Calculation of Collectors for Social Housing in Different Climate Floors of Ecuador

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Abstract. Ecuador has significant potential in the renewable energy industry, to which solar energy contributes. The current investigation proposes a method to determine the savings when using solar collectors. The analysis is made for social housing projects located in different climate environments around the country: dry tropical megathermic (coast), semi-humid equatorial mesothermic (mountains), rainy megathermic (amazon), equatorial highlands (equatorial highlands). The cases studied are located in: Pasaje, El Oro; Cuenca, Azuay; Huamboya, Morona Santiago; and Chordeleg, Azuay. The method used in this research is an evaluation of drinking water per user demand (litter/person/day) which can determine the annual energetic demand. Furthermore, from the geographic location, the average solar radiation, and useful hours of sunshine are obtained. Then, these are used to obtain the available net annual energy. Furthermore, a relationship between demand and available energy is obtained for the solar collectors that satisfy the demand for the different locations studied. Finally, an analysis of the cost of implementing this technology and the projected savings in comparison to using hydrocarbons to heat domestic hot water is presented.

1. Introduction

For humans, electrical and mechanical energy are indispensable, without them the way of life as we know it today is almost impossible. In almost all human activities, these types of energy are necessary to power different types of equipment or equipment. "As we all know, heat can be converted into mechanical and electrical energy, and vice versa" [2]. Therefore, electric power can be obtained from different sources such as solar energy, wind power and hydraulic energy. In the case of third-world countries and particularly Ecuador for its portability, accessibility and above all for the price, the most widely used energy source is undoubtedly the thermal energy generated by fossil fuels, which is mainly derived from oil, because being an oil-producing country and providing multiple subsidies liquefied petroleum gas is abundant and cheap. The problem is that it is more polluting energy than other energy sources [9].

In the face of global warming, it is necessary to explore alternative energy sources that can be introduced, which means reducing import costs, maintaining a clean and environmentally friendly environment, creating employment opportunities and realizing the possibility of current resources [9]. Proposals have therefore been made to change the current urban energy model for this some studies.
mention that renewable energy can be used in cities, but they have not determined the resources and technologies that can be used [3].

Natural resources and renewable energies are the basis of the three pillars of sustainable development: economic, social and environmental quality. The use of renewable energies requires the guarantee of sustainable development: the use of energy models that meet the current needs without compromising the capacity of future generations, taking into account economic aspects (economic growth), social (social progress), environmental dimensions (environmental protection) and rational use of resources) [5].

The participation of renewable energies in Ecuador's energy matrix considers the following aspects: (a) electricity generation, through the use of natural resources in hydroelectric, wind, biomass (con-generation) and solar (photovoltaic) projects; (b) obtaining combustible gas (biogas), uses organic waste produced by agribusiness; c) use of biofuels for transport, through partial replacement of the consumption of extra petrol with ethanol (pilot project in the city of Guayaquil); (d) solar-powered water heating to replace the use of electricity or liquefied petroleum gas [6].

At the local level, Ecuador, a fuel subsidy policy has been developed to alleviate economic deficiencies, especially for the social sectors most in need. However, these policies hinder the transition to clean and efficient alternatives [12], this giving excessive consumption of fossil fuels within most homes in the country.

This article examines climate-based irradiation conditions and environmental characteristics and household consumption, revealing great potential to use solar energy to compensate for these needs, as increased renewable energy in cities can replace energy imports and reduce energy use in fossil resources. To verify this proposal was analyzed the case studies are located in the Canton Pasaje-Province of El Oro, Guangzhou Cuenca-Province of Azuay, Canton Chordeleg-Province of Azuay and Guangzhou Huamboya- Province of Morona Santiago.

2. Problem
Relying almost entirely on energy models based on coal, natural gas and oil has led to climate change and have a catastrophic impact on life on earth. Gas emissions increase by approximately 0.4% each year, and if the energy supply is not changed, these emissions will continue to increase [8]. All petroleum products, although very common tend to be very polluting especially LPG, as it weighs more than air and tends to stay longer in the environment [1].

The ineffectiveness of these subsidies is that, being relatively low-cost, the end consumer prefers to opt for their use, even if they arrive at their waste or misuse, without becoming aware of the negative effects on the country's economy and the environment.

Currently the price of a gas cylinder is $1.60 and there is no coherent relationship between its price and its value. This has brought a high economic loss to the country and has fallen into a vicious cycle. In this circle, disadvantaged classes do not benefit from it, but the whole country loses valuable resources because of a lack of political decisions and miscalculations. At present, if the allocation of these resources goes to the populations of society based on the application and use of new technologies, it is possible to eliminate or target Ecuador's natural gas subsidies for households without generating economic setbacks in the population., using clean information from the ministries of social welfare, hydrocarbons and electricity [4].

However some heads of state as part of the solution has tried to eliminate aforementioned subsidies for fossil fuels, using tools such as the impetus for an energy revolution program. One of these sets of
activities is the construction of hydroelectric plants in order to meet energy demand in Ecuador and even generate a surplus that on the one hand lowers prices and that can be a good of sale outside the borders of Ecuador to neighboring countries such as Peru and Colombia. This with a view to generating investment in environmentally sustainable energies, allowing the costs of light consumption to be lower than current ones, thus managing to compete with subsidized polluting fuels.

One of the activities that was promoted at the time of these measures was generated among so many was the implementation of induction cookers, duty-free import to electric vehicles and support for micro-enterprises selling solar heaters among others.

Given the problems of the research topic, the benefits of implementing solar heaters in homes can be determined as an alternative to LPG. However, it should be noted that no projection of either this qualitative and/or quantitative type will gain economic advantages or short-term investment recovery.

2.1. Type of housing
The type house where solar heaters are installed are of social interest block, covered with fibroceimento, architecturally designed to house 4 people, with a construction area of 63.85 m², distributed in living room, kitchen, laundry room, three bedrooms, two bathrooms and front portal.

3. Methodology
This research according to its depth is descriptive, in order to know and understand the behavior of the variables raised. The data collection is made by primary sources and has a quantitative character, the climatic zones analyzed are Tropical Megathermal Dry, Equatorial Mesothermal Half-Damp, Megathermal Rainy and Equatorial High Mountain.

3.1. Determination of calculation parameters
The analysis featured a hp65 direct fluid vacuum solar collector with an absorption surface of 1.38m² and an opening area of 1.49m². For calculation, climate data from each study region is taken, through the geographic coordinates of the NASA page. The data obtained are:
- Radiation solar addition on a horizontal plane kwhr/m²/day.
- Maximum temperature T°C
- Minimum temperature T°C

The common data in the four case studies are the number of users, as already detailed are four inhabitants. The building is located in a rural area with a clean atmosphere, so the coefficient of correction of atmospheric conditions is 1.05 according to tables, overall loss coefficient 1.73 according to the manufacturer, required percentage of ACS is 30%. The final temperature of the water is 40°C, cover transmittance 0.94 according to manufacturer, specific heat of the heating fluid Cₑ x 1 thermic/ton s.C., the maximum η performance of the collector is 82.6% according to manufacturer data.

The demand for drinking water per user (lt/hab/day) for the dry megathermal tropical climate zone is 230, for the wet mesothermal equatorial zone 220, equatorial area of high mountain 180 and the rainy megathermal zone 200 [5].

3.2. Data analysis
For ease-of-calculation purposes, a spreadsheet was used, where all four analysis cases were loaded and intermediate results were found that are given by the following procedure.

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1 https://power.larc.nasa.gov/
Step 1 = occupancy percentage (%) (number of occupants matching in the building).
Step 2 = monthly consume in m3, (multiplication between: occupancy percentage, number of occupants and monthly consume person).
Step 3 = water temperature in the mains (average between normal mean temperature and normal minimum temperature T).
Step 4 = thermal jump (Δt°) (difference between Final water temperature and water temperature in the mains).
Step 5 = monthly energy efficiency in therms Q=mC Δt°.
Step 6 = monthly energy needs in Mega Joules (conversion of monthly energy need into therms taking into account 1 termia=4,184 MJ).
Step 7 = daily energy need (the monthly energy need is divided into MJ for the number of days in each month).
Step 8 = global solar radiation on a horizontal plane (H) (NASA climate data is taken).
Step 9 = radiation global solar in a horizontal plane corrected by atmospheric conditions (multiplied by 1,05 correction coefficients by atmospheric conditions).
Step 10 = coefficient correction by inclination of the collector by geographical latitude (K factor in tables according to geographical location).
Step 11 = net available energy (\(E = 0,94kh\))(\(E = 0,94 \times \text{Pas}010 \times \text{Pas}08\))
Step 12 = determination of useful sunny hours (graphics solar minus obstructions).
Step 13 = average monthly solar radiation intensity.
\[
(I = \frac{E}{\text{#horas sol}}(277,78\text{W/m}^2))
\]
Step 14 = ambient temperature in sunny hours.
(\text{Promedio ente }T_{\text{max. normal y Tmed. normal}})
Step 15 = collector performance equation.
\[
\left(\frac{\text{Temp. final} - \text{Temp. amb horas sol}}{I}\right) \times \text{coef. global de perdidas} \times 100
\]
Step 16 = current collector performance.
(\text{Rend. max(n) \times transmittancia de cubierta}) – \text{Ecuacion de rendimiento del colector}
Step 17 = solar contribution per m2 collector (available net energy product and current collector performance, the latter divided for 100).
Step 18 = net energy available per day per m2 (product between Solar contribution per m2 collector per 0,85 considering losses in the accumulator).
Step 19 - net energy available per month (product between net energy available per day per m2 for the days of the month.
Step 20 = total solar energy (product between net energy available per month by the installed collector area).
Step 21 = percentage of substitution (percentage temperature between total solar energy and necessity in monthly energy in MJ, represents the fraction of energy consumption that is satisfied by solar energy, in the months when the solar contribution is greater than consumption this percentage will be equal to 100).
Step 22 = energy deficit (difference between necessity in monthly energy in MJ and Total Solar Energy, represents the auxiliar and energy to be provided in the months where solar energy is not enough to meet all needs).

Finally, the relationship between annual energy demand and annual available net energy is obtained to find the collector area.

4. Results
By analyzing data using the detailed steps, energy demand is related to available energy. This determines the area of solar collectors needed to meet the demand for energy to obtain ACS from
housing on different climatic floors in Ecuador, and in turn economic savings through the investment of thermal solar collector versus the traditional method of heating ACS through LPG.

4.1. Sunlight
Table 1 presents the maximum and minimum sunbathing duration in all areas analyzed. It can be seen that in the climate zone of Tropical Megathermal Seco a maximum of 12.19 hours is obtained in the month of December and in the Mesothermal Semi-Wet Equatorial zone a minimum of 11.83 hours in the month of June.

| Table 1. Sunbathing |
|---------------------|
| **Tropical Dry Megathermal** | | | | | | |
| Ranges | Month | Day of the month | Day Analysis | Julian Day | Declension | Duration of sunny | useful hours |
| Max | Dec. 31 | 15 | 349 | -23,34 | 0,06 | 0,43 | 0,03 | 12,19 hours | 9,19 |
| Min | Mar. 30 | 15 | 166 | -23,34 | 0,05 | 0,43 | 0,02 | 12,17 hours | 9,17 |

| **Semi-Wet Mesothermal Equatorial** | | | | | | |
| Max | Dec. 31 | 15 | 349 | -23,34 | 0,05 | 0,43 | 0,02 | 12,17 hours | 9,17 |
| Min | Jun. 30 | 15 | 166 | 23,28 | 0,05 | 0,43 | 0,02 | 11,83 hours | 8,83 |

| **Rainy Megathermal** | | | | | | |
| Max | Dec. 31 | 15 | 349 | -23,34 | 0,03 | 0,43 | 0,01 | 12,11 hours | 9,11 |
| Min | Jun. 30 | 15 | 166 | 23,28 | 0,03 | 0,43 | 0,01 | 11,89 hours | 8,89 |

| **High Mountain Equatorial** | | | | | | |
| Max | Dec. 31 | 15 | 349 | -23,34 | 0,05 | 0,43 | 0,02 | 12,17 hours | 9,17 |
| Min | Jun. 30 | 15 | 166 | 23,28 | 0,05 | 0,43 | 0,02 | 11,83 hours | 8,83 |

Own elaboration.

4.2. Solar radiation
Table 2, has the maximum and minimum solar radiation in all areas analyzed. In the equatorial climatic zone Mesothermic Half-Damp is the maximum of 5.04 Kwh/m2/ day corresponding to March and a minimum of 3.63 Kwh/m2 in the Megathermal Rainy zone corresponding to April.

| Table 2. Radiation |
|---------------------|
| **Tropical Dry Megathermal** | | | | | |
| Ranges | month | kwh/m2/day | Mj |
| Max | November | 4,69 | 16.88 |
| Min | February | 3,78 | 13.61 |

| **Semi-Wet Mesothermal Equatorial** | | | | | |
| Max | September | 5,04 | 18.14 |
| Min | June | 4,49 | 16.16 |

| **Rainy Megathermal** | | | | | |
| Max | October | 4,22 | 15.19 |
| Min | April | 3,63 | 13.07 |

| **High Mountain Equatorial** | | | | | |
| Max | November | 4,73 | 17.03 |
| Min | June | 4,15 | 14.94 |

Own elaboration.

4.3. Temperature
The table 3 has the maximum and minimum extreme temperature in the different climatic zones. With a maximum value in the Dry Megathermal Tropical zone with a value of 27.87°C and a minimum of 7.40°C in the Equatorial Ezone of High Mountain in September in both cases.
Table 3. Temperature

| Tropical Dry Megathermal | Extreme Maximum (degrees Celsius) | Extreme Minimum (Degrees Celsius) | Month | C. |
|--------------------------|-----------------------------------|----------------------------------|-------|----|
| Semi-Wet Mesothermal Equatorial | Extreme Maximum (degrees Celsius) | Extreme Minimum (Degrees Celsius) | September | 27,87 |
| Rainy Megathermal | Extreme Maximum (degrees Celsius) | Extreme Minimum (Degrees Celsius) | September | 16,46 |
| High Mountain Equatorial | Extreme Maximum (degrees Celsius) | Extreme Minimum (Degrees Celsius) | August | 11,94 |
| | Extreme Maximum (degrees Celsius) | Extreme Minimum (Degrees Celsius) | September | 24,77 |
| | Extreme Maximum (degrees Celsius) | Extreme Minimum (Degrees Celsius) | October | 11,94 |
| | Extreme Maximum (degrees Celsius) | Extreme Minimum (Degrees Celsius) | July | 15,4 |
| | Extreme Maximum (degrees Celsius) | Extreme Minimum (Degrees Celsius) | November | 18,25 |
| | Extreme Minimum (Degrees Celsius) | September | 7,4 |

Own elaboration.

4.4. Energy Savings and Efficiency

The study focuses on determining which climate floor in the country gets the best results, in the implementation of solar collectors. Thus, this can be determined by the annual available net energy data analysis; economic savings from investment in a solar collector and the area of collectors required in square meters, which are detail in the table 4.

Table 4. Comparison of trials

| Parameters | Tropical Dry Megathermal | Mesothermal Equatorial | High Mountain Equatorial | Rainy Megathermal |
|------------|--------------------------|------------------------|--------------------------|-------------------|
| Number of Users | 4 | 4 | 4 | 4 |
| Zone | rural | rural | rural | rural |
| Demand for Drinking Water per user (liters/person/day) | 230 | 220 | 180 | 200 |
| % of hot water | 30% | 30% | 30% | 30% |
| Demand for hot water per user (liters/person/day) | 69 | 66 | 54 | 60 |
| Final temperature 'C' | 40 | 40 | 40 | 40 |
| Collector parameters | | | | |
| Collector area m2 | 1,49 | 1,49 | 1,49 | 1,49 |
| Maximum performance | 82,6 | 82,6 | 82,6 | 82,6 |
| Global loss ratio | 1,73 | 1,73 | 1,73 | 1,73 |
| Correction coefficient by atmospheric conditions | 1,05 | 1,05 | 1,05 | 1,05 |
| Cover transmittance | 0,94 | 0,94 | 0,94 | 0,94 |
| Specific heat of the heating fluid (term/ton C) | 1 | 1 | 1 | 1 |
| Results | | | | |
| Annual available net energy | 3121,98 | 3395,04 | 3154,75 | 2746,36 |
| Collectors’ area m2 | 2,52 | 2,69 | 2,85 | 2,62 |
| Number of collectors | 1,69 | 1,80 | 1,91 | 1,76 |
| Collectors installed | 1 | 1 | 1 | 1 |
| Area installed | 1,49 | 1,49 | 1,49 | 1,49 |
| Economic savings analysis of investment in a solar collector | | | | |
| Approximate cost in Ecuador of 1 solar collector installed (USD) | 1,200,00 | 1,200,00 | 1,200,00 | 1,200,00 |
| Collector Life (years) | 20 | 20 | 20 | 20 |
| Spending on 20 years of gas per home (USD) | 4,550,45 | 5,267,38 | 5,188,40 | 4,154,38 |
| Time to Recover Investment (years) | 9 | 8 | 9 | 10 |
| Economic savings including the collector in 20 years (USD) | 3,350,45 | 4,067,38 | 3,988,40 | 2,954,38 |
| Percentage of economic savings in 20 years | 74% | 77% | 77% | 71% |

Own elaboration.
The four dwellings were compared with the implementation of a collector instead of two, since, in this case, the initial investment directly affects the percentage of savings and the recovery of the investment in the period of time raised.

5. Analysis and Discussion

Table 4 shows that there is a higher supply of net energy available in the Semi-Wet Mesothermal Equatorial Zone with 3,395.04 MJ per year and the lowest of 2,746.36 MJ available in the Megathermal Rainy zone; however, with a value of 3,154.75 MJ of available annual net energy found in the equatorial high mountain area. In addition, it can be seen that the Tropical Megathermal Dry and Equatorial areas of High Mountain have an almost similar value of 3,121.98 MJ and 3154.75 MJ, respectively.

It can also be seen that the 20-year projected gas expenditure for all areas exceeds USD 4,154, $38 and savings from savings including the 20-year collector exceed $2,954.38.

With the same logic it is observed that the largest areas of solar energy collector are found in the Mesothermal Semi-Wet equatorial areas with 2.69 m², and that of High Mountain with 2.85 m². Therefore, in these areas it is more cost-effective to install a solar collector generating savings of 4,067.38 USD in 20 years.

It should be considered that all the analysis is carried out with real LPG values, to command in mind that there is no LPG subsidy by the central government, having a real market price the logical thing is that the value store to rise and with this the savings generated by implementing this technology.

It is important to note that there are several studies; today, due to high oil costs and its great environmental impact, it has been decided to return to the use of solar energy. If oil had not replaced solar energy, we would surely have greater technology in renewable energy today [8].

The Ecuadorian government seeks to diversify the country’s energy matrix, as well as attract foreign investment and displace generation with expensive fuels and pollutants such as the design 1. Several projects have been developed for the use of solar thermal energy in power generation through photovoltaic panels and water heating for the use of hotel facilities, restaurants, among others. Projects combined with wind generation reach a total power of 287.7 megawatts (MW) [10].

Faced with this reality, with the political-economic momentum of the state, with technological development, the benefit of solar radiation and with technical knowledge, the National Government of Ecuador has promoted the construction and improvements in sports and recreation centers, in order that the population has familiar places of healthy recreation and free access; where swimming pools, hydromassages and showers are required to warm water at a comfort temperature, in the face of policies to promote renewable energy and care for the environment [7].

It is able to use and efficiency solar collectors in different regions of Ecuador, but there is no analysis that compares their efficiency in the different climatic zones. For this reason, the importance of continuing to work on this line of research, to generate solar energy efficiency maps with their applications in the different equatorial areas.

The needs to switch from fossil fuel energy uses to cleaner energy are evident, not only locally, but globally. At great steps, in our environment through the change and reinforcement of public policies, as well as the execution of projects obtained in academic trials this is being achieved. It is no longer necessary to demonstrate the advantages and development of an environmentally friendly environment, it is one of the pillars of any society, because it should be noted that climate change together with its repercussions is no longer a myth. Por that, the management of new activities such as the implementation
of solar collectors for ACS, is a way to contribute to new energies applied for the benefit of the planet, thus giving economic and environmental advantages.

6. Conclusions
Through the three phases set out in this article, it is clear that the required collector area is different in the four regions analyzed in this study, this is due in full to the atmospheric conditions presented in these areas. The results obtained in warm and low altitude areas gave results of 2.52 to 2.62 m$^2$ of area of the solar collector, while in high areas give results of 2.85 to 2.69 m$^2$, necessary to have ACS for domestic use.

Savings, when purchasing a solar collector for ACS can range from $2,954.38 to $4,067.38 depending on the area where it is deployed, having a recovery period ranging from 8 to 10 years, demonstrating an economic advantage and in turn being an alternative to LPG consume option. According to the analyses obtained in the four zones it is concluded that it is more cost effective, install a solar panel in the Equatorial zone Mesothermal Half-Damp, generating savings over a period of 20 years equivalent to a value of 4,067.38 USD and a current available net energy of 3,395.04 MJ per year.

On the other hand, according to the calculations carried out that will serve as the basis for continuing this research, it can be observed that it is not profitable to place in homes an amount greater than a solar collector, because the initial investment is very high and this causes the economic savings in 20 years to fall by up to 25% on average, and the return time of investment drops by average 2 years.

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