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Solar Cooling in the Ecuadorian Contexts

María A. Sanchez del Hierro[1,2], Jairo Acuña[2] , Tannya K. Pico[2] , Jorge D. Czajkowski[3]

[1] Facultad de Arquitectura y Urbanismo Universidad Nacional de La Plata, Calle 124 & Avenida 51 E, La Plata, Argentina
e-mail: masanchezd@puce.edu.ec

[2] Pontificia Universidad Católica del Ecuador, Facultad de Arquitectura, Av. 12 de Octubre 1076 y Roca, Quito, Ecuador
e-mail: jairo.acuna.p@gmail.com , tkpico@puce.edu.ec

[3] Laboratorio de Arquitectura y Hábitat Sustentable. Facultad de Arquitectura y Urbanismo. Universidad Nacional de La Plata, Calle 124 & Avenida 51 E, La Plata, Argentina / CONICET
e-mail: czajko@ing.unlp.edu.ar

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Abstract. *Ecuador presents four specific climates: Coast, Andes, Amazonia and Galapagos. This paper discusses the interest of solar cooling systems implementation in each case. The hot and humid climate of the Coast and Amazonia is similar to other tropical and equatorial climates where these techniques have been tested and described widely. Besides, the Andean climate of Quito (2800 meters above the sea level) and the very constrained conditions of Galapagos Islands are not yet well documented. This paper sets some guidelines for furthest research in the Ecuadorian contexts.*

1. Introduction

Since the middle of the last century we depend on the use of conditioning equipment to reach comfort levels within our buildings, ignoring the pressure on nonrenewable energy resources and the consequent environmental degradation caused by their use. An alternative to change this view is aimed by trying to achieve comfortable buildings that function as efficient thermodynamic systems that interact with their environment and try to reach minimum energy consumption.

Research in the use of energy is generally focused in heating energy, which is the predominant concern in cold or moderate climates. In contrast we can see that the energy consumption of electrical appliances for cooling in summer (or in warm areas) has been less analyzed and regulated, although demand has risen sharply as the installation of equipment for cooling due to high thermal loads in buildings. We know that these charges have their roots in the attractive glass façade that poses several challenges when protecting from radiation, as well as the increased internal loads due to computer equipment, lighting and electrical appliances that define the current lifestyle . Depending on how extreme climate and the type of construction, energy demand for cooling often remains constant and can be covered by passive systems or active cooling systems.

Passive cooling systems can reduce the consumption of both cooling and heating, to a limited minimum. Considering this limit and potential, non-conventional technologies are being studied more intensively. This paper aims to synthetically describe the technologies being investigated or under experimentation. An assessment in the Ecuadorian context is presented.

2. Cooling Demand

The annual sale of electric refrigeration units reaches approximately 43 million, with China as the largest consumer (12 million), followed by the US (11.8 million). In Europe the number is less (about 2.8 million in 2002) but with growing demand. It is estimated that growth is 3m2 / hab. in 2000 to $6m^2$ / hab. in 2020.[1] This increase in sales of air conditioners is due, on the one hand, to the increased thermal loads in buildings that basically consists of two components: sensible load (external and internal), which has an effect on the ambient temperature; and latent load, that affects indoor air moisture. The internal loads are provided by heat sources in the building, mainly by the electronic devices we use today. On the other hand, the increased demand for comfort by the user during summer. To meet the cooling requirements there are a need to find new methods that are less energy intensive and less costly.

According to studies by Eicker (2009) on the normative present in the European Union for efficient buildings, they should achieve the following characteristics for winter:

Excellent thermal insulation skin, high quality glass with U-values of at least 1.5 $Wm^{-2}K^{-1}$, with a reasonable overall energy transmittance *g* of 60% and heat recovery from the air conditioning. But the performance of these buildings in the summer depends on some additional features: Excellent sunscreen façade (preferably outside the building), schemes of

⁑ Data from the European Commission, 2006 (Action Plan for Energy Efficiency: Realising the potential, 2006) night ventilation to partially remove the daytime loads, geothermal heat exchangers to pre cool the air conditioning or use directly in parts of the building, in addition to the internal load that should be the lowest possible[2].

3. Solar Cooling

If a building cannot be cooled by passive means as stated above, there are some active technologies that can be used. At present, the dominant method is compression refrigeration, which has 90% of the world market despite its coefficient of performance (COP) systems is 3.0 on average (the best equipments reach only a COP of 5.0). Under this premise it has been allowed a combined method that provides the same comfort conditions but allowing a supply of air conditioning that does not require the production of big quantities of cold water and a reduction of primary energy consumption.

Solar thermal conversion systems are a group of very varied and numerous technological solutions. It is not intended to deepen on each one, but to provide an overview of this type of energy exploitation systems. The basic conceptual diagram can be seen in Figure 1.

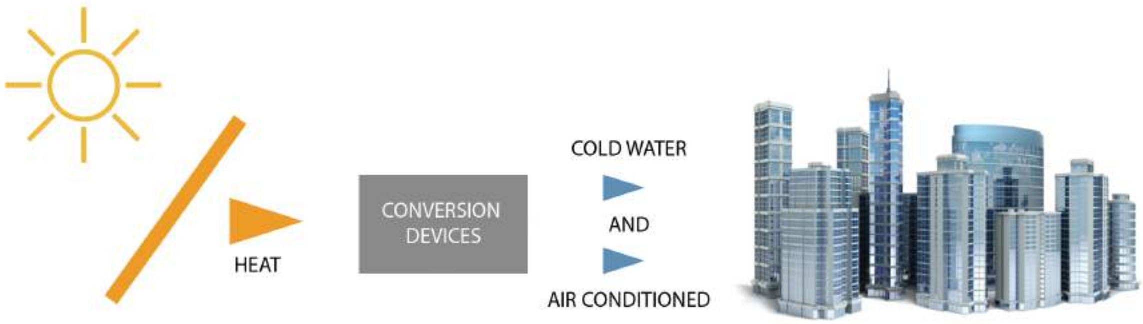

Figure 1. Basic conceptual diagram solar cooling

Source: based on König et al. (2012)

The solar cooling is based on harnessing the sun's heat to achieve cooling. As for solar radiation gain will depend on the location of the building in the earth's crust. There is a primary energy supply (sun) that has a temporal coincidence between the demand for air conditioning and maximum sunlight. The maximum radiation load is usually found within hours of delay in relation to the maximum exposure of the device, so you can easily offset this with a short term accumulator. That is why they have the great advantage to be used when matching the highest levels of demand and production, as the conditioning needs of a building occur at the time of greatest solar radiation (Henning et.al.2012).

2 In Argentina the normative in force on thermal conditioning in buildings are IRAM 11549, IRAM 11601, IRAM 11603, IRAM 11605, IRAM 11659-1, IRAM 11659-2.

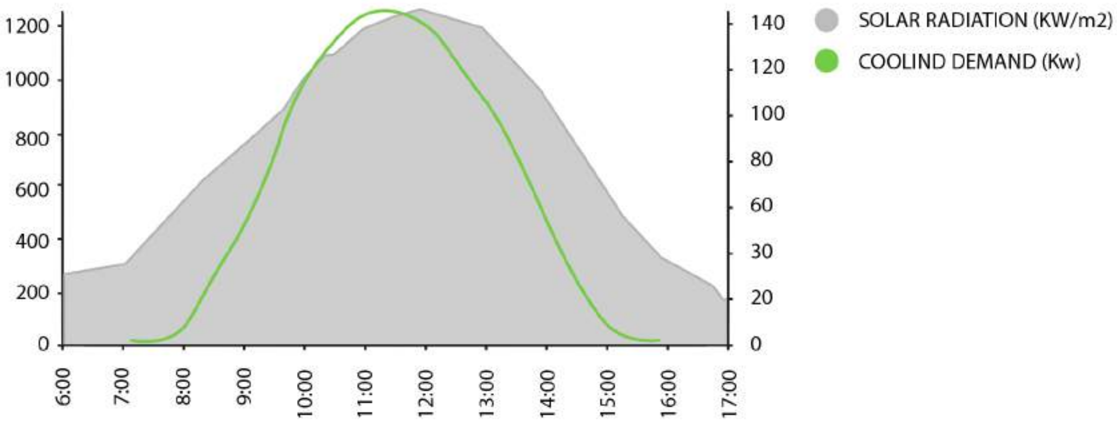

Figure 2. Graph of cooling demand and solar radiation

Source: Based on Martínez Sánchez, 2007

López Villada (2010) summarizes the wide variety of combinations between solar collection and cooling technologies. Following, there is a review of them.

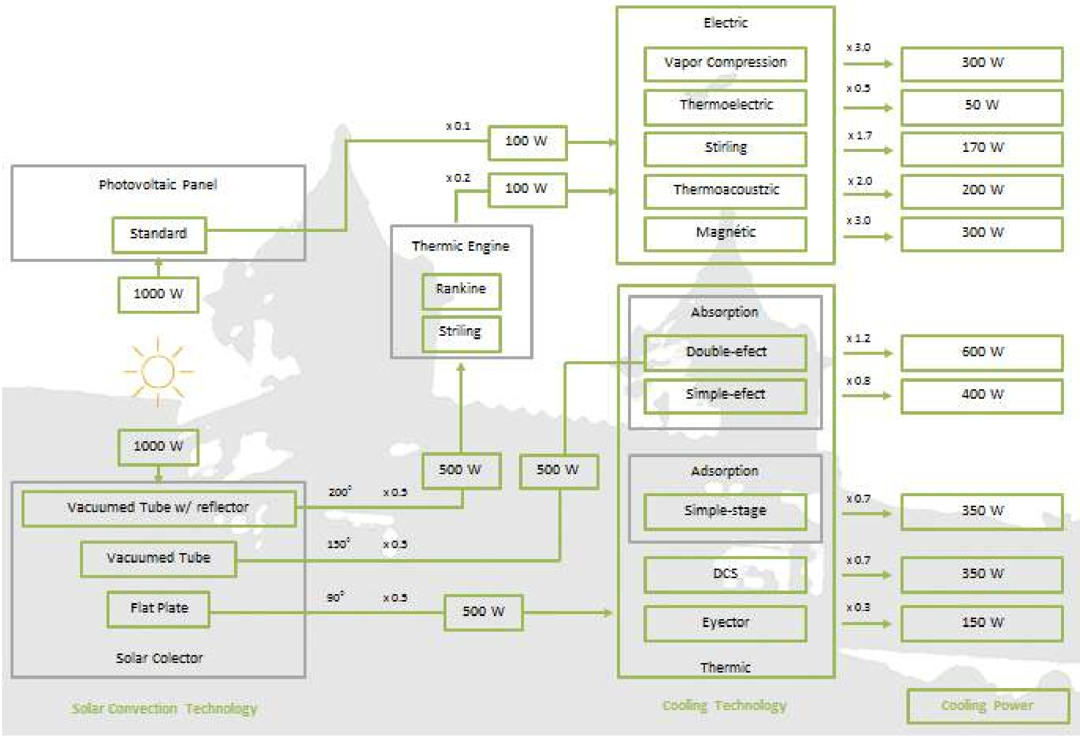

Figure 3. Performance of different technological options for solar cooling systems

Source: based on López Villada, 2010

3.1. Components

Collection system.- Solar cooling facilities feed hot liquid at varying temperatures based on different equipment. The collectors are selected according to the characteristics of the machine to be used.

Buffer tank accumulator.- These deposits are placed to stabilize the flow and temperature of liquid supplied to the machine. Dimensioning the flow rate and power depend on the installation.

Backup boiler.- Depending on the characteristics of the machine and the chosen type of solar collector sometimes is desirable to use a backup boiler to overheat the water from the solar collection system. Typically it uses the same boiler that provides hot water for heating in winter.

Backup cooler.- It is used for situations where solar hot water production is not enough.

Energy dissipation system.- It is necessary to count on this system, which may be a cooling tower or a wind turbine for cooling, or even geothermal dissipation.

Distribution system.- The energy produced can be distributed by a coolant floor or by fan coil systems.

Regulatory system.- Is important to have a team of regulatory probes, valves and other devices. These can be electronic.

3.2. Solar collection technologies

Thermal cooling systems can be connected with different solar thermal systems depending on the operating temperature. The main components of these systems are the collection system, plumbing system, hydraulic system, accumulation system and exchange system. We should note that careful selection of the type of collector in the planning stage is crucial to achieve energy saving goals. We will describe 3 types of collectors: flat plate collectors, vacuum tubes and parabolic dish concentrators.

Flat plate collectors .- They consist of an insulated metal box with a glass or plastic cover and a dark absorber plate. Solar radiation is absorbed by the plate and this quickly transfers heat to a fluid flowing through tubes in the manifold. The carrier fluid may be water or water-glycol, since the installation is at risk of low night temperatures and prevent freezing in the collector. By having a toxic element is necessary to install a secondary circuit. In the case of solar heating they are of great interest, collectors of high quality with selective coating of the absorber, which often have other features to reduce heat losses, hence expect an acceptable use in the temperature range of refrigerating machines for stationary use. (Cadena et.al. 2009)

Vacuum tube collectors.-They consist of a set of vacuum tubes (or evacuated) containing an absorber with selective treatment that collects solar energy and transfers it to a heat-bearer fluid. Due to the insulating properties of the vacuum, heat losses are reduced and temperatures of between 77 ° C and 117 ° C can be reached. Generally these collectors are used in high temperature applications. These collectors advantage is that they capture radiation more effectively than flat collectors due to its cylindrical shape, which allows rays impinge on the pipes during most of the day. They are well suited for industrial heating applications and can also be an effective alternative for domestic heating in regions where there is little or poor radiation. There are two types of vacuum tube collectors according to the method for the heat exchange between the plate and the carrier fluid: direct flow and heat pipe.

Compound parabolic concentrators (CPC) .- The stationary CPC concentration have a radiation system for higher temperatures , achieving minimization of losses and a yield close to 50%. Collectors are high performance and high quality.

CPCs large magnitude is made of a highly reflective material. These need a tracking system to keep the paraboloid axis pointing towards the sun, which can be achieved in two ways: tracking azimuth / elevation: where the hub rotates about an axis perpendicular to the plane tangent of the place varying its azimuth and also another perpendicular to vary its inclination. The polar tracking where the hub swivels parallel to the axis of rotation of the earth has a constant rate of 15 ° / hour.

3.3. Cooling technologies

Absorption.- The absorption chiller is a device that allows transferring energy from one source to another, from low temperature to high temperature with a small additional energy consumption. Its operation is based on the ability of certain substances to absorb a refrigerant that may be lithium bromide (acts as absorbent) and water or ammonia (as the cooler) and water. One distinguishes between single acting machines and double effect by the temperature at which water is: the double acting need superheated water (120-190 ° C) or steam (3-10 bar) while single effect can operate with hot water (80-95 ° C).

You can also use a triple-phase technology without refrigerant. The process alternating three states of aggregation (solid, liquid and gas) allowing continuous cooling or heating. These teams can operate in three different modes: loading, heating and cooling. Charging mode stores energy drying a salt (lithium chloride) can then be used when necessary. You can also receive thermal energy while supplying heat or cold and hot water production simultaneously. These machines differ in three aspects of lithium bromide type: have an internal storage reservoir in each of the storage where you can store chemical energy intensive; they work intermittently with two parallel accumulators; they have been designed to use relatively low and stable inside the storage temperature, which is optimized for use with solar thermal collectors (Sitio Solar, 2013).

Adsorption.- Unlike absorption machines instead of a liquid absorbent a solid adsorbent, silica-gel, and water is used as coolant. These teams consist of: an evaporator, two adsorbent chambers and a condenser. In the evaporator, the low pressure water evaporates; cooling water at 6 ° C or at the temperatures required (can cool water of up to 6 ° C to 3 ° C). Evaporation of water produced, is adsorbed in an adsorption chamber by dehydrating, which is saturated. While, in the other chamber the hot water passes through the heat exchanger, regenerating the desiccant that had previously adsorbed water vapor. The evaporated water is condensed dehydrating by cooling water in the condenser to be returned back to the evaporator. The cooling water passes through the exchanger equipment of the adsorption chamber, absorbing power delivered by the condensation of water vapor and then passed through the condenser. By a cooling tower is cooled to the temperature required to be introduced again in the equipment (Sitio Solar, 2013).

The operating cycle is not continuous (has a loading phase and another discharge). The COP of these machines is between 0.55 to 0.65. The temperature of the hot source may be from 55 ° C , ie lower than absorption machines .

Steam jet.- It is a compression technology that has a steam jet compressor that allows the use of solar energy or waste heat from processes as its source of energy. The compressor contains two refrigerant circuits: one for the generation of cold and the other for steam generation. The compressor compresses the refrigerant vapor and transports it into the condenser.

In the refrigeration cycle part of the condensed refrigerant flows into the evaporator which is connected to the jet compressor suction side. The refrigerant absorbs ambient heat or heat of the heater and evaporated. Refrigerant vapor is sucked by the jet compressor and recompressed vapor.

The steam cycle pumps the other part of the condensate into a steam generator. A deposit evaporates the refrigerant electrically heated; steam generated drives the steam jet compressor.

Heat engines.- The application of Stirling engines that we want to mention is the small-scale cogeneration and micro- cogeneration , ie the simultaneous production of electricity and thermal energy . The use of Stirling engines in solar applications is not a new issue, as work done by John Ericsson in 1864 invented a hot air engine running on solar energy are cited(Garcia Menendez,2013). It is an external combustion engine, allowing it to adapt to solar energy and are machines that develop a regenerative cycle; does not require the generation of thermal energy within, it only needs to add heat at one end while at the other is removed. That heat can come from any source, in this case: solar.

Within the energy conversion systems based on Stirling engines, the Dish-Stirling systems are the most developed. Solar concentrators are usually paraboloids of revolution with point source. The receiver is the link between the hub and the engine, ie is where the electro-mechanical energy is converted into thermal energy as efficiently as possible. Most receptors are cavity with an opening through which enters the radiation from the concentrator and stored in the absorber, which is situated behind the opening and reaches high temperatures. Receptors can be classified into direct and indirect, depending on the manner in which heat is transferred from the absorber to the working gas of the Stirling engine. In the direct recipients as heater tubes are those which absorb radiation, while in the indirect recipients fluids are used in phase change between the absorber and the heater tubes.

Research in such systems is a hot topic in the northern hemisphere, in Europe and North America[3]. We investigated the possibility of developing systems operating at low temperatures (typically reaches temperatures of 400-450 ° C) that would be in the order of 180 ° C, given that you can achieve a technological simplification and cheapening of the installation. One possibility is to use vacuum tubes as capture system, then convert the thermal energy in a turbine cycle organic fluid Rankine (ORC). This system still has high costs but expected to fall in the future.

One advantage of Stirling engines is that they are able to operate with very low temperature differences, making them potentially suitable machines used in combination with flat plate collectors or other low temperature devices. Stirling engines promise advantages with a particular focus on small-scale microgeneration, raising less than 1 kW units. (Garcia Menendez,2013)

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3 The company Stirling Energy Systems marketed the system based on a 26kW U4-95 engine that had a solar conversion efficiency of more than 31% reached on March 31, 2008 in New Mexico USA. At present there are 3 systems emphasizing marketing Ripasso Energy 30kW, measured in South Africa; Cleanenergy 22kW with V161 engine, Swedish company; And Infinia 3kW developed by Sunpower and incorporates a free piston Stirling engine (Garcìa Menendez, 2013)

We can name some mechanisms that use different fuels, have different yields or sizes, and produce heat at different temperature levels: steam turbines, turbines, organic Rankine cycle turbines process Kalina, Stirling engines, steam engines, engines gas, liquid fuel engines, a standard gas, micro turbines and fuel cells. That is why this waste heat and cooling are linked.

Peltier effect.- It was discovered in the early nineteenth century by J. Peltier and involves passing an electric current through the junction of two dissimilar metals being capable of cooling the board if you drive in the right direction.

Elements currently used in solid form, rather than two metals. These thermoelectric coolers are performing well when it comes to produce cold in a small volume. The main advantages lean in their small size, they are silent because they have no moving parts, also contain liquid or gas which makes them harmless to the environment. One of the drawbacks of these units is that when the passage of electric current is interrupted, the temperature inside rises rapidly to the one of the environment.

Magneto - Caloric effect.- Magnetic refrigeration is based on magneto caloric effect , it ie an intrinsic property of some magnetic materials . It is defined as the response of some magnetic materials to a varying magnetic field which manifests as changing the isothermal entropy and adiabatic temperature change. Modern magnetic refrigeration jumped when Zimm et al. developed machines operating successfully for applications for domestic and industrial use. One of the first tests operated with a magnetic field of a superconducting magnet 5Tesla . With 10K temperature range reached a cooling power of 600W , a COP of 10 and a maximum of 60 % of Carnot efficiency (Forofrío , 2008). The main material used in prototypes is gadolinium (Gd) and their compounds, getting cool below ambient temperature.

Cooling is achieved in the stage where suddenly suppresses magnetic field , the material is placed in thermal contact with the object to be cooled . The object is cooled and the material is heated until both reach an equilibrium temperature. The process can be repeated reaching a stable value in which the cooling capacity of the material equals heat leakage from the outside to the object. (Aragon Investiga, 2010) Several commercial houses and technological laboratories are testing prototypes for cooling systems based on magnetic materials including Astronautics Laboratory - Arnes , Chubu Electric- Toshiba , Sichuan Institute - University of Nanking.

Thermo-acoustic methods.- The thermal noise machines are devices that convert thermal energy into acoustic power and vice versa. There are two main branches of study in this discipline: cooling and pressure machines. It is based on two important thermodynamic principles: raising the temperature of a gas when compressed and temperature drop when expanded; and when two substances are placed in direct contact, heat will flow from the hotter to the colder substance. Higgins, in 1777, Rijke in 1859, Sondhauss in 1850 investigated the acoustic oscillations in tubes with heat at one end. In the 1980s Wheatley, Swift and Hofles Los Alamos National Laboratory are, among others, responsible for several advances in practice with thermos acoustic engines and refrigerators.

This system must have basically a resonant tube, a speaker attached to one end, a stack thermos acoustics is simply a solid with small channels or pores, two heat exchangers and a working gas. When the speaker is excited by an acoustic signal, a wave causes the working fluid to move through the stack, where the pressure, temperature and speed vary with time is generated. This process is intended to heat transfer from the coldest to the hottest part side thereby promoting the cooling cycle. (Peinado Rodriguez, et al, 2011)

4. Assessment

4.1. Ecuadorian climatic conditions

Ecuador has a very diverse climatic condition, that also varies over the years, due to the influence of el Niño and Humboldt ocean currents. The topography plays an important role in the distribution of climatic conditions, since altitude varies from sea level to 6,000 meters; and the location right on the Equator. The study of the climate in Ecuador started in 1890 with the Astronomical Observatory of Quito, with the first meteorological station. Then in 1944 the meteorological Service of Ecuador was created, and the first meteorological network was put into place. After a few years the National Institute of Meteorology and Hydrology (INAMHI) started the publication of its Meteorological Yearbook up to date. Nowadays the network has around 383 stations, differentiated by the installed equipment and the data collected.

Ecuador is divided into four regions: Amazonia, Andes, Coastal and Galapagos Islands.

Cities in the Coast .- This region contains the most populated cities of the country. The coastal region covers a coastal strip of about 100 km. Wide, with extreme values of 180 km in the latitude of Guayaquil and 40 km in the southern part. It can be divided into two distinct units:

The coastal mountain range extends on the Western and North - Western areas (Canguillo and mountains of Jama, Cuaque hills, mountains of Chindul and Mache) which maximum height does not exceed 800 m. At Puerto Lopez the mountain range slouches eastward at Guayaquil where it disappears (Colonche hills and Chongén).

At the South, the peninsula of Santa Elena and the Puna Island are characterized by small mountain ranges between 100m and 200m height, isolated hills (Yoma Animas: 420 m) and lowlands near the sea.

At the foot of the Andes, the Guayas River Plain is a pit collapse with fluvio-marine, filling about 80 km wide; bordered to the east by alluvial fans is bounded on the north by reliefs raised. This plain slopes gently to the south where it is replaced by an alluvial Plain, in floodable part, which is extended by a narrow strip to Peru (INAMHI, 1983).

With the elaboration of the new building code NEC 2011, it opens up the opportunity to include the use of renewable energy in buildings. There was a lack of onsite information regarding the solar resource, the stations network only measures the sunshine duration. Therefore in 2008, the National Council of Electrification CONELEC, developed the Solar Map of Ecuador based on satellite information of the US NREL between 1985 and 1991 using interpolation of 1Km2 cells. One must take into consideration that this method has its limits, several studies show this differences (Suehrcke, et.al. 2013; Grossi Gallegos, Raichijk, 2010)

The following table summarizes the characteristics of major cities in the coast of Ecuador.

City	Population 2016	Latitude	Longitude	[K] 22- Year Averaged Insolation Clearness Index (0 to 1.0)	Altitude (M.A.S.L.)	Mean solar radiation Wh/m^2 (day)
GUAYAQUIL	2,617,349	-2.2038160	-79.8974530	0.46	35.19	4370
SANTO DOMINGO DE LOS TSACHILAS	426,910	-0.2205563	-79.2902133	0.39	520.48	3440
MACHALA	276,669	-3.2664990	-79.9538270	0.49	8.45	4200
ESMERALDAS	210,833	0.9500000	-79.6666667	0.41	12.66	4350
QUEVEDO	200,217	-1.0225124	-79.4604035	0.42	55.86	3780

Note: Population figures from INEC (2016), Latitude, Longitude and Altitude from IGM (2016), [K] Insolation Clearness Index, Temperature and Humidity from NASA (2016), Mean Solar Radiation from NEC (2011)

Table 1: CHARACTERISTICS OF THE MAIN CITIES IN THE Coast

Considering the solar input of 4KWh/m^2 day, the cooling power production can be between 200W up to 2400W depending the technology that can be used. The electric technologies can produce between 200W and 1200W. The thermic technologies can produce from 450W up to 2400W. Research has shown that in similar climates like Malasya (Assilzadeh et. al. 2005), Burkina Faso (Buchter et al., 2005), or in Shangai and Hong Kong (La et.al., 2011) in China, these technologies have a wide range of operationg conditions and therefore a good opportunity for application. In Guayaquil, research has been done with adsoption cooling in a single story office building (Boera, A, 2012).

Cities in the Amazonia.- This region is the less populated area of Ecuador, thus is the most biological diverse and where petroleum is exploited.

It is characterized by a strong average temperature, around 25 ° C and by significant total rainfall, almost always greater than 3000 mm, up to more than 6,000 mm. The rainfall distribution is very regular throughout the year except for a weak recession between December and February. The relative humidity is high, in the order of 90% and the sky is often cloudy (approximately 1,000 hours annually insolation). In addition to the Amazonia plain, this kind of weather affects the North end of the country. There are few data on the Amazon region but it is likely that, in general, the annual sunshine duration does not exceed 1,200 hours, with some exceptions in less rainy sites (INAMHI, 1983).

As there is no break in the growing season, vegetation is evergreen forest.

The following table summarizes the characteristics of major cities in the amazonia of Ecuador.

City	Population 2016	Latitude	Longitude	[K] 22- Year Averaged Insolation Clearness Index (0 to 1.0)	Altitude (M.A.S.L.)	Mean solar radiation Wh/m^2 (day)
TENA	72,499	-0.9962970	-77.8136040	0.38	507.29	43350
PUYO	33,557	-1.4923930	-78.0024130	0.44	929.25	3800
ZAMORA	30,355	-4.0620940	-78.9486230	0.42	910.14	4350
MACAS	18,984	-2.3062240	-78.1153710	0.42	1032.83	4090

Note: Population figures from INEC (2016), Latitude, Longitude and Altitude from IGM (2016), [K] Insolation Clearness Index, Temperature and Humidity from NASA (2016), Mean Solar Radiation from NEC (2011)

Table 2: CHARACTERISTICS OF THE MAIN CITIES IN THE Amazonia

The solar input varies among the cities, but in average the solar input is the same as in the coastal cities. The cooling power production can be between 200W up to 2400W depending on the technology. In these areas is not common to find conventional AC units, offering an advantage for insertion of solar cooling technologies

Cities in the Andes.- This region is the most active in the country. Quito, the capital city, is located in the Andean region, as well as many medium size cities.

In the Sierra and the inter-zone, the insolation is almost always greater than 1,000 hours per year, except for the very rainy places. It is possible to say that varies from 600 to 1400 h between 500 and 1,500 meters high; and between 1,000 and 2,000 h in 1500-3000 meters high. One can reach even higher values at higher places. (INAMHI, 1983).

The following table summarizes the characteristics of major cities in the Sierra of Ecuador.

City	Population 2016	Latitude	Longitude	[K] 22- Year Averaged Insolation Clearness Index (0 to 1.0)	Altitude (M.A.S.L.)	Mean solar radiation Wh/m² (day)
QUITO	2,597,989	-0.1806530	-78.4678340	0.42	2930.11	4990
CUENCA	591,996	-2.8966170	-79.0076210	0.45	2547.56	4350
AMBATO	369,578	-1.2402100	-78.6200790	0.44	2675.05	4550
LOJA	253,625	-3.9901380	-79.2044600	0.49	2081.68	4350
RIOBAMBA	252,865	-1.6734850	-78.6479920	0.44	2772.45	4490
IBARRA	207,907	0.3626778	-78.1306667	0.39	2218.29	4560

Note: Population figures from INEC (2016), Latitude, Longitude and Altitude from IGM (2016), [K] Insolation Clearness Index, Temperature and Humidity from NASA (2016), Mean Solar Radiation from NEC (2011)

Table 3: CHARACTERISTICS OF THE MAIN CITIES IN THE Sierra

The solar input is higher than in the coast or Amazonia areas. Considering that the solar input can be 4.5KWh/m^{2}d, the cooling production could be in ranges from 225W up to 2700W depending on the technology. But there has to be one special consideration, since the temperature and humidity in this areas is not high. Uses of this technology could be for high rise buildings or special cooling needs.

Cities in Galapagos.- In the archipelago only 5% of the territory can be urbanized. The major city is Puerto Ayora in Santa Cruz Island. "The island province of Colon (Galapagos Archipelago) has a variety of thermal and rainfall climates. The coastal areas are generally dry and arid and rain increases with altitude up to a certain limit and then drops again the frequency and intensity of rain". This statement defines quite well the general conditions of the insular climate that, ultimately, is comprised of a series of microclimates at very short distances. The truth is that dominated the influences of the Humboldt current, height and exposure to the winds; the climatological information available in this region is still scarce.

In the lower parts the average temperatures fluctuate around 23°C and annual rains could vary between 150 and 500 mm. In the highlands temperatures drop a few degrees and the precipitations reach 2,000 mm near annual values, spread over two seasons, from January to May and August to September. (INAMHI, 1983).

In the Archipelago of Colon, the annual number of hours of sunshine should be equal to or greater than 2,000 hours in the coastal strip.

City	Population 2016	Latitude	Longitude	[K] 22- Year Averaged Insolation Clearness Index (0 to 1.0)	Altitude (M.A.S.L.)	Mean solar radiation Wh/m² (day)
GALAPAGOS	25,124	-0.8292780	-90.9820670	0.59	151.47	5835

Note: Population figures from INEC (2016), Latitude, Longitude and Altitude from IGM (2016), [K] Insolation Clearness Index, Temperature and Humidity from NASA (2016), Mean Solar Radiation from NEC (2011)

Table 4: CHARACTERISTICS OF THE MAIN CITIES IN THE GALAPAGOS ARCHIPIELAGO

The solar input is the highest among the country. The cooling power production can be between 290W up to 3480W depending the technology that can be used. The electric technologies can produce between 290W and 1740W. The thermic technologies can produce from 870W up to 3480W. Since it is a special environment that is away from the continent, the potential of use for this cooling option is seen as an opportunity.

5. Remarks and future research

Taking into consideration that the solar input in Ecuador ranges from 3000 Wh/m^{2}d to 5000 Wh/m^{2}d, the opportunities to harvest the resource are great. There has to be a consideration on the solar collection technology then there is a low clearness sky coefficient (kt) for the majority of cities in the country.

The technologies that can be applied for solar cooling need to continue research. For the main coastal cities there is a need for further applied research to get on site results. It is important to find the optimal solution for each environment, besides considering the climate also the final use.

There is a need for future assessment of barriers of implementation. With regard to the economic investment, a study in Europe showed that the initial investment is higher for these technologies and the savings range from 16% to 55% (Allouhi, A. et. al., 2015). The social appropriation of the technological solutions has to be discussed; the habit to own an AC device versus a new technology depends on the awareness of the end user.

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