FINANCIAL VIABILITY STUDY USING A HEAT PUMP AS AN ALTERNATIVE TO SUPPORT SOLAR COLLECTOR FOR WATER HEATING IN SOUTHEASTERN BRAZIL

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Abstract. *Along with related greenhouse effect environmental issues, constant problems changes in oil prices,make the use of solar energy an important renewable energy source. Brazil is a country which is privilege, considering the high rates of solar irradiation present throughout most of the entire national territory. Nevertheless, during certain times of the year, a solar energy deficit, leads solar systems to require electrical resistance support. The use of electrical resistance represents 23.5% of electric energy consumption and it presents a low residential energy efficiency. The purpose of this work is conducting a study of Brazilian States in the Southeast region regarding the financial viability of replacing a resistive system combined with the use of solar collector and a heat pump. One such heat pump has been designed, constructed and tested experimentally. The average performance coefficient is equal to 2.10, a low value due to the use of a hermetic reciprocating compressor. Despite this low-moderate price coefficient of acquisition and installation of a heat pump, a return on investment in from 2.1 to 2.7 years can be expected. Whereas the equipment has a useful life of about 20 years, this period of return on investment is interesting.*

Keywords. *alternate equipment, energy savings, heating water*

1. INTRODUCTION

Concern with the efficient use of energy is a subject that has motivated countries to invest in energy efficiency programs, highlighting the replacement of non-renewable sources with renewable sources. World energy consumption is made up of 87,1% of non-renewable energy sources, versus only 12.9% of renewable sources, according to the Key World Energy Statistics 2008-International Energy Agency cited by BEN national energy balance [1] (www.epe.gov.br). Figure 1 depicts the sources of energy used in world energy matrix and their respective shares in terms of percentage.

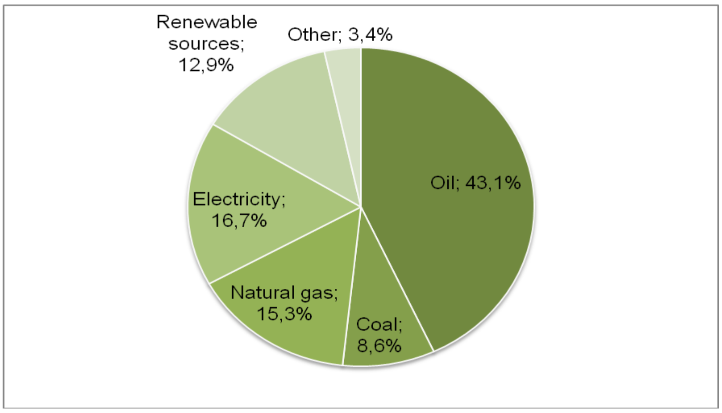


Figure 1: Final Consumption by Energy Source
Source: EIA International Energy Agency apud BEN [1]

Interest in this issue has become even stronger as of the drafting of the Kyoto Protocol [2], where the industrialised nations commited themselves to an average reduction of 5% of their greenhouse gas emissions for the period of 2008-2012, taking data raised in 1990 as reference.

The report by Procel evaluates energy efficiency market in Brazil, (2008) [3] and data obtained from the monthly review of the electrical energy market for due use of electric showers. As a way of reducing this electric energy consumption and contribute to the use of alternative sources of energy, solar energy for heating water in the home has been put to use. However, a restriction to the use of this system with water warming is the solar energy deficit over the year, i.e. the absence of sunny days over the years. This aspect warrants the use of solar collectors shared with water heating through electrical resistance on low incidence solar days.

The solar collector with electrical resistance for heating water may evolve into more technical, economical and ecological efficient systems, while presenting other options in addition to the use of electrical resistance.

2. PURPOSE

This article aims at presenting an alternative technical design for reduction of electric energy consumption through the use of a solar energy system along with a generating heat pump for water heaters in households in the capitals of the Southeast region of Brazil, as well as the financial feasibility study on the use of this system.

3. PROFILE OF RESIDENTIAL ELECTRIC ENERGY CONSUMPTION

According to the Procel report on the evaluation of an energy efficient market in Brazil (2008) [3], the energy consumption profile of Brazilian residences is shown in table 1.

Table 1: invoiced average consumption group, in kilowatt hours/month (kWh/month)

Consumer groups	Brazil	West Centre	Northeast	North	Southeast	South
Group 1	**59,24**	**57,06**	**54,99**	**54,34**	**64,10**	**62,42**
Group 2	**146,72**	**135,54**	**133,55**	**140,18**	**154,90**	**140,21**
Group 3	**235,58**	**242,04**	**240,40**	**242,88**	**233,71**	**235,82**
Group 4	**497,84**	**482,61**	**573,83**	**595,81**	**482,40**	**462,57**

Source: report on assessment of the energy efficiency market in Brazil [3]

The limits of each group are shown below making table 1 more comprehensible:
_Group 1: monthly average consumption between 0-100 kWh/month/residence.
_Group 2: monthly average consumption between 101-200 kWh/month/residence.
_Group 3: monthly average consumption between 201-300 kWh/month/residence.
_Group 4: monthly average consumption greater than 300 kWh/month/residence.

According Procel report on the evaluation of energy efficiency market in Brazil (2008) [3], approximately 65% of electric energy consumption in a residence is distributed as follows: electric showers (water heating), lamps (lighting), freezers, refrigerators and air conditioners (thermal conditioning). Figure 2 shows the average data electric energy consumption per residence in Brazil.

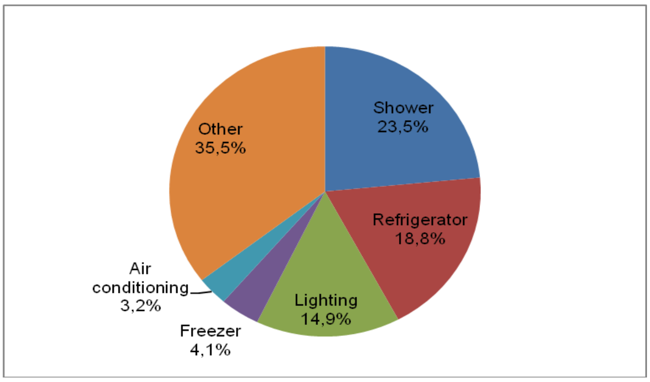


Figure 2: Sources Of Electrical Energy Consumption In Residence
Source: Evaluation Report on the energy efficiency market in Brazil 2008 and monthly review electrical energy market for June 2009. [4]

Since the focus of this project is water heating for home use, it was considered as the basis of the electric energy consumption related to water heating, specifically the electric shower. As shown in Procel report on the evaluation of energy efficiency market in Brazil (2008)[3], the energy consumption in the residential shower is presented in table 2.

Table 2: consumption and electric shower participation in each group

Consumer groups	Monthly Consumption	Participation in total consumption of groups
Group 1	24,91 (in kWh/month)	43,65 (%)
Group 2	31,36 (in kWh/month)	23,14 (%)
Group 3	40,28 (in kWh/month)	16,64 (%)
Group 4	30,67 (in kWh/month)	6,36 (%)

Source: Report on Assessment of the Energy Efficiency Market in Brazil.[3]

With reference to the monthly consumption of energy, the average number of persons and the average time the in the bathroom will determine the amount of heated water required. For example, the Southeast region, as shown in table 3, and later data, were used in the region of the country with the largest concentration of population.

Table 3: relationship between the average number of persons and the average time bath per month– southeastern Region

Consumer groups	Average number of people	Average Bath Time (h/month)
Group 1	2,67	15,01
Group 2	3,25	19,56
Group 3	3,29	20,58
Group 4	2,92	18,39

Source: Report on Assessment of the Energy Efficiency Market in Brazil.[3]

The annual consumption of residential electric energy, according to the Monthly Review Electrical Energy Market for June, 2010 – EPE (energy research firm – www.epe.gov.br) [4], is 104.040 TWh, and the consumption of the Southeast region is 55.745 TWh, representing 53.6% of the consumption throughout Brazil. Based on the assumption that 23.5% of the electric energy consumption of households comes from electric showers (Procel report on the assessment of the energy efficiency market in Brazil [3], 2008 and Monthly Review Electrical Energy Market for June 2009[4]), it is possible to calculate that the amount paid for water heating by means of electric showers in Southeast region is $ 3.63 billion (dollar quotation: $ 1.7657 – Brazilian Central Bank [5] source on 14/07/2010. Residential average KWh fare: $ 0.2772 – meeting regulatory source).

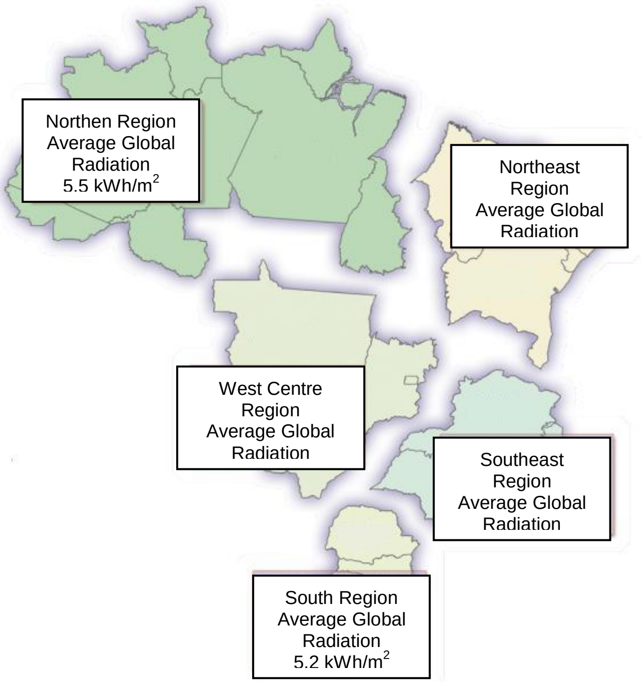


Figure 3: Distribution of the average global radiation by regions of the country
Source: Brazilian Atlas of Solar Energy (2006) [6]

The total amount paid by the Southeast region for water heating through electrical resistance is significant, and it shows the need to search for alternative sources and equipment that are technically, economically, and ecologically correct.

4. SOLAR RADIATION IN THE MAIN BRAZILIAN REGIONS

According to the Brazilian Solar Energy Atlas (2006) [6], developed through the Solar and Wind (SWERA energy resources Assessment) project in partnership between INPE (Instituto Nacional de Pesquisas Espaciais – www. inpe. br) and LABSOLAR (Solar energy Lab of the Universidade Federal de Santa Catarina – www. labsolar. ufsc. br), the overall average solar radiation by region is shown in Figure 3.

In Figure 3, the Brazilian region with the greatest concentration of solar radiation is the Northeast, while all Brazilian regions evince average higher figures (4200-6700 kWh/m²) than the majority of countries that use this technology as an alternative source of energy. It is posible to cite the example of Germany (900-1250 kWh/m2), France (900-1650 kWh/m2) and Spain (1200-1850 kWh/m²), according to data from the Brazilian Energy Atlas (2006) [6]. This information has great potential for exploiting this energy as an alternative source for Brazil.

For determination of the parameters of radiation INPE and LABSOLAR BRAZILSR computation model estimated the surface incident solar radiation from effective coverage data obtained through clouds of a geosynchronous satellite and transmission in the two extreme weather conditions: clear skies and cloudy skies.

Figure 3 shows the solar irradiation values of five Brazilian regions, where one sees that in terms of energy deficit caused by cloudy sky days, it is necessary to use an alternative system for additional heating to solar collector system for water heating.

5. SOLAR COLLECTOR AND HEAT PUMP SYSTEM

As shown in table 3, the average number of people per residence for groups 3 and 4, are 3.29 and 2.92 respectively. The study concentrated on groups 3 and 4 as a consumer profile with greater purchasing power, above 200 kWh/month.

Equipment scaling used average daily consumption of 60 litres water per person (as provided by the manufacturer of solar heating. Maxtemper – www.maxtemper.com.br [7]). By multiplying the average number of dwellers by water consumption per resident for Group 3, there was a daily consumption of 197,4 litres of water. And for Group 4, the value was 175.2 litres per day.

5.1 Boiler

Boilers most commercially used are, 200, 300 and 400 litres (Procel 2008 [3]) and the 300 litres boiler represents 70% of sales. For the purpose of this project, a 200 litres tank was used, because it most closely approximates the average consumption by residence calculated above. The average cost of a manufacturer-supplied boiler is MAXTEMPER [7] US$ 463.84.

5.2 Solar Collector

The flat solar collector card required has a 2 m^2 surface area, capable of generating energy 159.4 kWh/month (used as a reference the manufacturer MAXTEMPER [7], TOP brand: Max: 2000 MTH model). The cost of solar collector card is US$ 308.66.

5.3 Heat Pump

The costs of equipment employed in manufacturing a heat pump are presented in table 4.

Table 4 – BDC equipment cost.

Equipment	**Value (US$)**
Embraco FF12HBX Compressor	166.94
Capillary tube	2.83
MWP 610psig / 43bar Filter accumulator	6.80
.½ HP Evaporator	38.79
20mHP Electro-fan	15.15
Condensor	8.49
Other materials (insulating and other)	16.99
Total	**255.99**

Source: solar Maxtemper heating systems manufacturing data [7]

5.4 Total Cost of Solar Collector and Heat Pump System

Table 5 presents complete costs of product, detailing materials, labour and installation of the equipment.

Table 5- Solar Collector And Heat Pump Product Costs.

Material	**Cost (US$)**
Boiler	463.84
Solar Collector's Card	308.66
Labor	158.57
Materials for work	170.46
Subtotal	**1,101.53**

Cost of BDC	255.99
Grand total	**1,357.52**

Source: Maxtemper heating systems data of solar manufacturer [7]

Heat pump used in solar collector system – heat pump is similar to that designed, constructed and tested in the cooling laboratory of Universidade Federal de Minas Gerais – UFMG, presented partially KOURY (2007) [8].

6. HEAT PUMP PERFORMANCE DESIGNED

The prototype heat pump was assembled by the Maxtemper solar heating systems manufacturers, and after this, activity has been subjected to experimental tests plan in refrigeration in UFMG laboratory in accordance with the methodology proposed by Figliola (2007)[9].

Figure 4 presents the sketch of solar panel hot water and heat pump system reservoir, and Figure 5 shows the assembled overview heat pump system.

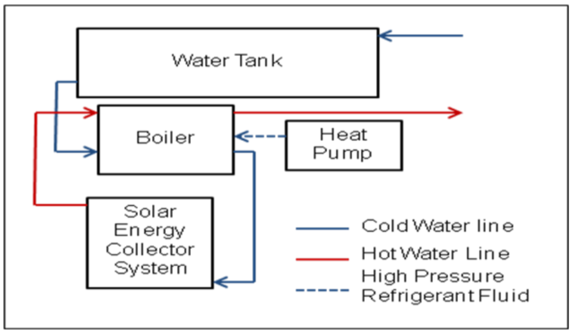


Figure 4 - Schematic solar panel system - boiler and heat pump.
Source: Project team refrigeration laboratory -UFMG

Figure 5: Overview of Heat Pump
Source: Silva, IC-refrigeration laboratory - UFMG [20]

One of the main issues of the test was to experimentally determine the coefficient of heat pump performance (COP). Five batteries were held, which generated test results data summarised in Figure 6, demonstrating the COP degradation over time.

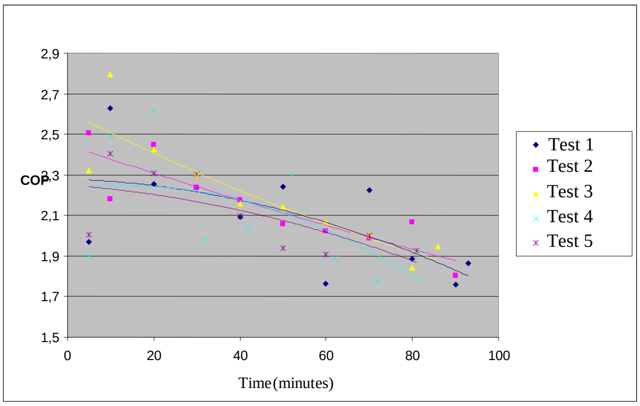


Figure 6 – COPr degradation
Source: Silva, IC - Refrigeration Laboratory UFMG

Using a Wattimeter, it was possible to measure the actual quantity of electric energy consumed by the process. Office starting and ending temperature of water during the tests; this made it possible to measure the energy consumed by the system. In this way, the COP was calculated by:

$$COP = \frac{m_a c_{pa} \left(T_{oa} - T_{fa} \right)}{q_e} \qquad (1)$$

Where q_e is power measured at Wattimeter, m_a is the mass of water heated, c_{pa} is the specific heat of water, T_{oa} is the initial temperature of the water, T_{fa} is the end water temperature.

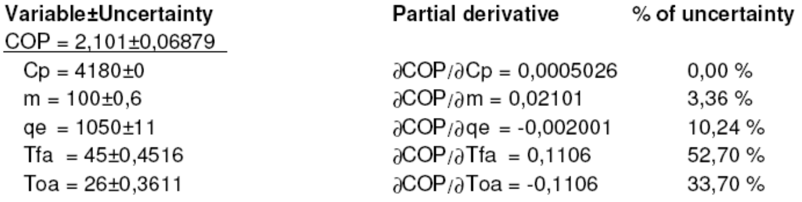
Table 6 shows the final COP for each heat pump test.

Table 6. Results of measurements.

Test	T_{oa}(°C)	Time (mim)	COP
1	26.2	92	2.079
2	26.1	90	2.126
3	26.5	85	2.161
4	27.9	83	2.071
5	27.6	82	2.079

Source: Silva, IC - Refrigeration Laboratory –UFMG [20]

The standard deviation also showed low (σ =) and used the average value of 2.10 as the value of the COP to heat pump. For the completion of the calculation of the COP, the following instruments and their associated uncertainties were used: a) Digital temperature sensor manufacturer Full Gauge [10], model TIC-17RGT, uncertainty 0.3°C - www. fullgauge.com.br. b) Digital power meter Kron[11], model manufacturer MKE-01, uncertainty 1%-www. kronweb.br. C) Thermocouple type K manufacturer ECIL[12], uncertainty of 0.75% - www.ecil.com.br. d) Graduated from the 2000 ml manufacturer Nalgon[13], uncertainty of 0.6% - www.nalgon.com.br. The values of uncertainties were provided by manufacturers. On the basis of information, EES Engineering Equation Solver [14] software was used to calculate the measurement COP uncertainty finding the value of ± 0.06879, as shown below.



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Variable±Uncertainty                 Partial derivative        % of uncertainty
COP = 2,101±0,06879
   Cp = 4180±0                       ∂COP/∂Cp = 0,0005026         0,00 %
   m = 100±0,6                       ∂COP/∂m = 0,02101            3,36 %
   qe  = 1050±11                     ∂COP/∂qe  = -0,002001        10,24 %
   Tfa  = 45±0,4516                  ∂COP/∂Tfa  = 0,1106          52,70 %
   Toa = 26±0,3611                   ∂COP/∂Toa = -0,1106          33,70 %
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7. DEMAND FOR ENERGY AND COSTS

To perform the calculations, determining how to reference the four capitals of southeastern Brazil was needed: São Paulo, capital of the State of São Paulo; Rio de Janeiro, capital of the State Rio de Janeiro; Belo Horizonte, capital of Minas Gerais; Vitoria capital of Espírito Santo.

Tables 8, 9, 10 and 11 present calculations performed for each of the four capitals of the Southestern Brazil. As databases for the preparation of the worksheet, three references were used. The first monthly average temperature and solar radiation was– horizontal average daily per month, based on Software database (RETscreen4 of 11/19/2008) version being chosen [15], drawn up by the Government of Canada in partnership with NASA, UNEP (United Nations Environment Programme, Global Environment Facility (PG). Solar and project (SWERA Wind energy resources Assessment). Second, the monthly average of daily sunshine was extracted from Atlas Solarimétrico of Brazil (2000) [16] – prepared by CRESESB (reference centre for wind and solar energy) and Sergio Brito UFPE (Federal University of Pernambuco). The third reference of electricity tariffs in $/kWh-national meeting regulatory – (ANEEL[17] accessed power on 07/15/2010).

The daily consumption of water (m) considered was 200 l serial temperature to be reached from 45°C (T_f). Knowing the specific heat of water (c_p) and its specific mass, through which it was possible to calculate the amount of energy required for heating water, according to the initial temperature of each city/region studied.

Tables 7 to 10, developed by the project team, present calculations for each of the four capitals of the Southestern Brazil.

Table 8 – Energy costs worksheet for the São Paulo

São Paulo-SP-Southeast Region

	Unit	Location of climatic data	Project location
Latitude	˚N	-19,8	-19,8
Longitude	˚E	-43,9	-43,9
Elevation	m	917	917

Month		Air temperature	Daily-horizontal solar radiation	Teperature of hot water	Energy to heat the water	Energy extracted by 2m^2 Solar collector	Difference between the demand and solar collector's ability	Cost for electrical resistance heating	Cost for solar collector heating with support eletrica resistance	Cost for solar collector heating with heat pump support
	Days month	°C	kWh/m²/d	°C	KWh/d	KWh/d	KWh/d	US$	US$	US$
January	31	22,5	4,28	45,0	5,19	4,96	-0,22	43,90	1,89	0,90
February	28	22,8	5,56	45,0	5,15	6,45	1,30	39,37	0,00	0,00
March	31	22,4	4,06	45,0	5,24	4,71	-0,53	44,37	4,52	2,15
April	30	21,3	4,28	45,0	5,50	4,96	-0,53	45,03	4,37	2,08
May	31	19,2	3,69	45,0	5,99	4,28	-1,71	50,65	14,43	6,87
June	30	17,7	3,72	45,0	6,33	4,32	-2,02	51,87	16,53	7,87
July	31	17,2	3,97	45,0	6,45	4,61	-1,84	54,58	15,61	7,43
August	31	18,9	4,36	45,0	6,06	5,06	-1,00	51,24	8,44	4,02
Septemb	30	20,5	4,69	45,0	5,68	5,44	-0,24	46,55	1,99	0,95
October	31	21,4	4,44	45,0	5,48	5,15	-0,32	46,33	2,75	1,31
Novembe	30	21,7	4,81	45,0	5,41	5,58	0,17	44,27	0,00	0,00
Decembe	31	21,9	4,33	45,0	5,36	5,02	-0,34	45,35	2,85	1,36
Annual		20,6	4,34					563,50	73,37	34,94

Value US$/kWh	0,27298
COP	2,10

Table 9 – Energy costs worksheet for the Rio de janeiro

Rio de janeiro-RJ-Southeast Region

	Unit	Location of climatic data	Project location
Latitude	˚N	-22,9	-22,9
Longitude	˚E	-43,2	-43,2
Elevation	m	0	0

Month		Air temperature	Daily-horizontal solar radiation	Teperature of hot water	Energy to heat the water	Energy extracted by 2m^2 Solar collector	Difference between the demand and solar collector's ability	Cost for electrical resistance heating	Cost for solar collector heating with support eletrica resistance	Cost for solar collector heating with heat pump support
	Days month	°C	kWh/m²/d	°C	KWh/d	KWh/d	KWh/d	US$	US$	US$
January	31	26,2	5,21	45,0	4,33	6,04	1,71	37,20	-14,67	-6,98
February	28	26,5	5,41	45,0	4,29	6,28	1,98	33,27	0,00	0,00
March	31	26,0	4,76	45,0	4,41	5,52	1,11	37,83	-9,56	-4,55
April	30	24,5	4,31	45,0	4,76	5,00	0,24	39,50	-2,02	-0,96
May	31	23,0	3,66	45,0	5,10	4,25	-0,86	43,80	7,37	3,51
June	30	21,5	3,65	45,0	5,45	4,23	-1,22	45,28	10,12	4,82
July	31	21,3	3,66	45,0	5,50	4,25	-1,25	47,19	10,75	5,12
August	31	21,8	4,32	45,0	5,38	5,01	-0,37	46,19	3,19	1,52
Septemb	30	21,8	4,18	45,0	5,38	4,85	-0,53	44,70	4,43	2,11
October	31	22,8	4,74	45,0	5,15	5,50	0,35	44,20	-2,99	-1,42
Novembe	30	24,2	4,97	45,0	4,83	5,77	0,94	40,08	0,00	0,00
Decembe	31	25,2	5,02	45,0	4,59	5,82	1,23	39,42	-10,55	-5,03
Annual		23,7	4,49					498,67	-3,93	-1,87

Value US$/kWh	0,27684
COP	2,10

Table 10 – Energy costs worksheet for Belo Horizonte

Belo Horizonte-MG-Southeast Region

	Unit	climatic data	Project location
Latitude	˚N	-19,8	-19,8
Longitude	˚E	-43,9	-43,9
Elevation	m	917	917

Month		Air temperature	Daily-horizontal solar radiation	Teperature of hot water	Energy to heat the water	Energy extracted by 2m² Solar collector	Difference between the demand and solar collector's ability	Cost for electrical resistance heating	Cost for solar collector heating with support eletrica resistance	Cost for solar collector heating with heat pump support
	Days month	°C	kWh/m²/d	°C	KWh/d	KWh/d	KWh/d	US$	US$	US$
January	31	22,5	4,28	45,0	5,19	4,96	-0,22	53,79	2,31	1,10
February	28	22,8	5,56	45,0	5,15	6,45	1,30	48,23	0,00	0,00
March	31	22,4	4,06	45,0	5,24	4,71	-0,53	54,36	5,53	2,63
April	30	21,3	4,28	45,0	5,50	4,96	-0,53	55,17	5,35	2,55
May	31	19,2	3,69	45,0	5,99	4,28	-1,71	62,06	17,68	8,42
June	30	17,7	3,72	45,0	6,33	4,32	-2,02	63,55	20,25	9,64
July	31	17,2	3,97	45,0	6,45	4,61	-1,84	66,87	19,12	9,11
August	31	18,9	4,36	45,0	6,06	5,06	-1,00	62,78	10,34	4,93
September	30	20,5	4,69	45,0	5,68	5,44	-0,24	57,03	2,44	1,16
October	31	21,4	4,44	45,0	5,48	5,15	-0,32	56,77	3,37	1,60
November	30	21,7	4,81	45,0	5,41	5,58	0,17	54,24	0,00	0,00
December	31	21,9	4,33	45,0	5,36	5,02	-0,34	55,57	3,49	1,66
Annual		20,6	4,34					690,42	89,90	42,81

Value US$/kWh	0,33446
COP	2,10

Table 11 – Energy costs worksheet for Vitoria

Vitória-ES-Southeast Region

	Unit	Location of climatic data	Project location
Latitude	˚N	-20,3	-20,3
Longitude	˚E	-40,3	-40,3
Elevation	m	4	4

Month		Air temperature	Daily-horizontal solar radiation	Teperature of hot water	Energy to heat the water	Energy extracted by 2m² Solar collector	Difference between the demand and solar collector's ability	Cost for electrical resistance heating	Cost for solar collector heating with support eletrica resistance	Cost for solar collector heating with heat pump support
	Days month	°C	kWh/m²/d	°C	KWh/d	KWh/d	KWh/d	US$	US$	US$
January	31	27,2	5,49	45,0	4,10	6,37	2,26	37,21	-20,53	-9,77
February	28	27,9	5,67	45,0	3,97	6,58	2,61	32,48	0,00	0,00
March	31	27,2	4,97	45,0	4,13	5,77	1,64	37,44	-14,83	-7,06
April	30	26,2	4,31	45,0	4,36	5,00	0,64	38,26	-5,60	-2,67
May	31	24,6	3,79	45,0	4,73	4,40	-0,34	42,91	3,05	1,45
June	30	23,1	3,69	45,0	5,08	4,28	-0,80	44,57	7,02	3,34
July	31	22,7	3,71	45,0	5,17	4,30	-0,87	46,90	7,89	3,76
August	31	22,7	4,16	45,0	5,17	4,83	-0,35	46,90	3,15	1,50
September	30	23,3	4,21	45,0	5,03	4,88	-0,15	44,17	1,32	0,63
October	31	24,3	4,60	45,0	4,80	5,34	0,53	43,54	-4,84	-2,30
November	30	25,2	4,75	45,0	4,59	5,51	0,92	40,30	0,00	0,00
December	31	26,1	4,85	45,0	4,38	5,63	1,24	39,75	-11,25	-5,36
Annual		25,0	4,5					494,43	-34,60	-16,48

Value US$/kWh	0,29244
COP	2,10

8. FINANCIAL VIABILITY OF THE SYSTEM USE

For each region the financial viability of the use of Solar collector and heat pump system was calculated using two tools, payback and IRR – internal rate of return.

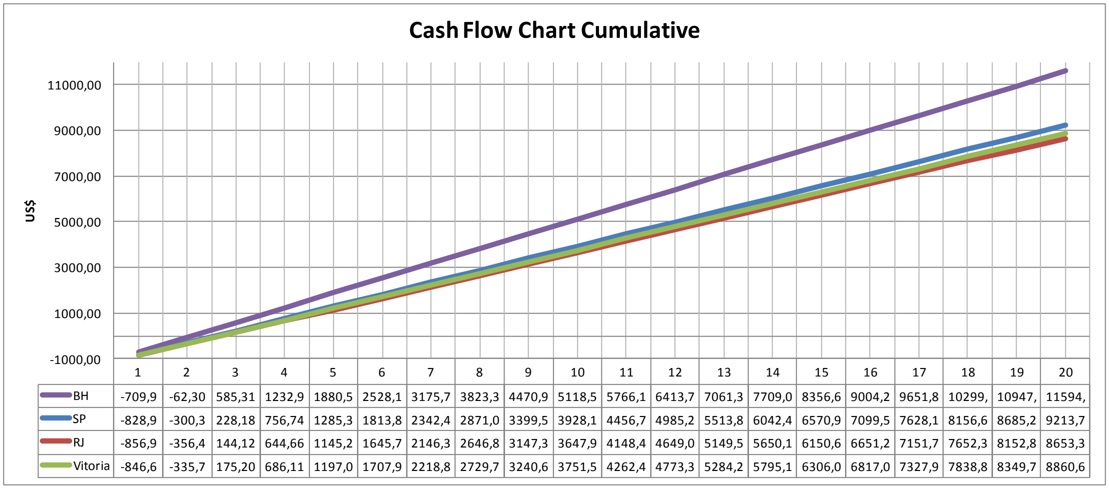
The payback was calculated as of the following formula: value of the investment / economy produced in a given period (year). The result is presented in years. (Ross, 2002)[18] The estimated period of production of the solar collector equipment is 20 years, according to the Brazilian Solar Energy Atlas (2006)[6]. As a project start, and due to lack of information on the duration of the life span of the combined system (solar Collector and heat pump) was used for the purposes of calculation of the period of 20 years, known value for the solar collector system.

The IRR – internal rate of return, as presented by Ross (2002)[18], “in general only trial and error procedure will work for initial output and three or more subsequent box entries. The calculators determine the IRR by trial and error.” To determine this calculation, a spreadsheet was used, thus facilitating the fixing of this value. For the purposes of calculation of the IRR, a return rate of 10% for year was used.

Table 12, developed by the project team, presents the results of the analysis of financial viability and cash flow for the four capitals of southeastern Brazil.

Table 12 – Financial Viability and Cash flow – Southeast Region

Financial Viability		São Paulo-SP	Rio de Janeiro-RJ	Belo Horizonte-MG	Vitoria-ES
IRR	%	39%	36%	48%	37%
Return on Equity	years	2,6	2,7	2,1	2,7



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
BH	-709,9	-62,30	585,31	1232,9	1880,5	2528,1	3175,7	3823,3	4470,9	5118,5	5766,1	6413,7	7061,3	7709,0	8356,6	9004,2	9651,8	10299,	10947,	11594,
SP	-828,9	-300,3	228,18	756,74	1285,3	1813,8	2342,4	2871,0	3399,5	3928,1	4456,7	4985,2	5513,8	6042,4	6570,9	7099,5	7628,1	8156,6	8685,2	9213,7
RJ	-856,9	-356,4	144,12	644,66	1145,2	1645,7	2146,3	2646,8	3147,3	3647,9	4148,4	4649,0	5149,5	5650,1	6150,6	6651,2	7151,7	7652,3	8152,8	8653,3
Vitoria	-846,6	-335,7	175,20	686,11	1197,0	1707,9	2218,8	2729,7	3240,6	3751,5	4262,4	4773,3	5284,2	5795,1	6306,0	6817,0	7327,9	7838,8	8349,7	8860,6

9. CONCLUSION

According to data presented in table 12, the water heating project - a combined system of solar collector and heat pump - proved to be financially viable for the cities of Sao Paulo, Rio de Janeiro, Belo Horizonte and Vitoria.

The project became financially viable in light of IRR (internal rate of return) which submitted values of 39% for the city of São Paulo, 36% for Rio de Janeiro, 48% for Belo Horizonte, and 37% for Vitoira. It should be noted that the higher the value for the IRR, the better the result of investment.

For the cities of Sao Paulo, Rio de Janeiro, Belo Horizonte and Vitoria, the use of solar collector system combined with heat pump, proved to be viable and had a return of 2.6; 2.7; 2.1; and 2.7 years respectively on equity investment. This variation was derived from the difference between the fares in three cities, as well as the need for water heating calories. The city of Sao Paulo, for example, presented a higher demand for energy in light of the monthly average temperatures below of the other cities. However, the electrical energy price is less in the city of Belo Horizonte.

As an initial design, the values of the equipment and materials used to scale manufacturing costs reflected the retail trade values (refrigeration parts stores). When this system combined (solar Collector and heat pump) is marketed on an industrial scale, they tend to reduce costs by reducing the turnaround time on invested capital, thus becoming even more attractive to consumers.

In this project, equipment and materials for low-cost and low efficiency were therefore used. The heat pump is highlighted, because it is the most important equipment which contributes to project efficiency. The system introduced a low thermal performance (COP of 2.10) and to improve this relationship, the use of a high performance heat pump is recommended, albeit more expensive; the increase in the cost of the project would bring a greater benefit for the system. It is estimated that this benefit becomes even more evident for industrial projects or residential/commercial buildings.

Keeping the same conditions of low project cost of, you can improve thermal efficiency using a static evaporator instead of a conventional evaporator. Some heat pump prototypes with static evaporator were developed in the UFMG cooling laboratory, as cited by Koury (2008)[19].

10. ACKNOWLEDGEMENTS

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12. RESPONSIBILITY NOTICE

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