ECONOMIC VIABILITY OF IMPLANTATION OF SOLAR COLLECTORS FOR WATER HEATING IN COMMERCIAL BUILDINGS – A CASE STUDY

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Abstract. *In this work, a simplified methodology for analyzing economic viability of implantation of water heating systems via solar collectors in commercial buildings is proposed. Starting from empirical data available in literature and obtained from commercial catalogs, energy and mass balances were used for dimensioning, selection and cost estimation of the solar heating system. A practical case of implantation of such a system in a commercial building (hotel) is analyzed. Results showed that it is advantageous to use this alternative energy source for water heating, depending only of the investment capability.*

Keywords: *Solar energy, Water heating, Economic viability.*

1. INTRODUCTION

The use of solar energy for water heating is an excellent alternative compared to conventional energy sources (electricity, fuel), since it is an infinite and non-pollutant source, available all over the world. Its use has become attractive, as the costs have been reduced. The continuous raising of the price of fossil fuels and the difficulties in expand electrical energy supply also justify its use (Palz, 1995). The flat solar collectors have the best cost-benefit obtained with a solar heating system. It can be used in residences, industries and commercial buildings. These systems are competitive even when an auxiliary heating system is necessary, in order to compensate the lack of solar radiation in some periods of year (Rodrigues and Matajs, 2005).

In Brazil, the use of solar energy has presented good performance as a technical solution for reducing the consumption of electricity in residences, replacing electrical showers. The market share of solar heating systems has raising continuously, as a consequence of its falling costs in the last twenty years; from US$ 500/m² to approximately US$ 100/m² (CEPEL, 2005). Despite of that, its cost is still considered high, when compared to the electrical showers found in 67.6 % of residences, what corresponds to 18 million of unities (Achão, 2005). The major challenges for the expansion of residential solar heating in Brazil are the high initial cost, non-friendly legal statements, a lack of technical capacity for design, selection and installation, high interest rates and inexistence of long-term financial facilities. An important factor is the absence or technical norms. In 1997 was created the *National Target of Energy conservation* (ENCE) for solar collectors, by INMETRO, what has triggered an improvement in the quality of solar equipment The ENCE allows to customers to get information about the performance of solar collectors. The indifference of energy distribution companies, because of the decline in revenues, is also a difficulty for the expansion of solar energy.

Although dimensioning of solar heating systems has been extensively described in literature, the economic viability of its implantation is not always obvious. In this work a dimensioning and cost estimative for a solar heating system is showed, through a case study. The implantation of a solar system for water heating is selected and its cost is rated and compared to a pure electrical one, already implemented in a virtual commercial building, and the time for payback is calculated. Results prove that solar energy is highly competitive, independent of the fraction used in the system.

2. DIMENSIONING OF A SOLAR COLLECTOR

The solar heating system consists of two basic components: the thermal reservoir or boiler and the solar collector. Both are filled with water and connected to the cold water supply. The water circulates between the reservoir and the collectors until water temperature becomes homogenous in the whole system. The fluid circulation is made by a pump (forced convection) or spontaneously (natural convection). In the last case, the system is called thermo-siphon, and this is model considered for use in this work, due its low cost (does not need electrical power). In order to assure warm water supply in days when the incidence of solar radiation is not enough, an auxiliary heating system is necessary. The most common system is an electrical resistance, dimensioned according to norm NBR 7198/82 (ABNT,1982).

Necessary inputs to dimensioning the solar heating system are daily consumption, installation placement and region of building. A bad placement and underdimensioning of collectors may reduce the system efficiency. To calculate the collector's plate surfaces, the local incidence of solar radiation should be known (Bezerra, 1990). The intensity of the incident radiation may vary according to the place, and also with the weather conditions. The mean anual insolation in some selected cities is showed in Tab. 1.

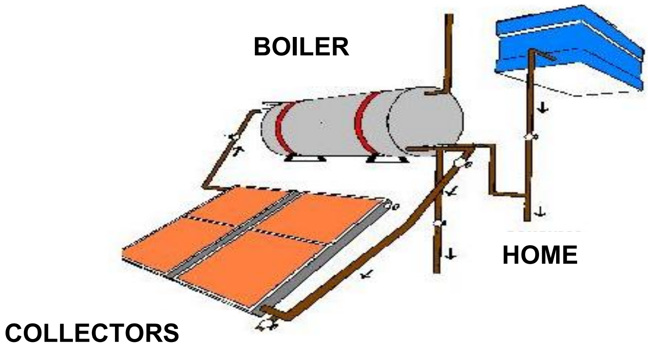

Figure 1. View of a thermo-siphon solar installation.

Table 1. Mean annual incidence of solar radiation in some Brazilian cities (CUMULUS, 2004).

City	Mean annual incidence of solar radiation (hours/year)
Fortaleza	2800
Natal	2800
Recife	2600
Salvador	2600
Campinas	2600
Belo Horizonte	2500
Brasília	2500
Porto Alegre	2300
Belém	2200
Rio de Janeiro	2100
São Paulo	2000
Curitiba	2000

The radiation heat flux varies during the day, from zero (at sunup) to a peak at noon, and decreases to zero at sunset. Table 2 presents mean annual rate of incident solar radiation for Brazilian capitals. For northeast region a value of 0.86 cal/cm^2 min can be assumed (UFPE, 2000).

Table 2. Solar radiation in some Brazilian cities (UFPE, 2000).

City	Mean annual temperature (^oC)	Incident solar radiation (kWh/m^2.year)
Belém	26.9	1783
São Luis	27.4	1929
Natal	25.9	2013
Salvador	25.1	1830
Belo Horizonte	21.5	1896
Rio de Janeiro	23.7	1602
São Paulo	23.0	1674
Curitiba	17.6	1656
Porto alegre	20.1	1594
Brasília	21.4	1934

It is necessary determine the total surface of solar collectors needed to reach the hot temperature, considering the estimated water volume of water to be warmed. This calculation may be done taking into account the inclination angle of collector (relative to earth's surface), or considering the collector in perfect horizontal position. In the first approach, the solar radiation is supposed to reach the collector's surface perpendicularly, allowing a reduction in its area. Normally the collectors are installed above an inclined roof. In all situations, it is strongly recommended that the minimum inclination be equal to the latitude of placement, plus 10^o. Since most of Brazilian territory is located in the south hemisphere, the collector should be inclined to the north direction. Even when the inclination is considered in the calculus, the reduction of collector's surface is quite small. Tables 3 and 4 supplies references for a estimative of warm water volume necessary in some kinds of buildings, and the approximate surface of correspondent flat plate collectors (according to its localization), respectively.

Table 3. Average warm water consumption (SOLETROL, 2005)

Building	Daily consumption
Residential building	110 l/inhabitant
Hotel	105 l/bed
Motel	800 l/apartment
Hospital	100 l/bed
Industrial dressroom	50 l/person
Industrial laundrery	30 l /kg dry clothes
Popular residence	40 l/person

Table 4. Collector surface per water volume (SOLETROL, 2005).

City	Collector surface / 100 liters of water
Manaus	0.9 m^2
Natal	0.8 m^2
Goiânia	1.0 m^2
Belo Horizonte	1.0 m^2
Rio de janeiro	1.1 m^2
São Paulo	1.6 m^2
Bauru	1.2 m^2
Porto Alegre	1.6 m^2

3. CASE STUDY – SOLAR SYSTEM FOR WATER HEATING IN A COMMERCIAL BUILDING

3.1. Inputs

Place: Rio de Janeiro
Building: Hotel, new (to be built), with enough surfaces for installation of solar collectors above its structure.
Resources: 40 beds, restaurant, without heated swimming pool, and external laundry service.
Warm water temperature: 70°C
Cold water temperature (input): 23.7°C

3.2. Dimensioning of solar system

The dimensioning will take into account the equipment available in the Brazilian market and its costs. From Tab. 2, the total water consumption is 105 liters/bed.day x 40 beds = 4200 l/day of warm water. Considering the restaurant: 40 beds x 2 guests/apartment x 3 meals/day x 12 liters /meal x 0.50 = 1440 liters/day, were 0.5 is the occupation rate. The number of 12 l/meal came from the norm NBR 7198/82 norm (ABNT,1982). The total demand will be 5640 l/day. According to this data, it will necessary 5 reservoirs of 1000 l plus one with 650 l. The characteristics of the selected reservoirs are showed in Tab. 5.

Table 5. Aproximate dimensions ofr thermal resorvois (CUMULUS, 2006)

Volume (l)		150	200	250	300	400	500	650	800	1000
Dimensions	A	1130	1450	1650	1480	1780	2180	2590	2570	2990
	B	1000	1320	1520	1400	1680	2080	2160	2000	2500
	C	795	1115	1315	1180	1460	930	950	810	1000
	D	560	560	560	670	670	670	730	840	840
Power (W)		1500	2000	2000	2000	2500	2500	4500	7500	9000
Current (A)		7	9	9	9	11	11	12/76	20/12/10	24/14/12
Input/Output diam. (in)		1	1	1	11/4	11/4	11/2	11/2	2	2
Pipe diameter (in)		1	1	1	11/4	11/4	11/2	11/2	2	2
Maximum work pressure (m.w.c)		40	40	40	40	40	40	40	40	40
Termoglas empty weight (kg)		78	90	100	-	-	-	-	-	-
Extra empty weight (kg)		100	115	127	138	162	194	270	330	415
Tension (V)		220 Moni´hasic						220/380/440 Threephasic		

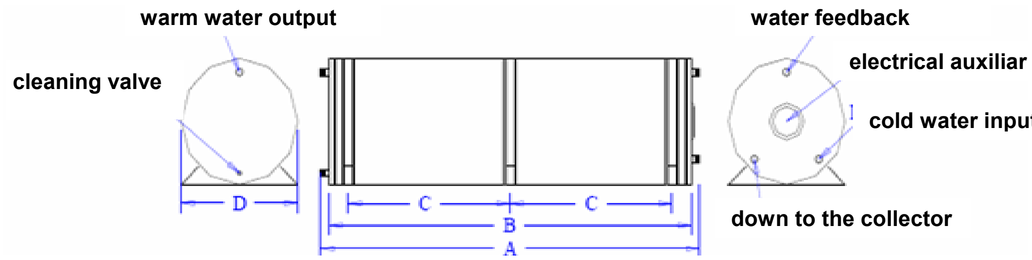

Figure 2. Schematic view of thermal reservoil (CUMULUS, 2004).

The amount of energy necessary to heat the estimated water volume is:

$$Q = MC(t_d - t_a) \quad (1)$$

where:

M = 5640 kg (1kg/litre of water)
C = 1 kcal/kg °C
T_d = 70 °C
T_a = 23,7 °C

Q = 5640 kg x 1 kcal/kg.°C x (70ºC –23,7°C) = 261132 kcal = 303,6965 kWh

The collector's surface is given as:

$$S = \frac{Q}{I.\eta} \quad (2)$$

where:

I = 1602 kWh/m².ano = 4,389 kWh/m². day
η = 54.54 (from Tab. 6)

The Collector's surface will be 126.87m^2. Since the hotel is in Rio de Janeiro, from Tab. 4 each collector will have 1.1 m^2 surface. The total number of collectors is 116, considering 100 % of solar energy for water heating. The Kisol Handbook (2006) recommends plus 10 % in the number of collectors, in order to assure that the system will reach the desired capacity.

Table 6. Collector data (CUMULUS, 2006).

Collector	*Super 100*	*Super*	*Super 200*
Pipe diameter (mm)	22	22	22
External surface (m^2)	1.00	1.42	1.95
Mean energetic efficiency - η (%)	54.54	54.54	54.54
Monthly energy generation (kWh/month)	75.70	107.80	148.86
IMETRO classification	B	B	B
Dimension A (mm)	941	1324	1817
Dimension B (mm)	861	1244	1737
Maximum work pressure (m.w.c)	40.00	40.00	40.00
Empty weight (kg)	15.49	20.50	28.05

4. ECONOMIC VIABILITY OF THE SOLAR HEATING SYSTEM

4.1. Solar energy in Brazil - historic evolution

The use of solar energy in Brazil has become more intensive from the 70's, especially due the oil shocks. In 1973 the *National Energy Commission* (*Comissão Nacional de Energia* – CNE) was created, and in the same year published the *Brazilian Energy Model* (*Modelo Energético Brasileiro* – MEB), (ANEEL, 2006). Behind implementing actions for replacing the oil products, CNE has defined strategies for using alternative energies, including subsidies and research programs for solar energy, wind energy, biomass, etc. Such government efforts, joined to the pressure due the crisis, were fundamental for the rising of alternative energy source utilization in Brazil. Since the 80's, an important market of solar collectors has being developed in Brazil, with increasing sales and players. Table 7 shows some data relative to surface of collectors sold in 1999 and cumulated sales.

Table 7. Use of solar collectors (FAE, 2006).

Country or region	surface in 1999 (m^2)	cummulated sales (m^2)
Brazil	240000	2037000 (since 1983)
Germany	366000	2070000 (since 1975)
Europe	814700	8488200 (since 1975)

The budget involved in the market of solar collectors in Brazil, in 2000, was R$ 100 million (FAE, 2003). The country owns now an effective area of 2 million of square meters and its market demands two hundred thousand square meters per year (PROCEL, 2006). Such big progress is also related to the country localization. Most of Brazilian territory (90%) is located in the high potential zone for solar energy utilization, Fig. 3.

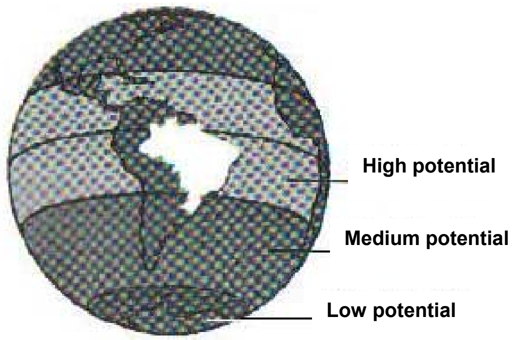

Figure 3. Potential of use for solar energy in Brazil (Bahia, 2006).

In Fig. 4, the graphics allows to identify three different phases during the evolution of the solar energy market in Brazil: until 1994, between 1994 and 2001, and after 2001. According to FAE (2006), until 1994 the market of solar collectors was incipient, and registered small rising rates, with an average of 5.6 %/year. From the beginning of the 90's, with the creation of the Brazilian Centre for Development of Thermal Solar Energy (*Centro Brasileiro para o Desenvolvimento da Energia Solar Térmica*) – GREEN Solar, in Belo Horizonte, and implantation of PBE (*Programa Brasileiro de Etiquetagem*), the national industries of solar heating started to improve its products and services, and yielded higher confidence from the costumers.

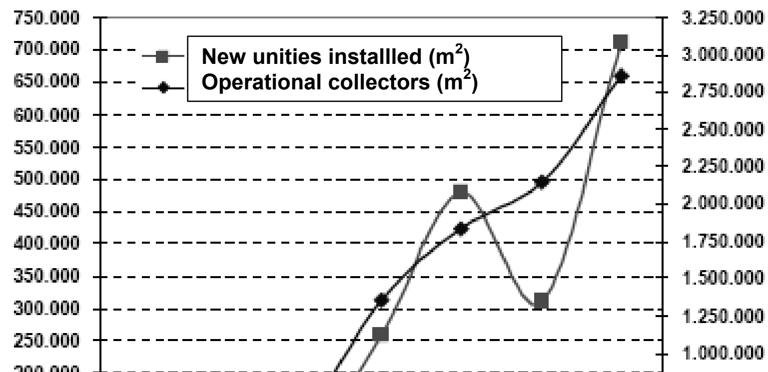

Figure 4. Evolution of solar collectors market in Brazil (AMBIENTE BRASIL, 2005).

After ELETROBRÁS (Brazilian Electricity Centrals), with the National Program for Conservation of Electricity (*Programa Nacional de Conservação de Energia Elétrica* - PROCEL), create some specific programs for incentive, the rising taxes have reached the order of 30.54 % per year (1994-2000). In 2001, Brazil has experimented an electricity supply crisis, and severe actions over consumption were adopted. At this point the solar energy market experimented a rising of 80 % compared to the former year. New companies had appeared and joined the old ones to attempt demand. Solar energy deserved a crescent attention from the public. As the crisis was overpassed, the market experimented a strong retraction in 2002, when compared to the crisis year 2001 (FARIA, 2004). Now a days, the market rises steadily at 33 % per year, and 320000 m^2 of solar collectors are installed every year in Brazil. If such a rate will be kept constant, at 2021 solar collectors would contribute with 22.1 % of thermal energy in the country (Faria, 2004).

4.2. Economic analysis

The decision of using solar collectors shall involve financial and non-financial aspects. As an example of the second ones, it must consider the possibility of a lack of electricity supply in dry weather periods, and also the black out at the peak of demand in a day. As such aspects are hard to quantify, in this work a pure financial analisys will be done.

4.2.1. *Net Actual Value* (*Valor Presente Líquido* - VPL)

The *Minimum Rate of Attractiveness* (*Taxa Mínima de Atratividade* - TMA) corresponds to the minimum financial return accepted by the investor (the interest rate, for example). The VLP is the value obtained from a cashier flux when brought to the present time, taking into account the TMA. The VPL is calculated from (Buarque, 1989):

$$VPL = \sum FC(1+i)^{-n} \tag{3}$$

where
:
FC = cashier flux, R$;
i = interest rate, %;
n = number of months

A typical criterion for decision is that VPL should be bigger than zero.

4.2.2. *Rate of Internal Return* (*Taxa Interna de Retorno* - TIR)

TIR is the interest rate that will produce a VPL equal to zero (Buarque, 1989):

$$TIR = \sum FC(1+i)^{-n} = 0 \tag{4}$$

In order to assure the investment, TIR should be greater than TMA.

4.2.3. *Payback* (PB)

PB will be the time necessary to recovery the investment (Buarque, 1989):

$$PB = \frac{I_0}{\sum FC_{ano}} \tag{5}$$

where:

I_0 = Cost of initial investment, R$;
FC = cashier flux, R$;

Some hypotheses were assumed, in order to complete the inputs for the financial analysis. A period of 10 years will be considered for depreciation of equipment (Motta, 2002). TMA will be 14.25 % / year, which corresponds to the Federal interest rate (SELIC tax) at 31 august, 2006.

Initial investment consists of buying and installation of equipment. Such values were obtained from catalogs of the manufacturers CUMULUS (2006) and KISOL (2006). From those catalogs, a constant rate of R$ 5.70 was considered for investment in the electrical support and R$ 1.60 /liter in the solar and hydraulic systems. The expenses with the electrical system were implicit in the building costs.

The cost of the annual consumption is the product among the annual consumption of electricity and the cost of energy, R$ 0,36424 (ANEEL, 2006). The forecast for ten years was done considering a annual correction of 3 % (AMPLA, 2006).

Maintenance costs for both systems, solar and electrical, will be considered negligible, since there is not enough information about that. The actual values assumed are the VPL's for each type of system. The cumulated flux will the difference among the VPL of the solar system and the electrical system. If the fraction of solar energy used for water heating is less than 100 %, an electricity complement will be necessary.

5. METODOLOGY

Figure 5 shows the sequence of calculation. Data were computing through the software MS EXCEL.

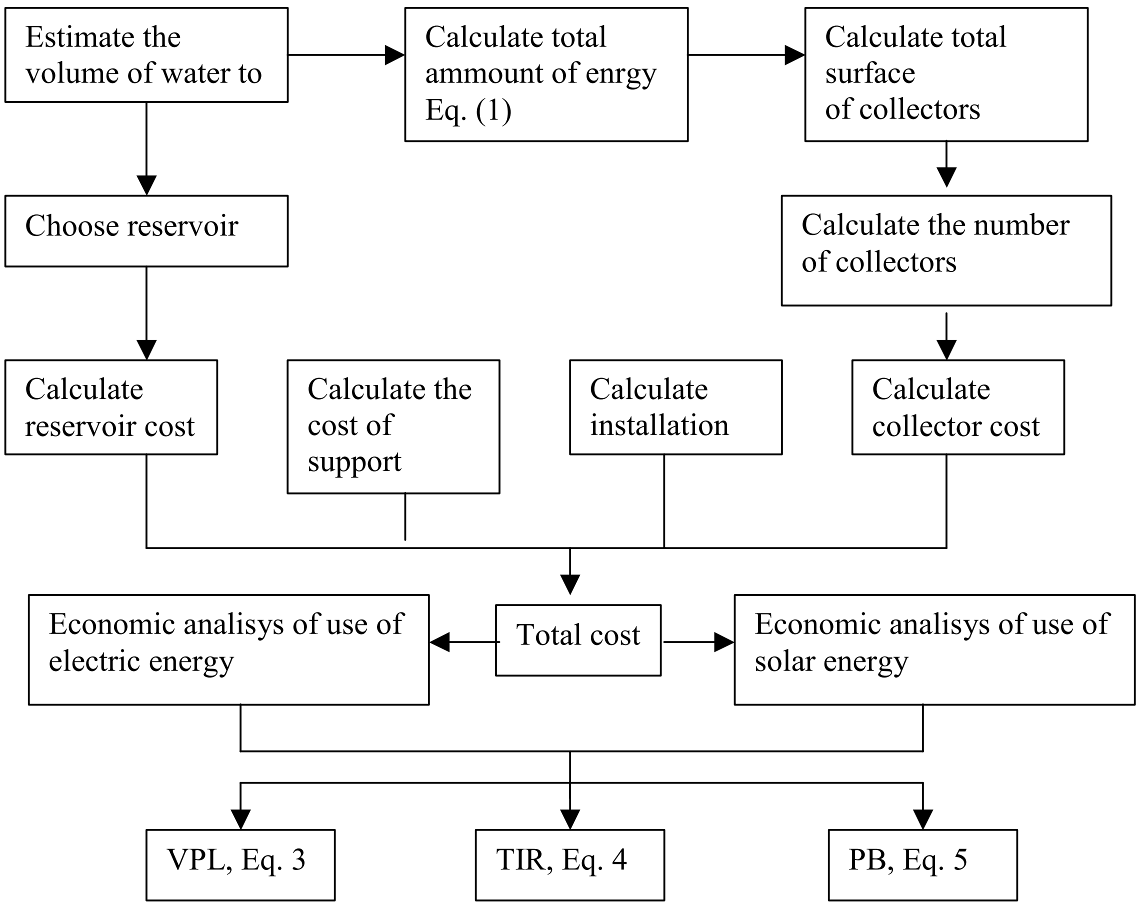

Figure 4. Sequence of calculation.

6. RESULTS

Table 8 presents cost estimative for a solar system capable to support variable demand. Based in this data, and after applying Eqs. 3-5, resulting budgets are presented in Tab. 9. In agreement with the hypothesis employed, the costs of maintenance and installation of the electrical system are neglected. Only the costs for installation of the solar energy system and electricity supply are considered. As a consequence, the Rate of Internal Return (RIR) decreases with the fraction of solar energy used, since the cost of the electrical supply rises.

Time evolution of costs for pure electrical systems and combined solar-electrical are showed in Figs. 5-8. In this case, the negative signal means the total budget expensed for water heating in the period. From those graphics, it is clear that the solar energy system presents a constant cost, once it is installed. If the fraction of solar energy is less than 100 %, the cost rising is due the electrical energy fraction.

Table 8. Price for system, according to the fraction of solar energy employed in the heating, considering values for the equipment from KISOL (2006) and CUMULUS (2006).

% Solar Energy	Thermal Reservoir (R$)	Collector (R$)	Support system (R$)	Installation cost (R$)	Total (R$)	Electricity Supply (R$)
100	16000	48411	32148	9024	105583	0
90	14560	43591	28933	8122	95206	11116
80	12740	38771	25718	7219	84448	22233
70	11200	33950	22504	6317	73971	33349
60	9750	29130	19289	5414	63583	44466
50	8060	24310	16074	4512	52956	55582
40	6450	19490	12859	3610	42409	66699
30	5260	14670	9644	2707	32281	77815
20	3360	9849	6430	1805	21444	88932
10	2000	5029	3215	902	11146	100048

Table 9. Summary of results.

% Solar energy	PB (years)	RIR (%)	LPV (R$)
100	1.9	42.6	794 868
90	1.9	42.3	712 801
80	1.9	42.5	634 914
70	1.9	42.4	553 947
60	1.9	42.0	471 990
50	1.9	41.9	392 673
40	1.9	41.7	312 476
30	2.0	39.9	227 659
20	2.0	39.8	150 652
10	2.2	34.5	67 705

7. CONCLUSION

The results presented here evidence that replacing conventional heating systems by solar ones, with or without electrical support, is always advantageous, and can yields financial return continuously, with a complete payback in less than 24 months. The Rate of Internal Return (RIR) found are quite higher than the minimum rate of attraction employed (14.25 % per year), which demonstrates the advantage of solar energy for this particular use.

Note that the variation of solar energy fraction used for heating has low influence in the investment decision, once the expenses for implantation decrease with that fraction but the use (and the cost) of electrical energy rises. Therefore solar energy has proved to be a better option for the particular use in hotels or similar buildings, considering the conditions of the Brazilian market.

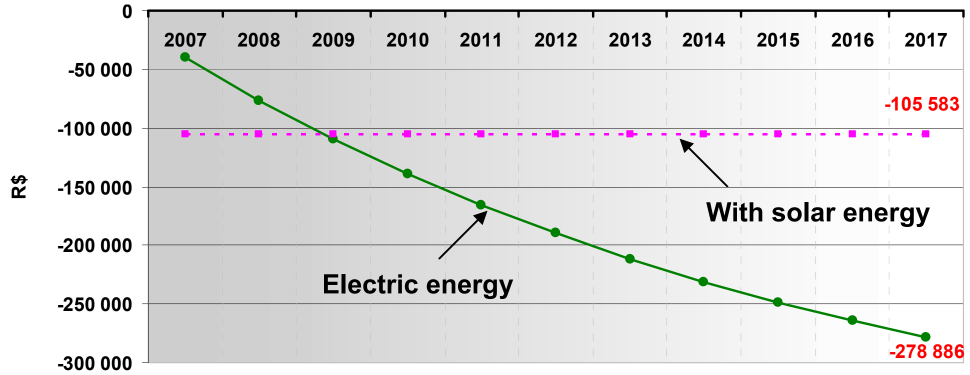

Figure 5. Comparison of cost evolution, with 100 % of solar energy.

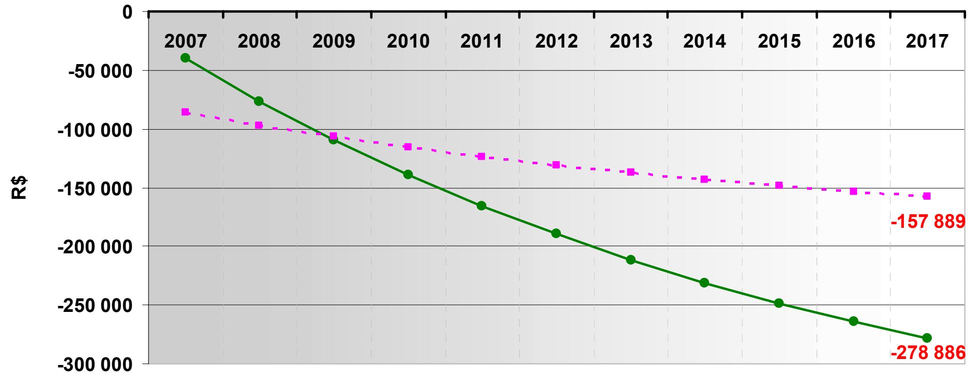

Figure 6. Comparison of cost evolution, with 70 % of solar energy.

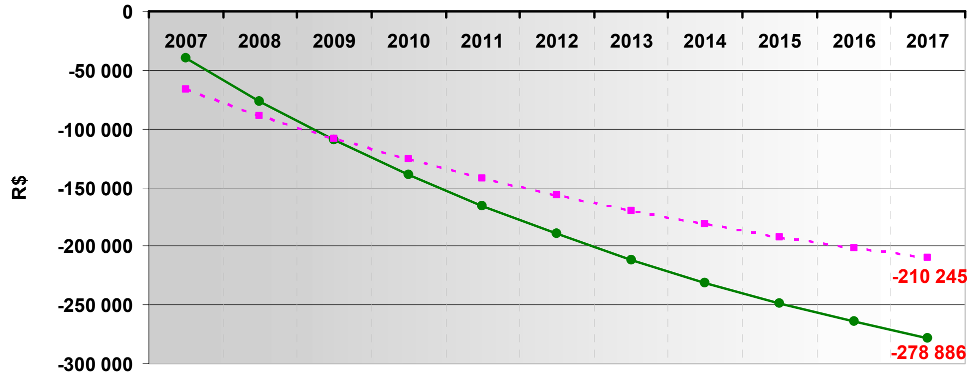

Figure 7. Comparison of cost evolution, with 40 % of solar energy.

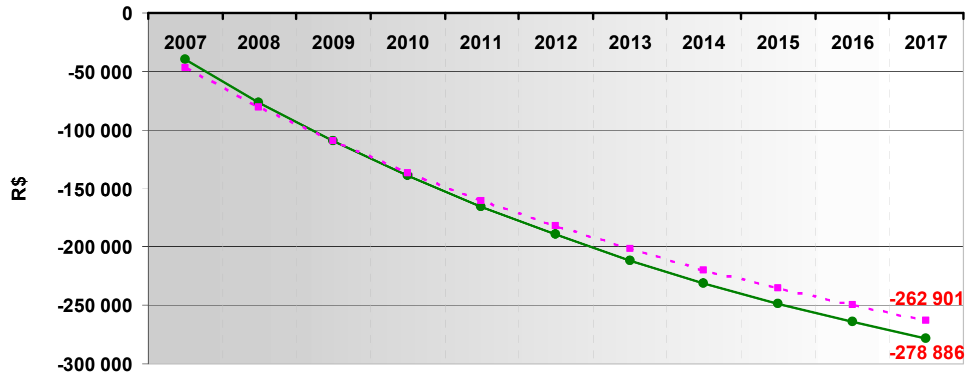

Figure 8. Comparison of cost evolution, with 10 % of solar energy.

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