necessary to manufacture more materials (e.g. glass, insulation, bricks, cement, strips, etc.) and to build new components. These activities require more energy, and produce additional environmental effects. The following table and graph represent the energy savings produced by each strategy, the additional energy consumptions due to the manufacture of the proposed technologies, the resulting net energy savings and some figures derived from the previous results.

Some considerations about the used methodology for the calculation of the energy consumptions and their associated environmental effects are required before analyzing the obtained results:

1. No major consumptions have been considered in the construction of frames for double glazing as compared to single glazing windows, due to the small modifications introduced. As a consequence, the differences in energy consumption in the compared windows are due only to the energy content of the additional glazing. For the energy content in glass a mean value among different figures reported by several authors has been calculated [14–17]. The obtained result (19.92 MJ/kg) is in good agreement with the mean value published by the Building Research Establishment, which gives a minimum value of 13 MJ/kg and a maximum of 31 MJ/kg [18].
2. For the net energy saving due to the reduction of air infiltrations when rubber gaskets are included in the windows the energy content of SBR has been considered. The value reported by Worrell, 77.5 MJ/kg has been adopted in this work [17].

From the analysis of the table and graph in Fig. 7 it can be concluded that even though the insulated walls save the largest amount of energy, they require also the biggest amount of additional energy for their construction. However, the net energy saved by the walls is still the main contribution to the total savings. Infiltration control by the strip is the opposite case: they produce a small saving compared with the other strategies, but with the highest efficiency (more energy saved by each energy unit invested).

To describe the environmental relevance of the different alternatives potential impacts have been used (e.g. global warming potential). In order to present all the analyzed environmental effects in comparable units, a normalization phase has been carried out once all the impacts have been calculated. This phase is called normalization, and consists in the calculation of indicators relative to reference values. Once each impact has been normalized with this procedure, a synthetic profile for each case can be established, which is called the environmental profile. There are several normalization procedures proposed by different institutions, and no general agreement has been reached. The method which has been followed in this study is that proposed by the Copenhagen University, which uses the concept of "person equivalent" [19]. This method relates the amount of emissions of a given substance released by the system studied with the mean value corresponding to a given region (e.g. global, regional, local emissions) apportioned to each person of the population of that region. The results are expressed here in 10^{-6} person equivalents (μPE). A comparison between the environmental profiles of the two cases (conventional and conservative) is presented in Fig. 8.

In that figure it can be observed that almost every environmental aspect considered is improved in the conservative case, except for the photochemical ozone creation potential. Tracing back to the cause of this undesired effect, it was found that it is caused by the use of uncontrolled wood combustion as heat source for the brick baking. This causes a big amount of CO releases, which promotes the photochemical ozone creation. For illustrative purposes, this situation was compared with a hypothetical one in which a natural gas fuelled system for the brick production were used, with the same energy efficiency as in the real case with wood. The environmental profile for the new conservative case is compared with the traditional one in Fig. 9.

It can be observed that all the environmental effects are now improved as compared with the traditional case. This result is, as every output coming from an LCA study, case specific, and it does not mean that, in general, there is an advantage in replacing a renewable fuel with a fossil fuel for brickmaking. Only for this specific case, in which wood has been used in an uncontrolled combustion with many harmful releases to the atmosphere, there is an improvement in the photochemical ozone creation potential when using natural gas instead. From comparison of Figs. 8 and 9, one can detect that the global warming potential for the hypothetical conservative case using natural gas is bigger than when

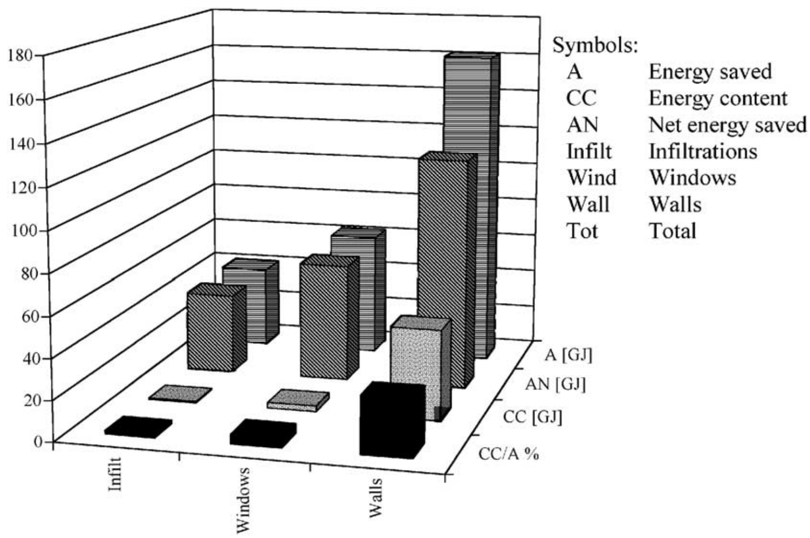

Fig. 7. Energy saved, energy content and net energy saved by each strategy.

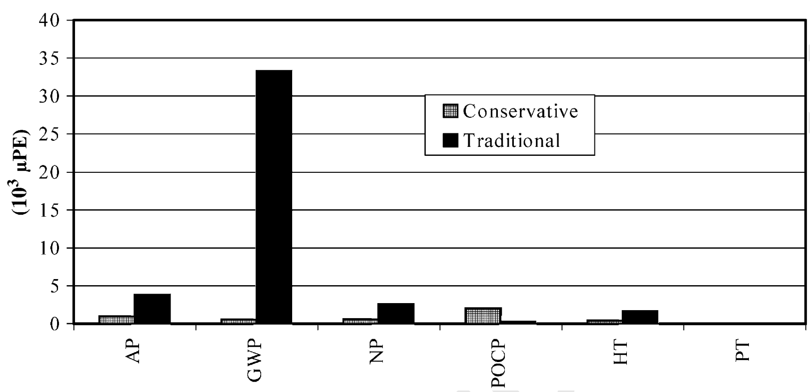

Fig. 8. Normalized effects for the conservative and traditional cases.

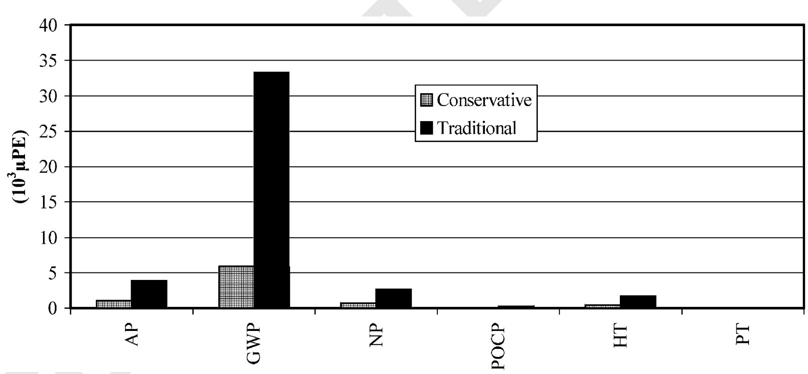

Fig. 9. Normalized effects for the two cases considering that natural gas has been used as heat source for brick baking in the conservative case.

wood is used as fuel. This is due to the CO_2 storing capacity of trees during their growth phase, which is released during their combustion with a zero net CO_2 balance.[1] In any case, when the conservative strategy is applied both using natural gas or wood as a fuel for baking the bricks, a net GWP reduction is obtained when compared with the traditional strategy.

[1] This is true only when the wood is extracted from planned plantings, where the tree felling rate equals the replanting rate.

5. Conclusions

Different studies of the building sector show that the energy content of a building can represent many times the annual energy consumption during operation. As a consequence, choosing less energy-intensive materials can be as effective as making use of solar energy, improve the thermal insulation, etc. But the energy consumption is not the only aspect to be taken into account in an environmentally conscious building. There are many others, which present complex relationships with the chosen materials and the design strategies. To obtain reliable conclusions to improve the design of a building, sound methods and reliable data are required. The LCA method is flexible enough to accomplish this task. There is a great international effort aimed at solving methodological issues and improving present data availability. At local level there is a delay in this aspect, which increases the difficulties to be overcome when an LCA study is to be carried out, and a great effort should be made in order to surmount this situation. In the current study, the energy and environmental effects of applying conservative strategies in school buildings in arid Andean regions of Mendoza has been assessed. Also the power of the LCA method for the energetic and environmental evaluation and comparison of different design alternatives and for pinpointing the undesired effects in a scientific way, for a school building, is shown. The environmental impacts produced by each design alternative as well as the materials or processes which are responsible for those impacts can be detected and evaluated using this tool. This detection and evaluation is the required first step for mitigating those impacts.

To describe the environmental relevance of the different alternatives potential impacts have been used (e.g. global warming potential). These reflect the worst case, that is the utmost effect that could be produced if every molecule released impact the corresponding compartment, but the calculation of real environmental damage or effects require models based on many assumptions and uncertainties.

The study compares two different cases, named traditional and conservative. The production and use phases of these buildings has been compared over their lifetime. The disposal of the building materials and components at the end of their life cycle has not been considered as, at present, there is no alternative disposal mechanism within the country.

The impact assessment phase of the LCA has been completed with a normalization method to compare the different alternatives. No overall environmental score has been used, such as eco-indicators.

It is shown that the analyzed conservative technologies reduce the energy consumption and the environmental impact of the studied school building. In particular, in the case studied, the following aspects have been analyzed:

(1) The energetic and environmental impact of the implementation of different conservative technologies applied in a school building have been quantified.
(2) It has been shown that almost all the environmental effects are improved when the conservative technologies are implemented.
(3) The only effect that worsen when the conservative technologies are applied is the photochemical ozone formation potential.
(4) The responsible element of that negative effect has been identified in the bricks.
(5) The responsible process of that negative effect has been identified in the use of wood as a fuel in brick baking.
(6) It has been shown that changing the fuel used in brick baking the negative effect is eliminated.
(7) The importance of using planned plantations over the CO_2 balance has been shown.

More conservative and passive solar strategies will be studied as the research advances but, as remarked before, a great effort will be necessary to improve data availability for the production of new materials, which is very poor at the moment in Argentina. A further step will be the LCA of a full school building, excluding the demolition/disposal phase due to the previously commented reasons. When different end-of-life scenarios and data will be available for our country, the full life cycle will be considered.

References

[1] Kim S. Life-cycle assessment of embodied energy for building materials—focused on high-rise apartments. Proceedings of the World Renewable Energy Congress (WREC), Florence, 1998. p. 1559–62.

[2] Cousins F, McGregor A. Specifying a Green Building. Green Building Challenge '98, An International Conference on the Performance Assessment of Buildings, Vancouver, Canada, October 26–28, 1998.

[3] Secretaría de Energía. Escenarios de demanda de energía eléctrica y uso racional de la energía, 1996.

[4] IDEE. Estudio Energético Integral de la Provincia de Mendoza. Diagnóstico Socioeconómico Provincial. Elementos del diagnóstico energético Provincial. Instituto de Economía Energética de la Fundación Bariloche, 1998.

[5] Suárez C, Torres S, Dobrusin A. Argentina: emisiones de CO_2 en el sector energético. Instituto de Economía Energética, Fundación Bariloche, 1993.

[6] Brown L, et al. State of the World 99. Stato del pianeta e sostenibilità. Rapporto annuale (Edizione italiana). Edizioni Ambiente, 1999.

[7] Lippiatt B. BEES. In: Environmental and Economic Balance: The 21st Century Outlook Conference, Miami, FL, November 1997.

[8] SETAC. Guidelines for life-cycle assessment: a code of practice. Bruxells: SETAC, 1993.

[9] ISO, 14040. Environmental management. Life cycle assessment—principles and framework, 1997.

[10] Fawer M. The use of LCA and ecolabels in developing countries. Proceedings of the Third International Conference on EcoBalance, Tsukuba, Japan, November 1998.

[11] Basso M, de Rosa C, Esteves A, Pattini A, Mitchell J, Cantón A, Mesa A, Fernández J.C, Cortegoso J. Un edificio escolar energéticamente eficiente en el centro-oeste de Argentina. Presented in ANTAC'99, Fortaleza, Brazil, 1999.

[12] Petersen E. LCA tool for use in the building industry. International Journal of Low Energy and Sustainable Buildings 1999;1.

[13] Balcomb J, et al. Passive Solar Design Handbook. Boulder, Co, USA: ASES, 1983.

[14] Adalbert K. Energy use during the life cycle of buildings: a method. Building and Environment 1997;32(4):317–20.

[15] Buchanan A, Honey B. Energy and carbon dioxide implications of building construction. Energy and Buildings 1994;20:205–17.

[16] Goulding J, Owen Lewis J, Steemers T. Energy in arquitecture. The European passive solar handbook. CEE, 1992.

[17] Worrell E, van Heijningen J, de Castro J, Hazewinkel J, de Beer J, Faaij A, Vringer K. Energy 1994;19(6):627–40.

[18] Building Research Establishment. Embodied Energy of Building Materials. Range of published figures, UK, 1994.

[19] Wenzel H, Hauschild M, Alting L. Environmental assessment of industrial products. London, UK: Chapman & Hall, 1997.