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Solar assisted cooling with sorption systems: status of the research in Mexico and Latin America

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Solar refrigeration projects both national and international with sorption and other refrigeration systems have been developed in Mexico and other Latin American countries in the last 15 years. A review of the main projects, both for solar cooling and refrigeration and the results obtained are presented in this paper. A methodology where 19 solar technologies for cooling were identified is also presented. Although solar cooling is still not an economically viable technology, the advances made and the experience gained in the projects described and the improved systems envisaged, will make solar refrigeration systems play an important role in the future. © 1998 Elsevier Science Ltd and IIR. All rights reserved.

(Keywords: refrigeration system; solar energy; economic research; Mexico))

Systèmes frigorifiques à sorption utilisant l'énergie solaire: etat de la recherche au Mexique et en Amérique Latine

Dans les derniers quinze ans, le Mexique et des autres pays de l'Amerique Latine ont été siège de nombreux projects nationaux et internationaux concernant à la réfrigération solaire avec de différents systèmes, en particulier les basés sur le principe de la sorption. Dans ce travail on montre les principaux résultats des projects, les plus importants qu'on été développés dans le domain du conditionnemet de l'air et la réfrigération solaire, ainsi qu'une méthodologie où 19 technologies de refroidissement ont été identifiées. Jusqu'au présent, la réfrigération solaire n'est pas une tecnologie viable au point de vue économique, mais, le développement atteinte et les experiences gagnées dans les différents projects décrits ainsi que les améliorations prévues, feront que les systèmes de réfrigération jouent au future un rôle très important. © 1998 Elsevier Science Ltd et IIR. All rights reserved.

(Mots clés: système frigorifique; énergie solaire; économie recherche; Mexique)

Introduction

Mexico and all of Latin America suffer from a deficit in refrigerated storage facilities in the production areas and refrigerated transport as well in the rural areas. In the future, with a tremendous increment in production and consumption with the improvement in the quality of life and population, the need for refrigeration facilities will become one of the main problems to solve.

This great need for refrigeration combined with the high insolation in most of the countries of the area makes solar refrigeration very attractive, especially where electricity from central power stations is not available.

Several solar-driven refrigeration systems have been proposed and are under development: sorption systems including liquid/vapour and solid vapour absorption, adsorption, Rankine/vapour compression systems; photovoltaic/vapour compression, adsorption systems, etc. The technical viability of a number of systems has been proven but has not been justified economically, maybe only in some very particular cases of small size such as vaccine refrigerators with photovoltaic cells.

In this work only absorption systems and their development and experience in Mexico and other Latin American countries are discussed.

Solar cooling alternatives

A study on solar technologies available for cooling production and their characteristics

A study was carried out at the Solar Energy Laboratory at UNAM in 1991 in order to evaluate the potential of solar cooling systems[1]. In order to show the

Nomenclature

COP	coefficient of performance (dimensionless)
I	insolation ($W\ m^{-2}$)
M	solution flow rate ($kg\ s^{-1}$)
T	temperature (K or°C)

Greek Letters

η	collector efficiency (dimensionless)

Subscripts

a	ambient
AB	absorber
EV	evaporator
m	mean

methodology employed, a short summary of the study is included.

There are three main concepts that can be combined with each other for cooling with solar energy: the solar collector technologies, technologies for cold production, and specific uses.

The solar collector technologies considered relevant were:

(1) flat plate collectors;
(2) evacuated tube collectors;
(3) stationary non-imaging concentrating collectors such as CPC;
(4) dish type concentrating collectors;
(5) linear focusing concentrators (parabolic trough);
(6) solar ponds;
(7) photovoltaic systems.

The solar cooling technologies considered were:

A. compression/NH_3;
B. compression/CFC;
C. absorption H_2O/LiBr;
D. absorption NH_3/H_2O;
E. absorption/diffusion;
F. solid/gas absorption;
G. adsorption;
H. thermoelectric.

Desiccant cooling systems were not considered and no information from the experts was received.

It was decided to classify the specific use by temperature range:

I. 25 to 4°C.
II. 4 to −10°C.
III. −10 to −20°C.

The relationship between these three concepts defines the technologies for refrigeration production in the triad scheme resource–technology–use.

In order to identify the possible combinations which are viable options, a survey was carried out by means of a questionnaire. The following three actions were requested.

(i) To suggest the triads that were viable.

(ii) To evaluate the degree of development of each one of them according to the following criteria:

(1) Research, including prototype in laboratory.

(2) Pre-production, demonstration prototype in order to reduce costs and increase in efficiency with the idea of making them commercial.

(3) Commercial introduction, a product with a technical and economical feasibility that is available under order.

(4) Market maturity, has captured part of the market.

The last action requested was:

(iii) To propose a probable date for commercial introduction for those triads that were found to be in the two first levels or categories of development.

The answers obtained from a panel of 16 experts is shown in *Figure 1* for the solar refrigeration technologies selected as viable. A triad was selected as viable when it appeared at least with a frequency of two. It can be seen that three solar technologies, flat plate collectors/absorption LiBr (1-C), flat plate collectors/absorption NH_3 (1-D), and photovoltaic/compression CFC (7-B), had the most number of answers. Some solar technologies appear twice, as the three temperature ranges are also considered, the first six columns corresponding to the first temperature range, 25 to 4°C, the next 10 columns to the middle range, 4 to −10°C, the lowest temperature range, −10 to −20°C, corresponding to the last three columns.

To determine the state of development, an arithmetic average was obtained of the answers assigning a numerical value to each category. This value corresponds to 1 for research, 2 for pre-production, 3 for commercial introduction and 4 for market maturity. The results are shown in *Figure 2*, for the range 4 to −10°C. The results show that only photovoltaic/thermoelectric was considered mature. Photovoltaic/compression CFC according to one of the experts were not considered reliable due to small operational faults that are difficult to correct in site especially in developing countries and dish type concentrators/solid gas absorption were in the phase of commercial introduction.

The probable date for commercial introduction was the arithmetical average of the answers. This is shown in *Figure 3*. All probable dates suggested were after the year 2005.

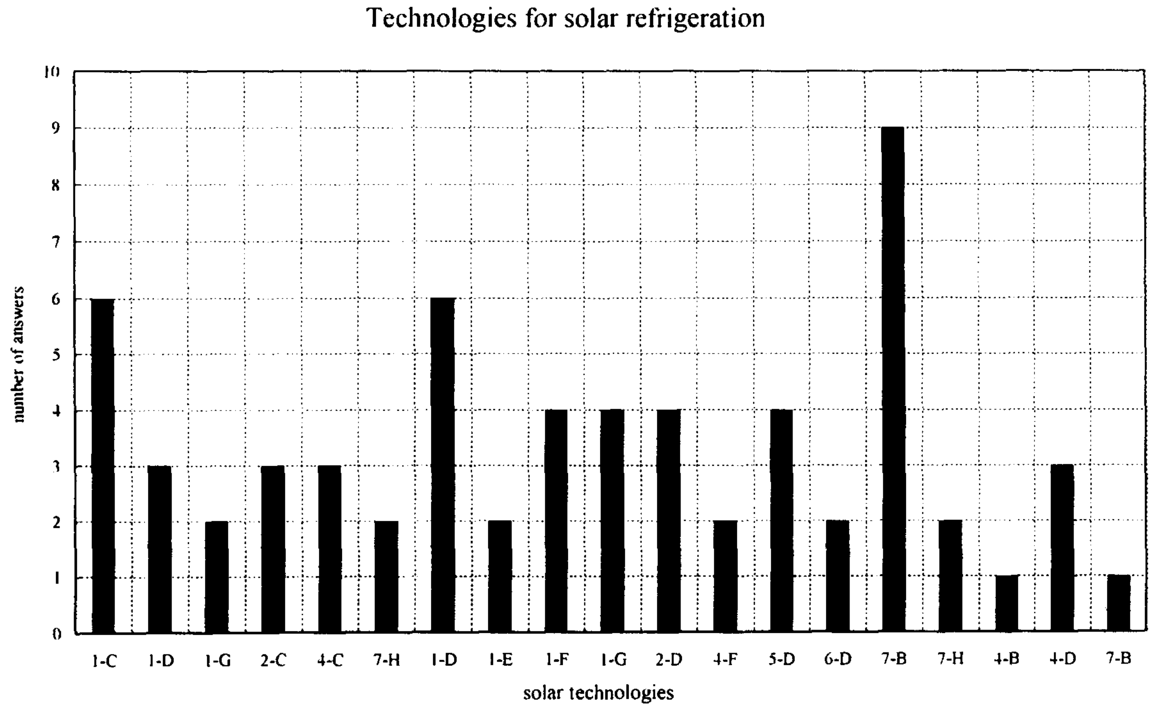

Figure 1 Technologies for solar refrigeration
Figure 1 *Technologies pour la froid solaire*

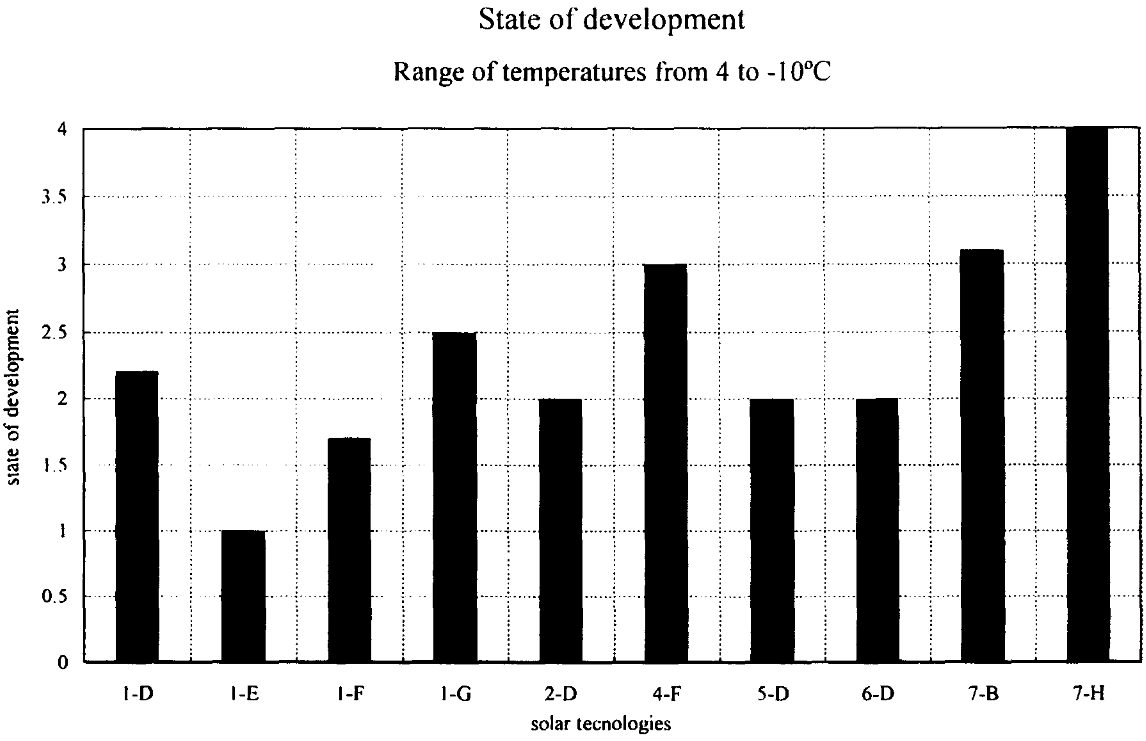

Figure 2 State of development for the range of temperatures 4 to −10 °C
Figure 2 *État de développement dans le domaine de températures de 4 à −10°C*

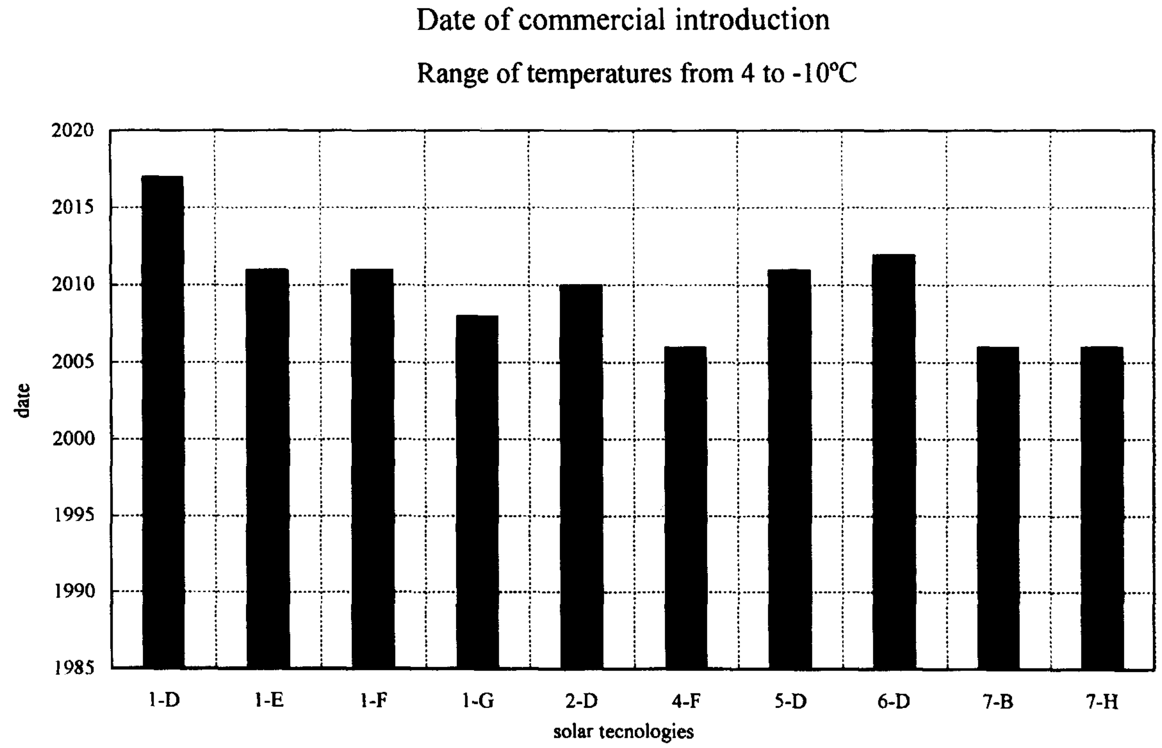

Figure 3 Possible date of commercial introduction for the range 4 to −10°C

Figure 3 *Date possible d'introduction commerciale pour le domaine de températures de 4 à −10°C*

Diagnosis

According to the experts, 19 possible technologies were identified for solar refrigeration. The photovoltaic/vapour-compression systems and the photovoltaic/thermoelectric have predominated in the application of small refrigerators for medical use in isolated areas, such as vaccine conservation where high system cost is justified.

Solar thermal systems, such as flat plate collectors and lithium bromide/water absorption cooling systems, are in the stage of pre-production and commercial introduction,

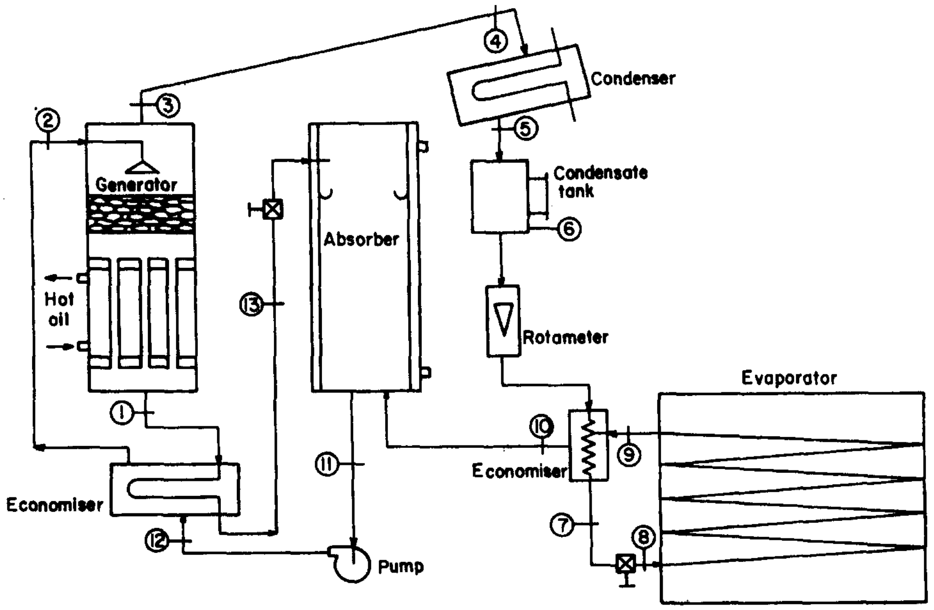

Figure 4 Schematic diagram of the ammonia/water absorption refrigeration system at the Solar Energy Laboratory

Figure 4 *Diagramme schématique du système de réfrigération par absorption ammoniac–eau au Laboratoire d'Energie Solaire* also for small capacities. Five companies are not fabricating systems due to a lack of a market for their products.

The global efficiency of solar refrigeration systems oscillated between 7% and 20% and differs because of insolation conditions. Critoph[2] mentions that under sufficient insolation (5.5 kWh m^{-2} day^{-1}) the majority of systems have a global efficiency of between 8 and 11%. In the situation that electricity prices continue to be invariable (low), the solar refrigeration systems will have to reduce their costs by a factor of three to five times the actual costs in order to become competitive with the traditional vapour compression systems.

It was expected by the experts that 18 of the 19 technologies identified for solar refrigeration would achieve the state of commercial introduction by 1995. Only the technology 1-D, ammonia/water absorption systems with flat plate collectors, would achieve commercial introduction by the year 2000.

It was considered difficult to predict the date when these solar technologies reach maturity. The problem is not only technical but it incorporates economical, social and environmental aspects.

In general it is expected that a technology will have to wait 15 years to pass from the stage of commercial introduction to the one of maturity. It does not always happen that a technology that reaches a development stage continues to the next.

Results derived from the study

Apart from flat plate collectors/$LiBr-H_2O$, the photovoltaic/vapour compression and photovoltaic/thermoelectric, the other technologies that have the major potential to reach maturity are as follows.

For uses between 4 and 25°C, evacuated tube with ammonia/water absorption systems.
For uses between −10 and 4°C, dish type concentrating collectors with solid/gas absorption.
For uses between −20 and −10°C, parabolic trough concentrators with ammonia/water absorption.

Although the study was carried out in 1991 and the number of experts that answered all the questions were only 16, the methodology employed and the type of results obtained gave a clear view of the potential of solar refrigeration technology and what is needed to do in terms of cost and efficiency.

It should again be mentioned that desiccant cooling systems were not included in this study and that no information was provided by the experts consulted.

Solar cooling activities in Mexico

Research on solar cooling and refrigeration in Mexico has been carried out by universities and research institutes, the following is a brief summary.

Experimental continuous absorption refrigeration system

An experimental system has been developed at UNAM that is designed for a production of 100 kg of ice per day[3]. The system tries to optimize heat transfer in the generator and the absorber utilizing a falling film design. An interesting feature of the system is the storage of cold in a brine tank where the ice is made. *Figure 4* shows a schematic diagram and *Figure 5* a photograph of the system. *Figure 6* shows the experimental results obtained at three different experimental conditions

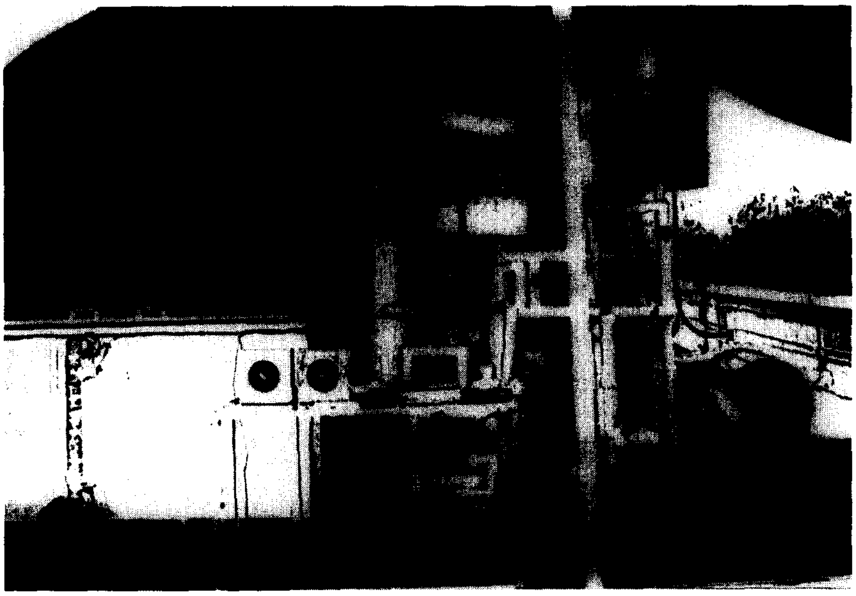

Figure 5 Experimental ammonia/water absorption system at the Solar Energy Laboratory

Figure 5 *Système expérimental d'absorption ammoniac–eau au Laboratoire d'Energie Solaire*

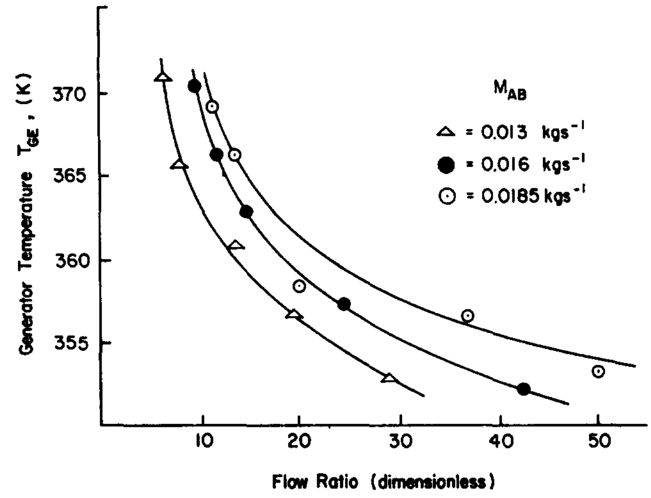

Figure 6 Generator temperature against flow ratio for 3 strong ammonia solution flow rates

Figure 6 *Température de génération en fonction du rapport de flux pour trois débits differentes relations de flux de la solution concentrée*

which allow operation even at low generator temperatures at higher flow ratio values. *Table 1* shows the operating conditions of the system. Generator temperatures in the range of 80 to 100°C were used using hot oil heated by an electric heater simulating non-focusing collectors. The system is now being tested with small modifications and with an evacuated tube solar collector system, which is shown in *Figure 7*. The collectors are NEG Model 2800 that have an efficiency curve shown in *Figure 8*.

Absorption–diffusion experimental units

An old 250 l capacity Servel brand refrigerator was used for the prototype[4]. A high-temperature, flat plate solar collector was installed instead of the original generator

Table 1 Operating conditions of the ammonia–water refrigeration prototype

Tableau 1 *Conditions de fonctionnement du prototype de réfrigérateur ammoniaque–eau*

Generator	
Working pressure	1.072 MPa
Heating medium inlet/outlet temperature	102.7/98.0°C
Ammonia–water solution inlet/outlet temperature	54.5/96.1°C
Refrigerant vapour leaving generator	67.2°C
Mass flow rates Strong solution	$1.49\text{x}10^{-2}$ kg s^{-1}
Weak solution	$1.37\text{x}10^{-2}$ kg s^{-1}
Ammonia	$0.12\text{x}10^{-2}$ kg s^{-1}
Hot oil	0.58 kg s^{-1}
Heat load solution	4.6 kW
Heat load hot oil	5.9 kW
Rectifier	
Working pressure	1.072 MPa
Temperature inlet/outlet	67.2/62.1°C
Mass flow rate	$0.12\text{x}10^{-2}$ kg s^{-1}
Concentration inlet/outlet[a]	0.987/0.991
Heat load[a]	$3.3\text{x}10^{-2}$ kW
Condenser	
Condensing pressure	1.072 MPa
Condensing temperature	28.1°C
Heat load ammonia[a]	1.53 kW
Heat load water	1.16 kW
Cooling water inlet/outlet temperature	11.6/14.5
Cooling water consumption	$9.5\text{x}10^{-2}$ kg s^{-1}

Precooler	
Liquid ammonia pressure	1.072 MPa
Liquid ammonia inlet/outlet temperature	28/8.4
Ammonia vapour pressure	0.155 MPa
Ammonia vapour inlet/outlet temperature	−12/−10.8
Heat exchange rate	0.22 kW
Economizer	
Working pressure	0.993 MPa
Inlet/outlet temperature	
weak solution	96.1/68.4°C
strong solution	31.0/57.0°C
Heat exchange rate	1.83 kW
Evaporator	
Evaporating temperature	−13.0°C
Evaporating pressure	0.155 MPa
Refrigeration heat load	1.62 kW
Absorber	
Absorption pressure	0.141 MPa
Final absorption temperature	33.2°C
Ammonia vapour temperature	−10.8°C
Cooling water inlet/outlet temperature	11.7/14.7°C
Cooling water consumption	0.18 kg s^{-1}
Heat load water	2.26 kW
Heat load solution	3.9 kW

[a] Calculated.

heated by a gas burner. The concentration of the ammonia–water solution was increased in order to achieve boiling in the generator when the temperature was changed from its original 160°C to the 105°C reached by the collector. Under good insolation conditions the refrigerator maintained freezing temperatures during 5 h a day, provided that ambient temperature does not exceed 28°C.

A COP value of 0.11 was obtained with the collector operating at constant radiation of (850 W m^{-2}) with an exit temperature of 105°C, which is around one third of the value reached when the refrigerator works with a gas burner and a generator temperature of 160°C.

A conventional Electrolux system was modified to work with a heating fluid instead of a burner. This project has the objective of using different types of inert gases. In this project helium instead of hydrogen has been used,

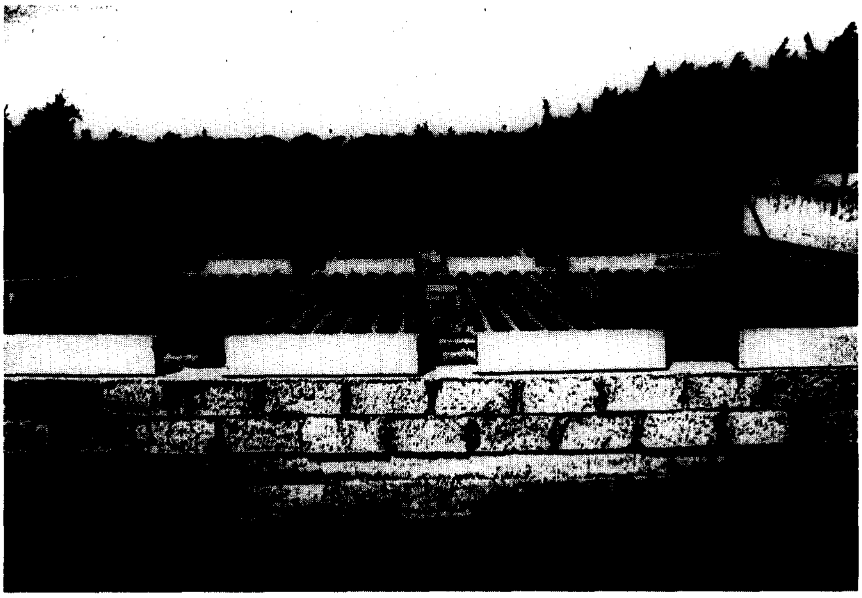

Figure 7 NEG Model 2800 evacuated tube collector bank at the Solar Energy Laboratory

Figure 7 *Champ de capteurs solaires à depression NEG modèle 2800 au Laboratoire d'Énergie Solaire*

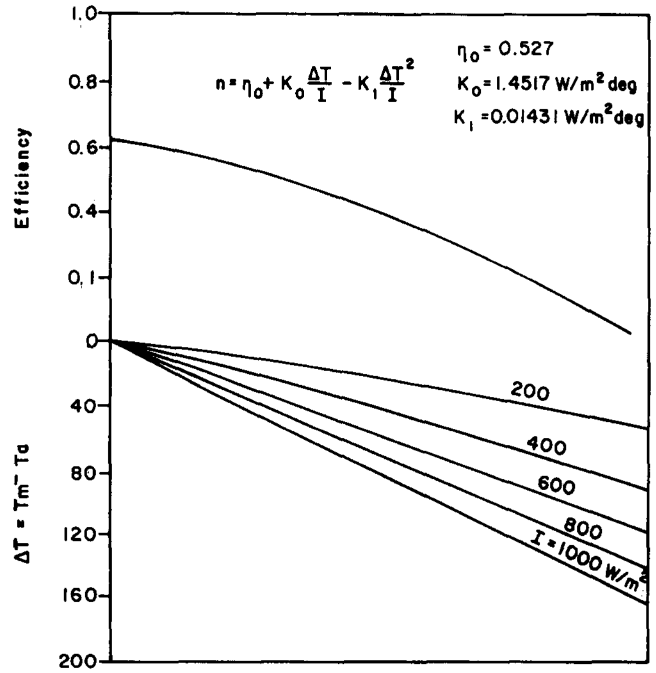

Figure 8 Efficiency curve for NEG Model 2800 evacuated tube collector

Figure 8 *Courbe d'éfficacité pour le capteur solaire NEG 2000 à dépression sous vide* which is difficult to handle and has problems when scaling the system to higher capacities[5].

Intermittent solid/gas system

Studies are being carried out on the use of adsorption refrigeration systems at the Universidad Autonoma Metropolitana using activated carbon and zeolites as adsorbents and methanol as adsorbate, small prototypes have been constructed and are being tested[6].

An intermittent prototype system for conservation of medicines in hot arid zones using calcium chloride and monomethylamine as refrigerant is being constructed at the Solar Energy Laboratory. The system is designed for condenser temperatures of 40°C, generating temperatures of more than 100°C are necessary. *Figure 9* shows a schematic diagram of the system.

Systems operated with low temperature geothermal energy

In an co-operative program between the Solar Energy Laboratory and the Geothermal Department of the Instituto de Investigaciones Eléctricas, an experimental absorption refrigeration system was operated in the Cerro Prieto geothermal field in Baja, California, with low temperature geothermal steam in the range 90 to 130°C and ammonia/water and later on ammonia/lithium nitrate[7,8]. Evaporator temperatures in the range of −20 to −10°C were produced and used for a cooling storage and for ice production.

Demonstration projects in Mexico

The Instituto de Investigaciones Eléctricas/laboratorio de Energía Solar–IIM-UNAM Solar Cooling Project in Mexicali

A solar cooling demonstration was carried out in the city of Mexicali during the years of 1981 and 1982 in a co-operative program between the Materials Research Institute of the University of Mexico and the Electric Research Institute[9].

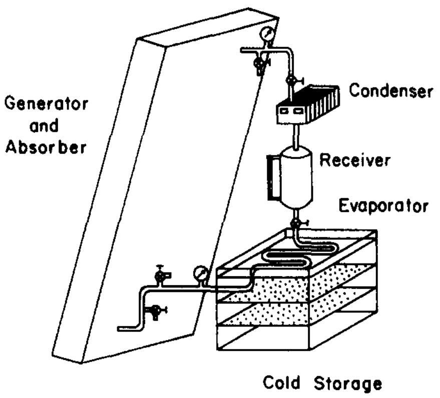

Figure 9 Schematic diagram of calcium chloride/monomethylamine intermittent solar refrigeration system at the Solar Energy Laboratory

Figure 9 *Diagramme schématique du système de réfrigération solaire à chlorure de calcium/monométhylamine à fonctionnement intermittent, au Laboratoire d'Énergie Solaire*

System description. The solar subsystem consisted of 30 flat plate collectors with a total area of 48 m^2, the collectors shown in *Figure 10*, of Mexican design, were doubled glazed with black chrome as selective surface and were not available commercially in Mexico, they were developed specially for the project modifying a commercial version of a single glazed domestic hot water heating system. The collectors were installed on the roof of the IIE administrative building oriented south with an optimized inclination for the summer months of 12°. A 2 m^3 hot water storage tank, with height 1.71 m and diameter 1.22 m, was installed as storage. The absorption cooling system selected for the demonstration project was a lithium bromide/water Yazaki unit model WFC-600 with a nominal capacity of 7 kW. The unit produced chilled water that was fed to the two Yazaki fan coils model YF600 of 3.5 kW capacity each that were installed in the conference room in the building. A compact cooling tower Yazaki model CT-500 with a capacity of 18.6 kW was part of the system as well as an auxiliary hot water gas fired boiler which was never used. The tank and all the other components except the collectors were installed in the parking lot of the building due to safety restrictions as Mexicali is located in a zone of high seismic risk. The system was operated during the summer months of 1981. A data acquisition system was installed and the system was monitored during the last days the month of August and all the month of September. Due to operational and instrumentation problems the data was collected intermittently and incomplete. The main problems encountered were the constant failure of the turbine flow meters to register the hot water flow in the collector system and the lower than recommended flow of the chilled water circuit. This low flow rate caused a reduced cooling capacity of around 3 kW. With the purpose of optimization of the system a simulation of the solar cooling system was carried out[10]. The objective of the simulation was to model the operation of the system at the design conditions and to evaluate the real potential of the equipment. The most important conclusion of the simulation was to show that the system was capable to operate with high efficiencies and higher than nominal cooling capacities. The operation of the system for three different chilled water temperatures is shown in *Figure 11*. It can be seen that the cooling capacity has a large dependence on chilled water temperature and increases for most of the time over the nominal capacity of 7 kW, for evaporator temperatures above 7°C.

The Sonntlan German–Mexican project

Sonntlan was an international collaboration program between the governments of the Federal German Republic and Mexico on solar energy for rural and

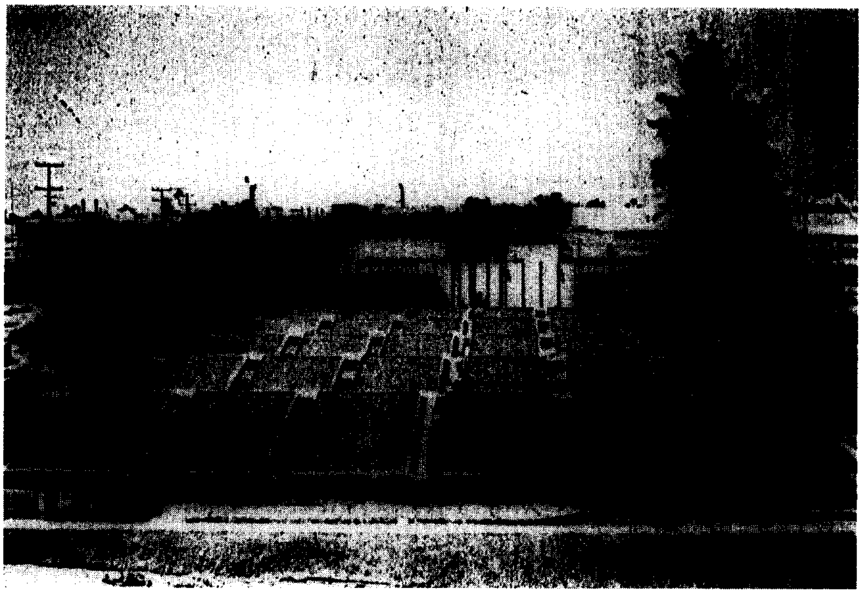

Figure 10 Double glazed flat plate collector bank for solar cooling project IIE/UNAM in Mexicali

Figure 10 *Champ de capteurs solaires plans avec double paroi pour le projet de refroidissement solaire IIE/UNAM à Mexicali*

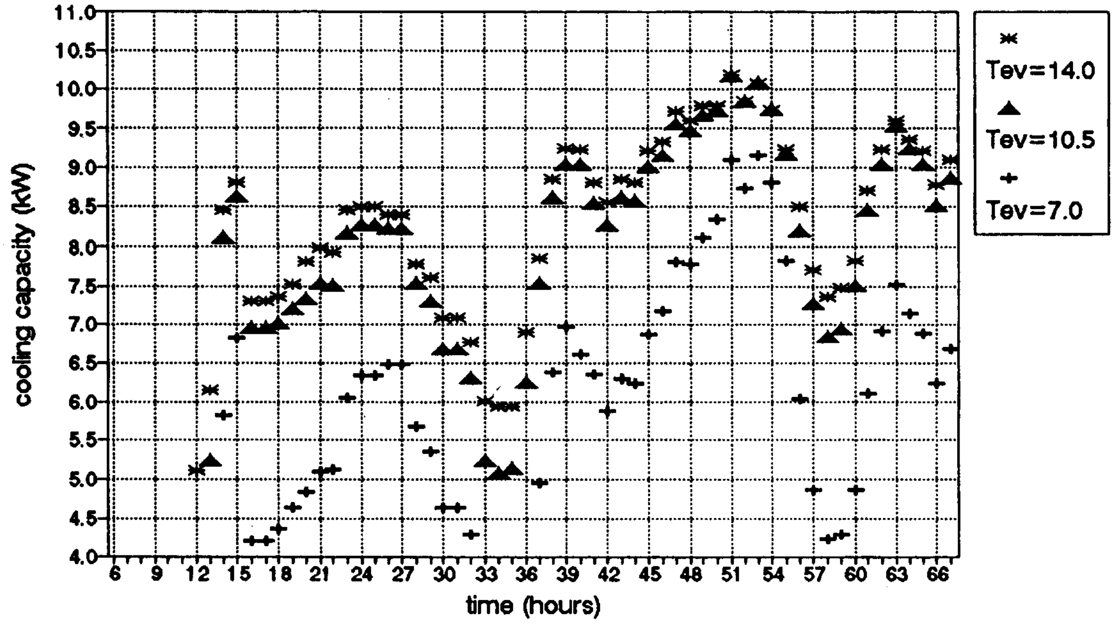

Figure 11 Cooling capacity against time for three evaporating temperatures

Figure 11 *Puissance de refroidissement en fonction du temps pour trois températures d'évaporation*

urban uses[11]. There were two projects, Sonntlan Las Barrancas and Sonntlan Mexicali. The first one was intended to satisfy the energy needs of a fisher community, including drinking water, electricity, hot water and communications. For this it included solar desalination plants, photovoltaic systems and diesel plants for electricity generation. For economic development the project offered freezing and conservation of fish products, ice making and fish processing. The cooling systems were ammonia/water absorption systems.

The Sonntlan Mexicali Solar Cooling Project

The Solar Cooling Project consisted of six one-family houses, five attached to each other and one separated, that all incorporated passive elements for reducing the cooling load and a machine tower containing components of the active solar system[12]. The collectors were installed on the roofs of the houses. The reduced cooling load of 7 kW (against a typical value of 18 kW for a normal house in Mexicali) was provided by a 90 kW

ARKLA-WFB 300 solaire lithium bromide/water absorption chiller. The chilled water was first delivered to a cold-water storage tank and then distributed to air handling units installed on the upper level of each house. The system is shown schematically in *Figure 12*. *Table 2* shows the technical data for the system.

During 1983 the houses were not yet occupied and system operation was for test purposes only. A modification of subsystem components based on the operational experience of 1983 and 1984 was completed by the end of 1985. The modifications included decentralization of air handler control, replacement of control computer capable of withstanding the severe environmental conditions in the machine tower, bypassing of the heat exchanger between collector area and hot water storage tanks, elimination of parts of hot water and chilled water tubing. These modifications increased the overall collector field efficiency from 26 to 29%. The yearly solar fraction increased from 59% in 1985 to 75% in 1986, as shown in *Figure 13*. The efficiency of the chiller varied from 53 to 73%. For reasonable operating hot water inlet conditions of 75–95°C, cooling water temperatures of 29 to 32°C and chilled water temperatures of 8 to 10°C, the steady-state efficiency showed almost constant figures of about 69% and daily efficiencies of 64%. From 1984 to 1986, the major part of the houses were inhabited continuously and cooling service was provided to the houses. Inside conditions were regularly kept within a comfortable range of approximately 26–28°C and 50% relative humidity even during the extreme hot season with outside highs of 42–48°C.

The Sonntlan Barrancas solar thermal system

The solar thermal systems in Las Barrancas consisted of two subsystems, one of 'low temperature or hot water utilizing flat plate collectors' and one of 'high temperature using concentrators and a hot oil circuit'[13].

Hot water subsystem. The solar collector system consisted of 56 modules of five heat pipe collectors each one connected in series. The collector field was divided in two sections of 4 × 7 modules connected in parallel. The effective area was of 1540 m^2. The energy generated (3000 kWh day^{-1} at 120°C theoretically) was used for the instantaneous multistage desalinization plant (75.8%), the ammonia/water absorption refrigeration plant for ice production (17.7%) and hot water for the fish processing plant (6.5%). The solar subsystem included three hot water storage tanks with a volume of 38 m^3 each that allowed for a continuous availability of hot water.

Hot oil subsystem. The solar subsystem consisted of 18 modules of Helioman parabolic trough concentrating collectors with an effective area of 30.6 m^2 each adding up to an area of 550.8 m^2 for a theoretical energy production of 1650 kWh day^{-1} at a temperature of 180°C. The hot oil subsystem included a 16 m^3 storage tank capable of storing 700 kWh. The hot oil subsystem included a heat exchanger with the hot water circuit as a backup for the flat plate collector system.

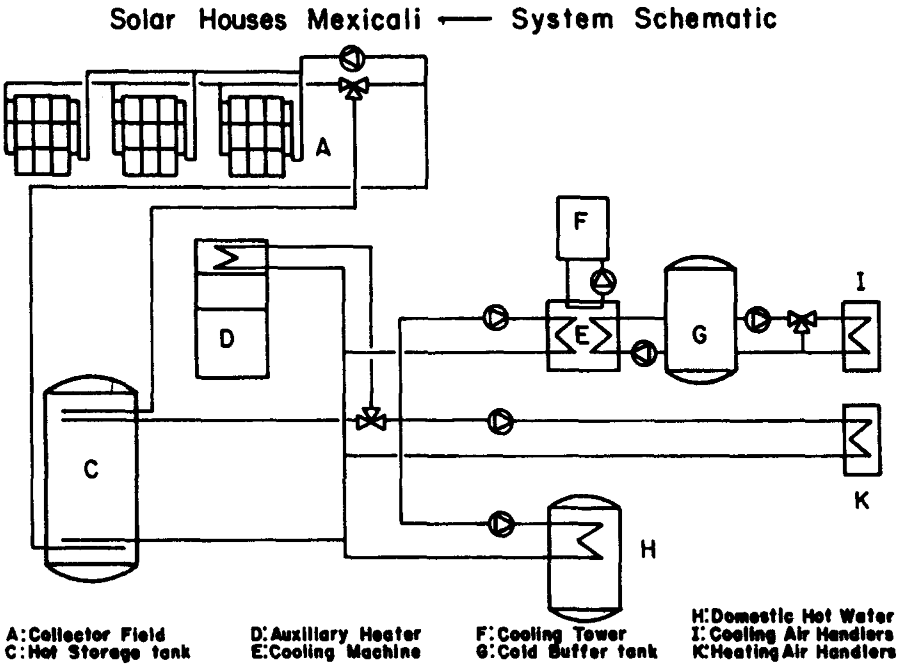

Figure 12 Schematic diagram of the solar cooling system of the Sonntlan Solar Houses in Mexicali

Figure 12 *Diagramme schématique du système de refroidissement solaire des maisons solaires 'Sonntlan' à Mexicali*

Table 2 Sonntlan Mexicali lithium bromide/water absorption cooling system

Tableau 2 *Système de refroidissement par absorption bromure de lithium/eau du project Sonntlan en Mexicali*

Technical data	
Solar Collector System	
Flat plate collectors (288 modules of 1.1 m^2 each)	316 m^2
Operation temperature summer	70–90°C
Heat storage capacity (2 tanks)	30 m^3
Thermal gain in summer	up to 1800 kWh day^{-1}
Heat transport and storage medium	water
Air Conditioning System	
Arkla-WFB 300 Solaire absorption chiller	max. 90 kW
Temperature hot water	70–90°C
Temperature chilled water	min 7–11°C
Temperature cooling water	25–28°C
Capacity of wet cooling tower	max. 200 kW
Cooling load in summer	up to 500 kWh day^{-1}
Air handling units	1 in each house (6)
Air outlets/inlets	1 in each floor (12)

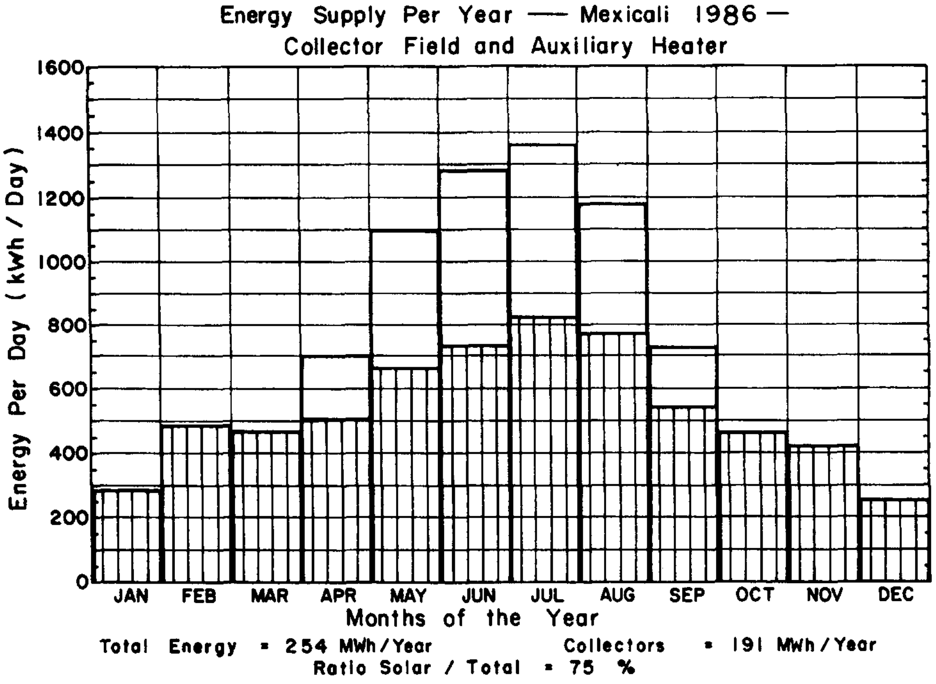

Figure 13 Yearly solar fraction for collector field of the Sonntlan Solar Houses in Mexicali

Figure 13 *Fraction solaire journalière pour le champ des capteurs solaires des maisons solaires 'Sonntlan' à Mexicali*

Refrigeration. An ammonia/water absorption refrigeration plant was operated for quick freezing and storage of sea food in a cooling container. It was designed for an 8 h freezing during daytime with simultaneous energy supply and a 12 h storage operation by cold storage.

As the freezing and storage room were working at different temperatures, the low pressure part (evaporator and absorber) was designed for two stages with different pressure levels. The plant was designed for the processing of 650 kg fish per day. *Table 3* shows the technical data for the system and *Figure 14* is a schematic diagram of the system. The design data was fulfilled by measurements in April 1984. *Figure 15* shows the daily energy balance and efficiency of the refrigeration plant for a period of a month, and *Figure 16* shows the actual coefficient of performance against the temperature difference between hot oil in the generator and the cooling water in the condenser and absorber.

Operation had shown that because of the two-stage process more personal supervision was required for getting steady-state operational conditions. Therefore a first step of simplification was performed by installing the expansion valve stations for ammonia outside the cooling container for better adjusting of ammonia flow and evaporator pressures. In contrary to design and

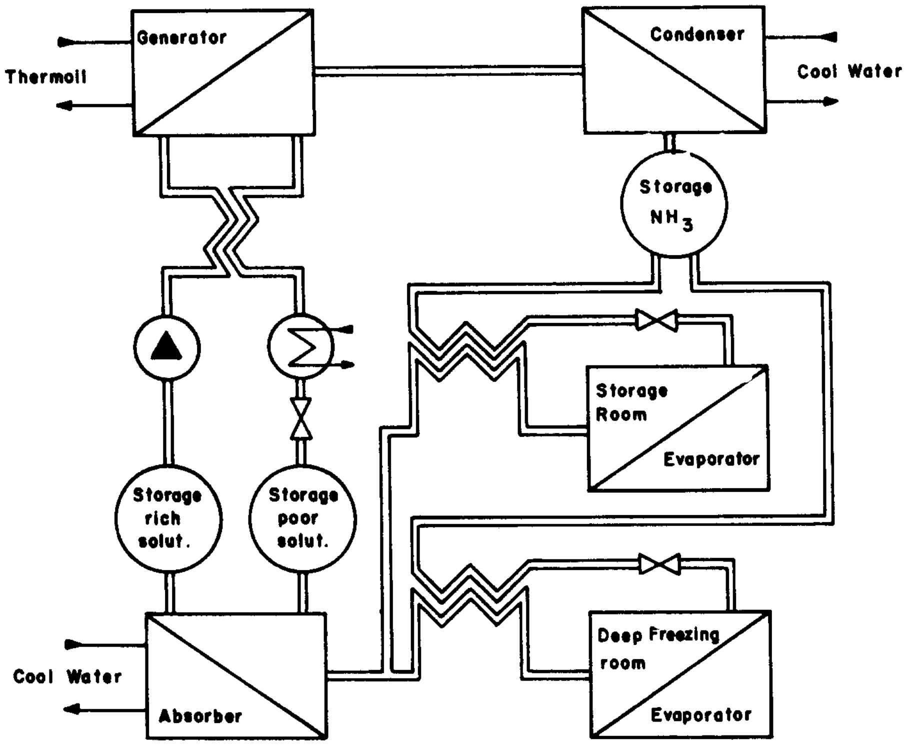

Figure 14 Schematic diagram of the Sonntlan Las Barrancas absorption refrigeration system for deep freezing and storage

Figure 14 *Diagramme schématique du système frigorifique par absorption pour la surgélation et le stockage du project 'Sonntlan' à Las Barrancas*

operation mode is the real behaviour of consumers, which during their fishing sessions were freezing one to two tons of sea food per day up to twice a week and usually would start in the late evening. As a result the freezing operation was considerably exceeded, so that a displacement of solution into the storage room part where the solution storages were placed, and an unsteady operation of the plant occurred.

Ice making unit

The basis of the design of the refrigeration plant for ice making was a daily quasi-continuous operation of 20 h at a production rate of 2000 kg of ice per day, the setting period for charging and discharging was 4 h. For this reason a brine storage with 7500 kg of brine (H_2O + 20% $CaCl_2$) for the ice making was designed, in which water cans of steel are submerged. The evaporator of the

Table 3 Sonntlan Las Barrancas ammonia/water absorption refrigeration unit

Tableau 3 *Unité de réfrigération par absorption ammoniaque/eau du project Sonntlan en Las Barrancas*

Technical data	
Performance generator	40 kW
Thermoil temperature inlet/outlet	160/150°C
Pressure condensator	13.6 bar
Refrigeration capacity freezer room	11.3 kW
Pressure freezer room	0.71 bar
Evaporation temperature freezer room	−40°C
Temperature freezer room	−30°C
Refrigeration capacity storage room	1.7 kW
Pressure storage room	1.2 bar
Evaporation temperature storage room	−18°C

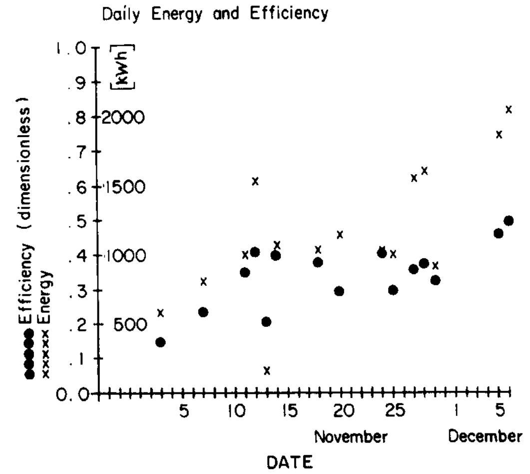

Figure 15 Daily energy balance and efficiency for the deep freezing and storage room absorption refrigeration system in Sonntlan Las Barrancas

Figure 15 *Bilan d'énergie journalièr et l'eficacité des chambres de surcongélation et de stockage dans le project 'Sonntlan' à Las Barrancas*

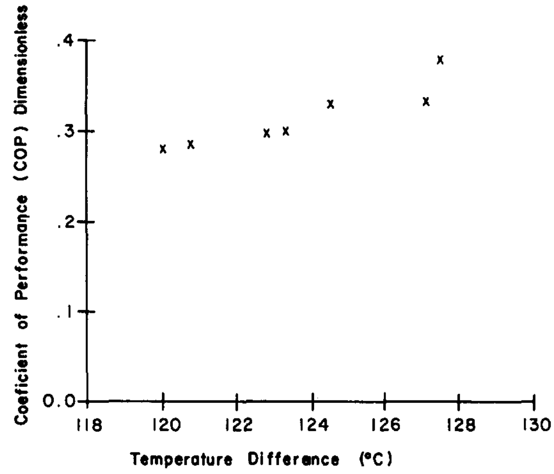

Figure 16 Actual coefficient of performance against the temperature difference between hot oil and the cooling water for the deep freezing and storage system in Sonntlan Las Barrancas

Figure 16 *Coefficient d'efficacité actuel en fonction de la difference de temperature entre l'huile chaud et l'eau de refroidissement pour les systèmes de surgélation et de stockage du project 'Sonntlan' à Las Barrancas*

refrigerating plant removes the heat from the brine and cools it down to −4°C. The water inside the cans is then cooled down from approximately ambient temperature to 0°C and starts to freeze. This operation is advantageous, because the brine storage serves as a cold storage because of its high heat capacity. The technical data is shown in *Table 4* and *Figure 17* shows an schematic diagram of the ammonia/water absorption unit.

The design data was fulfilled as documented by the test measurements in April 1994. *Figure 18* shows the measured coefficient of performance of the system against the temperature difference between the hot water in the generator and the cooling water in the condenser and absorber.

The practical operation, however, showed that the design value for the required refrigeration energy of 256 kWh (12.8 kW × 20 h), which mainly considers cooling down of water from ambient temperature and the heat of fusion, was not sufficient if the plant is in operation only once or twice a week. Then the brine (7.5 tons) and the ice cans (app. 1.6 tons) have to be cooled down from the higher temperature, in the extreme from the ambient. The necessary refrigerating capacity then will be approximately 390 kW.

The Muruata installation

Under the sponsorship of the Mexican government PRONASOL program, a fishing village on the Pacific coast of Michoacan, the American Company Energy Concepts Co., installed six Double Isaac systems, three for ice production and three for cooling a cold storage room[14]. The project started in October 1991 with the installation of two double Isaac systems and after being hit by two hurricanes which damaged the most of the concentrating collectors has now been completed and is under the management of the local authorities. The double Isaac have a nominal capacity of 66 kg of ice per day. Measurements in Maruata made in November–December 1994 showed an average ice production of 29 kg per day per unit. The cold storage had an average temperature of 5°C during these months which is quite adequate for short time preservation of fish. The village at the time of installation had no electricity but now it has. It is imperative to have a good supervision and maintenance of the system in order to have the system operational so that it can survive the temptation of changing them for a conventional unit.

Table 4 Sonntlan Las Barrancas ammonia/water absorption ice making unit

Tableau 4 *Unité de production de glace par absorption ammoniaque/eau du project Sonntlan en Las Barrancas*

Technical data	
Performance generator	25 kW
Hot water inlet/outlet	120/110°C
Pressure condenser	13.6 bar
Refrigeration capacity	12.8 kW
Pressure	2.85 bar
Evaporation temperature	−9°C
Brine temperature	−4°C

Unison and Sandia National Laboratory project evaluation of the Isaac system

Evaluation of the Isaac unit is being carried out at the University of Sonora in a collaboration project with Sandia National Laboratories. A small unit is being analyzed and data is being collected for temperatures, solar radiation and ice production[15].

Puerto Lobos

The Puerto Lobos Development Project is the second PRONASOL funded solar project for rural development[16]. The fishing village is localized in the state of Sonora. The objectives are to provide the 230 inhabitants with drinking water (3000 l day^{-1}, electricity (30 kW), refrigeration for 3000 kg of fish and ice production of 1500 kg per day. The refrigeration and ice production systems will be of conventional design using mechanical vapour compression units. The collector field will consist of 72 concentrating parabolic trough collectors with an aperture of 13.93 m^2 giving a total area of 1003 m^2. Until now only the solar water distillers are installed. There are financial problems for the installation of the rest.

Conclusions

For the last 15 years there has been a continued effort to develop solar refrigeration systems in Mexico. A number of experimental prototypes have been constructed and the result has been the accumulation of solar refrigeration know-how in research centres and universities. The main obstacles for the development of these systems

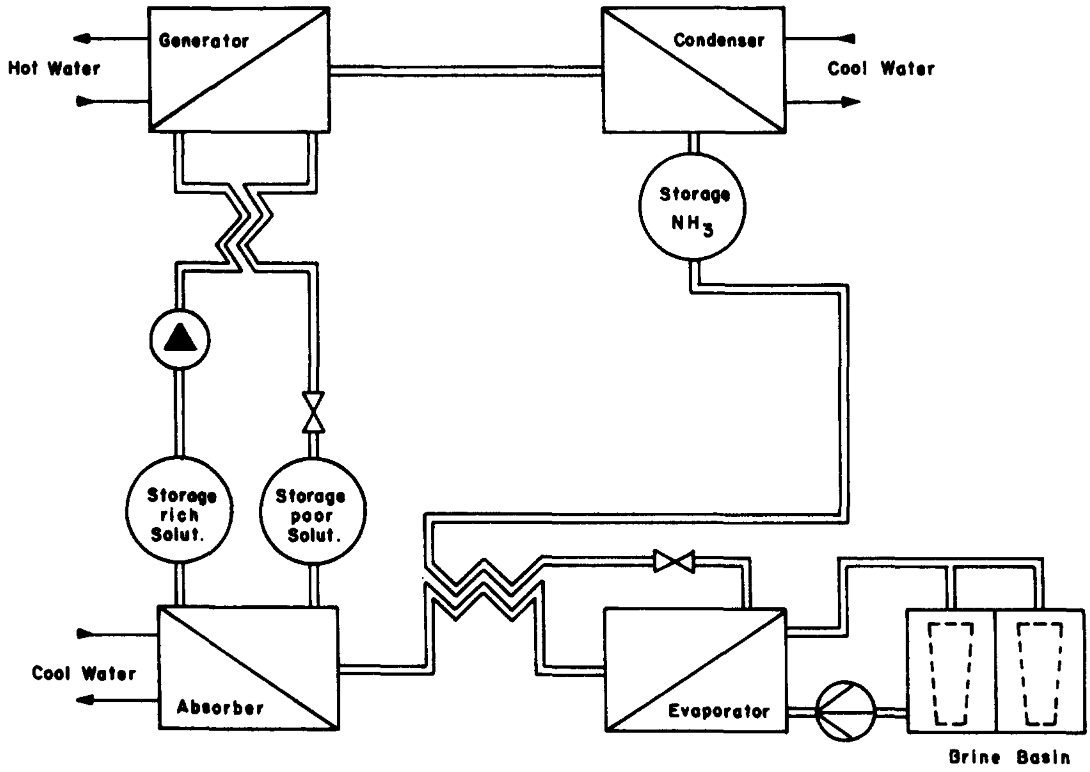

Figure 17 Schematic diagram of Sonntlan Las Barrancas absorption refrigeration ice making system

Figure 17 *Diagramme schématique du système de production de glace du project 'Sonntlan' à Las Barrancas*

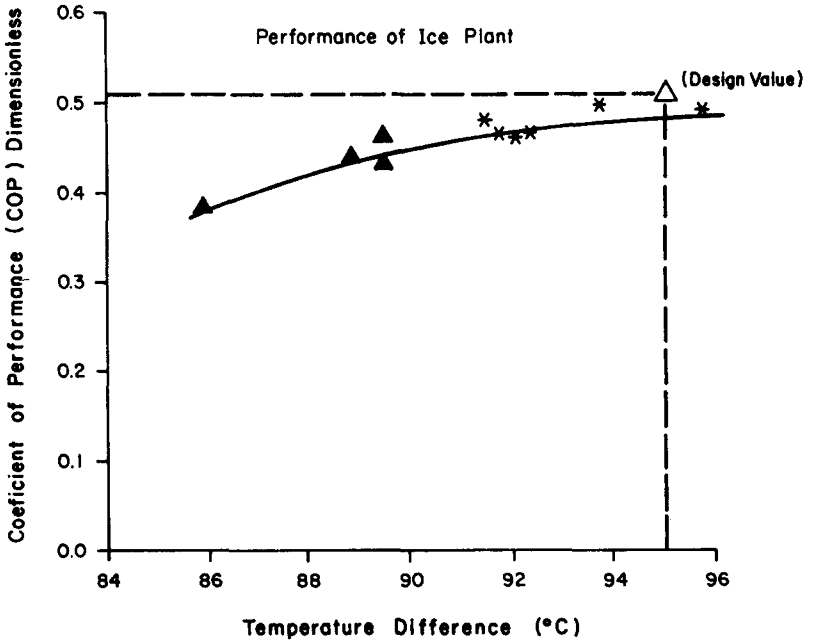

Figure 18 Actual coefficient of performance against the temperature difference between the hot water and cooling water for the ice making absorption system at Sonntlan Las Barrancas

Figure 18 *Coefficient d'efficacité réalisé en fonction de la difference de temperature entre l'eau chaude et l'eau de refroidissement pour le système de réfrigération par absorption pour la production de glace du projet Sonntlan Las Barrancas* have been the lack of industrial experience and the low economic viability in the short term.

A series of solar cooling demonstration projects both national and international were carried out in the 1980s with the objective of reducing conventional energy consumption such as in air conditioning and also to satisfy the needs of refrigeration and ice making needs of small rural communities. Unfortunately these projects have had a very small impact on the national usage of renewable energy resources and in the indigenous technological development of solar cooling.

Present costs of solar refrigeration systems remain high and as the study presented here concluded, the present costs should be reduced in many cases by a factor of three at current energy prices. Although it is expected that energy prices will increase in the medium term, improvements are needed in the cost of solar collectors by using light weight and inexpensive materials with improved optical and thermal efficiencies and an increase in the efficiency of the refrigeration systems as a result of improvements in absorption and other technologies previously mentioned.

Even so, the enormous potential demand for refrigeration in certain areas of Mexico and Latin America without interconnected electricity grids will need to be met by all the available technologies and solar absorption refrigeration should play an important role in meeting this demand.

Activities in other Latin American countries

Most of the information concerning the state of research on solar absorption cooling in other Latin American countries was obtained through contacts with members of the Ciencia y Tecnología para el Desarrollo, CyTED, (Science and Technology for Development) subprogram VI: New Energy Resources and Energy Conservation.

Cuba

Activities in solar refrigeration have been hindered due to the economic situation. The Universidad de Cienfuegos has constructed a prototype of an adsorption machine using methanol and activated carbon obtaining evaporator temperatures of 11°C cooling water. In the Instituto Superior Politecnico Jose A. Echeverria, a zeolite/water prototype was made.

In both cases there were encountered design and technical problems so the Polytechnic has focused on ammonia/water and lithium bromide/water.

Brazil

Two theoretical studies on solar cooling are reported. One concerning the use of activated carbon–methanol as working pair in an intermittent system and one concerning the use of ammonia water for cooling milk in remote areas of Brazil[17,18].

It seems that there are no experimental or prototypes being tested of solar absorption units. Only small-scale photovoltaic refrigerators are being fabricated by a company called Heliodinamica. In general, the interest in solar energy applications seems to be small at the moment.

Peru

As in most other Latin American countries, the interest in solar cooling is actually small. This was not the case 15 years ago. It seems that only small photovoltaic vaccine systems are being evaluated in rural clinics. The use of radiative cooling is being developed together with a research group in Israel.

Guatemala

The use of some isolated photovoltaic vaccine refrigeration systems is reported. No work is being done in absorption cooling systems.

Trinidad and Tobago

A study was reported in 1992 using a compound parabolic concentrating collector (CPC) of concentration ratio 3.9 and aperture area of 2.0 m^2 to power an intermittent solid adsorption refrigerator and ice maker using activated charcoal as adsorber and methanol as refrigerant, a solar coefficient of performance of 0.02 was measured[19].

Ecuador

Only theoretical works have been reported some years ago.

Argentina

It seems that solar refrigeration technology has not been seen as a particular need in the country and only a few unsuccessful individual efforts were made to build a system have been reported.

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