TECHNICAL AND ECONOMICAL ANALYSIS OF THERMAL SOLAR ENERGY AND RAINWATER USE IN A SCHOOL BUILDING HYDRAULIC SYSTEM: A CASE STUDY IN A BRAZILIAN CITY

Leila Maria Beloni C. Proti [1], Ederaldo Godoy Júnior [2], José Rui Camargo [3]
[1]Belo Horizonte City Hall , 288, Carangola street, 30330-240, Belo Horizonte (MG), Brazil
[2,3] Mechanical Engineering Department, University of Taubaté, Daniel Danelli street,12060-440, Taubaté (SP), Brazil

Leilabeloni@ig.com.br; rui@mec.unitau.br

Abstract

Thermal solar energy and rainwater utilization systems are presented as effective alternatives to the sole use of potable water and electricity in a Brazilian school building in Belo Horizonte's metropolitan area. In this paper, economic and technical analyses are made concerning the use of solar energy as a source of heat to warm up bath water and of individual tanks as rainwater storage devices for toilet flushing. Furthermore, these eco-friendly systems were designed with a view to raising public students' environmental education and awareness of the benefits of thermal solar energy and rainwater utilization in their communities. Mean annual rainfall and solar irradiation data were obtained in order to set parameters within which water collect systems, reservoirs and solar collectors were designed. The results of the analysis revealed the feasibility of using these alternative systems.

Key words: rainwater collect and utilization, thermal solar energy, environmental awareness.

Introduction

The aim of the present paper is to assess economical and technical issues involved in the implementation of eco-efficient building facilities in a Brazilian public high school. The feasibility of a system for rainwater harvesting that is able to meet the school demand for non-potable water and the use of solar energy to heat bath water is analyzed. A second aim of the project is to increase environmental awareness among the students of Municipal Schools, which will certainly have spin-offs in other social communities. The importance of current environmental concerns such as the strong possibility of water shortages in the near future, the need to conserve resources, avoid waste and control floods was addressed in tandem with the design of an effective system for colleting, storing and utilizing rainwater and thermal solar energy. This paper objective is to increase the students sensibility to the world problem of water supplies, lack of energy and the awareness of the technique of rainfall capture, use of thermal solar energy and its mobilization, towards irradiating this knowledge to their families and their community.

Defining the scenario

It was defined that the rainwater and solar power collect and distribution systems would be installed in the school building "Professor Arthur Versiani Velloso Educational Center" (CEPAVV), in Belo Horizonte. The educational center comprises three municipal schools, a canteen that furnishes around three thousand meals a day, the Municipal Education Secretariat, the Teacher Specialization Center, the Teacher's Library, Belo Horizonte's Children and Teenager Library, the Memorial Center of the Municipal Education Office, the Public and Pedagogical Policie's Office and the Municipal School's Scholarships Management Office, being used by over five thousand people every day.

Environmental Education

Environmental education requires real knowledge of our planet. Social, political, economic, ethical as well as ecological issues must be taken into consideration. Countless authors have written about this theme, such as Cascino (2001), Dias (2000), Goldemberg (2003), Leff (2001), Santos (2002), Mota (2001), Viera Ribeiro (1999), Hoepel (1997) and UNESCO itself (1999).

In the 1992 UNO Conference on Environment and Development held in Rio de Janeiro, education was acknowledged as the foundation on which a sustainable society can be built. As Medina and Santos (2000) pointed out,

> *"Education can not dissociate itself from new realities that demand innovative and creative answers that will eventually lead to the making of a truly critical, reflective and deeply involved citizen, able to make decisions that foster democratic principles and institutions and without excluding most members from participating".*

Therefore, schools should be a place for reflection and for developing new ideas, where environmental issues are seen as questions of values and citizenship, as notions that must be instilled in the students. Analyzing the educator's role, the authors agree with Saviani (1996) when he says:

> *"It is hoped that the educator will be capable of understanding current changes in society, of identifying their basic characteristics and the trends underlying them, so that the education process becomes really capable of and accountable for meeting present and future needs.".*

The actual implementation of environmental education projects in schools goes through a number of stages: sensitizing and informing the school community, conducting a social and environmental local diagnosis, devising an action plan for solving problems, besides establishing and opening channels for external participation.

In the sensitizing stage, it is important to emphasize that when common social and environmental problems of the school and the community are brought up, people's feelings are aroused and this involvement increases their critical stance, fosters a better understanding of a wide scope of complex realities within their communities, of how they can be affected by these realities and of solutions that are in their power to find. The information acquisition stage is meant to guarantee sound foundations for the proposed solutions – they must be based on validated scientific and technical knowledge. It is the stage when cause-effect links are established so that environmental problems can be correctly traced back to their causes and the best technical solution to tackle them selected.

It is of paramount importance to point out that the social and environmental local diagnosis plays a major role in this knowledge construction, especially when the research is based on the data obtained from studies of local environments, for they provide a clear picture of social and environmental relations in the students' actual living space.

As for the action plan, it is necessary to keep an agenda where the problems and their proposed solutions are recorded (actions and players, necessary resources, schedules, deadlines, assessment methods, etc). It is worth pointing out that according to the Brazilian National Curriculum Parameters, environmental issues must be addressed transversally, being considered a multi-, cross- and trans-curricula subject by the Environmental Education National Policy.

Rainwater Utilization

The present crisis in world water supply is due to a fast population growth and to changes in people's habits brought about by new lifestyles, which caused a drastic increase in the daily per capita demand of potable water. The degradation in the quality of river waters, their use in irrigation, growing pollution and so on, have greatly curtailed the quality and the amount of water that is available for human consumption.

Thus, alternatives to the exclusive use of potable water must be devised. Several of authors have addressed this issue, such as Gnadlinger (2001), Gigk (2001), Gould, Nissen-Pertersen (1999), Hartung (2001), Kolb (2001) and Thomas (2001).

In this context, besides the problems related to a 'culture of waste' and to an inefficient use of water two other must be added: the occurrence of floods in the rainy season and the likelihood of a future collapse in water supply, although over 90% of the Brazilian urban population is supplied with potable water at present, according to a survey conducted by the Brazilian Institute of Geography and Statistics (IBGE). Since Brazil's urban population exceeds the rural population, several factors contribute to the occurrence of floods: cities and towns contain large impermeable areas, which prevent rainwater from seeping into the ground and increases run-off The problem can be further aggravated by an inefficient urban drainage system.

Supplying rain water is one of the alternatives in the water resources management program. Although it is not a common practice in Brazil, it has been used in semi-arid regions, is economically and environmentally advantageous and guarantees water reserves.

Making use of rainwater is not a recent idea. History tells us that cave dwellers and ancient civilizations often built small reservoirs to store rainwater for later use. (Gould and Nissen-Petersen, 1999). In the early twentieth one century, rainwater utilization began to be applied to a wide range of uses as a substitute for potable water, whenever it is not necessary to use treated water.

In the semi-arid northeastern region, in islands like Fernando de Noronha and wherever the water supply service is either nonexistent or insufficient, people have always used and still use rainwater.

Considering all these facts, besides reducing the costs of sewage and water services, rainwater harvesting can contribute to improving the structure of urban drainage by reducing the volume of water pouring into sewer systems (Tucci, 2000). In addition to that, in spite of the constant rise in demand due to population growth, water companies would gradually be under less pressure of supplying more potable water to the whole population. For this reason, rainwater catchments and solar energy systems deserve to be rewarded with fiscal advantages as incentives for their users. Obviously, these governmental incentives should be extended to every product can contribute to a sustainable development and to a more rational use of the world's natural resources.

The rainwater utilization system

A study was carried out so as to define the model and size of the tanks suitable to the local scenario and to the mean monthly precipitation index. In order to obtain a technical analysis of the viability of the compensatory system, a simulation of its performance was made during a month (Fig.1).

When the occupation scenario was defined, the daily water consumption to be obtained both from the conventional hydraulic project and from the compensatory project was calculated. The reservoirs, the pipe network and the necessary equipment for having both the compensatory and the conventional system working were designed according to the building architecture.

Both costs and the volume of rainwater were determined before the technical and economic analysis of rainwater utilization in the hydraulic system of the building was made.

The following data were used in the simulation of the compensatory system: toilet flushing : 10liters/ flush (calculating that on average each user will use the flush twice a day), roof area = 1800 m^2, total of occupants: around 3000/day, 22 days/month.

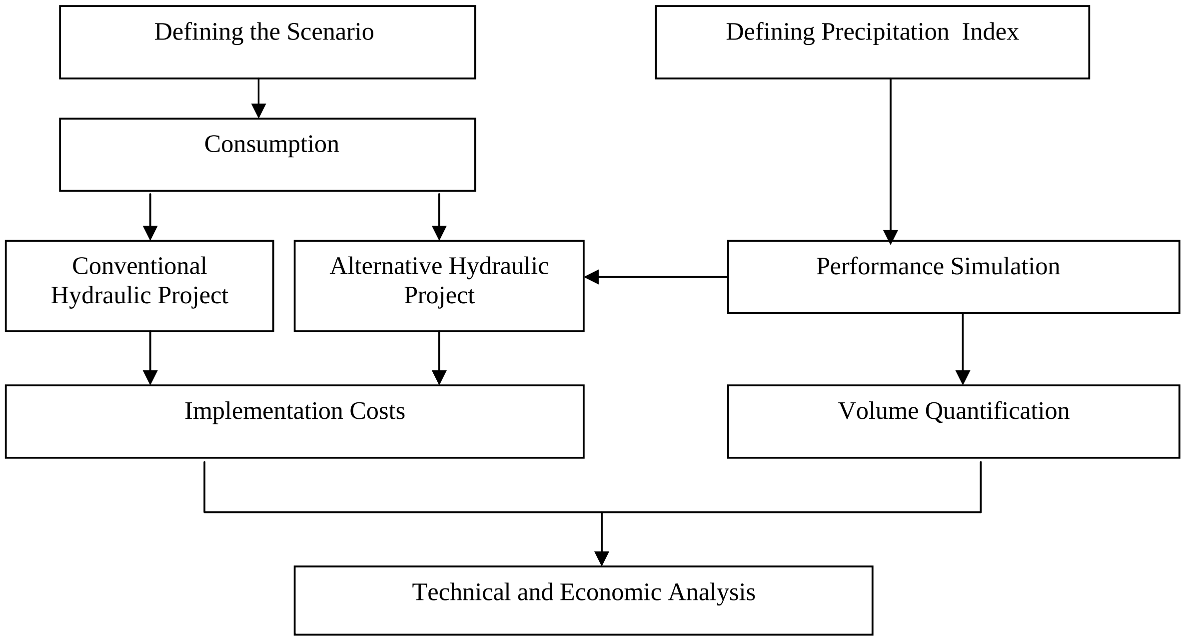

Figure 1 – Rainwater harvesting : Flowchart of the simulation sequence

The local rainfall pattern, the performance of the rainwater tank and the conventional hydraulic project were made following Macyntire (1996): in a building, the storage capacity of a tank must at least be enough to meet its daily demand In this specific scenario, the rainwater tank(s) storage capacity should be 20 $m^{3.}$

Cost estimates included collect, conveyance, storage and distribution equipment. Fiberglass tanks were considered to be the best option due to their low cost and low-maintenance requirements. Manpower costs were excluded in the calculations since the installation will be carried out by the maintenance team of the building which is part of the permanent personnel.

Implementation costs, the capital to be invested and the savings in water tariffs were calculated. It was calculated that the total cost of the compensatory project would be around U$ 3,000.00.

Table 1– Cost of the rainwater utilization system (April 2004)

Equipment	Number	Price/unit (US$)	Total price (US$)
Fiber glass tank	10	133	1,330
Control valve	02	47	94
Pipes	140	8,50	1,190
Filter, float, siphon and water brake	01	416	416
TOTAL			3,000

Thermal solar energy utilization

In primitive eras, men were keenly aware of the importance of the sun in their lives. In the XIV century, coal became a growing source of energy in Europe, and its use was intensified in the XVIII and XIX centuries. In the XX century, oil and natural gas became the main sources of energy in the industrialized world, but the environmental costs that this consumption of natural resources entail have not been calculated in the productive process. (Merico, 1996).

Environmental degradation and energy resources are now the two main concerns of mankind. These issues are closely linked and one of the possible solutions is the rational and efficient use of freely available energy (Molina Jr. et al, 1995).

It stands to reason that the use of thermal solar energy is a sensible substitute for fossil fuels since it is abundant, renewable, nonpolluting and environmentally friendly. Besides, it can easily be collected as low temperature heat.

The invention of the solar collectors as a source of energy to obtain heat is attributed to Nicolas de Saussure, a seventeenth century Swiss scientist, who managed to reach a temperature of over 87^{o}C by using a wooden box with a dark bottom and a glass cover. (Hayes, 1977). In Brazil, the first boom years of solar power heating technologies were in the 70’s as a result of the fossil fuel crisis. Because of its geographical location, Brazil has an enormous solar energy potential and a rational utilization of this energy has a promising future.

After defining the scenario, it was necessary to determine the cost and the amount of electricity demanded by the conventional electric showers used in the building, so that an economic analysis of using thermal solar energy to heat bath water could be made (Fig. 2). For this economic and technical analysis, the installation cost as well as the maintenance and operational costs for utilizing each thermal system were taken into consideration.

Based on a projection of 50 people using the shower for an average of 10 minutes, consuming 3,000 liters of hot water a day, it is possible to estimate the consumption of electric energy by considering the performance of a 5,4 kW shower over a total period of 24 hours. By calculating the mean annual irradiation and the volume of hot water needed, it is possible to have a simulation of the solar power device performance and to size the solar heater system: fifteen 2mx1mcollectors, 3 stainless steel reservoirs with a storage capacity of 1000 liters each and 3 anti-freezing valves.

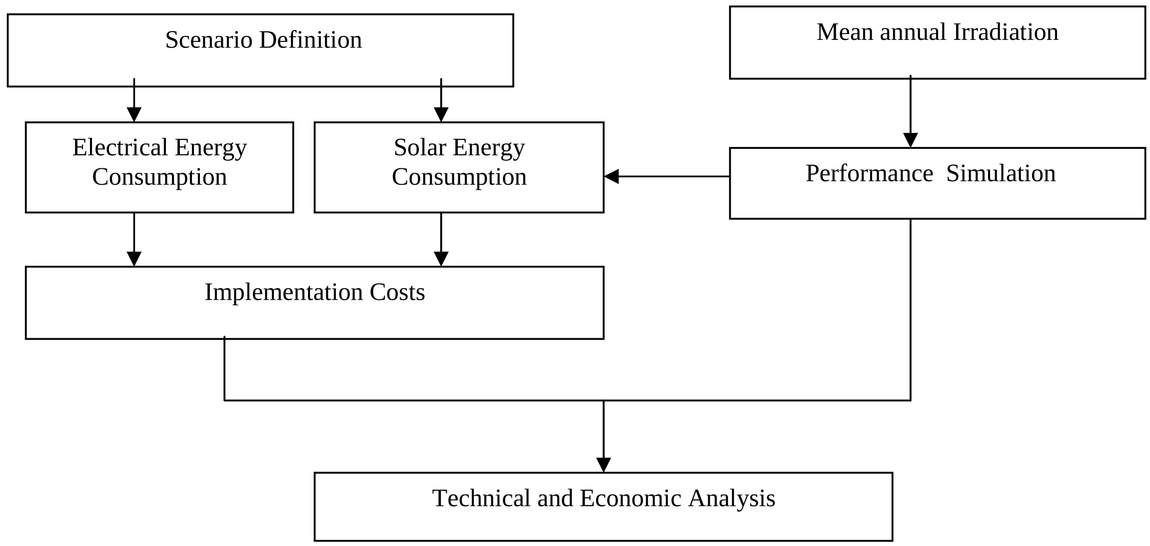

Figure 2 – Simulation flow chart – Thermal solar power utilization

Results and discussion

The rainwater utilization analysis was based on the following data: water/sewage tariffs = U$ 1,93/m^3; the cost of the conventional water distribution system that makes use of a 18 KW pump working 12h/day: KW= U$ 24.84. The existing conventional system comprises two underground 20,000 liters reservoirs, a 10,000 liters reservoir on the seventh floor, three 1,000 liters reservoirs in the roof reinforced cement floor, a set of 18HP pumps working 12 hours a day.

In the alternative rainwater utilization system, the rainwater collected will be stored in tanks installed on the reinforced cement roof floor, and this rainwater will be used in the rainy seasons and the other the other reservoirs in dry seasons. The rainwater stored will be used for toilet flushing while the other reservoirs will supply the building with potable water. The conventional system is to supply the demand of the building whenever the rainwater tank reaches its minimum level by means of a pipe network with retention valves. It was calculated that the total cost of the project will be US$3,000.

Economical analysis

In order to assess the economic viability of the design, the total to be invested and the financial proceeds were calculated by using the following equations:

$$C=\frac{IF}{HQ}+CI+CM \qquad (1)$$

$$R = HQ(P-C) \qquad (2)$$

where Q is the mean daily water outflow**;** H is the number of hours per year of the system performance; I is the system investment costs (since the conventional system of the building will be used, their investment costs were excluded); CI is the = operational cost of each system; CM is maintenance cost of the systems and P is the final water price (US$).

The implementation cost, the total investment and the savings in water tariffs were calculated and a technical and economic analysis of the rainwater utilization system in tandem with the conventional hydraulic system of the building were made (Tables 2 and 3). The proceeds/time graph (Fig. 3) compares rainwater utilization to public potable water supply tariffs and attests the economic advantage of its implementation. Will be around eleven year, but the environmental gains must be considered too.

Thermal Solar Energy

By weighing up the hot water outflow, the energy company tariffs, the cost of the energy required by the shower and the installation, maintenance and operational costs (Table 4), it is possible to calculate the investment returns and to make a technical analysis of the advantages of implementing the system (Table 5). The revenue/time graph compares the utilization of thermal solar energy for heating bath water with the electric energy supplied by the energy company and shows that utilizing thermal solar energy is economically advantageous.

Equations (3) and (4) are used to calculate the values presented in Tables 4 and 5.

$$C = \frac{IF}{HQ} + COI + CM \qquad (3)$$

$$R = HQ(P-C) \qquad (4)$$

where I is the investment in equipment: boiler, solar collector plates, filters, water brakes and piping (since the conventional system is already installed, no additional investment in equipment will be necessary); CM is the system maintenance costs; CO is the system operational cost; E is the yearly energy consumption of each system; P is the local tariffs for electricity; Q is the hot water outflow and H is the number of hours per year of the system performance.

Table 2- Rainwater utilization

Description	**Symbol**	**Unit**	**Case I Public water supply**	**Case II Rainwater utilization**
Mean daily outflow	Q	M³/h	3.90	3.90
System performance h/year	H	h/year	3,168	3,168
Investments	I	US$	-	3,000
Utilization Costs	CI	US$/m³	2.47	1.89
Maintenance Cost	CM	US$/m³	0.01623	0.01352
Water price	P	US$/m³	2.48623	1.90352

Table 3 – Investment recoup

		CASE I		CASE II	
K	Annuity Factor	Cost (US$/m³)	Proceeds (US$/year)	Cost (US$/m³)	Proceeds (US$/year)
K (years)	F (1/year)	C		C	R
0.1	10.5287	2.4862	-54,733.5	4.4600	- 31,258.1
0.3	3.5898	2.4862	-54,733.5	2.7751	-10378.2
0.5	2.1783	2.4862	-54,733.5	2.4323	-6205.9
0.8	1.3844	2.4862	-54,733.5	2.2396	-3706.5
1	1.12	2.4862	-54,733.5	2.1588	-2816.94
2	0.5916	2.4862	-54,733.5	2.0471	-1446.77
3	0.4163	2.4862	-54,733.5	2.0045	-920.44
4	0.3292	2.4862	-54,733.5	1.9834	-659.75
5	0.2774	2.4862	-54,733.5	1.9708	-504.08
6	0.2432	2.4862	-54,733.5	1.9625	-401.53
7	0.2191	2.4862	-54,733.5	1.9566	-247.1
8	0.2013	2.4862	-54,733.5	1.9523	-239.3
9	0.1876	2.4862	-54,733.5	1.9490	-234.4
10	0.1769	2.4862	-54,733.5	1.9464	-123.8
11	0.1591	2.4862	-54,733.5	1.9386	98.84

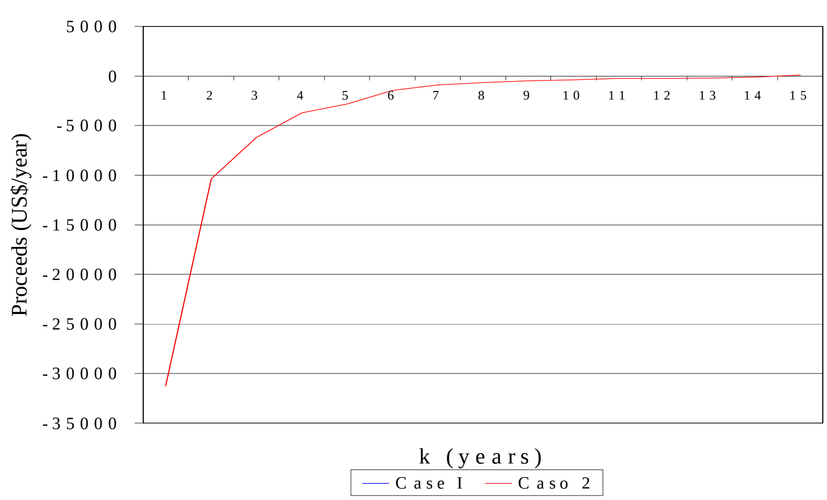

Figure 3 – Proceeds/ time ratio

Table 4 – Thermal solar energy utilization

Description Heating bath water	Symbol	Unit	Case I	Case II
Heat source		-	Solar energy	Electric shower
Investments	I	US$	5,000	-
Maintenance Cost	CM	US$/m^3	0.088	0.25
Operation Cost	CO	US$/ m^3	0.13	2.66
Power required in the equipment	E	KWh/year	750	14,400
Equipment power (electric shower)	W	KW	-	5,4
Kwh Price (Local CEMIG Tariff)	P	US$	0.14	0.14
Hot water outflow	Q	m^3	3	3
Performance hours/year	H	h/year	2,640	2,640
Hot water price	P	US$/ m^3	2.54	0.94

Table 5 – Investment Feedback

		CASE I		CASE II	
K	Yearly Factor	Cost (US$/m^3)	Income (US$/year)	Cost (US$/m^3)	Income (US$/year)
K	F (1/year)	C	R	C	R
0.1	10.5287	57.15	-50265.6	2.91	-231
1	1.12	6.,244	-3307.9	2.91	-231
2	0.5916	3.383	-668	2.91	-231
3	0.4163	2.436	206.97	2.91	-231
4	0.3292	1.92	683.76	2.91	-231
5	0.2774	1.68	905.52	2.91	-231

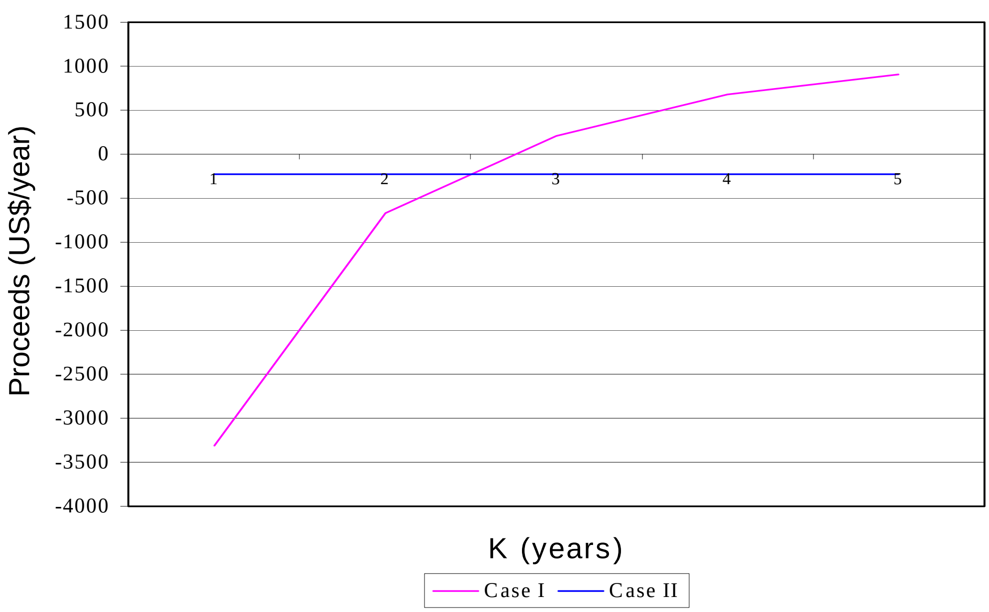

Figure 4 – Proceeds/time ratio

Conclusion

Environmental education can help reduce waste and raise a new ecological awareness. It is by showing our students the need to preserve water and , in particular, by highlighting the advantages of rainwater harvesting and the environmental benefits derived from thermal solar energy utilization that these issues are addressed and conclusions drawn.

Firstly, rainfall utilization is, in this particular case, not only feasible and economically advantageous but also sensible when one takes into consideration how much potable water can be saved and the public drainage system spared. Secondly, environmental gains and the amount of electric energy saved must be weighed up. Since the reservoir will be installed in the roof of the building, it will not be necessary to use pumps. As for ground water recharge concerns; the volume of water collected from the roof can be dismissed as irrelevant since it would otherwise fall down on impermeable ground, while the same recharge will be preserved in the permeable areas close to the building.

Solar energy is clean, natural, safe and also abundant in Brazil. It allows cut backs in electric energy bills and consumption, it can alleviate the distribution system during peak time and prevent blackouts, thus making the project not only economically viable but also desirable.

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