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Design and Construction for Hydroxides Based Air Conditioning System with Solar Collectors for Confined Roofs

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Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/intechopen.72188>

Abstract

In this chapter, the methodology to determinate heat load is revised and presented. The main parameters must be fixed as function of climatization, internal thermic conditions (comfort, temperature, and humid) and the activities. According with literature, the roof structural requirements were checked. These are an important parameter because it represents the limits to the system such as load by devices (weight of equipment), orientation in solar systems (operating conditions), and building materials. The method of calculation of solar available is shown; the aim is to achieve the major collection of solar energy. Finally, the plate heat exchangers can be fabricated in gasketed, welded or module welded design characterized by the model in which the flow channels for the two heat exchanging media are sealed. The kind of exchanger is suitable depending on your requirements. The thermodynamic method of calculation of sizing the exchangers is reviewed. The aim of this section is to find the suitable devices for the operation of air-conditioning absorption system based on hydroxide.

Keywords: air-conditioning system, plate heat exchanger, roof structural conditions, life cycle assessment, sustainable cycle

1. Introduction

The world's main development is the energy because the technological advances and economic growth in countries rely on it. The energy demand is basically affected by three major factors, namely, population, economy, and the per capita energy consumption. The increase in energy demand leads to increased greenhouse gas emissions associated with the burning of fossil fuels and contributes to global warming. The energy demand associated with air-conditioning in most industrialized countries has been increasing in recent years. Traditional mechanical steam compression systems have been used for decades; nevertheless, it demands large amounts of electrical energy for the operation of the compressor; this energy demand not only affects the environment but also negatively impacts the user in economic terms associated with the cost of operation. Therefore, it has become crucial to design air-conditioning systems that are respectful to the environment and are capable of operating using waste or renewable energy sources. Commercially available absorption chillers for air-conditioning applications usually operate with LiBr/H₂O mixture and use steam or hot water as the heat source [1]. It has been testified that single-effect LiBr/H₂O absorption units using fossil fuels are not competitive from the energy, economic, and environmental points of view. They are only competitive when using waste or renewable heat as part of the driving energy [2]. Besides, according to the operating temperature range of driving thermal source, single-effect LiBr/H₂O absorption chillers have the advantage of being powered by ordinary flat-plate or evacuated tubular solar collectors. The main advantages of solar absorption cooling systems concern the reduction of peak loads for electricity utilities, the use of zero ozone depletion impact refrigerants, the reduction of primary energy consumption, and the reduction of global warming impact [3, 4]. Cold production through absorption cycles has been considered one of the most desirable applications for solar thermal energy.

2. Thermal capacity of the building

2.1. Determination of the working operation time of the absorption cooling system

An analysis of the environmental temperature was carried out in order to select the operation time of cooling absorption system. The TRNSYS software was used to simulate the building because it has implemented meteorological data such as radiation, environmental temperature, wind velocity, and so on for different cities around the world. **Figure 1** shows environmental temperature and global radiation profiles along a year (0–8760 h) at Temixco city, Mexico. The selected period was from March to May (1460–3560 h) to operate absorption system due to the high environmental temperature (**Figure 2**).

2.2. Determination of the cooling capacity of the building

The TRNSYS software has the advantage to simulate different kinds of processes (called types) such as pumps, photovoltaic modules, solar collectors, controllers, buildings, among others, and they can interact with each other with the environment in a dynamic way along time. The heat generation of the building considers four people in a rest position and three computers turned on from 8:00 to 18:00. Dimensions and main building characteristics are shown in **Table 1**.

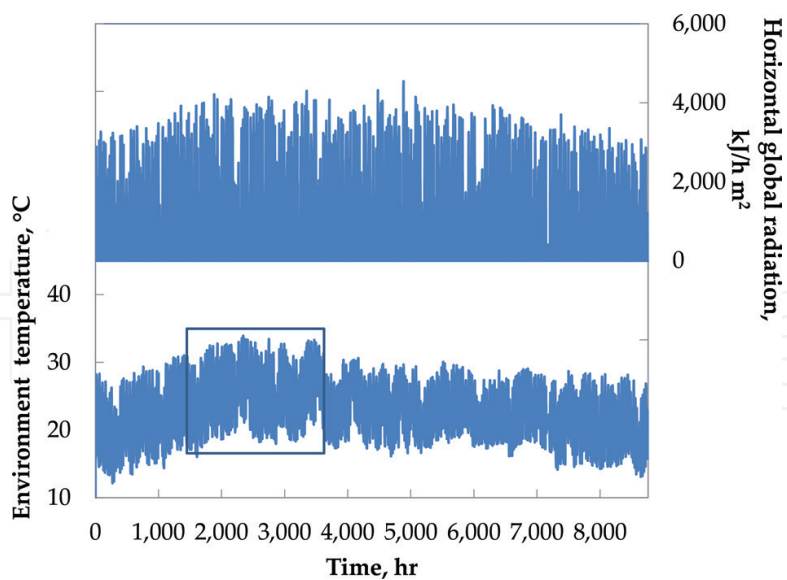


Figure 1. Environmental temperature data for an estimated year time in the TRNSYS software.



Figure 2. Photograph of the thermal and photovoltaic solar systems on the building roof.

Concept	Quantity
North and south wall	35 m ²
Ceiling and floor	75 m ²
West and east wall	12.5 m ²
Thickness of walls	0.12 m brick
Windows	4

Table 1. Home characteristics.

Figure 3 shows the behavior of environmental and building temperatures and relative humidity, as it can be seen 25°C was the set point temperature of the building. The relative humidity varied from 20 to 83%.

Figure 4 shows the behavior of cooling capacity of the building. The total energy consumed was 1.29×10^7 kJ from March to June. The maximum heat load capacity was 2.8×10^4 kJ/h (7.8 kW), and this value should be dissipated by the evaporator from absorption cooling system.

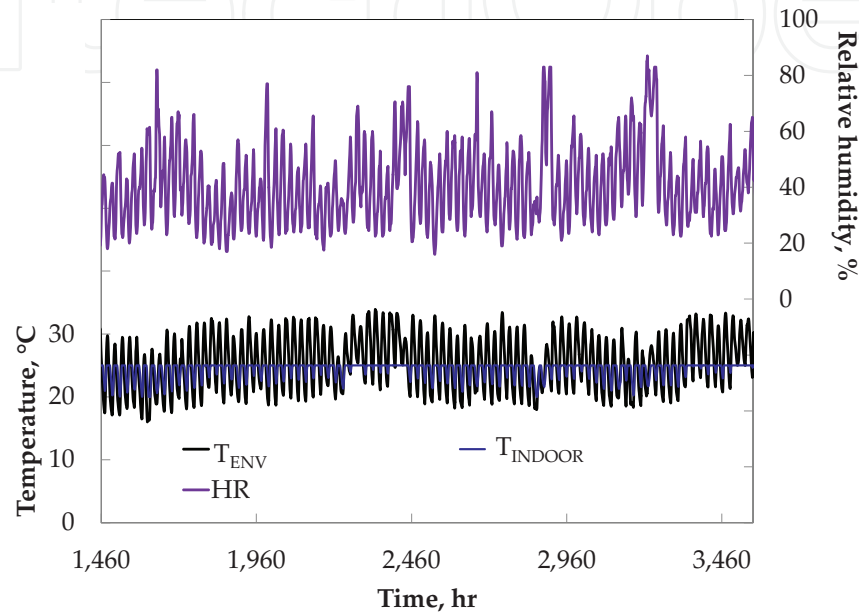


Figure 3. Indoor conditions of the building from 1417 to 2337 h (March).

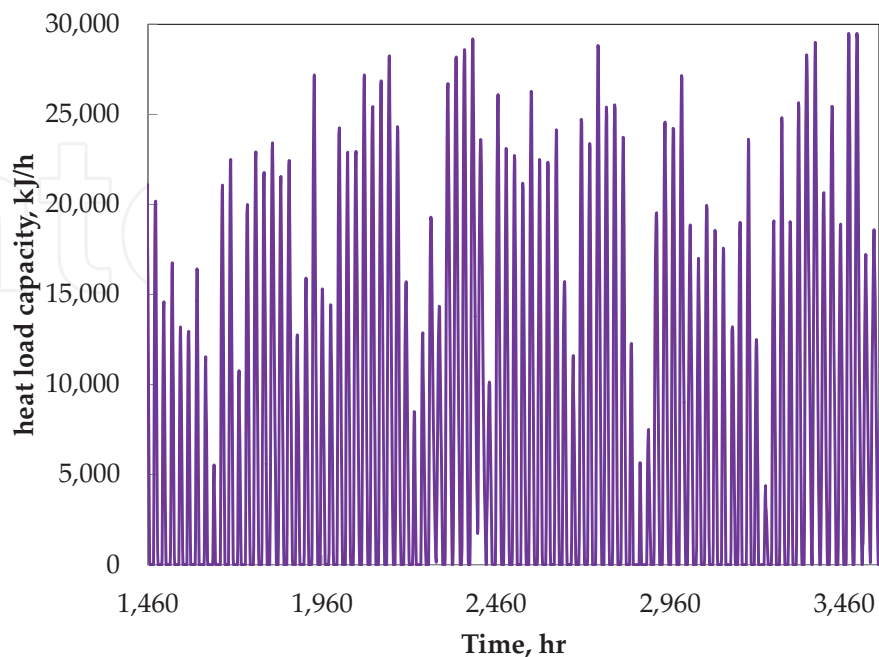


Figure 4. Cooling capacity profiles of the building from March to June.

3. Structural conditions of construction

It is so important to consider structural conditions for the installation of absorption system, for example, loads or static, dynamic and cyclical forces, the mechanical properties that it must satisfy are resilience, tenacity, ductility, and resistance to the deformation. The structures of materials are considered to accomplish the requirements that are available in the market. The following structural materials were revised.

3.1. Structures of wood

The main advantages are di-electrical materials or natural insulation, seismic resistance, and they are cheap in comparison with the girders of reinforced concrete. Nevertheless, they can be attacked and destroyed by insects, by fungi, and by natural rot; in addition, they are not resistant to the fire. The weight capacity of structures of wood support, according to the position in floor or ceiling, is in a range from 3.5 to 4.2 kN/m²; this means that they can support 2 kN/m² of useful load before suffering a deformation or fracture. Considered the wood type 2, the wood structures support from 1.5 to 2.2 kN/m², before suffer deformation or fracture [5].

3.2. Structures of reinforced concrete

The characteristics of the reinforced concrete are as follows: it increases the rigidity and offers the possibility of completing the build later. The structure is formed per rigid knots and non-deformable edges. The disadvantages are low capacity acoustic and thermal insulation and high cost [6].

Structure	Wood	Metallic	Concrete
Advantages	<ul style="list-style-type: none"> - Thermal low - isolation cost to comparison with the girders of concrete and of steel 	<ul style="list-style-type: none"> - Uniformity - Permanence - Ductility - Tenacity 	<ul style="list-style-type: none"> - Rigid knots - rigid edges - major inflexibility - possibility of using the continuity of the element
Disadvantages	<ul style="list-style-type: none"> - Irresolute and destroyed for insects, for fungi, and for the rot. - It is not resistant to the fire - the weight that can load 2 kN/m² they are of the same structure to load 1.5–2.2 kN/m² 	<ul style="list-style-type: none"> - Corrosion - elastic bulge - Fatigues low - resistance to high temperatures 	<ul style="list-style-type: none"> - Minor capacity of acoustic isolation - minor capacity thermal - high cost in comparison with armed with wood.
Loads	420 kN/m ²	>350 kN/m ²	>350 kN/m ²

Table 2. Comparison of structures.

3.3. Metallic structures

These structures are metallic and are characterized by their low cost in comparison with structures of reinforced concrete, high resistance of the metallic structures due to their properties of the steel such as useful long life, ductility, tenacity, and high electrical conductivity. Their advantages are as follows: rapidity of assembly, great capacity of laminated, resistance to the fatigue, armor with diverse types of shaped and possible structural reutilization after dismantling. The disadvantages are as follows: corrosion, elastic bulge, and high cost in comparison with the structures of wood.

Table 2 shows the advantages and disadvantages of the structural materials.

4. Air-conditioning absorption system

The use of solar energy to power an air-conditioning system is a convenient practice to replace conventional electricity [7]. This can be achieved by two methods: photovoltaic solar cooling and thermal driven sorption system [8]. However, thermal cooling technology is preferred because it can use more incident sunlight directly compared with the PV system [9]. Thermal cooling technologies include absorption, adsorption, desiccant systems, and ejector-compression systems; nevertheless, absorption cooling represents the most common globally technology due to the commercial availability [7, 10]. The process absorption is based on the absorption and desorption of a working fluid named refrigerant in an absorbent. Basic absorption cycle consists of four main components: generator, condenser, evaporator, and

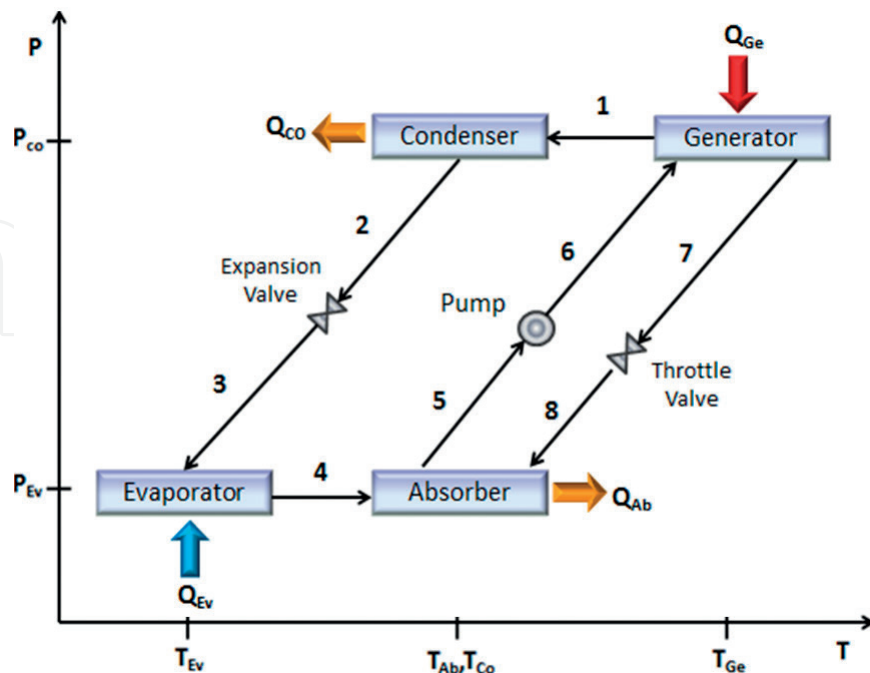


Figure 5. Schematic diagram of the absorption cooling cycle.

absorber; additionally, the system requires a solution pump and two valves, as shown in **Figure 5**. A quantity of heat (Q_{GE}) is added to the generator at a relatively high temperature (T_{GE}) to vaporize the working fluid from the solution. The vaporized working fluid (1) goes to the condenser, where it is condensed into a saturated liquid, and the heat released from this condensation process (Q_{CO}) is discharged to the atmosphere at an intermediate temperature (T_{CO}). The liquid leaving the condenser (2) passes through an expansion valve to reduce its pressure (3) and goes to the evaporator; as the saturation temperature of the refrigerant at lower pressure is much lower than room temperature (T_{EV}), the refrigerant absorbs the heat of the room (Q_{EV}), and it vaporizes, producing the cooling effect. Then, the vapor generated (4) moves to the absorber where it is absorbed by the strong solution of absorbent coming from generator (7, 8), delivering heat (Q_{AB}), which is dissipated to the ambient to keep the absorption process at a desirable temperature (T_{AB}). Finally, the mixture refrigerant/absorbent is pumped (5, 6) to the generator to restart the cycle.

The cycle can be mathematically described by the following equations derived from mass and energy balances:

$$Q_{GE} = m_6 H_6 - m_1 H_1 - m_7 H_7 \quad (1)$$

$$Q_{CO} = m_1 H_1 - m_2 H_2 \quad (2)$$

$$Q_{EV} = m_4 H_4 - m_3 H_3 \quad (3)$$

$$Q_{AB} = m_4 H_4 + m_8 H_8 - m_5 H_5 \quad (4)$$

$$COP = \frac{Q_{EV}}{Q_{GE} + W_p} \quad (5)$$

The coefficient of performance (COP) is a parameter that is defined as the ratio of available useful energy to the total power supplied to the system. As the work from the pump solution, W_p is relatively small (about 1%) with respect to the heat supplied in the generator, and it is usually negligible for analysis purposes.

These equations allow us to compute the system in order to simulate various operating conditions and determine which those that meet the requirements.

4.1. Working pair

The mixture refrigerant/absorbent is better known as working pair, and the performance of the cycle depends critically on it [11]. Generally, a suitable working pair should satisfy some requirements such as a high boiling point difference and a good miscibility between the components, chemically stable, nontoxic, environmental-friendly to mention a few [12, 13]. A wide variety of refrigerant/absorbent combinations have been suggested for absorption cooling systems [13], being the mixtures of water/LiBr and ammonia/water as the two most

Property	Sodium	Potassium
Vapor pressure	Olsson et al. [20], Balej [21]	Balej [21]
Density	Olsson et al. [20]	Akfcrlf et al. [22], Kelly et al. [25]
Enthalpy	Olsson et al. [20]	Biermann [23], Ginzburg et al. [24]
Viscosity	Olsson et al. [20]	Kelly et al. [25]

Table 3. Properties for sodium hydroxide and potassium hydroxide.

common working fluids [12]. However, both systems have their limitations, which make necessary to research different working pairs [14].

4.2. Hydroxides

According to research, the 2,497,819 and 4,151,721 U.S. patents proposed an arrangement for absorption of refrigeration systems based on aqueous solutions of hydroxides in order to present alternative mixtures with the aim to avoid the problems presented by the conventional working fluids. The patents propose soluble basic hydroxides such as sodium and potassium [15–17], and cesium hydroxide was considered later [15]. Subsequently, an aqueous mixture of ternary hydroxide was developed [18], and its performance was theoretically compared with the solution of lithium bromide showing promising results [19]. To calculate and optimize absorption processes, accurate data about the different properties of the mixtures are required. Unfortunately, the available information is scarce, and in most cases, it does not cover the full range of concentration and operating temperatures. However, **Table 3** presents different properties for sodium hydroxide and potassium hydroxide according to the analysis of authors.

Based on this lack, we can conclude that there is an area of knowledge yet to be explored.

5. Heat exchanger: selection and sizing

As it has been described previously, a conventional absorption heat pump includes, at least, four heat exchangers (generator, condenser, evaporator, and absorber), and the coefficient of performance (COP) is strongly affected by the heat and mass transfer efficiency of these components. The fact that the heat exchangers are widely used in many industrial applications allows that the new developments on heat transfer subject promote new designs on absorption heat pumps. Annex 33 of the International Energy Agency (IEA) Heat Pump Program, which was aimed at promoting use of compact heat exchangers in heat pump systems, included three main goals [26]:

1. Identify compact heat exchangers, either existing or under development, that may be applied in heat pumping equipment. This has the aims of decreasing the working fluid inventory, minimizing the environmental impact of system manufacture and disposal, and/or

increasing the system performance during the equipment life, thereby reducing the possible direct and indirect effects of the systems on the global and local environments.

2. Identify, where necessary propose, and document reasonably accurate methods of predicting heat transfer, pressure drop and void fractions in these types of heat exchangers, thereby promoting or simplifying their commercial use by heat pump manufacturers. Integral with these activities was an examination of manifolding/flow distribution in compact/microheat exchangers, in particular in evaporators.
3. Present listings of operating limits for different types of compact heat exchangers, for example, maximum pressures, maximum temperatures, material compatibility, minimum diameters, and so on and of estimated manufacturing costs or possible market prices in a large-scale production. It is intended within this context that opportunities for technology transfer from sectors where mass-produced CHEs are used (e.g., automotive) will be examined, and recommendations are made.

Plate heat exchanger (PHE) is a compact heat exchanger and has been used for absorption system applications [27–30]. Design, sizing, and selection of a PHE for absorption systems are restricted by the thermodynamic properties of the working mixture because they limit the heat transfer rate; consequently, the heat transfer area is in function of this. Other parameter to consider in heat exchanger selection is the operating conditions (temperature and pressure). Aqueous solutions such as LiBr, NaOH, CaCl, LiCl operate at vacuum pressure conditions (from 0.8 to 7 kPa) [31–35], but there are configurations that include a high-pressure generator (from 150 to 300 kPa) [30, 36, 37].

To the performance, a thermal or heat transfer analysis to heat exchanger is suitable to apply some of the methods such as LMTD, ϵ -Ntu, and P-Ntu. The methodologies have subtle variations but in essential are the same. P-Ntu method is often used for the calculation of the correlation factor F for the first method. LMDT and ϵ -Ntu methods have been widely applied in industrial practice [38]. A calculation procedure for plate heat exchanger and useful charts was developed as functions of the number of transfer units (Ntu) and the heat capacity ratio (R) for different heat exchanger configurations. Number of channels, number of passes of each fluids, and flow arrangement were the terms to classify the heat exchangers [39]. The ϵ -Ntu method avoids a rather cumbersome iteration through logarithmic terms, necessary in the LMTD method, and provides a very elegant method using dimensionless parameters that can be applied in easy way to new design and performance rating problems of heat exchangers.

The effectiveness (ϵ) is the ratio of heat transfer rate (\dot{Q}), to the maximum heat transfer potential rate (\dot{Q}_{max}), when the heat exchanger area is infinite:

$$\epsilon = \frac{\dot{Q}}{\dot{Q}_{max}} \quad (6)$$

Heat capacity rates are obtained by multiplying the specific heat and mass flow rate of the fluid. The fluid with the higher heat capacity is designated C_{max} and the lower one C_{min} . If the cold fluid has the minimum heat capacity, then the effectiveness is defined as:

$$\varepsilon = \frac{C_{max}(T_{h,i} - T_{h,o})}{C_{min}(T_{h,i} - T_{c,i})} = \frac{C_{min}(T_{c,o} - T_{c,i})}{C_{min}(T_{h,i} - T_{c,i})} \quad (7)$$

where $T_{h,i}$ and $T_{h,o}$ are the inlet and outlet temperatures of the hot fluid and $T_{c,i}$ and $T_{c,o}$ are the inlet and outlet temperatures of the cold fluid. The ratio of capacities is defined by:

$$R = \frac{C_{min}}{C_{max}} \quad (8)$$

The dimensionless parameter Ntu (number of transfer units) expresses the size of the heat exchanger and is commonly used in heat exchanger analysis and is expressed as [40]:

$$Ntu = \frac{UA}{C_{min}} \quad (9)$$

Effectiveness correlations for different types of heat exchangers are summarized in **Table 4**.

If there is a phase change in a heat exchanger, the heat capacity of the fluid-changing phase becomes infinite, and Cr is zero, then effectiveness correlations reduce to:

$$\varepsilon = 1 - \exp(-Ntu) \quad (10)$$

Regardless of the type of heat exchanger.

Heat exchanger type	Effectiveness (ε) relations
Parallel flow	$\varepsilon = \frac{1 - \exp[-Ntu(1+R)]}{1+R}$
Counter flow	
R<1	$\varepsilon = \frac{1 - \exp[-Ntu(1-R)]}{1+R \exp[-Ntu(1-R)]}$
R=1	$\varepsilon = \frac{Ntu}{1+Ntu}$
Cross flow both fluid unmixed	$\varepsilon = 1 - \exp\left[\left(\frac{1}{R}\right) Ntu^{0.22}\{ \exp[-R(-Ntu^{0.78})] - 1\}\right]$
Cross flow	
C_{min} (unmixed)	$\varepsilon = \frac{1 - \exp\{-R[1 - \exp(-Ntu)]\}}{R}$
C_{max} (mixed)	
Cross flow	
C_{max} (unmixed)	$\varepsilon = 1 - \exp\left\{-\frac{1}{R}[1 - \exp(-Ntu * R)]\right\}$
C_{min} (mixed)	
Shell and tube one shell pas (2,4...tube passes)	$\varepsilon_1 = 2\left\{1 + R + (1 + R^2)^{\frac{1}{2}} \frac{1 + \exp[-Ntu (R^2)^{\frac{1}{2}}]}{1 - \exp[-Ntu (1 + R^2)^{\frac{1}{2}}]}\right\}$
n Shell passes (2n, 4n... tube passes)	$\varepsilon_n = \left[\left(\frac{1 - \varepsilon_1 R}{1 - \varepsilon_1}\right)^n - 1\right] \left[\left(\frac{1 - \varepsilon_1 R}{1 - \varepsilon_1}\right)^n - R\right]^{-1}$

Table 4. Effectiveness relations for different types of heat exchangers [41].

5.1. Condenser and evaporator

These devices for air-conditioning applications are designed considering the coil flooded with two-phase refrigerant and also a wall temperature equal to the refrigerant in general [42]. The outer side heat transfer coefficient and the physical properties are assumed constant. Thereby, the heat transfer rate is calculated according to [43]:

$$\dot{Q} = \dot{m} Cp(T_o - T_i) = \varepsilon \dot{m} Cp(T_s - T_i) \quad (11)$$

where \dot{m} is the mass flow rate, T_i , T_o and T_s , are the inlet, outlet, and surface temperatures, respectively.

$$\dot{Q} = \varphi A_s(T_s - T_m) \quad (12)$$

The equation number 12 is the heat transfer rate, T_m is the mean flow temperature over the heat transfer area, and A_s and ε are the heat exchanger effectiveness.

6. Solar thermal technologies selection

Around the world are different types of sources of renewable energy. However, solar thermal energy is the most abundant, and the interest in their development has increased in recent years [44, 45]. This subsection describes the technologies used with solar thermal energy, advantages and disadvantages, and a guide to choose one of them depending on the project.

6.1. Solar radiation

The interest in solar energy has grown since the environmental problems caused by burning fossil fuels have become severe. One of the most important parameters for the use of solar energy is the estimate of solar radiation [46]. Solar radiation is compound of three elements: *direct radiation*, which is received direct from the sun without diffusion by the atmosphere and is used by the solar energy technologies; *diffuse radiation*, formed with sunlight diffused by atmosphere when in the sky, air molecules, dust and cloud interfere the natural path of the rays, "fragmenting" the sunlight; and *albedo*, which is the radiation reflected by the floor [43]. In order to reduce the greenhouse gases pollution, there exist technologies that transform the solar energy in thermal energy, which is called "solar thermal technologies".

6.2. Solar thermal technologies

Solar energy technologies are special kind of heat exchangers that transform solar radiation energy to thermal energy storing it in a fluid. The most important component of any solar technology is the solar collector, which is a device that absorbs the incoming solar radiation, converts it into heat, and transfers that heat to a fluid flowing through the collector [48].

These collectors can be divided into two types: nonconcentrating (NC) and concentrating (CC). Then, it describes their advantages and disadvantages [48, 49].

Advantages

- Heat transfer fluid (HTF) can achieve higher temperatures because the solar beam is focused on a point.
- The thermal efficiency is greater because of the small heat-loss area relative to the receiver area.
- With these systems, the HTF reduces exergetic losses through the STT; it means that the interchange between the fluid temperature and environment is less according to the smaller area of the receiver.
- For a CC, the cost per unit area of the solar collecting surface is cheaper than of a NC collector.

Disadvantages

- In a cloudy day, it may not work; it means, without solar radiation, these systems do not transform energy.
- Concentrator systems collect little diffuse radiation depending on the concentration ratio.
- Some form of tracking system is required to follow the Sun, generating more monetary and energetic costs.
- Solar reflecting surfaces may lose their reflectance with time and require periodic cleaning and refurbishing.

Even with these characteristics, not all solar collectors have the same design, depending on different concentrators and receivers; for that reason, they are divided into: linear fresnel reflector (LFR), parabolic trough collector (PTC), parabolic dish reflector (PDR) and central receiver (CR); finally, they are subdivided into solar tower (ST) and solar furnace (SF) [48, 49].

The **Figure 6(a)** shows the focus method to achieve the recollected energy of sun and increase the efficiency of collector; the PTC and PD are divided into mobile receivers; it means that the collector and the receiver need a tracking sun technology. On the other hand, LFR, SF, and ST are classified as fixed receivers because the receiver is static. In **Figure 6(b)**, a graph is shown comparing the concentration ratio with the temperature that can be achieved. LFR has a concentration ratio from 10 to 40 units, and a temperature ranges from 60 to 250°C. PTC increases its concentration compared with LFR, between 15 and 45 units; thus, the temperature range can reach from 60 to 300°C. On one hand, ST achieves a concentration ratio of 300–600 and can achieve a temperature above 800°C. On the other hand, PD has a concentration ratio between 100 and 1000 and a temperature range from 100 to 1600°C. Furthermore, SF has the highest concentration range of all STT, reaching 10,000 units; thus, this technology can arrive temperatures above 2000°C [48, 49].

6.2.1. Linear Fresnel reflector

LFR is a type of solar collector that collects sunlight by adapting long, narrow or slightly curved mirrors to reflect the Sun's ray into an absorber tube and concentrate that energy. They usually use water as HTF, which passes through the receiver and change to steam. Considering that the focal line in the LFR can be distorted by astigmatism of the mirror, usually a secondary mirror is placed above the receiver to refocus the Sun's ray [6]. They have the advantages of easy manufacture and maintenance, and low cost comparing with other solar thermal technologies. However, these systems have the disadvantage of losing some portion of reflector aperture because the arrangement between each other blocks part of the sunlight and affecting their efficiency [50].

6.2.2. Parabolic trough collectors

PTCs have a parabolic shape and are covered by a bending sheet of reflective material. A metal black tube, covered with a glass tube to reduce heat losses, is placed along the focal line of the receiver. Then, parallel ray's incident on the reflective material and are reflected onto the receiver where a HTF absorbs the solar power [48]. Each collector is connected together in long lines, and a system tracks the Sun's path throughout the day along a single axis, usually east to west [49]. These technologies have the following advantages: they are feasible commercial options to transform heat, and they are the most advanced of STT because of considerable experience and have several applications [51]. One of their principal disadvantages is the tracking mechanism because it must be reliable and able to follow the Sun with a certain degree of accuracy, returning the collector to its original position at the end of the day, increasing their cost and energy supply [48].

6.2.3. Parabolic dish (PD)

The parabolic dish (PD) is one of the most important methods in solar power generation. It is a point-focus collector that tracks the Sun in two axes, concentrating solar energy onto a receiver. The receiver absorbs solar radiation, transforming it into thermal energy. The thermal energy can either be transported through piped to a central power-conversion system or it can be transformed into electricity [48]. Solar dish presents some advantages such as high efficiency, hardness against deflection and wind load, modularity, versatility, durability against moisture and temperature changes, long-term low maintenance operation, and long lifetime. There are some disadvantages such as conversion of heat into electricity is needed in the system to have moving parts, increasing maintenance and cost, and is necessary for a great supply of energy to the tracking solar system [52].

6.2.4. Solar tower (ST)

This is a technology composed of multiple mirrors called heliostats distributed on a field, ordered and oriented automatically using a solar tracking system to reflect the direct radiation to a receiver situated a great height. Usually, each heliostat has 50–150 m² of reflective surface

transferring the thermal energy onto the receiver. The heat transportation system consists of pipelines, pumps, and valves, where the fluid flows in a closed circuit between receiver and storage tank. Some of the advantages of these are highly effective as much in the solar collection as in its transformation to electricity. Also, there is no necessity to flatten the field; therefore, this technology can be installed in a hill. One of the most important disadvantages is the higher cost of the solar tracking system compared with the same system installed in PTC because in ST, it is necessary to install in each heliostat one of these systems and in PTC, the tracking system can be installed by row [48, 53].

6.2.5. Solar furnace (SF)

These devices are used in tests, high-temperature processes, and other applications and are constituted by one or more heliostats, which track the Sun, reflecting the sunrays horizontal and parallel to an optical axis of the parabolic concentrator, which in turn concentrates the incoming rays into the focus of the parabola. This reflector can be composed of a parabolic mirror or a group of spherical mirrors. The furnace power can be attenuated by a shutter, which controls the amount of solar radiation. The concentrated radiation reaches the test area, which is located at the concentrator focus [44]. One of the most important advantages is that it can reach temperatures above 2000°C, allowing the scientific community to do specific researches. However, this technology is the most expensive between STT and needs high technical knowledge to operate them.

6.3. How to select one of the solar thermal technologies

There is no single criterion to make the selection of one of all STTs presented in this chapter; however, by looking applied examples of each technology, it is possible to facilitate the choice of the best technology for a project. Solar collectors have been used in a variety of applications. In **Table 5**, there are listed the most important solar thermal applications with the type of collector that can be used in each case. Other way to decide the best technology is to know first the temperature required for your process. As it is shown in **Figure 6(b)** depending on

Application	Collector
Solar water heating (temp range $\approx 90^\circ\text{C}$)	LFR PTC
Space heating and cooling (temp range $\approx 90^\circ\text{C}$)	LFR PTC PD
Solar refrigeration (temp range $\approx 150\text{--}200^\circ\text{C}$)	LFR PTC PD
Industrial process heat (temp range $\approx 80\text{--}240^\circ\text{C}$)	LFR PTC PD
Solar desalination (temp range $\approx 100^\circ\text{C}$)	LFR PTC PD
Solar thermal power systems (temp range $\approx 800\text{--}2000^\circ\text{C}$)	PD ST SF
High performance experiment like melting tungsten (temp range $\approx 3000^\circ\text{C}$)	PD SF

Table 5. Solar energy applications and type of collectors used [9].

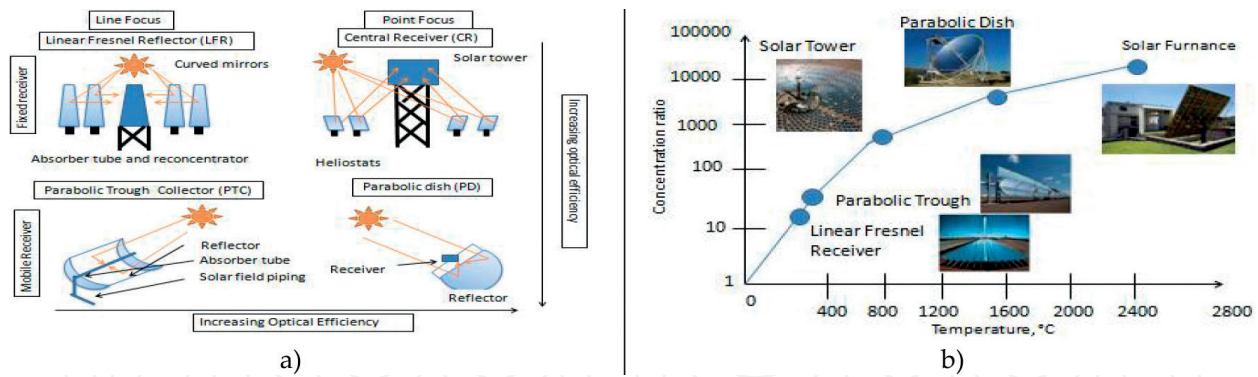


Figure 6. (a) Solar thermal energy technologies and (b) concentration ratio of STT [6].

your temperature range, it can be possible to select one of them. For example, if the project wants to transform solar energy into solar water heating with a range of 90°C, the possible technologies to use will be LFR and PTC.

The last aspect to take into account is the heat transfer fluid selection. This fluid is critical for storing and transferring thermal energy and can be used to directly drive a turbine to produce power or more commonly, be combined with a heat exchanger and secondary cycle to generate steam. Desired characteristics include [49]:

- Low melting point.
- High boiling point and thermal stability.
- Low vapor pressure (lower than 1 atm) at high temperature.
- Low corrosion with metal alloys used to contain *HTF*.
- Low viscosity.
- High thermal conductivity.
- High heat capacity for energy storage.
- Low cost

The HTFs can be divided into six main groups, according to the type of material [49]:

- *Air and other gases.* It is not common. However, the very low dynamic viscosity compared to the one of molten salts gives good flow that favors the heat transfer and may compensate its low thermal conductivity.
- *Water/steam.* They present corrosion problems and imply high operating pressures and complex controls for plant operation.
- *Thermal oils.* Mainly in PTC. There are three types: mineral oil, silicone oil, and synthetic oil and can be thermally stable only up to 400 °C. They have high cost.

- *Organics*. The most common are biphenyl/diphenyl oxide, which is a mixture of biphenyl ($C_{12}H_{10}$) and diphenyl oxide ($C_{12}H_{10}O$).
- *Molten salts*. They have stability at high temperature (greater than 500 °C); they also have properties comparable to water at high temperature, such as viscosity and low vapor pressure. Most of them are based on nitrates/nitrites, but salt production is restricted.
- *Liquid metals*. They have promising properties such as extensive operating temperature range, low viscosity, and efficient heat transfer characteristics. As a reference, liquid sodium has an operating temperature range between 98°C and 833°C.

7. Comparison of the environmental performance of a solar air-conditioning system vs a conventional electrical system, using LCA

Nowadays, the topic of global warming has become a top trending around the world. Life cycle assessment (LCA) was created in 1960. It is a tool to evaluate the environmental impacts and is an instrument to help take decisions, ecodesign, and comparative of alternatives. This section shows a comparison of environmental performance of air-conditioning absorption system with conventional air-conditioning system by LCA according to international laws ISO 14040 and ISO 14044.

7.1. The solar system description

The air-conditioning absorption solar system (ACASS) considered for this study is installed as a prototype on the Research Center in Engineering and Applied Sciences (CIICAp) of the Autonomous University of the State of Morelos (UAEM), located in Cuernavaca, Mexico, with a warm subhumid climate. In this place, March, April, and May are the warmest months during the year, thus the required demand of air-conditioning increases, with an average per day solar radiation of 7.31, 6.85, and 6.16 kWh/m², respectively [54].

The capacity of ACASS installed is 17.6 kW such as providing air-conditioning for five offices. The design temperature average was proposed around 23°C, which is considered the comfort temperature. The system will be employed from Monday to Friday, during March to May, with a schedule from 11:00 to 16:00.

A plant of cylindrical-parabolic collectors that generate 26.44 kW was installed to drive the cycle, and 12 photovoltaic panels have been coupled to ACASS to generate 1.89 kW and supply electrical energy to the auxiliary devices that require it, covering 98.9% of the demand. Twenty-five years was considered as the useful period, according to the literature review [55].

7.2. Conventional air-conditioning system

This study considers a window-type conventional air conditioning (CAC) of 3.52 kW of capacity, and average energy demand is 1300 W. The operations conditions and useful life are considered for both systems; therefore, 12.5 units of 39.34 kg in average was evaluated. These units have a lifespan of 10 years according to the literature review [56].

7.3. Life cycle assessment

According to the international standards ISO 14040 and 14044, LCA is defined as the assessment of the environmental impacts associated with a product, process, or service throughout their life cycle, tied in closely with the paradigm of “cradle to grave.” This methodology consists of four phases, which can cross-interact at any point of the assessment, as shown in **Figure 7**.

7.3.1. Phase 1: objectives and scope definition

At this phase, it is important to fully understand the system under consideration and then be able to define the objectives and scope of the analysis. The functional unit and the system limitations are defined during this phase. The functional unit will allow to compare the two different systems based on a common function.

Therefore, the following aspects are defined at this phase for the case study:

- Objective: to compare the environmental performance between a ACASS system and a CAC system, in terms of CO₂ equivalent (CO₂eq).
- Scope: the stages of construction and operation are analyzed. The end-of-life stage is not considered in this study; however, it can be anticipated that this stage can lead to avoid impacts if a good final disposal scenario is proposed based on the recycling of the components, and this scenario would be a greater advantage for ACASS for ACS for the amount of material.
- System limitations: the construction stage will cover the material inputs, the energy consumption during the assembly of main components, and the transport of materials up to the construction site.

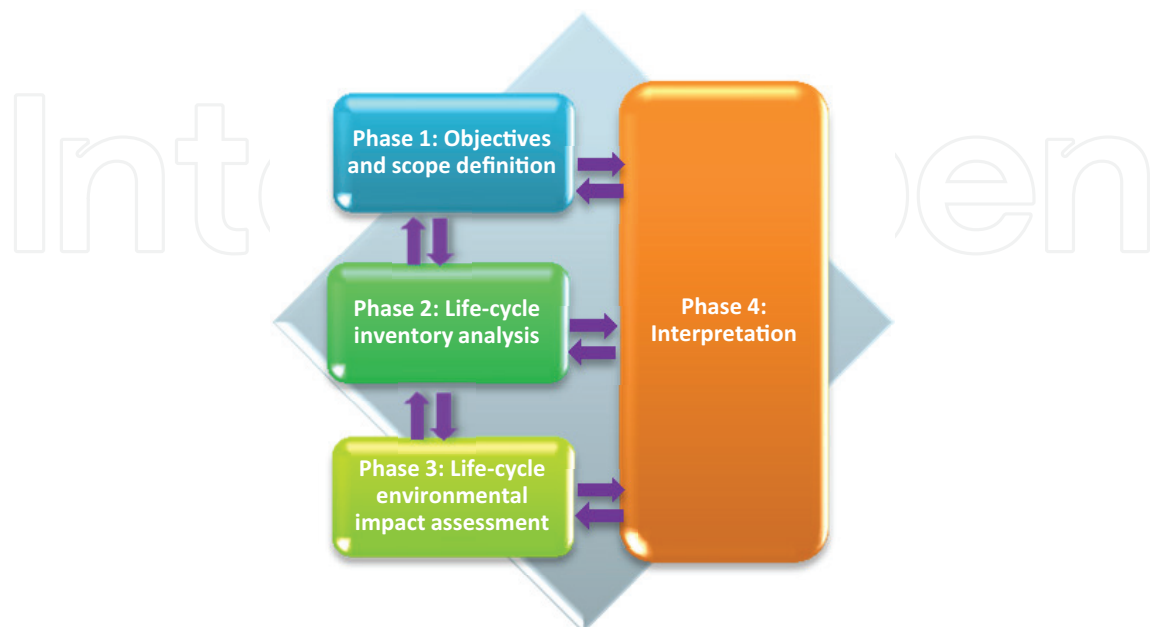


Figure 7. Life cycle Assessment phases.

- System function: to provide thermal comfort for five spaces of a ton of refrigeration each one.
- Functional unit: the total amount of refrigeration produced throughout the useful life of the system.

7.3.2. Phase 2: life cycle inventory analysis

During this phase, data are compiled for the inventory of the system at issue. For this analysis, the life cycle inventory (LCI) of the ACASS system is obtained from primary sources. The information was directly quantified on site, and some data are obtained from suppliers, some assumptions have also been made in the absence of some data, such as the type of transport used. For the LCI of the CAC system, the material content and percentages have been taken from the literature [57], suited to the requirements of the analysis. For the use stage, the equipment maintenance, part replacement, and electrical energy consumption are taken into consideration.

7.3.3. Phase 3: life cycle environmental impact assessment

LCA software is used at this phase for assessing the environmental impact of the systems. In this case, SimaPro™ PhD 8.3.0.3 is used for the case study. The assessment method considered in this analysis is the Intergovernmental Panel on Climate Change (IPCC) 2007 GWP 100 years, which only includes the impact category of global warming potential (GWP).

7.3.4. Phase 4: interpretation

A summary of the results and the corresponding discussion are carried out, and the final conclusions and recommendations are produced according to the results. In **Figure 8**, the ACASS system presents a reduction in CO₂e emissions of 77.34% compared with the CAC system, during the analyzed life cycle stages. In addition, employing the ACASS system also contributes to mitigate the environmental impacts due to the use of renewable solar energy. **Figure 9** shows the percentage of CO₂eq emissions at each life cycle stage for both

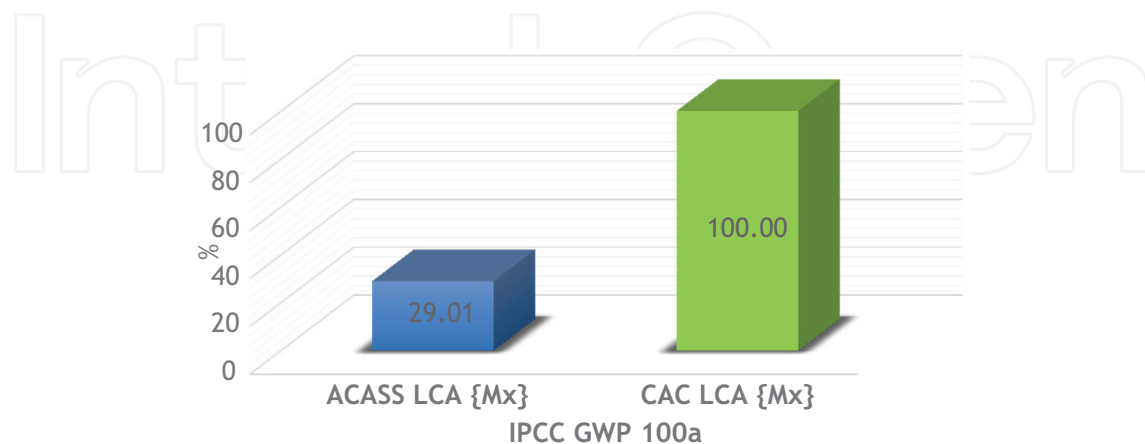


Figure 8. Total percentage of CO₂e emissions for the ACASS system compared against the CAS system at the stages of construction and operation.

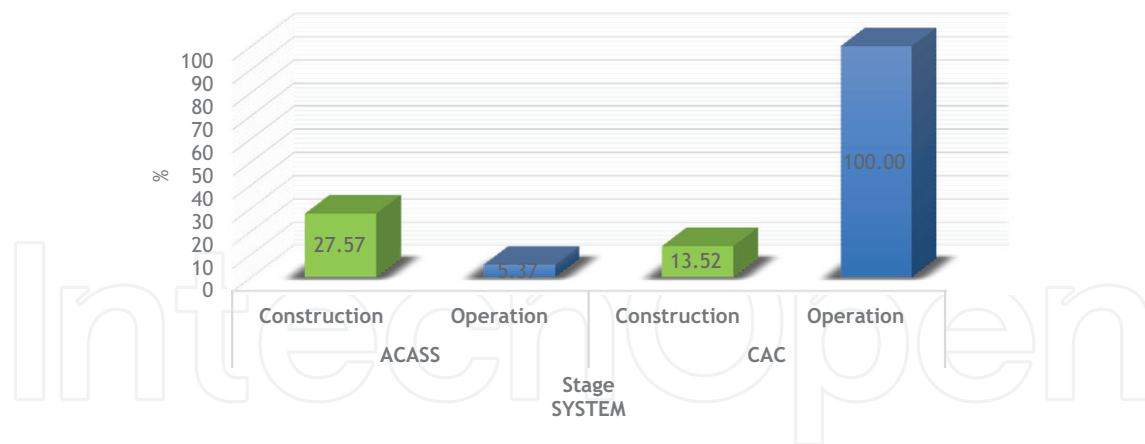


Figure 9. Percentage of CO₂eq emissions at each life cycle stage for both air-conditioning systems.

air-conditioning systems. The operation stage of the CAC system presents the highest CO₂eq emissions due to consumption of fossil fuel energy, while the ACASS system emits only 5.37% of the emissions at this stage.

During the construction stage, ACASS presents 14.05% higher CO₂eq emissions than the CAC system. This is attributed mainly to the difference in infrastructure demand for the construction of each system, and ACASS demands 79.20% more than CAC. It is important to note that the analysis is carried out considering 25 years of air-conditioning.

According to the results, it can be concluded that the ACASS system reduces greenhouse gas emissions due to lower consumption of fossil fuel energy. Therefore, for geographical regions where enough solar energy is available, the implementation of ACASS systems is a viable option for mitigating the environmental impacts related to global warming.

The high initial investment of the ACASS system might represent a barrier for its market, but it is necessary to continue working on the improvement of this type of systems, leading toward a massive production and aiming to reduce costs. As well, the intervention of decision makers is relevant to facilitate and incentivize the development of this kind of clean technologies.

8. Parameterized cost

Energy devices are expensive caused for the bin number of small parts to become a single product. In the air-conditioning systems, the parts for a roof device are based on three sections: solar concentrators, thermodynamic cycle part, and auxiliary system part.

Population in general has no money for investment for the energy consumption for the next 20 years to pay now. Then financial is the key for the installation for renewable energy systems.

A first approach to the cost of the entire air-conditioning system is based on the area of solar incident energy. The buildings have large area, but only the roof is useful for installation, but the thermal gain from wall and window is bigger than the size the roof solar-collected energy.

Then, the strategy for a quick viability evaluation is to evaluate the available solar roof in square meters and compare it with the value for required air-conditioning expressed in kW. If this value ratio is close to 1, then a detailed analysis for selection of the parts must be followed, if the value is lower than 0.5, then there is no opportunity for this roof technology because the solar loads and wall conduction are bigger than the total energy than a solar roof air conditional can exchange.

8.1. Solar concentrator system cost

There are some parts in the solar concentrator, which determines the total cost of this part. Installation is the biggest part [58], and it represents 38% of the investment, followed by storage thermal tank with a 24% of the total cost, and just a 14% from the solar thermal collector. The others are the cost from pipes with a 8%, thermal fluid with a 1%, pumping and controller 8% and fixing and mounting with a 7% (**Figure 10**).

8.2. Thermodynamic cycle cost

For the air-conditioning systems, there are just a few certified companies to build these devices. People have lack of information about the uncommercial devices. Considering than a conventional air-conditioning by compression is based on an evaporator, a condenser and a compressor, two of those heat exchangers are the same for an absorption cycle, but the metal is so different. In compression systems, aluminum and copper are used for the cycle. In an absorption cycle, the metal for the heat exchanger is stainless steel to avoid corrosion problems. This is a disadvantage for the cost because the cost of the stainless steel is higher than copper. Nowadays, the SS 304 has an average price about 1.62 USD by pound; aluminum has an almost constant price about 1.58 USD by pound, and copper has unstable price around 2.87 USD by pound.

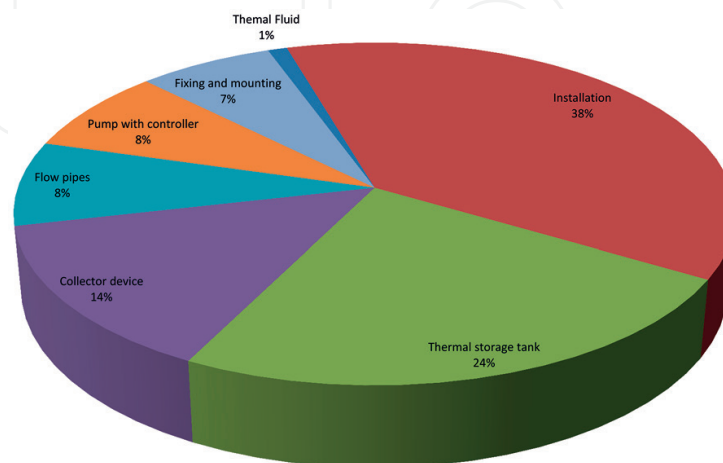


Figure 10. Cost for solar concentrator parts.

The heat exchanger areas are not the same for copper, aluminum or stainless steel because the thermal conductivity is quite different: copper is 386 W/mK, aluminum is 204 W/mK, and SS is 45 W/mK. This means that the thermal conductivity of the stainless steel is nine times lower than the copper.

Therefore, the four heat exchanger for the thermodynamic cycle must be costly, compared with a conventional compression air-conditioning, about 4.5 times the cost, based on the thermal conductivity and the cost today.

8.3. Auxiliary systems

The auxiliary systems are the installation and control between the solar concentrator and the thermodynamic cycle. The cost is based on the electronic device to control the pump as function of temperature, solar irradiation, and the instantaneous load into the building. The design is not commercial today, but it is not expensive because the energy for the operation has shown consumption about 1% of the total system by connection with inversed devices and solid-state circuits. The controller must be designed for the power of the pumps, those into the thermodynamic cycle and a circulator in the solar concentrator on the roof.

Electronic devices are really cheap based on Arduino © experiences, and these represent no more than 300 USD, and installation by a professional technician must be considered and the time for the installation by several hours may be expensive, as function of the building location, security conditions, roof access facilities. Then, in agree with the local cost by specialist cost hour, the auxiliary system may represent even a 30% of the installation device cost.

Finally, the total cost must be under a projected value for the lifetime of the roof air-conditioning system. This means that the cost must be compared with a cost for the actual technology and the total cost, for example, a storage tank of 243 L used by day into the roof air-conditioning system by the next 12 years [59] (Figure 11).

In the near future, the air-conditioning must be by solar, from the roof energy from thermal, photovoltaic, or a combination of those [60].

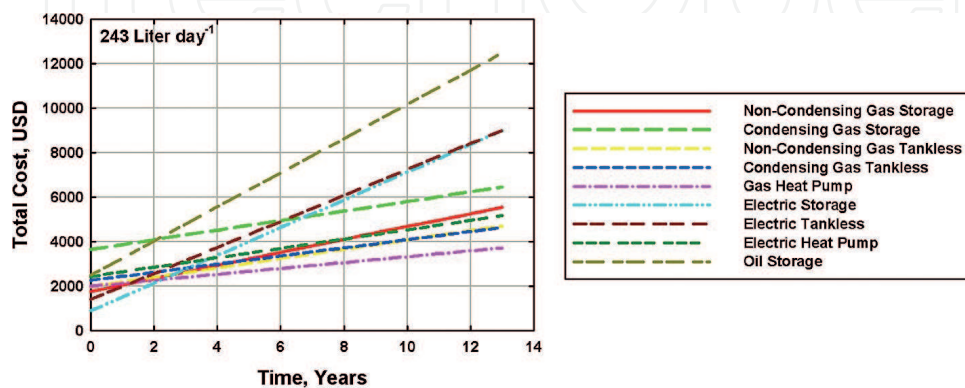


Figure 11. Total cost with actual technologies for air-conditioning [59].

9. Conclusions

This chapter shows a thermal load quantities based on physical values for a typical central Mexico location. The values for the home areas are common in the actual sizes for medium-prized houses for Temixco location. A conclusion for this scenario is that the medium-prized houses must have 4.2 kN/m^2 in weight capacity for a secure installation of solar roof facilities.

There are two aqueous solutions candidates to operate solar air-conditioning for roof applications: aqueous lithium bromide and aqueous hydroxides. Based on the working pair selection, the size for the heat exchanger must be defined by following the given methodology.

The solar devices are selected as function of the temperature and final use. These temperature values are higher than 90°C . The entire system (heat exchanger and solar devices) was evaluated just in operation phase and compared with a conventional air-conditioning system for 3.52 kW . The life cycle assessment concluded that in construction phase, the solar system is twice the emission in CO_2eq , but in operation phase, the CO_2eq is just 5.37% compared with the electrical device.

Acknowledgements

The authors are grateful to CEMIE-SOL-P09 for partial support. J. Ibarra-Bahena is thankful for the DGAPA-UNAM Postdoctoral Fellowship and Red Temática Sustentabilidad Energética Medioambiente y Sociedad.

Nomenclature

A	area, m^2
C_p	specific heat at constant pressure, $\text{kJ kg}^{-1}\text{K}^{-1}$
C	heat capacity flow rate, $\text{kJ s}^{-1} \text{K}^{-1}$
H	enthalpy, kJ kg^{-1}
m	mass flow rate, kg s^{-1}
Q	heat load, kW
R	heat capacity ratio, dimensionless
T	temperature, $^\circ\text{C}$
U	overall heat transfer coefficient, $\text{kW m}^{-2} \text{K}^{-1}$
W	mechanical work, kW

Subscripts

<i>AB</i>	absorber
<i>CO</i>	condenser
<i>c</i>	cold fluid
<i>EV</i>	evaporator
<i>GE</i>	generator
<i>h</i>	hot fluid
<i>i</i>	inlet condition
<i>m</i>	mean condition
<i>min</i>	minimum
<i>max</i>	maximum
<i>o</i>	outlet condition
<i>p</i>	pump
<i>s</i>	surface condition

Greek symbols

ε	effectiveness, dimensionless
φ	convective heat transfer coefficient, $\text{Wm}^{-2}\text{C}^{-1}$

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