WATER HEATING FOR DOMESTIC USE IN SMALL FAMILY RESIDENCES: DEVELOPMENT OF A COMPACT HEAT PUMP.

Daniel Elpídio Marinho, danielmarin@ig.com.br
Bernardo de Almeida Freitas, bernardoaf_puc@yahoo.com.au
Grupo de Estudos em Energia – Pontifícia Universidade Católica de Minas Gerais – Avenida Dom José Gaspar, 500 – Coração Eucarístico – CEP.: 30.535-901 – Belo Horizonte – Minas Gerais – Brasil

Daniela Pereira Dias, daniela.dias@green.pucminas.br
Grupo de Estudos em Energia – Pontifícia Universidade Católica de Minas Gerais – Avenida Dom José Gaspar, 500 – Coração Eucarístico – CEP.: 30.535-901 – Belo Horizonte – Minas Gerais – Brasil

Fabiano Lara de Paula, enalter@enalter.com.br
Enalter Engenharia Indrustria e Comercio Ltda – Rua.Lúcio Bertoldo 144 – Bairro Vila Odete – Nova Lima – Minas Gerais – Brasil

Elizabeth Marques Duarte Pereira, green@pucminas.br
Grupo de Estudos em Energia – Pontifícia Universidade Católica de Minas Gerais – Avenida Dom José Gaspar, 500 – Coração Eucarístico – CEP.: 30.535-901 – Belo Horizonte – Minas Gerais – Brasil

Abstract. *The purpose of this project research was to develop and to evalue small sized heat pump, although, in Brazil, the heat pump is often used to heat great amount of water. Therefore, the challenge of this project is to evaluate the small sized prototypes, designated to attend a family, four people. So, three machines has been the developed and tested. The test was designed and built one experimental bench in conformity with the brazilian standard MB-1306. The results of coefficient of performance, COP, for the final prototype have been considered very satisfatory: it was reached values between 4.7 to 2.5 for the temperature of the water in the entrace of condenser was 293.15 K (20º C) and 323.15 K (50º C), respectively. Based on the economic studies for consume and tipical tax for the A, B and C social classes, the conclusion achieved was that the application of the heat pump for A class is the best option for using this system. However, to make come true in a massive use, it is necessary the reduction of initial price of the product, derivative of market scale factor and/or policy of incentive to be implanted by the Government.*

Keywords*: Efficacy Energy, Heat Pump, Coefficient of Performance*

1. INTRODUCTION

The objective of the research project was to develop and to evaluate heat pump of small size, seeking to promote the energy efficacy of the heating of water in the residential section. Now in the country, electric and heating showers are used to gas, with thermal efficiency of the order of 92% and 80%, respectively. However, in heat pump each 1kW consumed in the electric power form arrives to generate about 4 kW (of thermal energy) for heating of water. Like this, it is verified, a priori, the important technical viability of such equipment.

Therefore, the challenge of this project lives in the development and evaluation of prototypes of small load, destined to assist a single family residential. The energy residential market differ a lot of the other segments, due to its user's heterogeneity and also the purpose of its use. The electric energy consumption is related with the geographical location, with the culture of each area and with the purchasing power.

It has been developed three heat pump equipments, among then two were installed in small family residences and the third were destined to the test in the laboratory GREEN, Group of Study in Energy. For detailed its evaluation was projected and mounted an experimental bench in service to the MB-1306 standard.

The heat pump was developed in 1940's that used geothermal source to heat or cool small buildings. Now a days, in Brazil, the heat pump is used to heat a great amount of water (e.g. hotel, swimming pools, industrial process, central heating of buildings and so on) and some times is used as refrigeration system. In operation, the evaporator absorbs whatever heat energy is available to it from the atmosphere (air) to vaporize the refrigerant. The compression of the fluid causes a pressure and a temperature elevation. This superheated vapour is passed through special pipes which is located outside of the water storage tank, forming the condenser. As the refrigerant vapour it is then condenses, that transmit its heat to the stored water. As this happens, the fluid condensed raisin for the expansion valve, where it is vaporized, flows in the evaporator, after this the cycle is repeated.

2. IMPORTANCE OF THE WORK

Due to the rationing of electricity caused by the reduction of the energy generation in hydroelectric plants, it increased the use and the development of none conventional technologies. The water heating for domestic use is necessary in practically all social layers, which is use for bath, at the most cases. The use of the heat pump makes possible the substitution of electric and instantaneous heating gas showers. This last one is highly spread in the state and in the city of Rio de Janeiro.

The energy company had interest in the use of the heat pump in residences that was seeking the efficacy of the water heating process in substitution to the gas heater. The goal of the project is to move the electric power consumption, obtaining a consumption profile out of the time peak demand of energy. Therefore, the implementation of the heat pump is going to make possible positive results, because it will reduce the electric energy consumption that is used to heat residential water, turning a more homogeneous distribution and it not cause an overload in the generation system and at the electric power transmission.

3. EXPERIMENTAL METHODOLOGY

The experimental method adopted seeks to evaluate the thermal performance of the water heating system (compact heat pump) at laboratory based on the MB-1306 standard. The used technical standard proposed two experimental methods; the first method evaluates the air cooling capacity based on the heat transfer between the air and the refrigerant fluid, which happens in the evaporator. In this case, the test needs to be done in an acclimatized atmosphere. The second method evaluates the air cooling capacity from the heat transfer between the water and the refrigerant fluid in the condenser.

3.1. Experimental procedure

The procedure adopted to evaluate the system that composes the workbench consists in the second method. Which was the method of the external coil of water that seek to measure the capacity of cooling of the air starting from the heat transfer between the water and the refrigerant fluid in the heat pump condenser. The total heating capacity (q_a) is determinate from measurements of the water temperature variations between the exit and the entrance in the condenser (T_{as} and T_{ae}), the specific heat at constant pressure (c_{pa}) and its mass flow (m_a), described in “eq. (1)”.

$$q_a = m_a\, c_{pa} \left(T_{as} - T_{ae}\right) \tag{1}$$

Through the relationship among the total heating capacity of the water and the cooling power of the compressor (P_t) it is possible to determine the coefficient of performance (COP) of the heat pump, “eq. (2)”.

$$COP = \frac{q_a}{P_t} \tag{2}$$

3.2. Principle Operation

The principle operation of the equipment is based on the vapor refrigeration cycle and it is characterized by high coefficients of performance (COP). The schematic drawing of the equipments and thermal accessories can be seen at “Fig. 1” and at “Fig. 2”. The heat pump operation system involves energy flows where heat is transferred from a cold to a hot area, that is why is necessary the job of the electric power for turning on the compressor. This way, the gain of thermal energy that is transferred to the system happens through two energy sources, regarding cold source and the electric power gains.

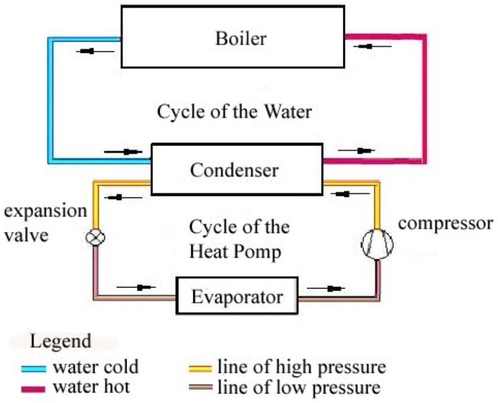

Figure 1. Sketch of the equipments and of the test bench at laboratory GREEN.

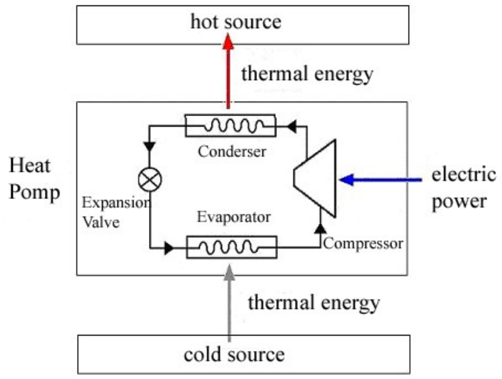

Figure 2. Diagram regarding the system principle operation.

4. EXPERIMENTAL TESTS

During the tests to determine the coefficient of performance, the heat pump equipment was submitted to technical modifications, promoting the improvement of the final product. In this way, the subsequent prototypes were tested in function of the operational and climatic conditions, which were evaluated the pertinent parameters to the test method adopted.

During the project, it was realized two stages in the heat pump tests. The first stage was evaluated the COP of the heat pump, in order to determine the best prototype to be produced. After defined the final prototype and their operation characteristic, the second stage of test was elaborated to determine the water heating capacity of the water heating system in function of the hot water daily consumption. In this way, it was found the relationship of the total number of baths capable of being offered by the heat pump during the period of one day.

4.1 Determination of the Coefficient of Performance

The tests involved the circulation of water between heat pump and thermal reservoir. The test’s duration were determined by the time that was necessary to heat all the water inside the thermal reservoir from the temperature 20°C to 50°C, which the average duration of the test was around 4 hours.

The monitoring system used an acquisition board to obtain the experimental data in specific and effective software. Among the parameters collected for tests evaluation can stand out the following parameters: entrance and exit water temperatures in the heat pump, volumetric flow of water in the heat pump, climatic conditions (room temperature and relative humidity), electric current and average power of the compressor and of the heat pump. The collection of data was stipulated through the standard, which was accomplished in intervals of five minutes.

The analysis of the obtained data was accomplished in the program CATT (Computer Aided Thermodynamic Tables), destined to the evaluation of the thermodynamic characteristics of the fluid refrigerant Freon R-22, used in the cycle of cooling of the heat pump. In this way, through the monitored parameters it was possible to determine the characteristics of the fluid refrigerant, obtaining a technical report of the operation of the following involved equipments: compressor, evaporator, expansion valve and condenser. In “Figure 3”, it shows the interface and the pertinent data used in the program CATT.

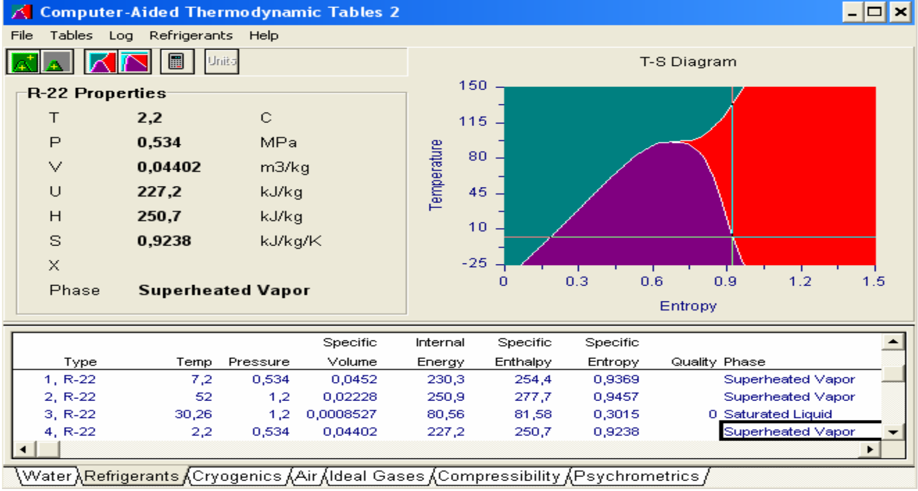

Figure 3 - Interface of the CATT program with the user.

The results of the prototype of the heat pump coefficient of performance (COP) were considered quite satisfactory, reaching values between 4.7 to 2.5 for temperatures of the entrance water (T_{ae}) in the condenser of 293.15 K (20º C) and 323.15 K (50º C), respectively, and with 3.5 of mean COP. The results can be seeing in the graph of "Fig. 4".

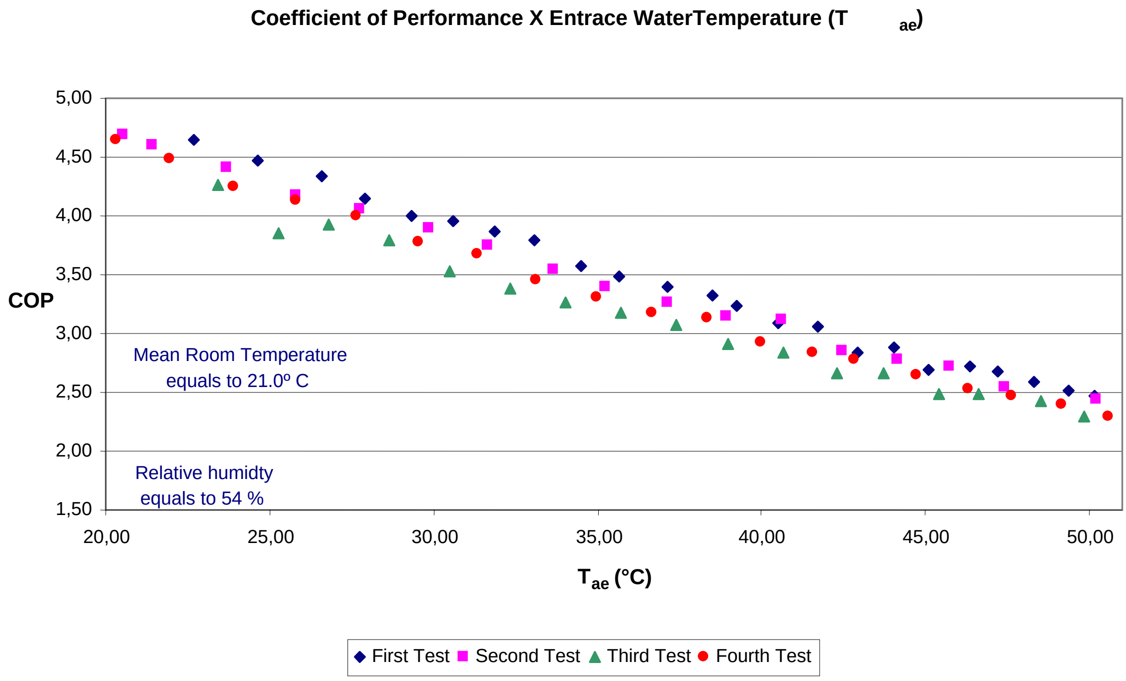

Figure 4. Representative Curves of the thermal acting of the final prototype of the Compact Heat pump in function of the feeding temperature.

4.2 Daily consumption of hot water

The tests have the purpose of evaluating at laboratory the capacity of the system to heat water in order to determine the number of baths capable of be accomplished during the period of one day. Starting from a previous study of the heat pump tests, it determined the parameters that influence in the control and in the simulation of the baths. The control parameters were appraised in way to characterize the temperature of the consumption water that is the comfortable temperature for a bath. The test consists in simulated a small family residence of social class C, which posses the 4 residents. These data were based on a typical small family of the southeast of Brazil, it is related through PNB-128 standard. The workbench can be seen in "Fig. 5" and "Fig 6".

The test constitutes to realize in one day five bath simulations with duration 10 minutes, each one. It was defined that the experimental data would be collected in the interval of 2 minutes, being obtained the consumption temperatures, entrance and exit temperatures of the heat pump and the flow of bath water. Also the parameters were analyzed regarding the climatic conditions (room temperature and relative humidity of the air) and of the consumption of electric power of the heat pump compressor. To reach the wanted temperature of the water for consumption, among 39°C to 41°C, a mix of water was used, obtaining a mixture of hot water and cold water that it results in the flow of 70 litres per minute, being accomplished the mixture at the room atmosphere (around 10 meters of water or 100 kPa). The daily demand of simulated hot water is same to 60 liters of hot water per person and the capacity of the thermal reservoir is 200 liters.

Figure 5. General vision of the test room in the laboratory GREEN.

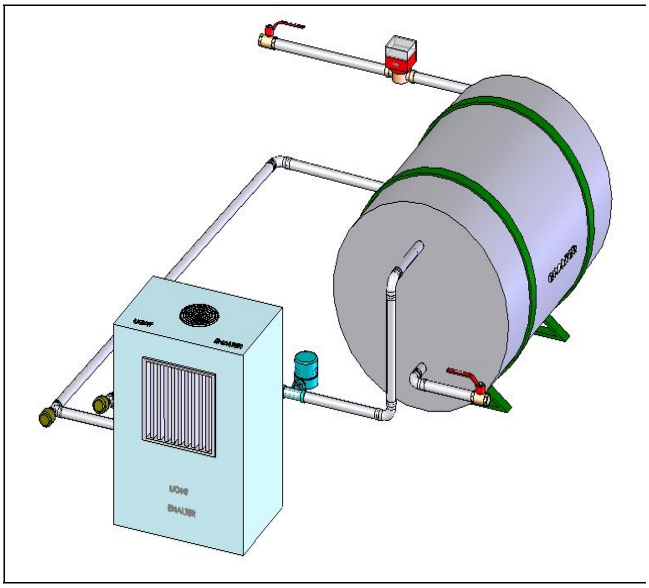

Figure 6. Draw of the equipments realized in the program Solid Works.

The results of referring tests above capacity of the consumption of water of the equipment of the heat pump are represented in Tab. 1. It can be noticed through the relationship of the daily electric power consumption, through the operation of the heat pump, the total number of available baths. This way the equipment is shown favorable tends the capacity to assist the consumption of 210 liters of hot water a day.

Table 1 -Relationship between the rehearsals and consumption of energy of the accomplished baths.

Number of Baths	**Timetable of baths**					**Daily consumption of electric power(1)**	**COP**	**Time of operation(2)**
5	**10:21**	**11:22**	**14:17**	**16:32**	**18:09**	**3.076**	**3.28**	**04:21**
4	**15:18**	**15:52**	**16:37**	**18:13**	**_**	**1.999**	**3.48**	**02:45**
5	**12:09**	**12:56**	**15:12**	**16:12**	**17:27**	**3.267**	**3.39**	**04:44**
4	**15:46**	**16:09**	**18:16**	**18:40**	**_**	**2.555**	**3.25**	**04:26**
5	**11:53**	**13:48**	**19:10**	**20:45**	**21:12**	**2.461**	**3.06**	**02:36**
5	**15:33**	**15:53**	**20:34**	**20:55**	**21:55**	**3.411**	**3.72**	**04:20**

(1): kWh
(2): Total time operation during one day of test

5. EQUIPMENTS USED IN THE TETS

All the materials used for the assembly of the test bench in the laboratory, the system monitoring was specified on MB-1306 standard. Among the used equipments it can be described: the platinum thermo-resistance PT-100 (4 wires) destined to measure the temperatures of the water; a turbine water flow meter (model FTB-104); pressure gauge (GITTA), to obtain the discharge pressure and pressure of drop of the system of the cycle of cooling; thermocouples (K type), Cromel-Alumel(Cr-Al), destined to measure to temperatures of the refrigerant Freon R-22; sensor of relative humidity (OMEGA ENGINEERING); oscilloscope (FLUKE), to monitor the tension level and current of the electric system; plate of data acquisition, (OMEGA ENGINEERING) and software WORKBENCH PC FOR WINDOWS, with the purpose of data acquisition.

6. ECONOMICAL VIABILITY

With purpose to realize the proportionate economical viability in the installation of residential hot water system, it developed a comparative simulations among two technologies: heat pump and instantaneous heating gas. The comparison was accomplished inside of a projection of costs in 10 year period, which understands the useful life of a heat pump.

The economical analysis was developed being considered the monthly energy demand relative to the daily consumption of 120, 90, 60 liters of hot water per person, relative to the comfort levels and habits attributed to the three social classes, denominated A, B and C, respectively. The electric energy tariff used was of R$ 0.43 for kWh and the price of GLP was same to R$ 2.84 for kilogram (kg).

6.1. Definition of the study parameters for analysis of economical viability

Comparative simulations were developed among the two technologies: heat pump and instantaneous gas heater, which had the purposed to realize the proportionate economical viability in the installation of residential hot water. Inside the related parameters for it analyzes her financial it could stand out:

- Temperature and relative humidity of the air;
- COP of the heat pump;
- Efficiency of gas heater;
- Power of the compressor of the heat pump;
- Power of the burner of the gas heater;
- Cost of the installation equipments and maintenance of the system of heating of the heat pump and instantaneous gas heaters;
- Electric power tax and price of the kilogram of the gas, applied to the residential section;
- Financial taxes of market and financing interests.

6.2. Analysis of the economical viability

The heat pump system cost is considerably high in comparison with the passage gas heater, mainly due a thermal reservoir, which accumulated hot water. The initial value of investment in the purchase and installation of heating of water equipment is the decisive element in the choice of the system to be implanted in residences of the B and C classes. This way, the heat pump represents a longer pay back investment than observed it in the installation with to instantaneous gas heater. However, the significant decreasing pay back was verified in function of increase the demand of hot water in a residence, which is this proportional the families social class. The pay back for the A class equivalent the more than 4 years that is more attractive, when compared with the B class, where it is around 5 years and 10 months. Consequently, the C class does not present positive results when adopting heat pump to heat up the water of the residence, presented the pay back more than 10 years. Analyze of data is in the graphs of “Fig. 7”, “Fig. 8” and “Fig. 9”.

However, the significant decrease of pay back is verified since they grow up current incentives of political market and/or incentive implemented by the electric power dealership.

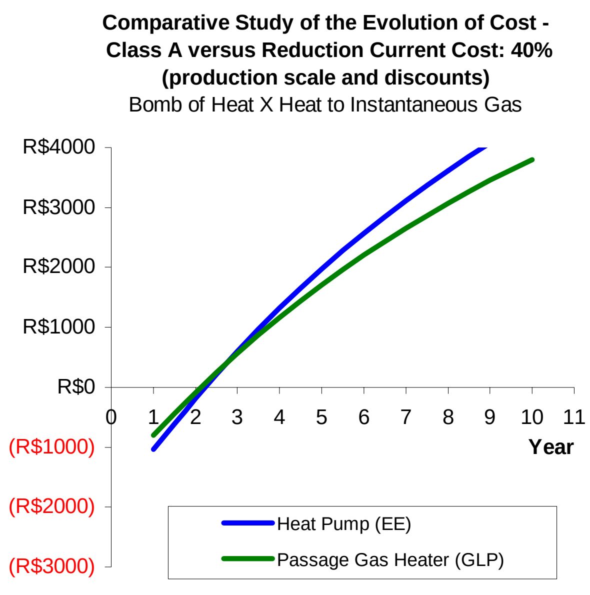

Figure 7. Comparative Study for Evolution - A Class

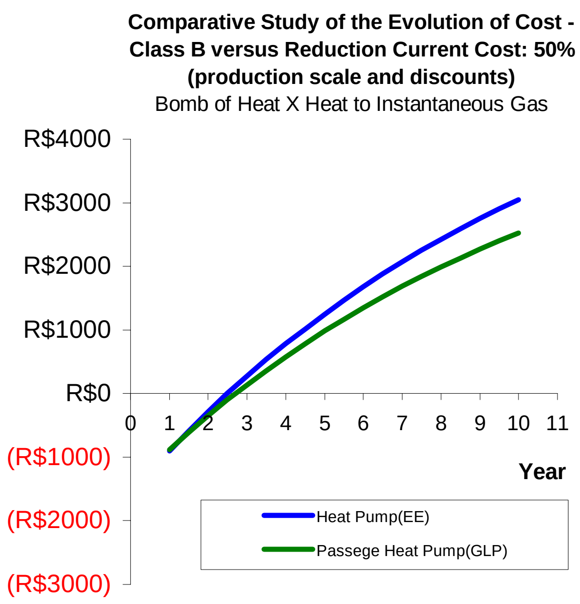

Figure 8. Study Comparative for Evolution - B Class

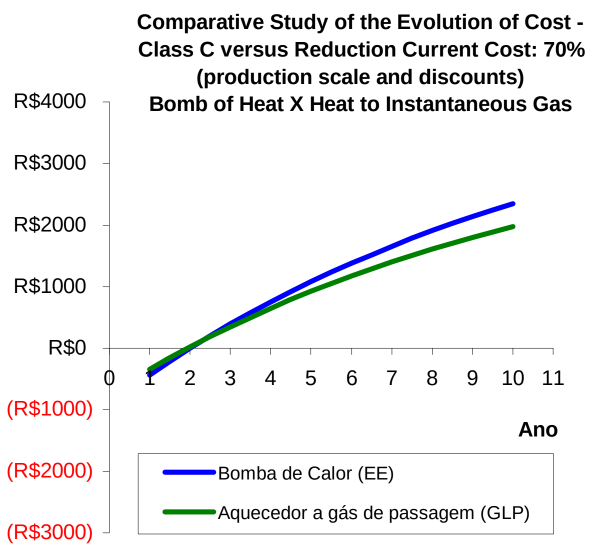

Figure 9. Comparative Study for Evolution of Costs - Class C

Before that, it was evaluated factors of reduction of 40, 50 and 70% for the A, B and C classes, respectively. Such results are evidenced in "Tab. 2". A larger attention should be to C class that presents the smallest consumption of hot water per person, around 60 liters a day. In this case, the reduction in the initial cost of the heat pump for the consumer should be of, at least, 70%. The pay back is reduced to 2 years with the aid of that incentive, the result of gas system overcome by the heat pump in 2 years and 3 months.

Table 2. Analyze of the economical viability of implementation of the bomb of the heat.

Social Class	Incentive	Pay Back[1]	Pay Back[2]	Time heat pump exceed gas heater
A Classe	Null	51 months	26 months	no
	30%	33 months	26 months	72 months
	40%	27 months	26 months	34 months
B Classe	Null	70 months	38 months	no
	30%	54 months	51 months	72 months
	40%	45 months	51 months	33 months
	50%	36 months	51 months	12 months
C Classe	Null	> 10 years	24 months	no
	60%	34 months	24 months	114 months
	70%	24 months	24 months	27 months

[1]: Heat pump
[2]: Gas Heater

5. CONCLUSION

The project demonstrate that the last prototype of the compact heat pump developed had excellent results, which presented a 3.5 mean COP. The COP found of project was superior then esteemed: being equals 2.0.

Through the economical viability study developed was verified that the heat pump possesses a social economical cost smaller than the residential instantaneous gas heater. A positive expectation is possible in search of its sustainable and implementation of the technology of heat pump in the residential section, since they grow up current incentives of market scale factor or through politics of incentives implemented by the electric power dealership. Another favorable factor to the development of the prototype of the heat pump is the economical situation of the residential section and the incentive to the elevation of the levels of energy efficiency in Brazil.

The heat pump developed is characterized by being portable equipment of easy installation and of small load. This way, there was developed a prototype’s installation manual that facilitating its diffusion in the market.

As the benefits obtained in this research project, three prototypes of heat pump were installed in residences of the metropolitan area of Belo Horizonte and another was dedicated to swimming pool water heating, in the laboratory GREEN. In such a way to allow the attendance and monitoring the system of long period of time, which results a comparative data of the reduction of the electric power consumption and the consumer's behavior regarding the new product.

6. ACKNOWLEDGEMENTS

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