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Economic assessment of two water heating systems using a simulation model on @RiskTM and their connection with the "gasolinazo" event in México

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Abstract. The objective is to analyze the economic feasibility under risk conditions of a water solar heating system. Based on economic and environmental data collected in 2014 and 2015 in Hidalgo State (Mexico), two different ways for heating water for domestic use were compared in the region considering the annual cost criteria. The first scenario (deterministic) analyzes a traditional heating system based on LP gas, while the second scenario considers a solar heating system coupled with an LP gas system, this one to be used as an alternative when there is not enough solar radiation. Both scenarios considerate the investment, operation and maintenance costs, however, the second scenario, which is studied by means of a simulation model constructed in @RiskTM, considers the annual days variability with low solar radiation. For a low level hot water demand (2 people), the results showed that the expected value of the annual cost, of the solar system was lower, up to an annual average of 220 days with low solar radiation. Also, for a high demand level of hot water (8 people), the annual average cost of the solar system was lower, even though, the average days with low solar radiation were approximately 300. As it is known, in the geographical area where the Hidalgo State is located, the average days with low solar radiation ranges from 30 to 40 annually. Therefore, the results show a considerable annually average saving of $ 2,000.00 and $ 10,000.00 MXP, for a low and high demand level respectively.

Keywords: Monte Carlo Simulation, Water Heaters, Economic Evaluation, @RiskTM

1. Introduction

In Mexico there are several types of solar heaters but the most commonly used is the one of vacuum tubes, this is reason why in this work it is taken as a base of comparison. In general, the feasibility for the installation of a solar heater depends on the technical parameters of design but also the economic ones. We must take into account the following technical parameters: daily consumption of hot water, orientation and angle of the collectors, geographical location, available area for its installation, types of sensors, solar tracking system, required final water temperature, and the temperature variability of incoming water. One of main components of the vacuum tubes solar heater are the glass tubes, the interior of which have a copper tube through which water passes, the second main component is the water storage tank. Based on the size of the tubes and the design, these heaters can reach temperatures between 50 ° and 190 ° C. The advantage of this type of heater relies in the long tubes of glass. Besides the geometrical shape of the tubes which can absorb the maximum solar energy from several directions, the internal design avoids any dispersion of heat towards the outside. Paradoxically the main disadvantage also relies on these, since they are fragile and their life time is smaller than for example solar flat plate collectors.

For economic feasibility studies, several methodologies have been reported such as the one discussed in [1] where the economic analysis is done comparing a solar heater prototype and a photovoltaic heater using the annualized value method. A mathematical model is used to compare the cost of heating water by solar and electric energy, as well as the social and economic possibilities (viability). It is also demonstrated that in the medium term (5 years), the solar heater is economically superior to a photovoltaic heater.

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Another way to determine the economic feasibility is by using the Payback Period and the Net Present Value (NPV) in terms of saving costs in electricity and gas consumption, as well as design parameters such as energy requirements for water heating, the performance of each type collector, which is useful when analyzing more than two heaters [2]. [3] used the annualized cost method, as well as the sensitivity analysis of the parameters; considering operating costs, maintenance costs, salvage value, and annual fuel costs, to evaluate two water heating systems in Jordan. It is also possible to use tailor-made software, both for numerical calculations of energy efficiencies and to perform simulations under different economic scenarios, making it possible to carry out comparative evaluation in the very long term and for several particular geographical regions [4]. When the hot water flow requirements are higher, such as medium-sized industrial and service facilities, [5], evaluates economically and technically the case of hospital centers in Algeria. Heating and hot water supply systems using air-to-water heat pumps in Romania have been evaluated thermo-economically with an acceptable coefficient of performance, but are economically worse than other heating systems, mainly due to the high initial investment [6].

2. Materials and Methods

In the elaboration of this simulation study we follow the methodology proposed by Law [7], Kelton et. al [8] and Rossetti [9], and it is described in the following sections. The model can be classified as Monte Carlo type simulation since we imitate the behavior of random variables present in the phenomenon of study.

2.1 Problem Definition

The recent increases in the price of both LP gas and gasoline in Mexico in 2017 promote the consumption of these fuels in a more rational manner. This is a good opportunity to use alternative energies like the solar. The use of hot water in Mexican homes is mainly intended for baths, washing clothes and kitchen items. To heat water we have the option to use a boiler that uses LP gas or electricity exclusively, or a coupled system of a boiler that uses LP gas or electricity with a device that uses solar energy. The use of solar water heaters is not a common practice in Mexico, partly because of the low diffusion of its benefits and also because of the relatively high initial investment involved in its purchase. Therefore, this study aims to determine the system with better economic performance to heat domestic water in Mexico, among the above mentioned alternatives.

2.2 Information gathering

Hidalgo State has the following climate: 39% is dry and semi-dry, 33% warm sub-humid, 16% hot humid, 6% warm sub-humid and the remaining 6% hot sub-humid, the latter occurs in the Huasteca zone. The average annual temperature is 16 ° C. The minimum temperature of the coldest month, January, is about 4 ° C and the maximum temperature occurs in April and May, which is 27 ° C on average. From June to September, the average state rainfall is 800 mm per year. (See Fig. 1).

According to climatological recordings and empirical information, it is supposed that in the Hidalgo State there is approximately one month without sufficient solar radiation to heat the water by means of the solar heater system, having this in mind, and with the purpose to model this random variable, we proposed a uniform distribution between 20 and 40 days, which is valid when the available information is not enough for the research [7], [9].

The investment costs of solar heater systems depend of many factors; however, the typical case is shown in the Figure 2. The linear regression equation was used in the simulation model inputs to calculate the costs in function of the members in the household.

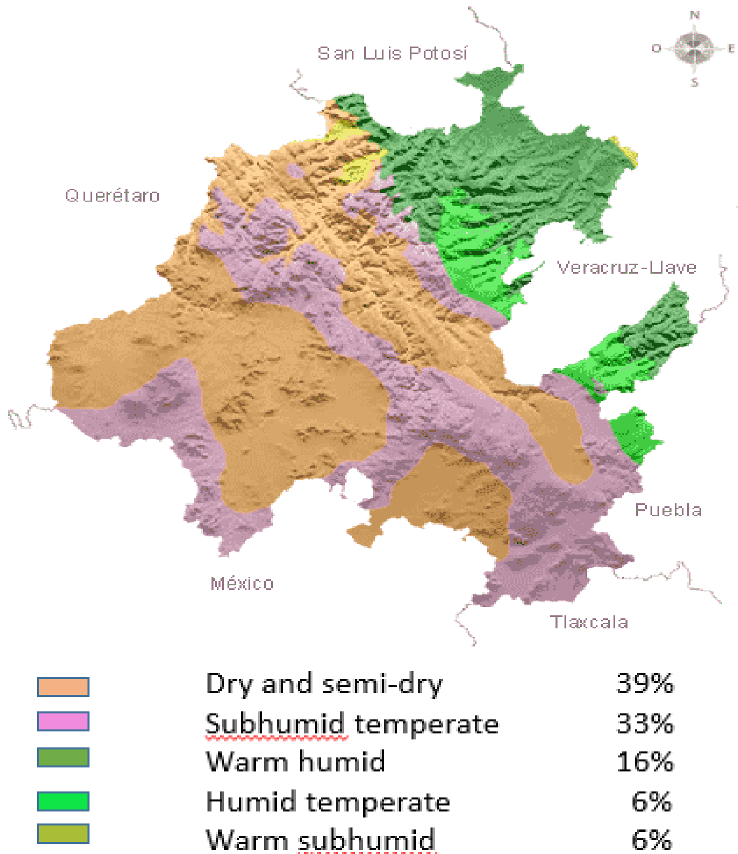

Fig. 1. Hidalgo State climate (INEGI, 2015).

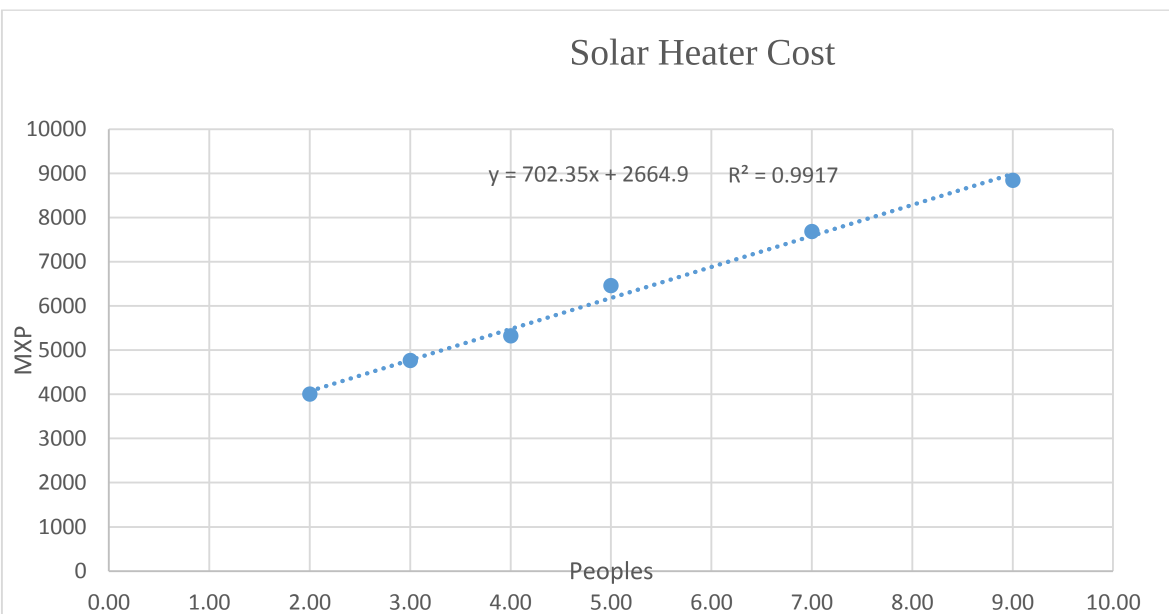

Fig 2. Solar heaters costs according to their capacity

2.3 Development of the conceptual model

The tool used to understand and then transfer the real situation to a simulation model was a variation of the influence diagrams [10], [11]. Fig. 3 shows the conceptual model developed with Palisade's BigPictureTM software [12]. Each of these factors is involved in the mathematical model to be developed in the next section.

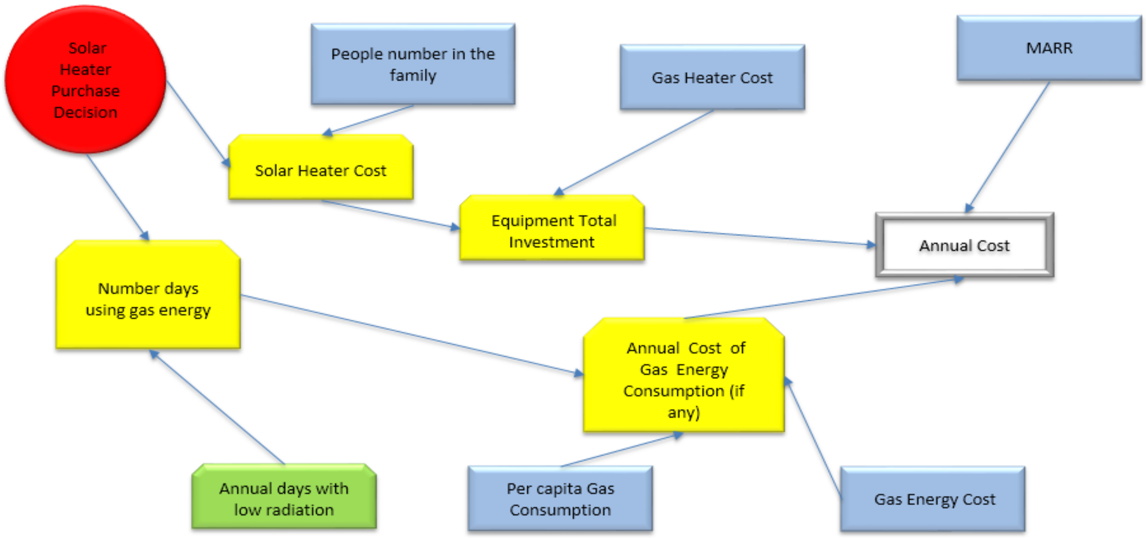

Fig. 3. Conceptual model with Palisade's BigPictureTM software

2.4 Computational model Development

Nomenclature	
P	People number in the household, persons
C_h	Gas Heater cost, $
C_s	Solar heater cost, $
C_{mg}	Annual maintenance gas heater cost, $/year
C_{ms}	Annual maintenance solar heater cost, $/year
ETI	Equipment total investment, $
MARR	Minimum attractive return rate
D	Annual days with low radiation (random variable), days/year
G	Per capita gas consumption, Kg/year-person
C_g	Gas energy cost, $/kg
ADG	Annual days using gas energy
ACG	Annual cost of gas energy consumption, $/year
AC	Annual cost, $/year
N	Lifetime, years
VPN	Annual present value, $

Figure 4 shows the model developed in Excel and executed with @Risk [12], all explications in this section refers to this figure. On the upper part to the left, schematizes the cells where the input parameters are captured. On the bottom part to the left shows one replication for 20 years, the days with low solar radiation per year, as well as the cash flows, generated from expenses for gas consumption and equipment maintenance. The right side of the worksheet shows the main outputs like the annual value, and the confidence intervals for one thousand model replications

The net present value and annual cost both estimated based on the number of years of equipment life (N), the attractive minimum return rate (MARR) and the cash flows in each year Fi, were determined by equations (1) and (2).

$$NPV = \sum_{i=0}^{N} \frac{F_i}{(1 + MARR)^i} \quad (1)$$

$$AC = NPV(A|P, N, MARR) \quad (2)$$

The values of these expressions are represented in cells J3 and J4. The cash flows F_i in each year are showed in cells E9: E29, which correspond to 20 years of the solar heater life. The days per year with low solar radiation were modeled as a uniform random variable distributed between 40 and 20 days ($D \sim U(max, min)$), and appear in cells B10: B29. The flow in the zero-year (cell E9) is $C_h + C_s$, if the solar heater is used andC_h, if we only use the heater with gas. The cost of gas consumption in any year (cells C10: C29) is determined by equation (3).

$$ACG = P * C_g * G * TD \quad (3)$$

Where TD = D, if solar heater is used, otherwise TD = 365. The annual maintenance cost (cells D10: D29) is $C_{mg} + C_{ms}$, if both heaters are used, or C_{mg} if only the gas heater is used. In this way, the total annual cost (cells F10: F29) is ACG + ACM = F_i. Finally, cells G13: M15 contain the calculations of the upper and lower limits of the confidence intervals at a 95% confidence level of the total annual cost for different mean values of the number of days with low annual solar radiation. When the input in the cell F3 is "no", the model corresponds to the deterministic scenario, and the number days with gas consumption is 365.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1													
2	Inputs								VNA=	$57,583.69			
3	Average days with low solar radiation	30	People number in the family	8	Solar Heater?	si		O U T P U T S	VNA+ INITIAL INVESTMENT=	$71,867.39			
4	Gas Cost $ /Kg	15.525	Solar heater cost	8283.7	Annual Solar Maintenance	1800			ANNUAL COST	$4,830.62			
5	Daily demand Kg/persona	0.3	Gas heater Cost	6000	Annual Gas Maintenance	990							
6													
7	Simulation						1	2	3	4	5	6	7
8	Years	days with low solar radiation	Gas consumption cost	Maintenance Total Cost	Annual Total Flow			REPLICATIONS					
9	0				14283.7		Average days with low solar radiation						
10	1	24	894.24	2790	3684.24		30	40	50	60	70	80	350
11	2	23	856.98	2790	3646.98	Average	4867.9	5240.5	5613.1	5985.7	6358.3	6730.9	16791.1
12	3	25	931.5	2790	3721.5	EstDesv	46.8	46.8	46.8	46.8	46.8	46.8	46.8
13	4	34	1266.84	2790	4056.84	Upper Limit	4870.8	5243.4	5616.0	5988.6	6361.2	6733.8	16794.0
14	5	23	856.98	2790	3646.98	Lower Limit	4865.0	5237.6	5610.2	5982.8	6355.4	6728.0	16788.2
15	6	39	1453.14	2790	4243.14								

Fig 4. Computational model in MSExcel and@Risk

3. Results and discussion

The confidence intervals at a 95% confidence level for the annual cost were plotted against the average number of days with low solar radiation for two levels of hot water consumption (2 and 8 people in the household) (See Figures 5 and 6). The horizontal line represents the scenario using only an LP Gas Heater. For example, Figure 5 shows a saving of approximately MX$2,000 annually for the solar system, if the average days with low solar radiation is 30. For 8 members in a household, the saving is MX $ 10,000 annually, under same climate conditions (see Fig. 6). After de "gasolinazo" event (1 January 2017) in México, the LP gas suffered an average increment approximately 15%. The Fig. 7 shows the consequences of the "gasolinazo" event on the savings using the solar heater.

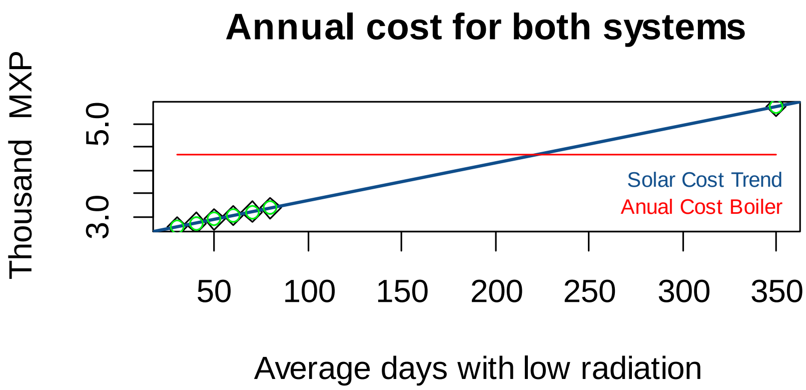

Fig. 5. Annual cost trends with the solar heater for a household size of two people

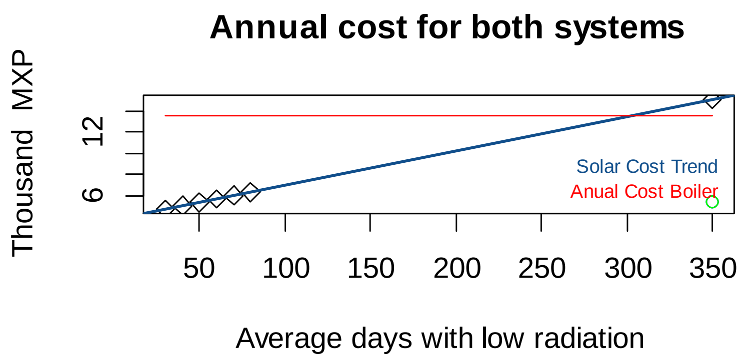

Fig. 6. Annual cost trends with the solar heater for a household size of eight people

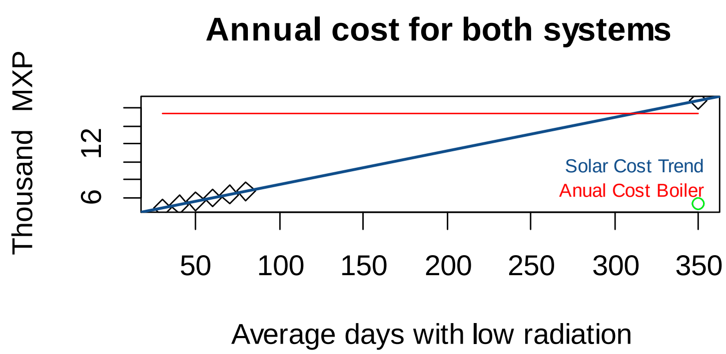

Fig. 7. Annual cost trend with the solar heater for a household size of eight people after the "gasolinazo" event

4. Conclusions

The monetary savings by using the solar heating system coupled with the gas-based boiler instead of the system that uses the gas-based boiler only, go from a saving of two thousand Mexican pesos per year when the demand for hot water is low (2 people), up to a saving little less than nine thousand Mexican pesos annually when the demand level is high (8 people) and savings a little more than ten thousand Mexican pesos per year after the "gasolinazo" event. These results invite us to think about the considerable economic saving that comes with the use of water heating systems based on solar energy. The Mexican government should seek ways to support the use of these systems by providing some financial plans to cover the relatively high initial investment involved in the equipment acquisition.

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