PROYECTO FIN DE CARRERA

INGENIERÍA INDUSTRIAL

CLIMATIZACIÓN DE UNA CASA UNIFAMILIAR MEDIANTE UNA MÁQUINA DE ABSORCIÓN DE TRIPLE ESTADO ALIMENTADA CON PANELES SOLARES TÉRMICOS. ESTUDIO DE VIABILIDAD ECONÓMICA Y MEDIOAMBIENTAL EN COMPARACIÓN CON SISTEMAS CONVENCIONALES.

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Área de máquinas y motores térmicos

Departamento de ingeniería mecánica

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Annex

Annex 1. Characteristic equations of the main equipment

This section contains the basic equations that define the behavior of the two main systems (Roca Calefacción, 2007) of the circuit, such as the plane collector and the heat exchanger.

1.1. Characteristic curve of equations and flat solar collector

The energy balance of a flat collector is:

$$Q1 = Q + Q2 + Q3$$

Where:

- Q1: Incident total energy (direct + diffuse + reflected).
- Q: Useful Energy.
- Q2: Energy lost by dissipation to the outside.
- Q3: Energy stored as heat in the collector.

The useful energy of the collector at a given time is depending on solar radiation and ambient temperature, being the difference between energy absorbed and the losses. The following equation shows the useful energy of the collector:

$$Q = S_C \times [R_I(\tau\alpha) - U_L \times (T_m - T_a)]$$

Where:

- S_c: Area of the collector (m^2).
- R_1: Total incident radiation over the collector by unit of area (W/m^2).
- τ: Transmittance of transparent surface.
- α: Plate absorptance.
- U_L: Global losses coefficient (W/mºC).
- T_m: Average temperature of the absorbing plate (ºC).
- T_a: Room temperature (ºC).

Is defined an efficiency factor of heat exchange between the plate and the solar fluid, F_R, as the ratio between the energy captured and that could capture, if the plate temperature was the same that of the temperature fluid at the entrance the collector. Based on this factor, the equation of Bliss or characteristic of the collector is defined as:

$$Q = S_C \times [F_R(\tau\alpha)_n R_I - F_R U_L \times (T_e - T_a)]$$

The new terms introduced in the equation are:

- Q: useful energy captured (W).
- F_R (τα)n: Orderly line of the performance curve of the sensor.

- F_RU_L: Straight slope of collector performance curve.
- T_e: temperature heat transfer fluid in the inlet (ºC).

Characteristic curve of a flat collector

The efficacy rate of the collector is defined by the ratio between the captured and received energy in a given time.

$$\eta = F_R(\tau\alpha)_n - F_R U_L \times \frac{(T_e - T_a)}{R_I}$$

Where:

- F_R (τα)n: Orderly line of the performance curve (dimensionless).
- F_RU_L: Straight slope of the collector performance curve.
- R_I: Radiation in the plane of collector (W/m^2).
- T_e: Heat transfer fluid temperature in the inlet (ºC).
- T_a: Room temperature (ºC).

This characteristic curve is provided by the manufacturer and it is determined through testing by the companies of approval. Basing on the curve can be deduced the operation of a collector from the thermal point of view. **A collector will be better when its orderly line F_R (τα)n will be highest and the slope F_R U_L will be lower.**

1.2. Heat Exchanger

When the liquid which circulates through the collector cannot be used directly for consumption, must be entered a heat exchanger between the collector (primary circuit) and the circuit of utilization (secondary circuit). This happens due to the presence of antifreeze in the circulating fluid. The exchange can be produced in a external heat exchanger to the storage tank or in the inside serpentine of the tank, both with a similar thermal behavior.

Heat exchanger effectiveness

The effectiveness of heat exchanger is a parameter that directly affects the determination of the collector's surface, and its dimension describes the operation of the system. The following figure shows the evolution of temperatures in heat exchange with two flows ($\dot{m}_1$ and $\dot{m}_2$) which have a specific heat (C_{p1} and C_{p2}) (Roca Heating, 2007).

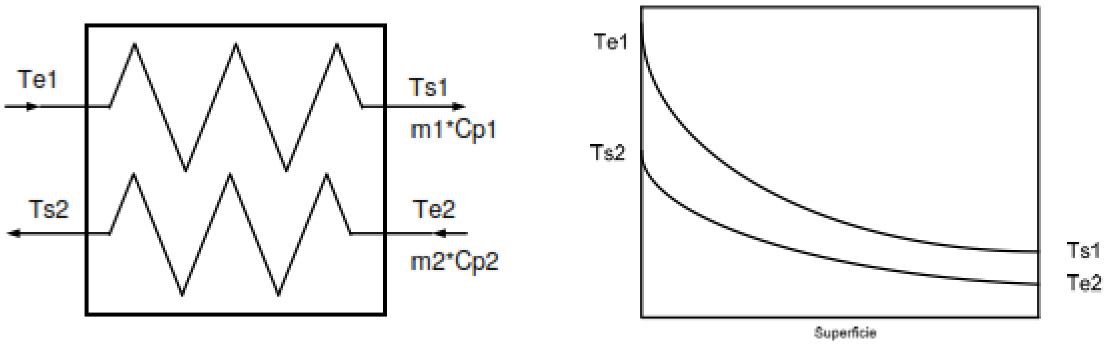


Figure 17: Temperatures evolution of heat exchanger.

The exchange power between the primary and secondary circuit, in ideal conditions (no losses) is:

$$Q = m1 \times Cp1 \times (Te1 - Ts1) = m2 \times Cp2 \times (Ts2 - Te2)$$

Performance of the heat exchanger is expressed in terms of effectiveness (E) and the speed minimum of heat capacity (mass flow x specific heat). Effectiveness is defined as:

$$E_I = \frac{Cantidad\ de\ calor\ real\ transmitida}{Máxima\ transmisión\ posible\ de\ calor} = \frac{m1 \times Cp1 \times (Te1 - Ts1)}{m1 \times Cp1 \times (Te1 - Te2)} = \frac{m2 \times Cp2 \times (Ts2 - Te2)}{m1 \times Cp1 \times (Te1 - Te2)}$$

The real transfer of heat depends on the constructive characteristics of the heat exchanger and also of heat capacity and temperatures speeds of circulating fluids. The advantage of the concept of effectiveness is the relation between the amount of actual heat transfer and the maximum, which is relatively constant regardless of the variations of temperature; if the flows are constant (Roca Calefacción, 2007).

Annex 2. Technical specifications

ESPECIFICACIÓN TÉCNICA ClimateWell™

Frío Solar

DENOMINACIÓN

CLIMATEWELL 10

DESCRIPCIÓN

Planta Enfriadora por absorción de triple estado. La tecnología revolucionaria de ClimateWell es la única que permite el almacenamiento de energía a través de la cristalización de la sal CILi. Permitiendo así, entregar energía de forma continua.

Esta tecnología modular da la posibilidad de adaptación a cualquier edificio a climatizar. Además de trabajar con energía solar la enfriadora puede trabajar con cualquier fuente generadora de calor como puede ser una cogeneración o la utilización del calor residual de cualquier proceso industrial.

DATOS TÉCNICOS

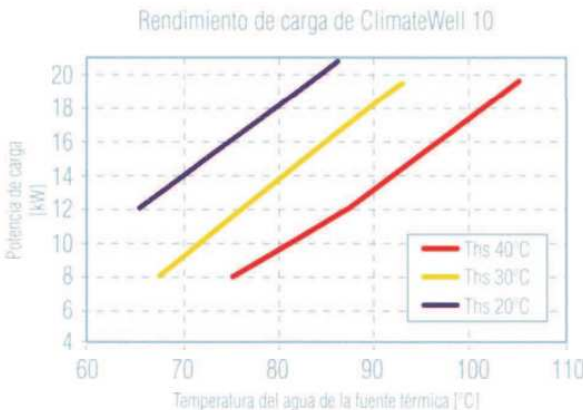
Capacidad Nominal	Refrigeración	10 kW
Consumo Nominal	Electricidad	18 W
COP térmico	Refrigeración	0.68
Capacidad de almacenamiento	Refrigeración	60 kWh
	Calefacción	76 kWh
Dimensiones	Altura	1527 mm
	Longitud	1211 mm
	Profundidad	807 mm
Peso	En funcionamiento	950 Kg
Nivel acústico		0 dB
Solución salina	Cloruro de Litio	LiCl

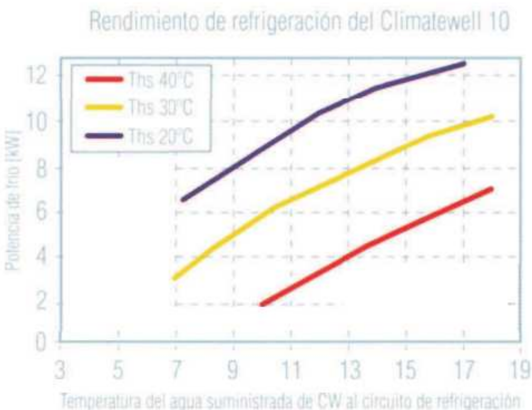
Circuito Disipación	Caudal	30 l/min
	Caída de presión	28 kPa
	Potencia nominal	25 kW
	Rango de temperatura	20-45 °C
	Conexiones de tubería	28 mm
	Tipo de soldadura unión de tuberías	Sn-4%Ag
Circuito Distribución	Caudal	15-20 l/min
	Caída de presión	28 kPa
	Potencia nominal	10 kW
	Rango de temperatura	7-20 °C
	Conexiones de tubería	28 mm
	Tipo de soldadura unión de tuberías	Sn-4%Ag
Circuito Captación solar	Caudal	15-20 l/min
	Caída de presión	28 kPa
	Potencia nominal	20 kW
	Rango de temperatura	Hasta 95 °C
	Conexiones de tubería	28 mm
	Tipo de soldadura unión de tuberías	Sn-4%Ag
Comunicación	Protocolo de comunicación	RS232
Conexión eléctrica	Vac	230

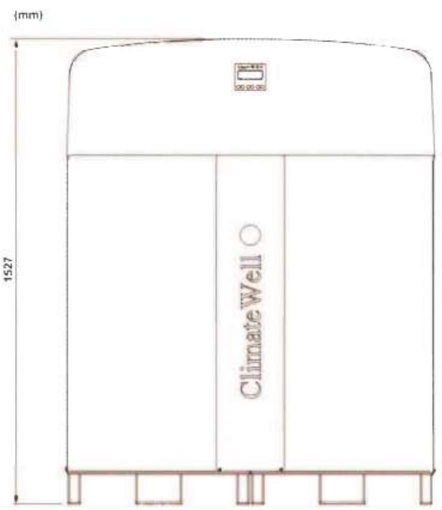
DISPLAY

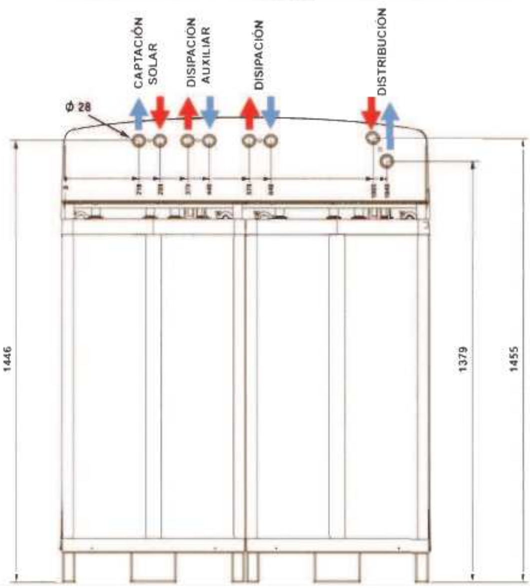
ESPECIFICACIÓN TÉCNICA ClimateWell™ Frío Solar

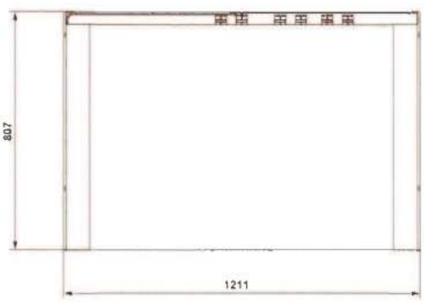
GRAFICOS DE COMPORTAMIENTO:











Annex 3. Solar collector

TECHNICAL INFORMATION

Wagner & Co

EURO Solar Collector Type C20/C22

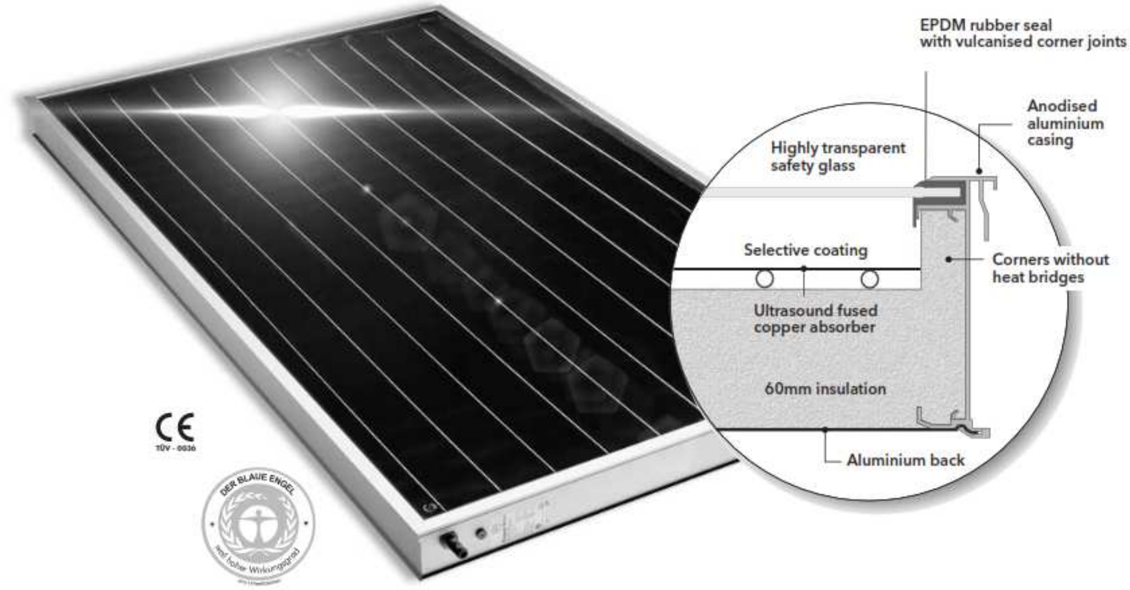


Figure 1 The EURO C20/C22 - powerful, versatile and rapidly installed

Advantages

High Efficiency through Perfect Details

Thanks to its highly selective vaccuum coated flat plate absorber, a 60 mm back insulation and the seamless side insulation, the EURO solar collector is characterized by very low heat losses. In addition it is equipped with highly transparent solar glass. The EURO C20 AR variation additionally features sunarc® anti reflection glass increasing the solar yield by an additional 6-10% thanks to intelligent nano-technology based upon the moth-eye effect.

High-Quality Materials

Anodised aluminium profiles, aluminium back, high-transparency safety glass cover, weather resistant EPDM rubber seals with vulcanised corner joints and ultrasound-fused, heat-resistant copper absorber ensure safe operation for decades.

Excellent Price/Performance Ratio

Tested quality according to European norm EN 12975 and the CE label. Repeated awards from the Independent Institute for Consumer's Goods Testing "Stiftung Warentest".

Simple and Fast Installation

Tried and tested installation kits, photo-instructions and weldless connections to the solar circuit.

Adaptable Arrangements and Installations

- *On-Roof Installation*
  The collectors can be installed above the roof surface with rafter brackets or mounting rails, either horizontally or vertically (horizontal preferred). Even during the installation, the roofing remains almost completely unharmed. We offer roof-anchors and rafter brackets for almost every roofing type. Up to 4 EURO collectors can be connected in series. The connection hoses with pre-assembled insulation also significantly simplify the on-roof pipeworks. Distribution pipes on the roof are not required.
- *In-Roof Installation*
  The attractive in-roof installation is possible for roofs with a minimum pitch of 27% and any tile cover. In this case the collectors are installed vertically, with the connections pointing upwards. The aluminium and corrugated lead flashing can be joint without solder.
- *Free Standing Installation*
  The free standing set up allows horizontal or vertical installation with adjustable inclination. Concrete slabs or gravel covered aluminium trays can be used as foundation.

1. Technical Data

Feature	EURO C20 AR	EURO C20 HTF	EURO C22 AR	EURO C22 HTF
Total area / aperture area	2.61 / 2.39 m²		2.24 / 2.02 m²	
Size W x H x D	2151 x 1215 x 110 mm		1930 x 1160 x 110 mm	
Efficiency (DIN 4757- 4)	η_o = 85.4 % k_1 = 3.37 W/m²K k_2 = 0.0104 W/m²K²	η_o = 81.8 % k_1 = 3.47 W/m²K k_2 = 0.0101 W/m²K²	η_o = 85.4 % k_1 = 3.37 W/m²K k_2 = 0.0104 W/m²K²	η_o = 81.8 % k_1 = 3.47 W/m²K k_2 = 0.0101 W/m²K²
Incident angle modifier	k_{dir} = 97 % k_{diff} = 94 %	k_{dir} = 94 % k_{diff} = 88 %	k_{dir} = 97 % k_{diff} = 94 %	k_{dir} = 94 % k_{diff} = 88 %
Annual collector yield (ITW 5 m² *)	546 kWh/m²a	509 kWh/m²a	546 kWh/m²a	509 kWh/m²a
Collector housing	60mm back insulated and frame insulated aluminium casing; specific heat capacity 4.7 kJ/(m²K)			
Glass cover	4 mm solar safety glass with sunarc®-antireflex-coating	4 mm solar safety glass	4 mm solar safety glass with sunarc®-antireflex-coating	4 mm solar safety glass
Transmission	τ = 96%	τ = 91 %	τ = 96%	τ = 91 %
Absorber	Heat conducting sheet and pipes made out of copper, max. pressure 10 bar			
Absorber coating	Highly selective vacuum coating, α = 95 %, ε = 5 %			
Absorber capacity	1.3 litre		1.1 litre	
Conductor fluid	DC20 (Propylenglycol with inhibitors), mixing ratio according to requirements			
Working pressure	Max. 10 bar			
Idle temperature (according to DIN 4757-3)	232°C	227°C	232°C	227°C
Sensor tube	6 mm internal diameter			
Connections	½" male			
CE lable	TÜV certificate 0036, EC type test (Module B) in accordance with EU direction 97/23/EC			
Max. allowed pressure/suction forces	2.25 kN/m² (take wind and snow loads into account! Consider static capacity of roof!)			
Inclination range	10 - 85° for on-roof and free standing setup, 27 - 85° for roof integration			
Weight	48 kg		43 kg	
* Calculated for 4 person household at Würzburg/Germany with 300 l solar cylinder and 5 m² collector area.				

Table 1 Technical Data EURO C20 / C22

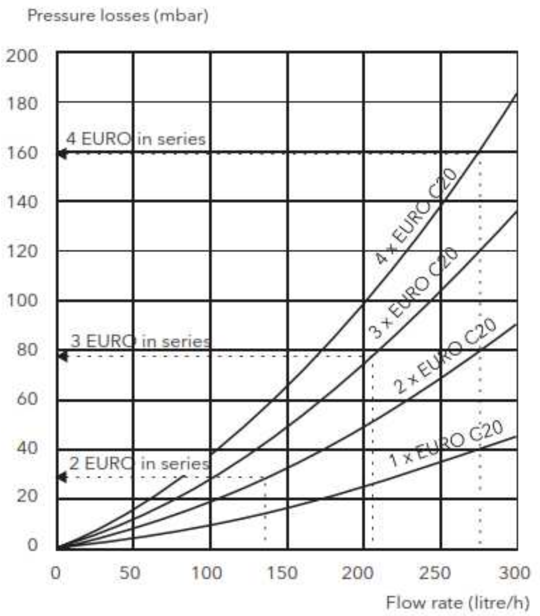


Figure 2 Pressure loss EURO C20 in relation to the volume flow and and the number of collectors connected in-row; Volume flow v=30 l/m²h; heat transfer medium: 40% glycol, 60% Water at 30 °C; examples with v=30l/m²h; pressure losses do not account for connections and connection pipes

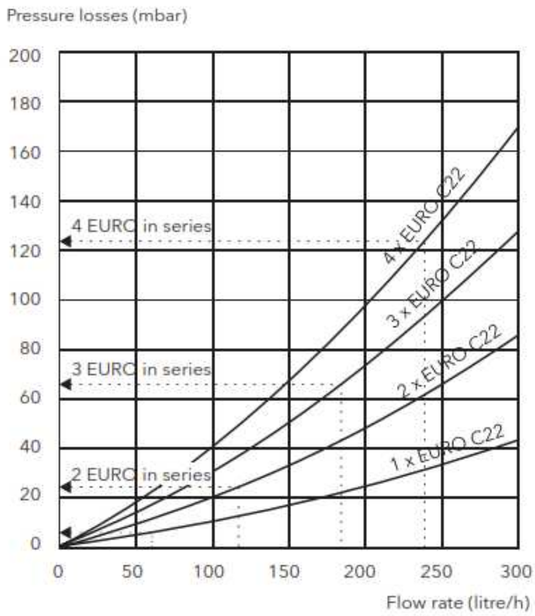


Figure 3 Pressure loss EURO C22 in relation to the volume flow and and the number of collectors connected in-row; Volume flow v=30 l/m²h; heat transfer medium: 40% glycol, 60% Water at 30 °C; examples with v=30l/m²h; pressure losses do not account for connections and connection pipes

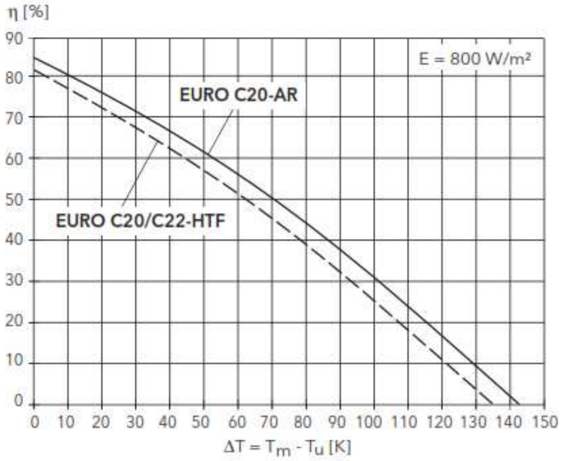


Figure 4 Characteristics curves of EURO C20 / C22 HTF and EURO C20 AR depending on Tm – TU (E = 800 W/m²) as measured at the ISFH Hameln according to DIN EN 12975.

2. Planning notes

2.1 Snow and Wind loads

Snow and wind loads are a significant factor for structural planning. European norms were established, albeit without specifically taking solar installations into account.
Wind and snow loads affect the collectors and the installation system.Depending on the conditions and height of the installation site as well as the collector inclination, the mechanical loads on the system can vary considerably. Also see guidelines for the planning of structural frameworks and standards EUROCODE 1, (European guidelines for structural planning). With combined snow and wind loads the maximum strain for the EURO solar collector is 2,250 N/m². Note that wind suction spikes may occur on roof edges! Please read the information in the appliccable guidelines for the planning of structural frameworks.
It is mandatory to follow best practice rules for static planning, especially related to snow and wind loads. Different codes and regulations apply in different countries and regions. For more information refer to our technical information "EURO Solar Collector" C20/C22 and the leaflet "Notes on Snow and Wind safe Installation of Solar Collectors".
In case of doubt and/or in absence of exact static calculations (not recommended!) always allow for additional fixtures, weight, anchors, and screws, especially in regions with known weather extremes.

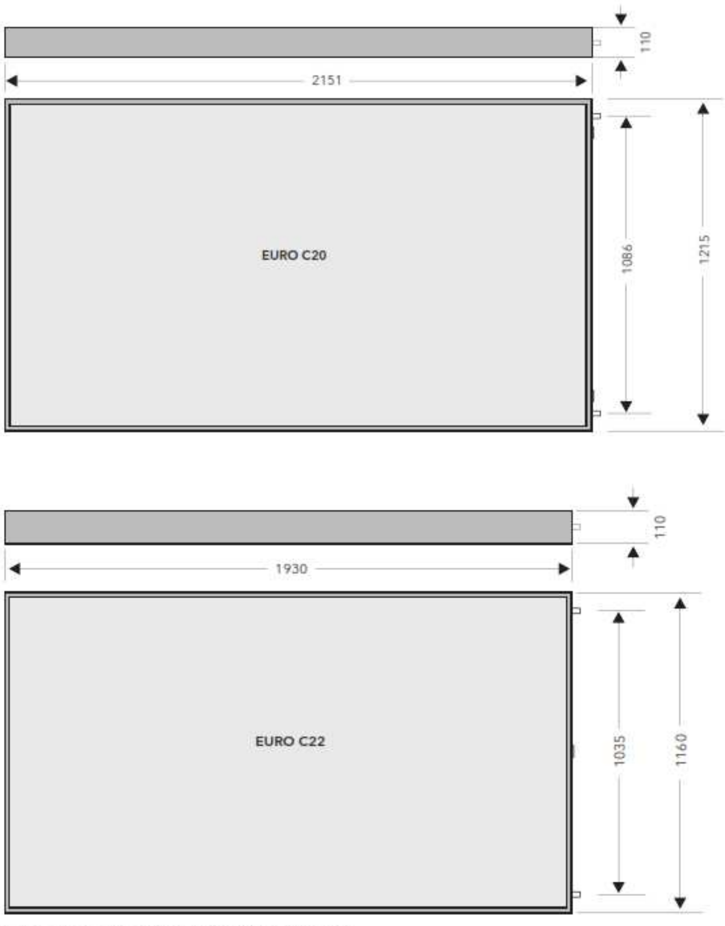


Figure 5 Dimensions EURO C20/EURO C22

2.2 Collector Field Layout with On-Roof Installation

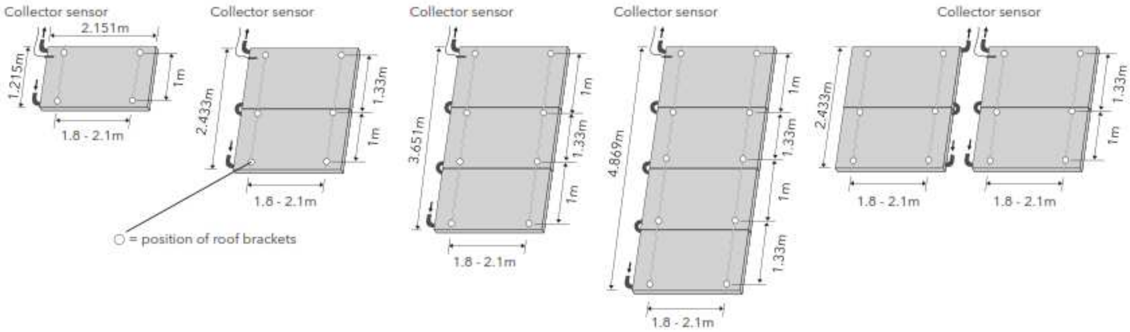


Figure 6 ***Horizontal collector arrangement:*** *Up to 4 EURO C20 connected in series. The mounting rails run vertically. Combination of parallel and serial connections (see right) is possible as well.*

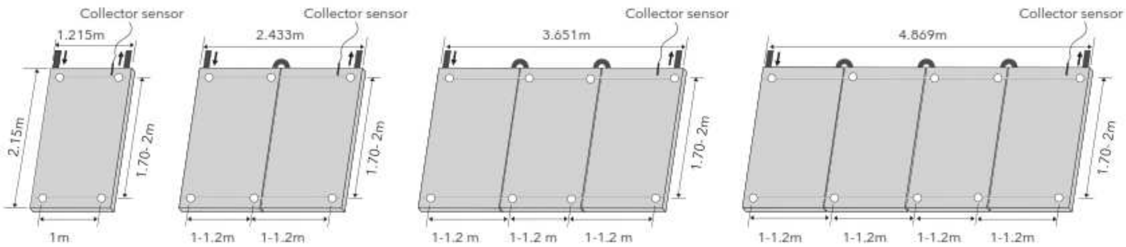


Figure 7 ***Vertical collector arrangement:*** *Up to 4 EURO C20 in serial connection. The mounting rails run horizontally. More than 4 EUROs are combined from serial and parallel connections.*

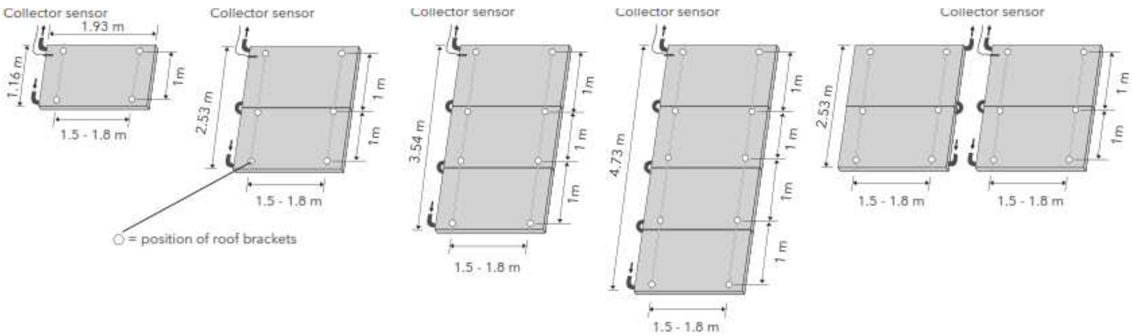


Figure 8 ***Horizontal collector arrangement:*** *Up to 4 EURO C22 in serial connection. The mounting rails run vertically. Combination of parallel and serial connection (see right) is possible as well.*

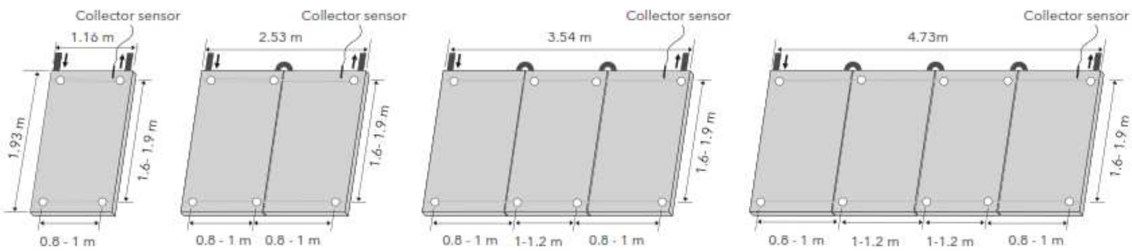


Figure 9 ***Vertical collector arrangement:*** *Up to 4 EURO C22 in serial connection. The mounting rails run vertically. More than 4 EUROs are combined from serial and parallel connections.*

Annex 4. Propilenglicol

Hoja de datos técnicos

Propilenglicol industrial de Dow

Descripción general

El propilenglicol industrial de Dow (PGI) es un material de alta pureza que se produce mediante la hidrólisis a alta temperatura y presión de óxido de propileno (PO) con un exceso de agua. El PGI es un producto destilado con una especificación de pureza del 99.5%. El PGI puede obtenerse de The Dow Chemical Company en tambores y en cantidades a granel.

El PGI es un líquido incoloro, soluble en agua, higroscópico, con un olor específico de glicoles, de viscosidad media, de baja presión de vapor y de baja toxicidad. El propilenglico industrial de Dow es de uso corriente an numerosas industrias y tiene una amplia gama de aplicaciones prácticas.

Propiedades[1] del propilenglicol industrial

Nombre químico	1,2-propanediol
Fórmula	CH_3 -CH(OH)-CH_2 OH; $C_3H_8O_2$
Peso molecular (g/mol)	76,10
Número en CAS	57-55-6
Número en EINECS	200-338-0
Punto de ebullición, 101,3 kPa (1 atm)	187,4 °C (369,3 °F)
Ámbito de destilación, 101,3 kPa (1 atm)	186 – 189 °C (367 – 372 °F)
Presión de vapor, 20 °C (68 °F)	0,011 kPa (0,08 mmHg)
25 °C (77 °F)	0,017 kPa (0,13 mmHg)
Punto de congelación	Sobre-enfría
Punto de fluidez	< - 57 °C (-71 °F)
Gravedad específica, 20/20 °C (68/68 °F)	1,038
25/4 °C (77/39 °F)	1,033
60/4 °C (140/39 °F)	1,007
Índice de refracción n20/D, 20 °C (68 °F)	1,4310 – 1,4330
Viscosidad, 25 °C (77 °F)	48,6 centipoise (mPa.s)
60 °C (140 °F)	8,42 centipoise (mPa.s)
Calor específico, 25 °C (77 °F)	2,51 J/(g°K) (0,60 Btu/lb/°F)
Tensión superficial, 25 °C (77 °F)	36 mN/m (36 dynes/cm)
Punto de inflamación, copa cerrada de Pensky-Martens	104 °C (220 °F)
Temperatura de autoignición	371 °C (700 °F)
Conductividad térmica, 25 °C (77 °F)	0,2061 W/(m°K) (0,1191 Btu hr^{-1} ft^{-1} $°F^{-1}$)
Conductividad eléctrica, 25 °C (77 °F)	10 micro S/m (0.1*10^{-7} mhos/cm)
Calor de formación	-422 kJ/mol (-101 Kcal/g-mol)
Calor de vaporización, 25 °C (77 °F)	67 kJ/mol (379 Btu/lb)

[1]Estos son resultados de laboratorio característicos del producto y no deben ser considerados como especificaciones.

Aplicaciones

El propilenglicol industrial de Dow se utiliza en una amplia gama de productos, incluyendo diversos productos básicos tales como resinas de poliéster, refrigerantes para motores, pinturas de látex, fluidos de transferencia de calor y compuestos antihielo. Asimismo, satisface los requisitos para la aplicación en limpiadores líquidos, lubricantes, plastificantes y aditivos para el triturado de cemento. Se emplea como disolvente, como medio para transferir calor o como producto químico intermedio, aprovechando sus grupos reactivos de hidroxilo.

El propilenglicol industrial de Dow es el glicol preferido para la fabricación de resinas de poliéster no saturadas, a su vez usadas en una variedad de aplicaciones, tales como laminados plásticos reforzados para la construcción naval, *gel coats*, materiales para moldeo de láminas (SMC, por sus siglas en inglés) y mármol sintético.

Las soluciones acuosas de propilenglicol industrial cuentan con excelentes propiedades anticongelantes y por lo tanto, son valiosas en la transferencia de calor a bajas temperaturas y en los fluidos antihielo para aeronaves.

El PGI es un codisolvente valioso para las pinturas con base de agua para edificaciones y asimismo se utiliza como producto intermedio en la producción de resinas alquídicas para pinturas y barnices. Por su capacidad de disolución es posible utilizarlo en limpiadores líquidos, incluyendo la estabilización de detergentes líquidos con enzimas para lavado de la ropa.

El propilenglicol industrial de Dow se utiliza únicamente en aplicaciones industriales. Para usos en la industria farmacéutica, de aseo personal, cosméticos, de alimentos y de forraje para animales, se recomienda utilizar el proplenglicol de grado USP/EP (PG USP/EP).

Almacenamiento y Manejo

El PGI tiene una vida útil de un año, siempre y cuando se almacene a una temperatura menor a 40 °C (104 °F) en recipients cerrados y protegidos de los rayos ultravioleta.

Para obtener mayores detalles sobre el manejo del producto e información sobre seguridad, favor referirse a las Hojas de Datos de Seguridad de Dow (MSDS/SDS).

Para recibir mayor información, favor ponerse en contacto con el representante de Dow de su localidad, visitar nuestro sitio *web* o llamar por teléfono en:

EEUU y Canadá:	1-800-447-4369
Europa:	(+32) 3-450-2240
Pacífico:	(+60) 3-7958-3392
China:	+800-600-0015
Latinoamérica:	+989-832-1426
www.dowpg.com	

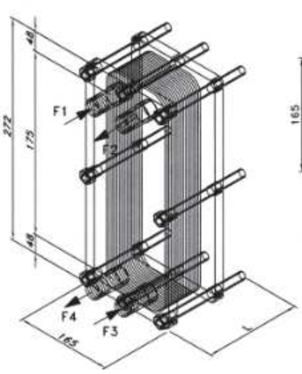
Modulo nº 117-01543-0604X-AA

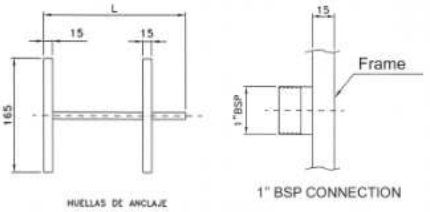
Annex 5. Heat exchanger

Plate Heat Exchangers - Series S1

Serialised Units designed to meet a wide range of duties in industrial, marine and HVAC installations. These series are of rugged design consisting of a steel frame fastened with bolts and a plate pack with rubber gaskets in between to provide tightness and circuit separation.. The plates can be in site expanded if process conditions required so. Plate Heat Exchangers are an excellent option when space savings are required while good heat transfer is kept. Fouling is minimal thanks to the vertical position of the plates thus ensuring minimal maintenance costs.
MAWP: 16 Kgs/cm2* MAWT: 130ºC * Max Flow Rate: 50 c.m (S7) * Max. plate surface: 3.80 sq.m * PED 97/23/CE under Category I and fluids Group II* Test Pressure in accordance with applicable code *

Dimensions





L = 100mm up to 17 Plates
L = 200mm from 21 to 36 Plates

The Heat exchangers S1 can be provided with a number of plates from 9 to 36 units. There are two standard widths depending on the number pf plates assembled. The frame dimensions are standardised to the indicated below and are independent of the plates number. This sketch must be understood as reference only, tailor made drawings for approval can be drawn by our design section on request.

Plate thickness: 0.5 mm
F1 Inlet connection: 1" threaded BSPP
F4 Outlet connection: 1" threaded BSPP
F3 Inlet connection: 1" threaded BSPP
F2 Outlet connection: 1" threaded BSPP

Parts and Materials

Part	Name	Material
1	Frame	Carbon Steel (painted)
2	Plates	St. Steel AISI 316
3	Screwed Connections	St. Steel AISI 316
4	Gaskets	NBR or EPDM
5	Plates Guides	St. Steel AISI 316

Selection Chart

The suitable standard unit can be selected out of the below listed models and serves as a quick guidance. The chart has been based on the following parameters:
Primary Circuit: Steam / Hot Water Inlet temp. 85ºC – Outlet temp. 69ºC
Secondary Circuit: Water Inlet Temp. 15ºC – Outlet Temp. 50ºC

Type	Duty (Kcal/h)	Flow Rate-I (m3/h)	ΔP-I (bar)	Flow Rate-II (m3/h)	ΔP-II (bar)	Surface (m2)
S1-9TLA	23.000	1,56	0,16	0,66	0,041	0,12
S1-12TLA	35.000	2,38	0,17	1	0,057	0,16
S1-15TLA	46.000	3,13	0,22	1,32	0,053	0,22
S1-17TLA	57.023	3,88	0,246	1,64	0,062	0,25
S1-21TLA	68.000	4,64	0,242	1,95	0,06	0,30
S1-24TLA	79.000	5,39	0,245	2,27	0,06	0,35
S1-28TLA	90.054	6,14	0,25	2,59	0,07	0,45
S1-33TLA	101.000	6,89	0,26	2,9	0,061	0,50
S1-36TLA	112.000	7,64	0,275	3,22	0,067	0,55

P-I: Pressure Drop in Primary Circuit
P-II: Pressure Drop in Secondary Circuit

Other units to comply with different performances on request.

Annex 6. ClimaDeck

ClimaDeck hollow core slab system offers one of the most energy efficient HVAC solutions available on the market while providing top rated comfort levels. This is possible by adding a massive thermal storage to the air distribution; the building itself.

ClimaDeck can be combined with all types of Air-Conditioning/Air Handling units (AHU) units. From the AHU-unit, generally placed on the roof, supply air ducts run in vertical shafts down to each floor inside the building and then to horizontal ducts placed in central corridors usually within false ceilings. Small branch ducts feed air into each slab, and the air then enters a room via diffusers fixed to the outlet of the slab. Diffusers are normally located close to external walls, or evenly spread over the ceiling in the office landscape. The exhaust air is normally transferred into the central corridor plenum and is returned to the AHU-unit in a conventional way.

The main distribution ductwork in the corridor is similar in construction to that found in conventional systems. The main difference with ClimaDeck is that every individual structural hollow core slab is supplied with a small quantity of air from the main supply duct.

The ClimaDeck system is different from conventional technologies because it is integrated with the heavy structure of the building. The last part of the ductwork system for the supply air consists of hollow core concrete slabs instead of traditional steel ducts.

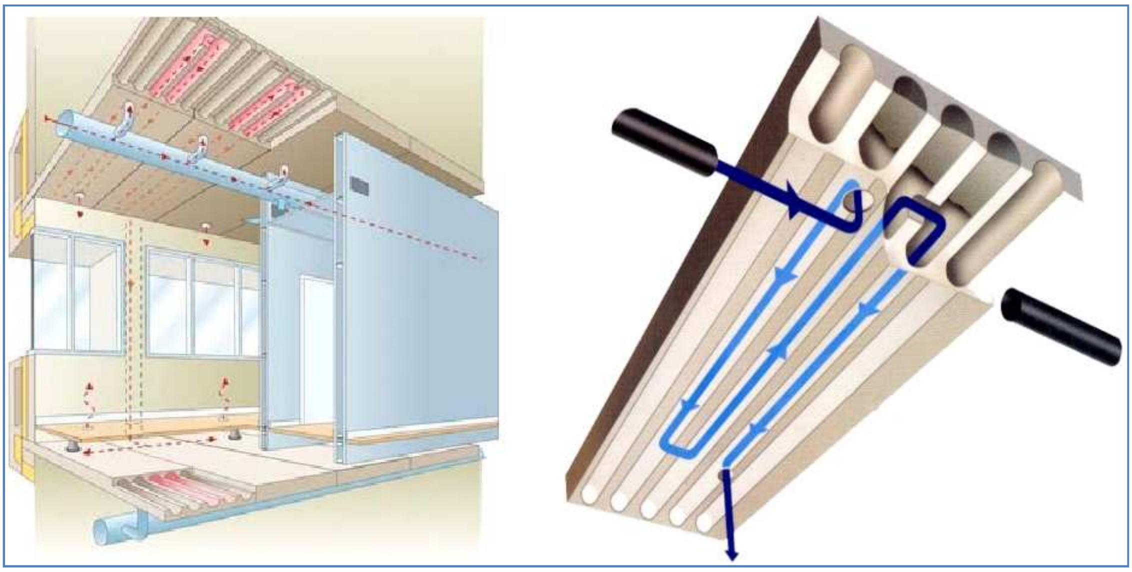


Figure 18: Air flow inside the hollow core slabs.

ClimaDeck uses the thermal storage capacity of the structural mass in the building to regulate the internal temperatures. The effectiveness of the building's thermal mass is enhanced by passing supply air through the slab before it enters the room. The slabs work as heat exchangers between the supply air and the rooms, see figure 18.

The floor/ceiling slabs serve many purposes: Besides from being the structural floor it also conveys fresh air into the building while serving as an energy store.

The slabs are incorporated into the building and the main supply duct would normally be situated in the corridor. No ducts and therefore no false ceilings are required in individual rooms. This allows total freedom for the interior designer to locate, or re-locate in the future, the internal wall partitions.

The distribution circuits depart from the supply and return manifolds. From there, the circuits are hydraulically balanced and the circulation of the water projected is regulated in accordance with the thermal needs of each space. The manifolds are placed centrally with respect to the areas to which they provide service. At least one electronic valve is necessary for every thermostat controlled space, and each manifold has a maximum of 12 circuits. For maximum comfort it is recommended to use one thermostat for each space (bedroom, kitchen, etc.

For optimum temperature control the advisable circuit design is either double coil or spiral. The supply and return pipes should always be contiguous so that the warmer pipe is always next to the colder pipe. This design ensures homogenised thermal distribution and increased comfort.

For heating, a separation of 20 cm between each individual pipe is considered normal, and for air-conditioning, a separation of 15 cm is necessary (except in bathrooms, with a 10 cm separation). The type of distribution pipe and the separation between pipes should remain constant throughout the entire installation.

Parts 1-4 of UNE EN 1264 specify the design and installation requirements of radiant floor heating systems. Nonetheless, this standard does not cover the design of floor-based cooling systems.

UNE EN 1264-2 establishes a characteristic base curve that determines the balance between thermal flow density (q) in W/m^2 and the mean temperature of the floor surface in ºC. It is applicable to all types of radiant systems. The proportion between these is established as follows:

Hot floor: $q = 8.92 * (T_{floor/ceiling} – T_{operative}) * 1,1$
Cold floor: $q = 7 * (T_{surface} – T_{operative})$

Radiant floors are considered suitable when the heating load is less than 100 W/m^2, and the cooling floor when the load is less than 40 W/m^2.

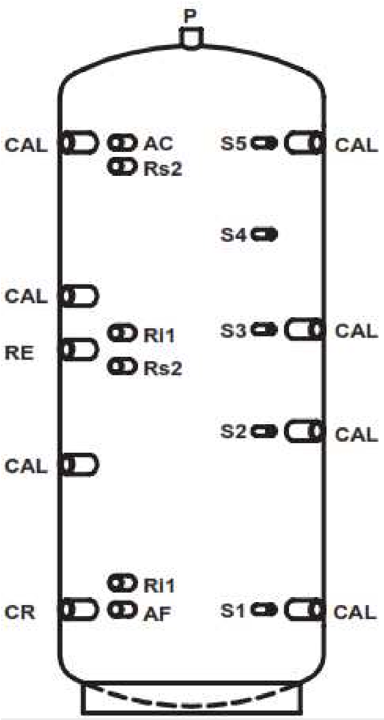
For the floor, the minimum temperature recommended is 18ºC, although it will always be necessary to take the dew point of the air into account so as not to generate condensation.

Annex 7. Hot water tank

AGUIDROVERT SOLAR

GASOKOL go ahead sunshine

Acumulador de capas combinado hyGenio - datos técnicos



Toma	Dimensión	Descripción
CR	1 ½"	Retorno calefacción (ingreso dispositivo estratificador)
CAL	1 ½"	Conexión acumulador de inercia
RE	1 ½"	Resistencia eléctrica
Ri1, Ri2	1"	Retorno circuito solar (hacia los paneles)
Rs1, Rs2	1"	impulsión circuito solar (de los paneles)
AF	1"	Agua fría de aguadota
AC	1"	Agua caliente hacia el utilizo
P	1 ½"	Purga de aire
S1,2,3,4,5	½"	Para sensores, termómetros etc.

Garantía de 5 años en vigor bajo siguientes condiciones:

La instalación de este acumulador se debe realizar por una persona autorizada y debe cumplir la reglamentación local en cuanto a Seguridad e Instalaciones Eléctricas y de Fontanería.
Válvula de seguridad 6 bares en la tubería de agua fría
Vaso de expansión en la tubería de agua fría
Un filtro fino en la tubería de agua fría
Intercambiador para ACS es diseñado para agua potable con un contenido de ***cloruros* máx. *70 mg/l.***

Datos técnicos:

Presión máxima intercambiador ACS	6 bares
Presión máxima intercambiador solar	6 bares
Presión máxima acumulador inercial	3 bares
Temperatura máxima	90 ºC

Acumulador volumen	Litri	600	800	1000	1250	1500	2000
Temperatura de impulsión caldera	°C	80	80	80	80	80	80
Superficie intercambiador ACS	m²	5	5,4	7,5	7,5	9	12
Volumen intercambiador ACS	l	38	43	58	58	76	93
Perdida de carga intercambiador ACS	mbar	160	170	180	180	200	220
Índice de rendimiento según DIN 4753*	NL	1,8	3,6	4,1	4,8	5,2	5,8
Producción de ACS continua	l/h	1900	2100	3400	3400	3800	4100
Caudal máx. de consumo durante 10 minutos	l/10 min	510	630	780	800	920	1020
Potencia caldera	kW	77,3	85,4	138,4	138,4	154,6	166,9
Intercambiador solar superior	m²	1,2	1,8	2,4	2,4	2,4	2,8
Volumen	l	7,38	11,07	14,77	14,77	14,77	17,23
Intercambiador solar inferior	m²	1,8	2,4	3	3	3,6	4,2
Volumen	l	11,07	14,77	18,46	18,46	22,15	25,84
Peso (vació) HGR con 1 intercambiador	kg	166	190	239	274	307	347
Peso (vació) HGRR con 2 intercambiadores	kg	184	217	275	310	343	388

* Índice de rendimiento según DIN 4753: temperatura de acumulación 60°C; producción ACS de 10°C a 45°C

AGUIDROVERT SOLAR

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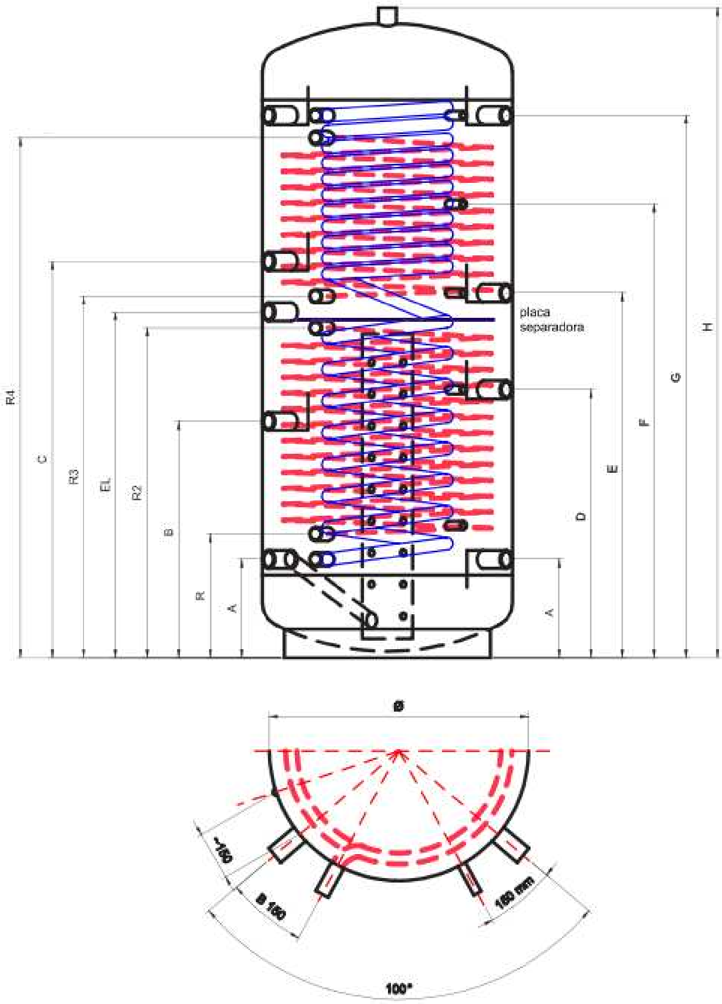
hyGenio Dimensiones



Volumen	Dimensiones (mm)														Inclinación	espesor de aislamiento	Ø inclusivo aislamiento	Serpentín	
L	*A	B	C	D	E	F	**G	H	ø	EL	R1	R2	R3	R4				arriba	abajo
600	235	620	1010	720	910	1142	1395	1640	700	895	335	845	945	1295	1740	100	900	1,2	1,8
800	260	630	1030	730	930	1173	1430	1700	790	915	365	865	965	1324	1800	100	990	1,8	2,4
1000	310	745	1250	845	1150	1430	1710	2050	790	1090	390	1040	1140	1640	2150	100	990	2,4	3,0
1250	295	730	1240	830	1140	1417	1700	2000	950	1080	380	1030	1130	1630	2200	125	1150	2,4	3,0
1500	335	825	1350	925	1250	1492	1760	2150	1000	1150	450	1100	1200	1670	2270	125	1200	2,4	3,6
2000	325	900	1490	1000	1390	1712	2035	2380	1100	1275	425	1225	1325	1935	2610	125	1300	2,8	4,2

* Altura A es, con pequeña tolerancia, valida para la conexión de agua fría
** Altura G es, con pequeña tolerancia, valida para la conexión de agua caliente

GASOKOL GmbH. hyGenio dimensiones ES

AGUIDROVERT, S.L.
Cervantes 20, pral izda, 50.006 Zaragoza (Spain)
Tel. 00-34-976302135 Fax. 00-34-976468085
www.aguidrovert.com info@aguidrovert.com

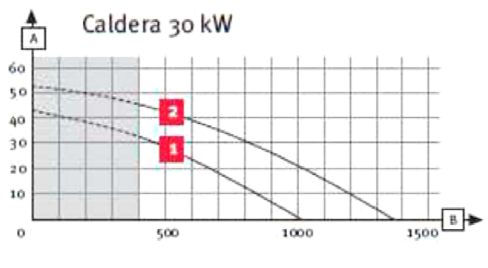
Annex 8. Boiler

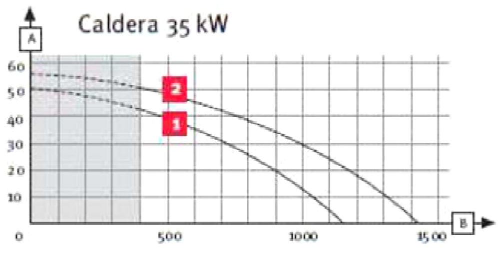
Características Técnicas

Características generales		ISOFAST21 CONDENS F30	ISOFAST 21 CONDENS F35	ISOMAX CONDENS F35
Tipo de gas		II2H3P	II2H3P	II2H3P
Capacidad del acumulador	L	21	21	21+21
Calefacción				
Potencia útil (50/30 °C)	kW	5,4 - 25,7	5,4 - 32,0	5,4 - 32,0
Potencia útil (80/60 °C)	kW	4,8 - 23,5	4,8 - 29,3	4,8 - 29,3
Rdto. 30% de carga (40/30 °C)	%	› 108	› 108	› 108
Temperatura ida	°C	10 - 80	10 - 80	10 - 80
Presión máxima	bar	3	3	3
Capacidad de vaso de expansión	L	12,0	12,0	12,0
Agua Caliente Sanitaria				
Potencia útil	kW	5,0 - 30,6	5,0 - 34,8	5,0 - 34,8
Temperatura de salida ACS	°C	45 - 65	45 - 65	45 - 65
Caudal específico s/EN13203 (ΔT25 °C)	L/min	21,0	22,8	27,6
Confort ACS s/EN13203		***	***	***
Presión máxima	bar	10	10	10
Capacidad de vaso de expansión	L	2	2	2
Evacuación de humos				
Longitud máxima horizontal C13 60/100	m		10	
Longitud máxima horizontal C13 80/125	m		12	
Longitud máxima vertical C33 60/100	m		10	
Longitud máxima vertical C33 80/125	m		13	
Longitud máxima horizontal a colectivo C43 60/100	m		10	
Longitud máxima doble flujo C85/C53 80/80	m		2x 20	
Circuito Eléctrico				
Alimentación	V/Ph/Hz	230/1/50	230/1/50	230/1/50
Consumo máximo	W	173	173	173
Intensidad	A	0,8	0,8	0,8
Protección eléctrica		IPX4D	IPX4D	IPX4D
Dimensiones y Pesos				
Dimensiones (alto/ancho/fondo)	mm	890/470/570	890/470/570	890/470/570
Peso de montaje	kg	59,5	64,5	70,5

Curvas de las bombas de calefacción

Muestran la relación entre presión y caudal





1 Velocidad mínima
2 Velocidad máxima
A Presión disponible (kPa)
B Caudal en circuito (L/h)

Annex 9. Simulation report

ClimateWell™ Frío Solar

INFORME DE SIMULACIÓN PARA SISTEMA DE CLIMATIZACIÓN CON MÁQUINA CLIMATEWELL DE FRIO SOLAR®

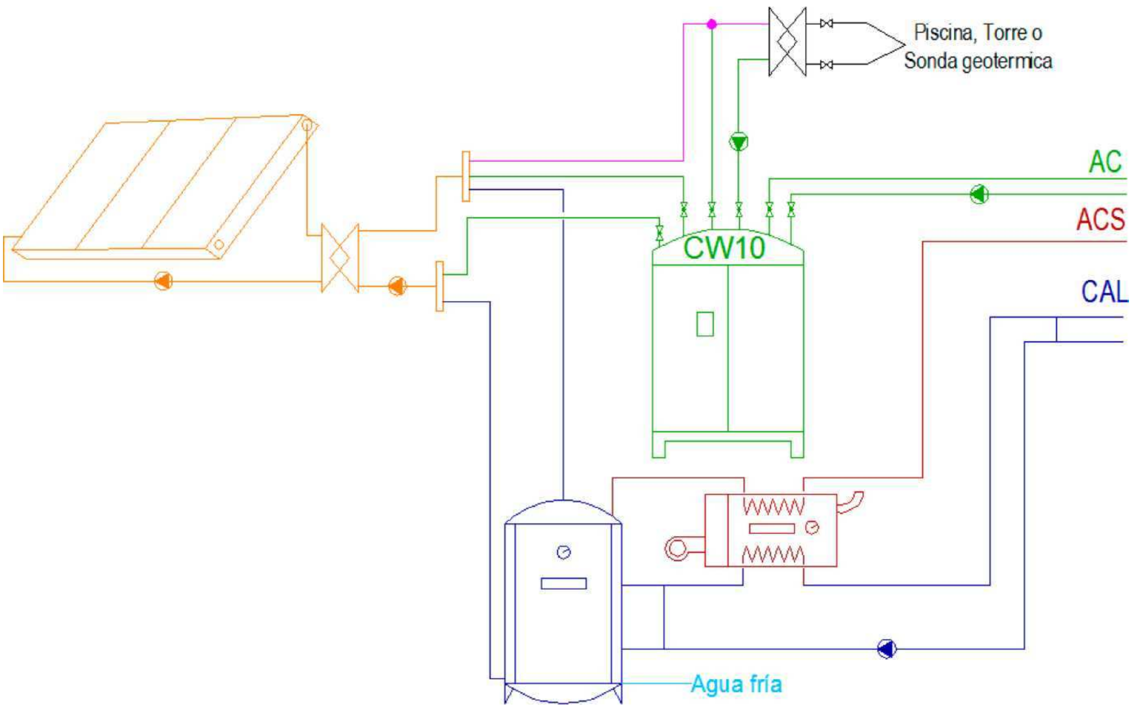
DATOS DEL CLIENTE

Empresa	Luis Gallardo Carro
Persona Contacto	
Teléfono	
Mail	

DATOS DEL PROYECTO

SIMULACION

ESQUEMA GENERAL



ClimateWell™
Frío Solar

INFORME DE SIMULACIÓN PARA SISTEMA DE CLIMATIZACIÓN CON MÁQUINA CLIMATEWELL DE FRIO SOLAR®

DATOS DE SIMULACION

Datos Climáticos

Ubicación		Madrid
Tipo de Edificio		Viviendas Unifamiliares

Sistema Captación

Captador (modelo)		Wagner C20HTF 2.01 m2
Superficie Captación Total	(m^2)	33.46
Inclinación	(º)	30
Azimut	(º)	0

Nº de Maquinas

Nº de maquinas CW 10		1

Datos del Edificio

Superficie a climatizar	(m^2)	200
Aislamiento (Envolvente)	W/K	Bien Aislado
Capacidad Térmica	kJ/K	Pesado
Ventilación por hora	(1/h)	1.0

Temperaturas de diseño del edificio

Temperatura en Invierno (día)	(ºC)	22
Temperatura en Invierno (noche)	(ºC)	19
Temperatura máxima en verano	(ºC)	24

Agua Caliente Sanitaria

Nº de Personas		6
ACS Total	(l/día)	360
Temperatura de ACS	(ºC)	60

Sistema distribución

Distribución		Suelo Radiante

ClimateWell™ Frío Solar

INFORME DE SIMULACIÓN PARA SISTEMA DE CLIMATIZACIÓN CON MÁQUINA CLIMATEWELL DE FRIO SOLAR®

Sistema disipación

Disipación		Piscina
Area	(m2)	40
Volumen	(m3)	80
Factor de obstáculos		6

Acumulación

Volumen Acumulación Solar	(m3)	1.25
Temperatura depósito verano	(ºC)	60
Temperatura depósito invierno	(ºC)	60

Sistemas Auxiliares

Potencia Equipo Auxiliar ACS	(kW)	30.6
Potencia Equipo Calefacción	(kW)	25.7
Rendimiento Caldera	(%)	1
Potencia Equipo Auxiliar Frío	(kW)	15
Rendimiento Enfriadora	(%)	2

Datos económicos

Precio gas/gasoil	(€/kWh)	0.0487582
Precio Electricidad	(€/kWh)	0.1400069

ClimateWell™ Frío Solar

INFORME DE SIMULACIÓN PARA SISTEMA DE CLIMATIZACIÓN CON MÁQUINA CLIMATEWELL DE FRIO SOLAR®

RESULTADOS

Demandas

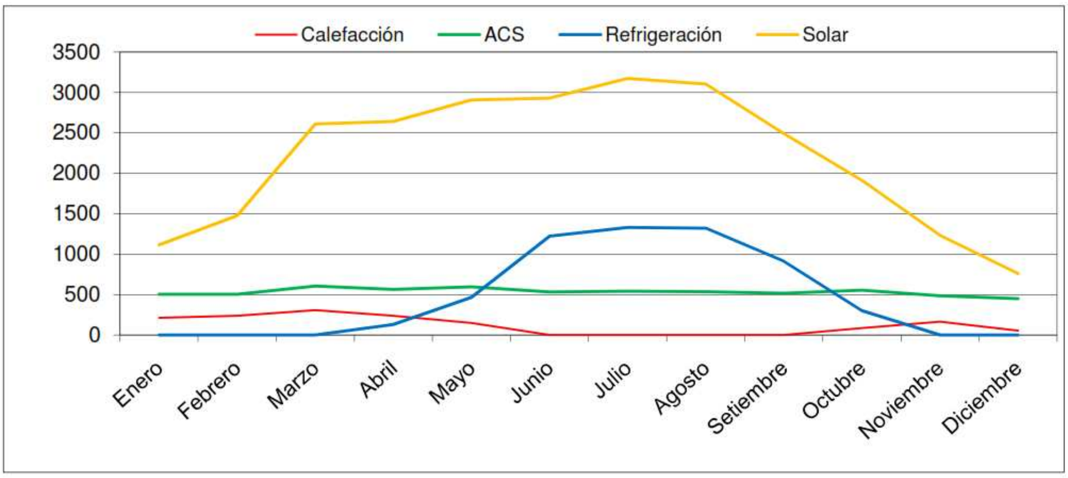
		ACS	Calefac.	Refrig.	Total
Demanda Energética Anual	(kWh)	7493.6	17969.1	13662.5	39125.3
Demanda Energética Anual	(kWh/m2)	37.5	89.8	68.3	195.6

Aportes

Campo Solar (Energía Total Año)	(kWh)	26367.8
Campo Solar (Potencia Máxima)	(kW)	27.3

		ACS	Calefac.	Refrig.	Total
Aporte Anual Auxiliar	(kWh)	1091.5	16514.4	7973.8	25579.6
Aporte Anual Auxiliar	(kWh/m2)	5.5	82.6	39.9	127.9

Potencia Máxima a Disipar	(kW)	26.0



Grafica 1. Aportes Solares: Captadores, ACS, Calefacción y Refrigeración

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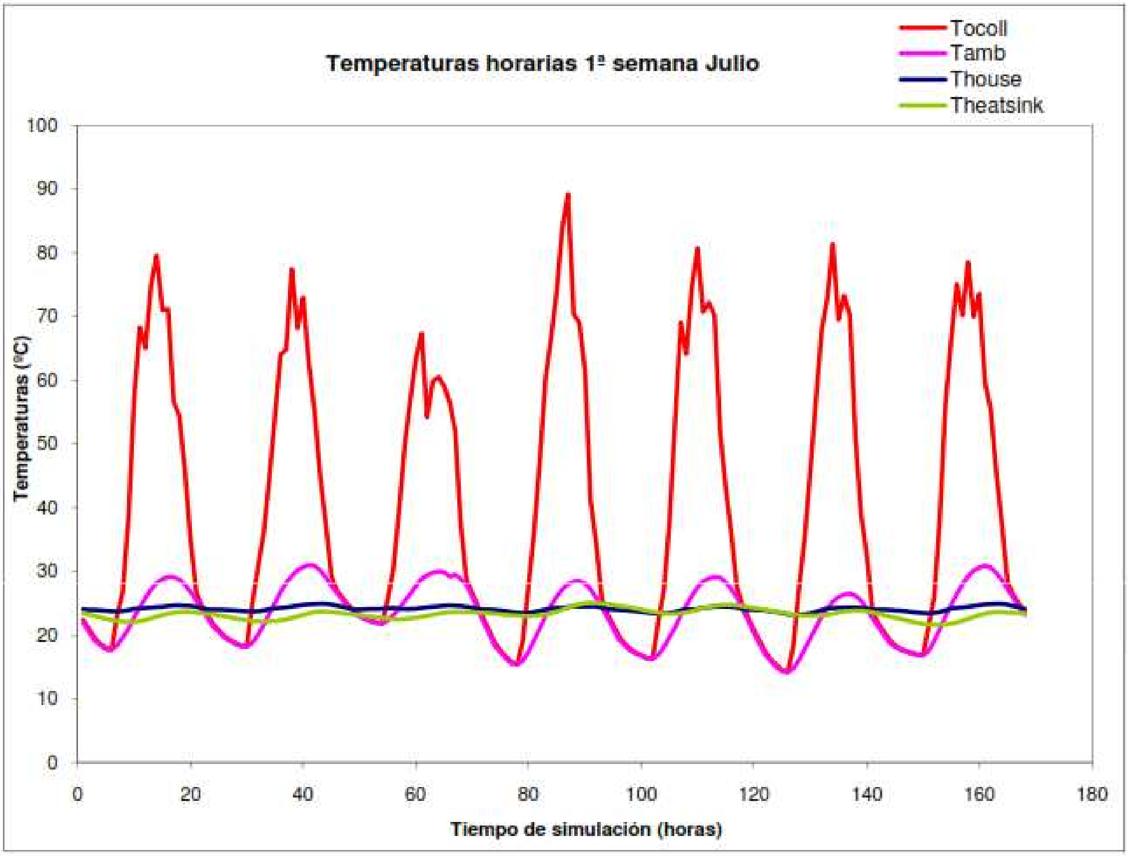
Frío Solar

INFORME DE SIMULACIÓN PARA SISTEMA DE CLIMATIZACIÓN CON MÁQUINA CLIMATEWELL DE FRIO SOLAR®



Grafica 2. Temperaturas: Colectores, ambiente, casa y disipación

Temperatura ambiente (media) (ºC)

Ene	Feb	Mar	Abr	May	Jun
6.4	7.8	11.7	13.5	17.6	24.0
Jul	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**
26.5	26.2	20.9	15.7	9.2	6.3

Temperatura Edificio (media) (ºC)

Ene	Feb	Mar	Abr	May	Jun
20.6	20.9	21.7	21.9	23.0	24.1
Jul	**Ago**	**Sep**	**Oct**	**Nov**	**Dic**
24.6	24.5	23.5	22.0	21.0	20.6

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Frío Solar

INFORME DE SIMULACIÓN PARA SISTEMA DE CLIMATIZACIÓN CON MÁQUINA CLIMATEWELL DE FRIO SOLAR®

RESUMEN

		ACS	Calefac.	Refrig.	Total
Cobertura	(%)	85.4	8.1	41.6	**34.6**

		ACS	Calefac.	Refrig.	Total
Ahorros	(eur)	312.2	70.9	398.2	**781.3**

Nº de Maquinas ClimateWell 10		1
Potencia Total ClimateWell	(kW)	**10**

DATOS MEDIOAMBIENTALES

Emisiones de CO2 evitadas	(T)	4.5
Area de bosque mediterraneo	(hec)	0.5
Distancia en coche	(km)	30223.0

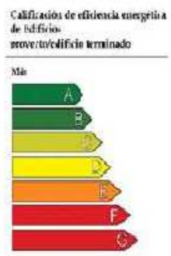
CERTIFICACION ENERGETICA

Zona Climática de Verano 3 Zona Climática de Invierno D

Localidad Peninsular Peninsular

Calificación Inicial Sin Sistema ClimateWell

Calef.	ACS	Refrig.	Calificación
C	D	E	**E**



Calificación Con Sistema ClimateWell

Calef.	ACS	Refrig.	Calificación
C	A	E	**D**

OBSERVACIONES

Este documento es un estudio preliminar y estimativo utilizando el programa de simulación dinámica basado en TRNSYS.

No se debe considerar como un documento técnico o contractual.

La demanda energética se ha estimado siguiendo los valores de la clasificación energética para cada zona. El valor oficial del etiqueta energética debe comprobase según las normativas y procedimientos vigentes.

Para calcular el espacio del sistema de captación se deberán considerar la orientación, inclinación y las sombras. Los datos de los captadores se han obtenido de Solar Keymark.

El sistema de disipación y distribución, a determinar por el cliente, afectará los resultados finales.

Annex 10. Economic profitability analysis

YEARS	1	2	3	4	5
SAVINGS (€)	781.3	865.3	958.2	1061.2	1175.2
NPV (WHITHOUT SUBV.)	-34578.8	-33713.6	-32755.3	-31694.1	-30518.9
NPV (GRANT SOLAR COLLECTORS)	-22031.3	-21166.1	-20207.8	-19146.6	-17971.4
NPV (GRANT 30%)	-23970.8	-23105.5	-22147.3	-21086.1	-19910.9
NPV (GRANT 70%)	-9826.7	-8961.5	-8003.2	-6942.0	-5766.8
	6	**7**	**8**	**9**	**10**
	1301.5	1441.4	1596.3	1767.8	1957.7
	-29217.4	-27776.0	-26179.7	-24412.0	-22454.2
	-16669.9	-15228.5	-13632.2	-11864.5	-9906.7
	-18609.3	-17168.0	-15571.7	-13803.9	-11846.2
	-4465.3	-3023.9	-1427.7	340.1	2297.9
	11	**12**	**13**	**14**	**15**
	2168.1	2401.1	2659.1	2944.9	3261.3
	-20286.1	-17885.0	-15225.9	-12281.0	-9019.7
	-7738.6	-5337.5	-2678.4	266.5	3527.8
	-9678.0	-7276.9	-4617.8	-1673.0	1588.3
	4466.0	6867.1	9526.2	12471.1	15732.4
	16	**17**	**18**	**19**	**20**
	3611.7	3999.8	4429.7	4905.6	5432.8
	-5408.0	-1408.1	3021.5	7927.2	13359.9
	7139.5	11139.4	15569.0	20474.7	25907.4
	5200.1	9199.9	13629.5	18535.2	23968.0
	19344.1	23343.9	27773.6	32679.2	38112.0

INSTALLATION COST (€)	**35360.1**

€/m² collect.	375.0
m² collect.	33.5
GRANT SOLAR COLLECTORS (€)	**12547.5**
GRANT (30%) (€)	**10608.0**
GRANT (70%) (€)	**24752.1**

	YEARS				
INCREASES (%)	2007 --> 2008	2008 --> 2009	2009 --> 2010	2010 --> 2011	**AVERAGE**
GAS	4.7	19.4	0.0	13.7	9.5
ELECTRICITY	19.3	5.2	4.8	19.0	12.0
					10.7%	**TOTAL AVERAGE**

Annex A. Thermal solar energy

Solar thermal energy (**STE**) is a technology for harnessing solar energy for thermal energy (heat). Solar thermal collectors are classified as low, medium, or high temperature collectors. Low temperature collectors are flat plates generally used to heat swimming pools. Medium temperature collectors are also usually flat plates but are used for heating water or air for residential and commercial use. High temperature collectors concentrate sunlight using mirrors or lenses and are generally used for electric power production. STE is different from photovoltaics, which convert solar energy directly into electricity. While only 600 megawatts of solar thermal power is up and running worldwide in October 2009, another 400 megawatts is under construction and there are 14.000 megawatts of the more serious concentrating solar thermal (CST) projects being developed.

A.1.Current situation

In Europe, during the past twenty years, solar thermal markets have shown an extremely positive evolution. Often however, periods of strong growth are followed by sharp downturns, a trend which was also visible in the past two years, where an outstanding growth of 60% in 2008 was followed by a contraction of 10% in 2009.

With more than 4 million square meters of solar collectors sold in Europe in 2009 for the second year in a row, the solar thermal sector however still outperformed a market environment distinguished by struggling building industries in many European countries and the global economic crisis.

Although there is an obvious correlation between solar thermal markets, fuel prices and economic activity, the market stability in our sector remains highly affected by the diversified and inconsistent landscape that support policies or solar thermal technologies show across Europe.

The business in 2010 was influenced by the effect that the financial and economic crisis have on public support and incentive policies. In this context, we should bear in mind that renewables are today an integral part of the energy policy agenda in most European countries which is primarily owed to the RES directive and its coming implementation into national legislations.

ESTIF will continue to influence the policy-making to improve the mid and long term framework conditions for the solar thermal sector.

In this text, I will show detailed charts and analyses on single markets and trends in the European solar thermal sector.

Following an outstanding growth in 2008, the European solar thermal market decreased by 10% in 2009. My initial forecast reflected the alarming news on the economic front as well as the concomitant recession in the building industry, and had prepared us for the worst. Finally, the market performed better than expected and for the second year in a row, over 4 million m² of solar panels were sold in Europe.

The outlook for 2010 was uncertain while the financial and economic crisis continues to have a negative impact on both public spending and incentive policies. It is anticipated that the main markets may be adversely affected by lack of government incentive programmers and stagnation in the construction sector. However, this is likely to be offset by the effect on national policies of the RES directive (2009/28/EC) implementation and also because renewable heat incentives are already firmly on the agenda in several European countries. Interestingly enough, and surely another positive sign, large solar installations seem to be unaffected by the market downturn and are gradually consolidating their market share.

The figure 19 shows the square meters and the KW_{th} installed in Europe for the past years.

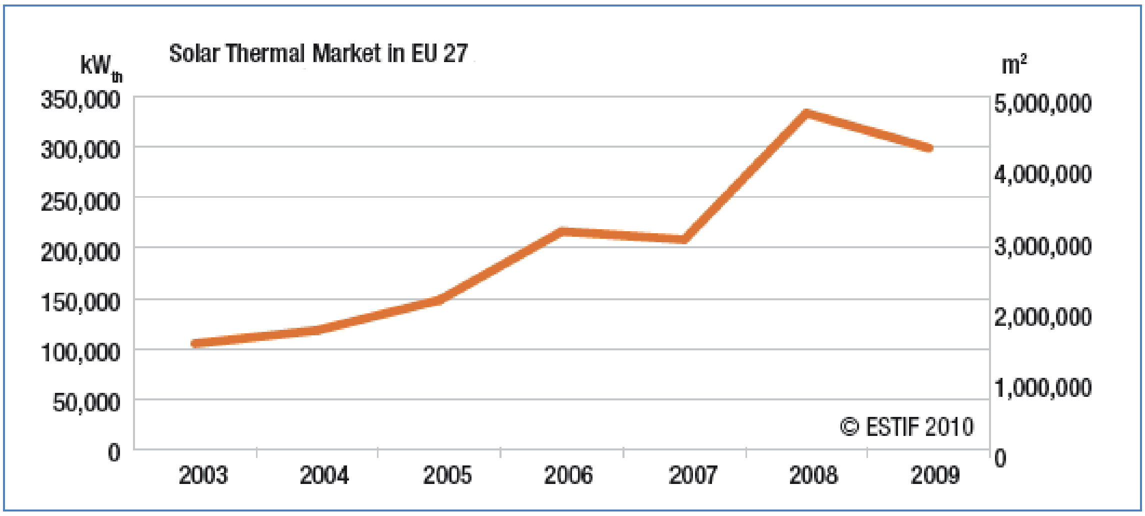


Figure 19: Square meter and KWth installed in Europe for the past years. (ESTIF, 2010)

In terms of solar thermal markets, Europe can be divided into three zones: markets above 400,000 m², between 200,000 and 400,000 m², and below 200,000 m² of newly installed capacity (glazed collectors). Interestingly, the solar thermal markets grouped in these categories present similar trends. The overall European market reliance on Germany (38% of the EU 27+CH) is decreasing with Austria, France, Greece, Italy and Spain together accounting for 39%; the other countries now representing 23% of the market and becoming increasingly relevant, showing a clear trend for fast growth. The effects of the current economic and financial downturn have been felt acutely in recently booming countries such as France, Spain and Greece. The smaller markets (below 200,000 m²) have in certain cases posted up to double digit growths (Denmark, the Netherlands, Switzerland and the United Kingdom) or even a two-fold increase, as has been the case in Portugal or Hungary thanks to a new financial incentive scheme. Finally new markets are emerging with Poland leading the way, despite the absence of incentives for individual consumers. This trend should continue throughout Europe with the implementation of the National Renewable Energy Action Plans (NREAPs) aimed at achieving the European 20/20/20 goals.

The following figure, figure 20, shows The Dynamic Evolution of the European Solar Thermal Market.

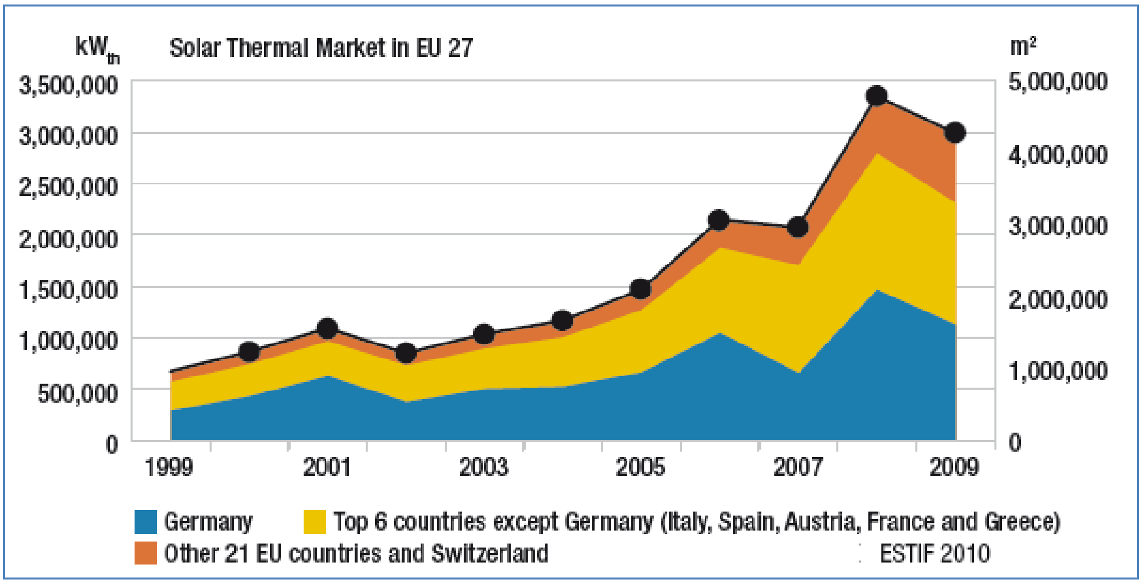


Figure 20: The Dynamic Evolution of the European Solar Thermal Market. (ESTIF 2010)

The Italian, Spanish, Austrian, French and Greek markets have experienced a steady growth over the past few years which cumulatively represent a fivefold increase and, for the larger South European markets such as Italy, Spain and France; the annual growth recorded has been multiplied by a factor of between 11 and 23. These markets are still above the 2007 level (42% in Spain). However, compared with 2007, the Greek market faced a substantial reduction in national sales, dipping even below the newly installed capacity in 2004.

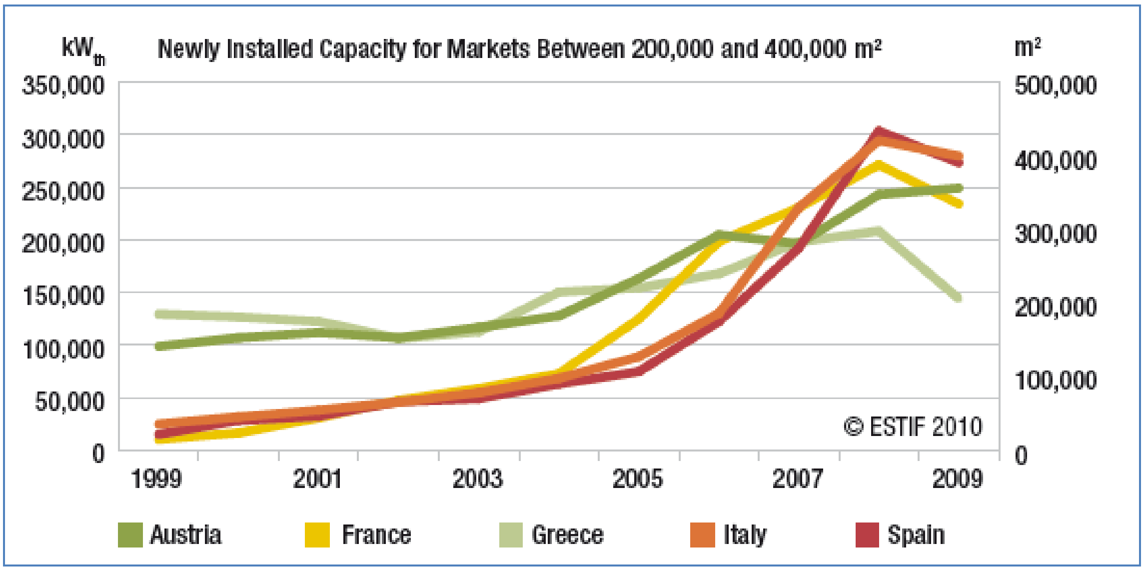


Figure 21: Newly Installed Capacity for Markets. (ESTIF 2010)

In Spain, one of the objectives of the PER (Renewable Energy Plan) was to install 4,9 million m^2 of collectors during the period 2005-2010. However at the end of 2010, only 2.432.000 m^2 were installed, which corresponds approximately to 50% of what was actually expected.

How we can see in the figure 21, after several years of strong and steady growth, at an annual average of 50%, the Spanish market has undergone a downturn of 10% in the newly installed capacity, compared with the previous year. In 2009, 274 KW_{th} were newly installed, corresponding to 391.000 m^2. The positive effect of the Spanish building code introduction has been negated by the collapse of the Spanish building sector. In addition, the reduced take-up rate of public subsidies available at national and regional levels led to this decline. Although the Spanish building code (CTE - Código Técnico de la Edificación) also covers other renewable energies and public support programmes did not contribute to market growth, the eventual introduction of a "feed-in" tariff for energy applicable to larger systems may have a positive impact on the market in the forthcoming years.

Figure 22: Solar Thermal Market in Spain. (ESTIF 2010)

The enactment of the Technical Building Code (CTE) in 2006, a regulation with the power of a Royal Decree which requires all new and refurbished buildings to be fitted with solar thermal energy, was the boost that this technology needed to become established in Spain.

Nevertheless, the recession, which has particularly affected the real estate sector, will slow down initially forecast growth. Despite this, in 2008, 465.000 m^2 were installed, with the accumulated total surface area reaching 1.710.000 m^2. In Spain, many homes are now fitted with some form of solar array (photovoltaic, and, above all, solar thermal), primarily installed over the last few years. The potential, however, is still huge. A large untapped market remains and the continuous upward trend gives rise to optimism.

Given the critical role of heat-generating renewable energies in reaching Spain's targets, this sector must increase its share of the energy balance. The drop in construction activity will undoubtedly be a hindrance, although the market still remains very large. Existing housing, large service-sector buildings, specific industrial applications, etc. will now be priority targets for solar thermal energy in Spain in forthcoming years.

To accelerate the roll-out of this technology, new support systems will have to be devised that are tailored to all situations and enable this technology to make a qualitative and quantitative leap forward and, in doing so, play a more important role in achieving Spain's objectives for 2020.

In the Community of Madrid, according to Plan of Renewable Energies 2004, 56.204 m^2 of solar collectors were installed, which represented 8% of Spain total collectors, knowing that the majority was in the tertiary sector. Due to the obligation of using it in the domestic sector, it was expected that in 2010, it would exceed the 338.709 m^2 installed. Nevertheless it was not the case, since only 17.024 m^2 were installed, about half of what was scheduled.

Since the appliance of the Solar Thermal Ordinance, the 10^{th} of November 2003, 89% of installed solar surface into the Community of Madrid in 2010, took place in residential buildings and only 3% in industrial ones.

A.2. Potential of solar thermal energy

As only three renewable sources (biomass, geothermal and solar) generate heat, it is crucial to clarify how these different sectors can contribute to the renewable energy target. Obviously, solar thermal systems will be needed to provide a substantial share of the low temperature heat: deep geothermal sources are limited to a few locations in Europe and shallow geothermal is considered as energy efficiency technology within this study; biomass will be used for transport fuels, electricity generation and medium to high temperature applications as well.

In order to provide the European Union and its Member States with substantiated information on the solar thermal contribution to the 20% renewable energy target and its long-term potential, detailed surveys were conducted using a representative sample of five European countries - Austria, Denmark, Germany, Poland and Spain. The information gathered was then extrapolated to the 27 EU countries. Both the technical and economic potential of solar thermal technologies were examined for different applications.

To determine the potential contribution solar thermal would make to the overall heat demand in the selected reference countries, a model was developed for the future demand - taking into account also energy efficiency measures. Based on this model, the future heating and cooling demand was calculated for the years 2020, 2030 and 2050.

The model includes three scenarios and focuses on the following segments:

- Space heating of residential buildings.
- Hot water preparation in the residential sector.
- Space heating in the service sector.
- Industrial low temperature heat (up to 250°C).
- Air conditioning and cooling in the residential and service sectors.

The three scenarios (figure 23) are a "Business As Usual scenario" (BAU), an "Advanced Market Deployment scenario" (AMD), including financial and political support mechanisms such as subsidies and obligations, moderate energy efficiency measures and improved research activities, and a "Full R&D and Policy scenario"

(RDP), which includes substantial financial and political support mechanisms, energy efficiency measures and research activities.

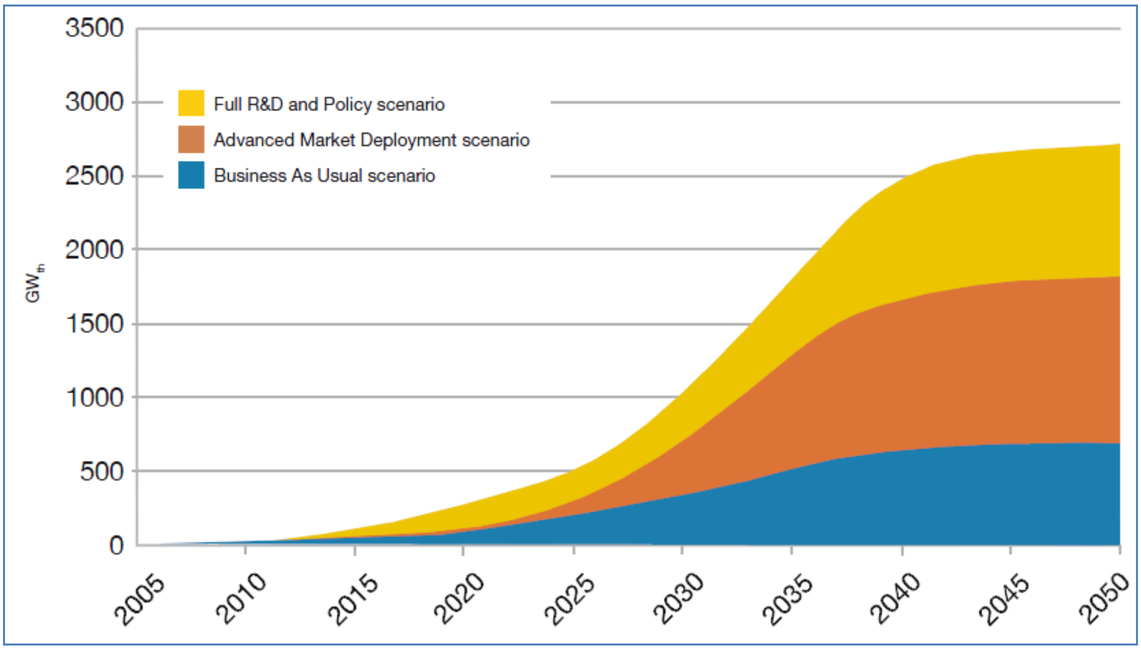


Figure 23: Development of EU-27 solar thermal capacity according to 3 scenarios (2005-2050). (ESTIF 2010)

A.2.1. Contribution of solar thermal to the EU 20% renewable energy target. (Figure 24)

Assuming there is a 9% reduction of the overall final energy demand due to energy efficiency measures by 2020 (compared with the year 2006), the contribution of solar thermal to the EU 20% Renewable Energy target would be 6,3% in the RDP scenario and 2,4% in the less ambitious AMD scenario.

Related to the required 11,5 percentage points increase in renewable energies (the share of renewable in 2005 was 8,5%) in the EU-27 countries by 2020, the contribution of solar thermal would be 12% according to the RDP scenario, 4,5% according to the AMD scenario and 2,9% in the BAU scenario.

To reach the goals of the RDP scenario, a 26% average annual growth rate of the European solar thermal market is needed up to 2020.

A 15% average annual growth rate is required to reach the goals of the AMD scenario and a 7% growth rate for the BAU scenario. The resulting total collector area by 2020 would be between 97 million m^2 (BAU) and 388 million square meters (RDP). These collector areas correspond to total installed capacities of 67,9 GW_{th} and 271,6 GW_{th}.

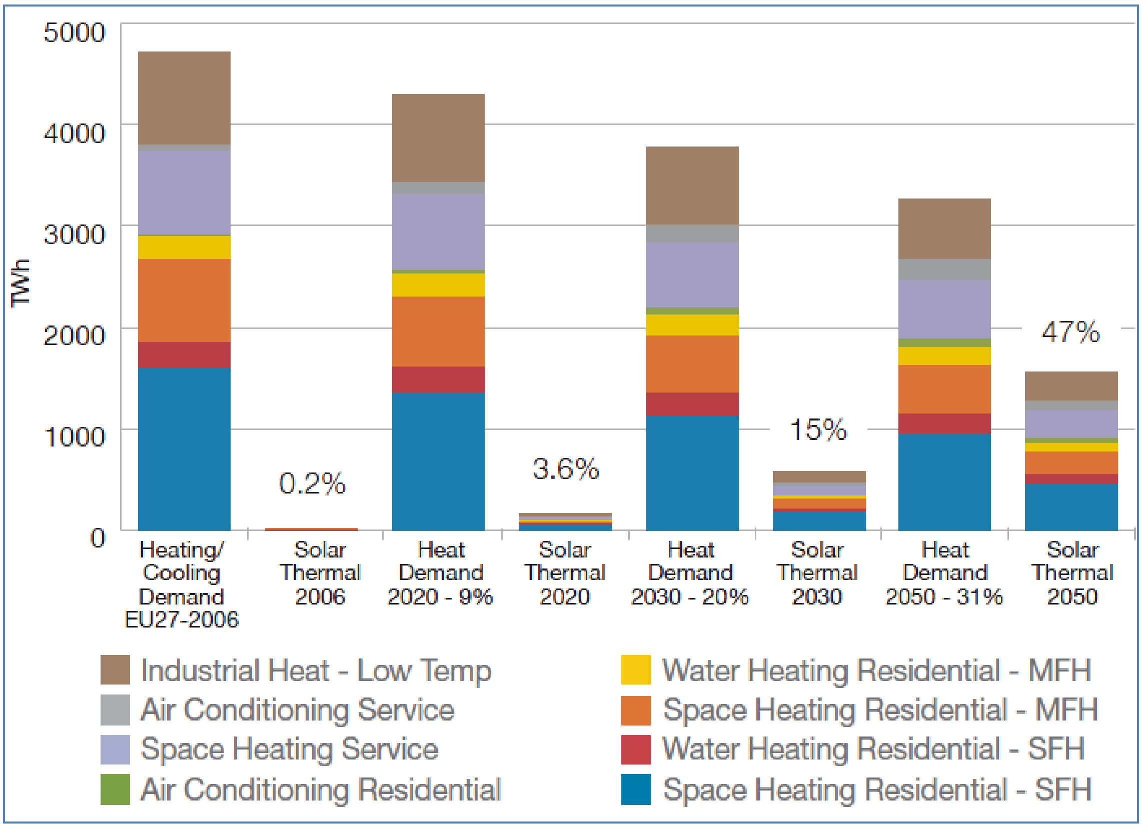


Figure 24: Total heating and cooling demand of EU-27 and contribution of solar thermal by sector according to the Full R&D and Policy Scenario (RDP). (ESTIF 2010)

A.2.2. Economic effects

In the figure 25, we can see that according to the RDP scenario the impact on employment would be considerable. In total, the solar thermal sector would encompass 470.000 full-time jobs in 2020, in the European Union domestic market alone.

An investment of the order of EUR 214 billion would be required in the solar thermal sector to reach the 2020 goals of the RDP scenario. This includes production, engineering, trade and installation of solar thermal systems from 2006 to 2020.

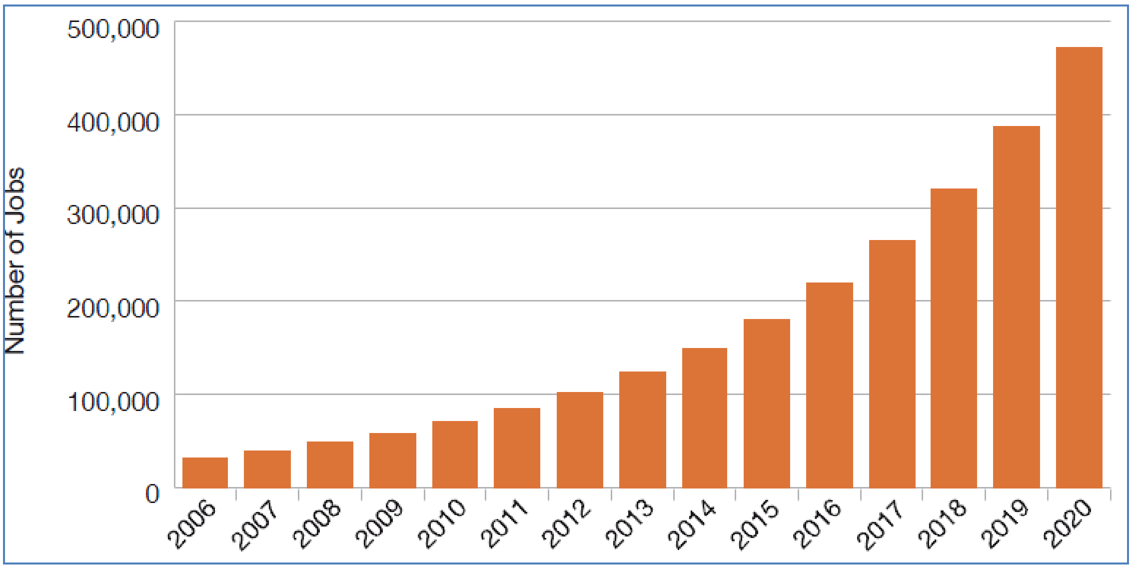


Figure 25: Jobs in the solar thermal sector based on the Full R&D and Policy Scenario (Calculations assume an average increase of productivity of 4% per annum). (ESTIF 2010)

A.2.3. Solar thermal contribution to the energy supply and CO_2 reduction. (Figure 26)

The solar yield in the RDP scenario is 155 TWh in 2020. This corresponds to an oil equivalent of 22 billion metric tons. Taking this oil equivalent into account the annual contribution to the CO_2 reduction by solar thermal systems is 69 million metric tons.

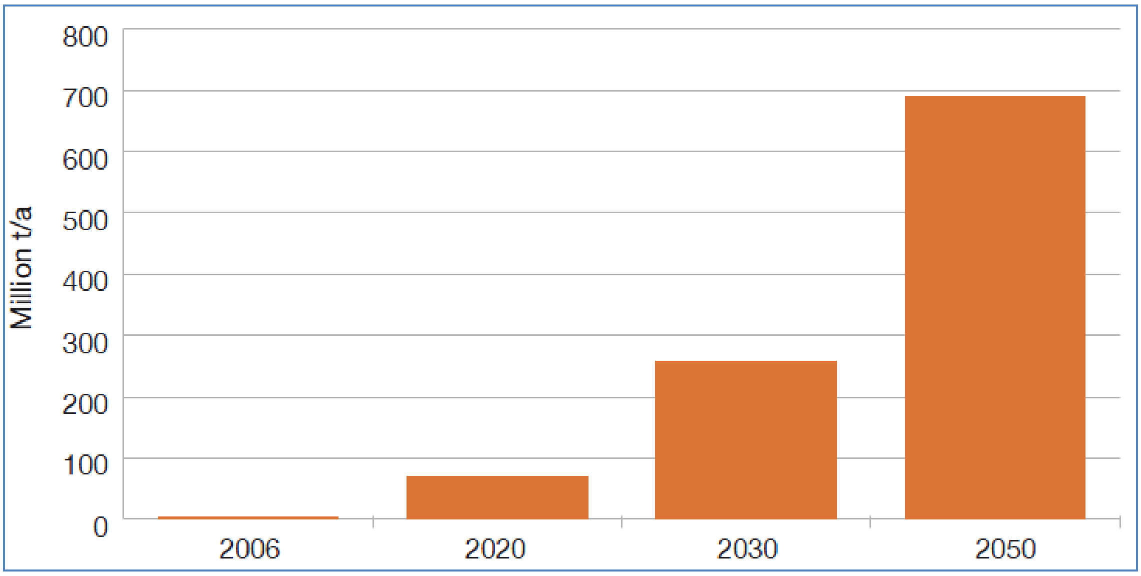


Figure 26: Annual contribution to the CO_2 reduction by solar thermal systems in the respective year - according to the Full R&D and Policy Scenario (RDP). (ESTIF 2010)

A.2.4. Long-term potential

In 2050, the solar thermal contribution to the European Union's (EU-27) low temperature heat demand ranges from 47% in the RDP scenario to 8% in the BAU scenario. The corresponding annual solar yields are 1552 TWh (RDP) and 391 TWh (BAU).

The collector area needed to reach these goals is between 2 m^2 (BAU) and 8 m^2 (RDP) per inhabitant in the EU-27. The resulting total collector area is between 970 million m^2 (BAU) and 3,88 billion m^2(RDP).

If solar thermal is to contribute significantly to the long-term heating and cooling demand in the EU-27 countries then the primary focus in central and northern Europe must be on systems for space heating (solar combisystem) and in the Mediterranean area on systems providing space heating, hot water and air conditioning (solar combi+ systems).

If the focus remains solely on solar thermal systems for domestic hot water preparation then the solar thermal contribution to the long-term final energy demand will be limited. By 2030 the full potential for these applications will have been reached and the market would be reduced mainly to the replacement of old systems.

Another important segment with considerable potential is low temperature process heat for industry.

Executive Summary

The European Union and its Member States have committed themselves to achieving a 20% share of renewable energy in Europe's final energy consumption by 2020.

To reach this target, the renewable heating sector will have to make a significant contribution since the demand for heating and cooling represents 49% of the total energy demand in Europe.

A.3. Regional and annual variations in heating and cooling power demand

In this section, for assessing the demands, I will take into consideration the demand of hot water, heating demand and cooling demand. However, I will disregard the demand of heating pool water because the ClimateWell_10 machine heats the pool water with the energy of the dissipation.

Following, you will find the explanation of the method for assessing energy demands through the figure 27 which show different dependences. I will not make an accurate calculation, since the simulation program used to calculate the graphs (demands) provide you the whole information and every equation into it.

If we show the energy needs for hot water production, they will be higher during the winter months (the mains water is colder) than the summer months (the water is warmer).

On the other hand, the availability of solar radiation is much higher during the summer than in winter.

In the figure 27 is showing that if by overlaying the graph of monthly power generated by solar collectors with the demand of hot water production, we make out clear that if the solar system provides the total needs in the summer months, it will not do 100% during the winter.

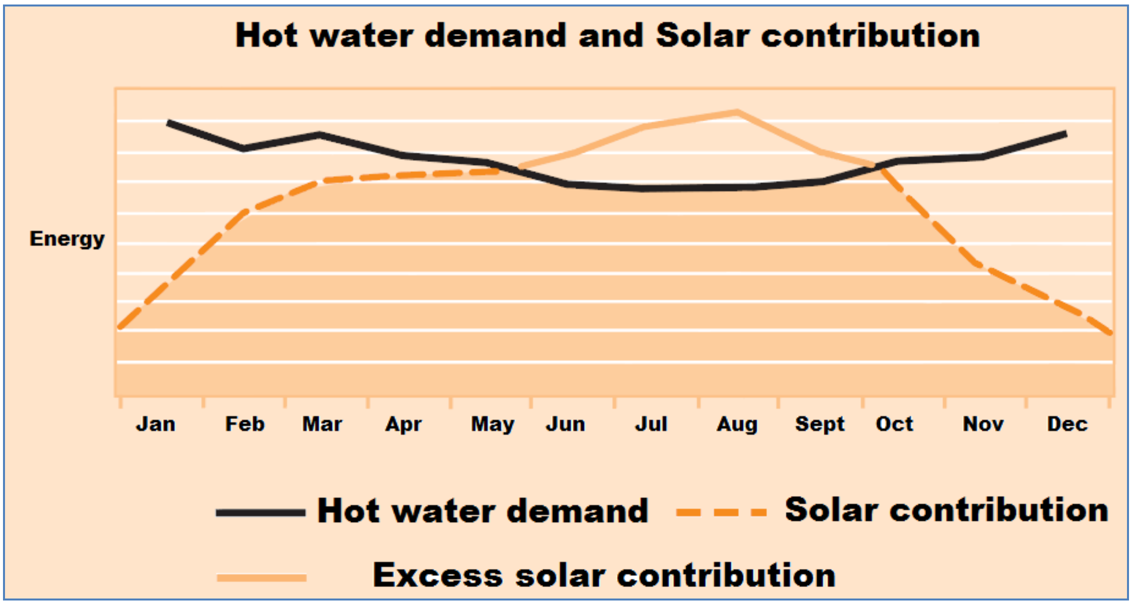


Figure 27: Hot water demand and solar contribution. (Energía Solar Térmica, guía de usuario, Junta Castilla y León)

Thus, for each application, there are an optimum number of collectors depending on the energy saving produced and the cost of placing more solar panels. We will take into consideration the number of collectors recommended by the manufacturer for a correct operation of the ClimateWell machine. Depending on the house size (square meter) and the people who are living in the house, we will place one or more machines.

All of these figures would be similar in applications of air conditioning indoor and indoor pool but it will be very different in outdoor pools.

Thus, for heating applications (with energy demand during the winter), solar system would be used for only 6-7 months per year (less radiation), missing a part of heat provide for the solar system when more heat is generated, as we can see in the figure 28.

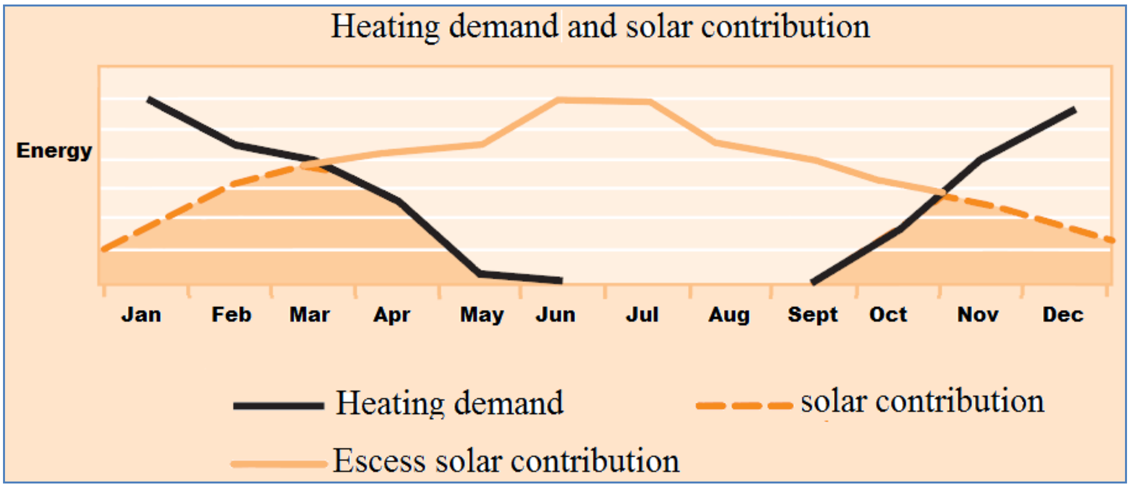


Figure 28: Heating demand and solar contribution. (Energía Solar Térmica, guía de usuario, Junta Castilla y León)

In addition, the use of solar energy for heating needs a system of heat distribution which is compatible with the solar panels used. Thus, if the heat is distributed through radiators, it is required 80-60ºC of working temperature which it cannot be provide for this system in winter. However, if the target system is radiant floor or fan-coil units, the working temperature drops to 40-30ºC which is compatible with these collectors.

Therefore, it must be reached that the annual demand will be similar to the input solar energy graph, which can be done, integrating different kinds of demand in one: demand during the winter (heating) must be compensate with other demand during the summer (cool), as we can see in the figure 29.

Thus, an installation of solar energy might provide energy for both applications simultaneously, using in an optimized way, the solar system (investment) during the whole year (fuel savings for each application depending on season).

The development of absorption refrigeration system as well as solar thermal systems, allows to cool Establishment, displacing the pools as absorbed of waste heat in summer months. This is achieved by squaring the circle: the house is heating and cooling with the same system without any wasting of solar energy. Taking into consideration that the transmission system used for heating or cooling (radiant floor) is the same.

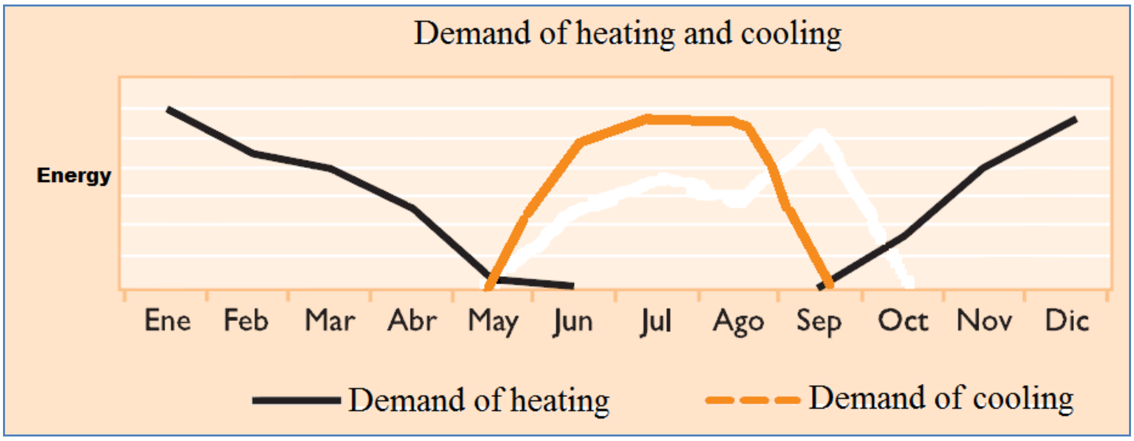


Figure 29: Heating and cooling demands. (Energía Solar Térmica, guía de usuario, Junta Castilla y León)

The percentage of energy generated by the solar system in comparison with the energy required for the system is called coverage or replacement solar. This is expressed like an annual percentage. For example, a solar system has coverage of 70% of demand.

In conclusion, the best applications of thermal solar energy are hot water production, heating and cooling as is noted in the regulation.

That regulation, is Code Technical of Building -CTE-(RD 314/2006 of 17 March), requires that new buildings and complete improved buildings with consumption of hot water and air-conditioning have solar thermal systems which provide part of the demand.

Following, I will explain a simple method for working out the energy demand of hot water and air conditioning.

A.3.1. Calculation of monthly energy demand of the building

The first step in the design of a hot water production system is: Assessing the energy demand of the building (DEmo), kWh/month.

12 values are usually calculated (one per month) which unit is kWh/month, according to the following formula:

$$\mathbf{DEmo = Qday * N * (T\ hot\ water - Tcw) * 1{,}16*10^{-3}}$$

Where:

- Demo: energy demand in kWh/month.
- Qday: daily consumption of hot water at the reference temperature T hot water, in liters/day.
- N: the number of days of the month considered, days/month.
- T hot water: the reference temperature used to quantify the consumption of hot water, in °C.
- Tcw: temperature of the water supply, in °C.

The temperature of hot water in a house changes depending on the application (bath, sink, shower ...). Typically, values of water consumption (Qday) are related to a given temperature (T hot water), which is used for calculating energy demand.

Values showed above change depending on each area, and particularly in each City Hall. Then, I will show some reference values for the consumption of hot water in houses which are used to calculate energy demand in different towns in Spain.

City Hall of Barcelona

Method for calculating energy demand:

- Qday: 40 liters per person per day.
- T hot water: 60ºC.
- Tcw: 10ºC.
- The number of people is worked out using a housing functional program. If this is not defined, it should be considered 2 people in each bedroom.
- For community facilities in residential buildings, consumption can reduced by f value which is calculated as the number of households n as follows:
  f = 1 for buildings with less than 10 houses.
  f = 1.2 to 0.02 • No buildings 10 to 25 houses.
  f = 0.7 for buildings more than 25 houses.

City Hall of Sevilla

Method for calculating energy demand:

- Qday: 40 liters per person per day.
- T hot water: 45ºC.
- Tcw: 10ºC.
- The number of people is worked out using a housing functional program. If this is not defined, it should be considered 2 people in each bedroom.
- For community facilities in residential buildings, consumption can reduced by f value which is calculated as the number of households n as follows:
  f = 1 for buildings with less than 10 houses.
  f = 1,2 to 0,02 • No buildings 10 to 25 houses.
  f = 0,7 for buildings more than 25 houses.

City Hall of Madrid

Method for calculating energy demand:

- Qday: 60 ºC, 22 liters per person per day for multifamily housing.
- Qday: 60 ºC, 30 liters per person per day for single family homes.
- The number of people determined from the number of bedrooms, according to the following table:
  Houses with a single room or apartments with 1 bedroom: 1,5 persons
  2 bedroom houses: 3 people
  3 bedroom houses: 4 people
  4 bedroom houses: 6 people

5 bedroom houses: 7 people
6 bedroom houses: 8 people
7 bedroom houses: 9 people

In the event that there is no ordinance that makes require the use of a particular value for water consumption:

- Qday: 30 liters per person per day for multifamily dwelling and 40 liters per person per day for single family house.
- T hot water: 60ºC.

The values of cold water temperature Tcw are taken from the table 12.

Table 12: Values of cold water temperature [Tcw]. (Salvador Escoda S.A., 2005)

	Provincia	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC	AÑO
1	ÁLAVA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
2	ALBACETE	5	6	8	10	11	12	13	12	11	10	8	5	9,3
3	ALICANTE	8	9	11	13	14	15	16	15	14	13	11	8	12,3
4	ALMERÍA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
5	ASTURIAS	6	7	9	11	12	13	14	13	12	11	9	6	10,3
6	ÁVILA	4	5	7	9	10	11	12	11	10	9	7	4	8,3
7	BADAJOZ	6	7	9	11	12	13	14	13	12	11	9	6	10,3
8	BALEARES	8	9	11	13	14	15	16	15	14	13	11	8	12,3
9	BARCELONA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
10	BURGOS	4	5	7	9	10	11	12	11	10	9	7	4	8,3
11	CÁCERES	6	7	9	11	12	13	14	13	12	11	9	6	10,3
12	CÁDIZ	8	9	11	13	14	15	16	15	14	13	11	8	12,3
13	CANTABRIA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
14	CASTELLÓN	8	9	11	13	14	15	16	15	14	13	11	8	12,3
15	CEUTA	8	9	10	12	13	13	14	13	13	12	11	8	11,9
16	CIUDAD REAL	5	6	8	10	11	12	13	12	11	10	8	5	9,3
17	CÓRDOBA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
18	LA CORUÑA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
19	CUENCA	4	5	7	9	10	11	12	11	10	9	7	4	8,3
20	GERONA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
21	GRANADA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
22	GUADALAJARA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
23	GUIPÚZCOA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
24	HUELVA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
25	HUESCA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
26	JAÉN	8	9	11	13	14	15	17	16	14	13	11	7	12,3
27	LEÓN	4	5	7	9	10	11	12	11	10	9	7	4	8,3
28	LÉRIDA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
29	LUGO	6	7	9	11	12	13	14	13	12	11	9	6	10,3
30	MADRID	6	7	9	11	12	13	14	13	12	11	9	6	10,3
31	MÁLAGA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
32	MELILLA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
33	MURCIA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
34	NAVARRA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
35	ORENSE	5	7	9	11	12	13	14	13	12	11	9	6	10,2
36	PALENCIA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
37	LAS PALMAS	8	9	11	13	14	15	16	15	14	13	11	8	12,3
38	PONTEVEDRA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
39	LA RIOJA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
40	SALAMANCA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
41	STA. C. TENERIFE	8	9	11	13	14	15	16	15	14	13	11	8	12,3
42	SEGOVIA	4	5	7	9	10	11	12	11	10	9	7	4	8,3
43	SEVILLA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
44	SORIA	4	5	7	9	10	11	12	11	10	9	7	4	8,3
45	TARRAGONA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
46	TERUEL	4	5	7	9	10	11	12	11	10	9	7	4	8,3
47	TOLEDO	6	7	9	11	12	13	14	13	12	11	9	6	10,3
48	VALENCIA	8	9	11	13	14	15	16	15	14	13	11	8	12,3
49	VALLADOLID	5	6	8	10	11	12	13	12	11	10	8	5	9,3
50	VIZCAYA	6	7	9	11	12	13	14	13	12	11	9	6	10,3
51	ZAMORA	5	6	8	10	11	12	13	12	11	10	8	5	9,3
52	ZARAGOZA	5	6	8	10	11	12	13	12	11	10	8	5	9,3

However, some Municipal ordinance set as water supply temperature (Tcw) for the calculation of thermal solar energy systems which might not be similar to the table above. The table 13 is used to calculate the demands of hot water.

Table 13: Calculate the demands of hot water. (Manual de cálculo de instalaciones de producción de ACS en edificaciones de viviendas mediante energía solar y apoyo individual de gas natural, Grupo gas natural, 2004).

Mes	N días/mes	T_{AF} ºC	DE_{mes} kWh
Ene			
Feb			
Mar			
Abr			
May			
Jun			
Jul			
Ago			
Sep			
Oct			
Nov			
Dic			
TOTAL			

A.3.2. Calculation of energy provides by a solar system for heating and cooling.

f - Chart method is commonly used to solve the calculation by the following equation:

$$f = 1{,}029\ D1 - 0{,}065\ D2 - 0{,}245\ D1^2 + 0{,}0018\ D2^2 + 0{,}0215\ D1^3$$

The procedure involves the following steps:

- Calculation of monthly solar radiation which incidents in the collectors.
- Calculation of the parameter D1.
- Calculation of the parameter D2.
- Assessment of monthly energy fraction (f) that is given by the solar collection system.
- Degree of coverage or solar annual fraction F.
- Calculation of the solar collection surface S_c
- Calculation of monthly and annual solar production.

The systematic application of the f-chart method consists on identifying the variables of solar heating system and applying iterative calculations until obtain the required collection area to achieve a certain degree of coverage or solar fraction.

The program will provide a calculation report depending on the input data (location of the house, latitude, inclination and position of the collectors and solar radiation). It has to be taken into consideration that the required collectors recommended by the manufacturer for the absorption chiller will be placed in the system. However, the calculation of monthly electricity (Elmo) is showed below to know how to make it, in case ClimateWell would not be used.

$$Elmo = Kmo \cdot Hday \cdot N \cdot (1 - por) \cdot (1 - pshadow)$$

Where:

- **Elmo:** The monthly incident solar energy over the surface of the collectors, kWh / (m^2 • month).
- **Kmo:** Coefficient which depends on the latitude and the tilt of the solar collector area per month.
- **Hday:** Solar radiation incident on a horizontal surface in kWh / (m^2 • day).
- **N:** Number of days in month.
- **por:** Depends on the orientation of the house (0 in our case).
- **pshadow:** Depends on the shade of the solar collectors (0 in our case).

To calculate the cold for refrigeration, that is calculated in the same way as above, taking into account that also depend on the average temperature in the street in each province during the daylight hours in each month, as can be seen in the table 14.

Table 14: Average temperatures in the street; depend on each province and during the daylight hours in each month. (Salvador Escoda S.A., 2005)

	Provincia	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SEP	OCT	NOV	DIC	AÑO
1	ÁLAVA	7	7	11	12	15	19	21	21	19	15	10	7	13,7
2	ALBACETE	6	8	11	13	17	22	26	26	22	16	11	7	15,4
3	ALICANTE	13	14	16	18	21	25	28	28	26	21	17	14	20,1
4	ALMERÍA	15	15	16	18	21	24	27	28	26	22	18	16	20,5
5	ASTURIAS	9	10	11	12	15	18	20	20	19	16	12	10	14,3
6	ÁVILA	4	5	8	11	14	18	22	22	18	13	8	5	12,3
7	BADAJOZ	11	12	15	17	20	25	28	28	25	20	15	11	18,9
8	BALEARES	12	13	14	17	19	23	26	27	25	20	16	14	18,8
9	BARCELONA	11	12	14	17	20	24	26	26	24	20	16	12	18,5
10	BURGOS	5	6	9	11	14	18	21	21	18	13	9	5	12,5
11	CÁCERES	10	11	14	16	19	25	28	28	25	19	14	10	18,3
12	CÁDIZ	13	15	17	19	21	24	27	27	25	22	18	15	20,3
13	CANTABRIA	11	11	14	14	16	19	21	21	20	17	14	12	15,8
14	CASTELLÓN	13	13	15	17	20	24	26	27	25	21	16	13	19,2
15	CEUTA	15	15	16	17	19	23	25	26	24	21	18	16	19,6
16	CIUDAD REAL	7	9	12	15	18	23	28	27	20	17	11	8	16,3
17	CÓRDOBA	11	13	16	18	21	26	30	30	26	21	16	12	20
18	LA CORUÑA	12	12	14	14	16	19	20	21	20	17	14	12	15,9
19	CUENCA	5	6	9	12	15	20	24	23	20	14	9	6	13,6
20	GERONA	9	10	13	15	19	23	26	25	23	18	13	10	17
21	GRANADA	9	10	13	16	18	24	27	27	24	18	13	9	17,3
22	GUADALAJARA	7	8	12	14	18	22	26	26	22	16	10	8	15,8
23	GUIPÚZCOA	10	10	13	14	16	19	21	21	20	17	13	10	15,3
24	HUELVA	13	14	16	20	21	24	27	27	25	21	17	14	19,9
25	HUESCA	7	8	12	15	18	22	25	25	21	16	11	7	15,6
26	JAÉN	11	11	14	17	21	26	30	29	25	19	15	10	19
27	LEÓN	5	6	10	12	15	19	22	22	19	14	9	6	13,3
28	LÉRIDA	7	10	14	15	21	24	27	27	23	18	11	8	17,1
29	LUGO	8	9	11	13	15	18	20	21	19	15	11	8	14
30	MADRID	6	8	11	13	18	23	28	26	21	15	11	7	15,6
31	MÁLAGA	15	15	17	19	21	25	27	28	26	22	18	15	20,7
32	MELILLA	15	15	16	18	21	25	27	28	26	22	18	16	20,6
33	MURCIA	12	12	15	17	21	25	28	28	25	20	16	12	19,3
34	NAVARRA	7	7	11	13	16	20	22	23	20	15	10	8	14,3
35	ORENSE	9	9	13	15	18	21	24	23	21	16	12	9	15,8
36	PALENCIA	5	7	10	13	16	20	23	23	20	14	9	6	13,8
37	LAS PALMAS	20	20	21	22	23	24	25	25	26	25	23	21	22,9
38	PONTEVEDRA	11	12	14	16	18	20	22	23	20	17	14	12	16,6
39	LA RIOJA	7	9	12	14	17	21	24	24	21	16	11	8	15,3
40	SALAMANCA	6	7	10	13	16	20	24	23	20	14	9	6	14
41	STA. C. TENERIFE	19	20	20	21	22	24	26	27	26	25	23	20	22,8
42	SEGOVIA	4	6	10	12	15	20	24	23	20	14	9	5	13,5
43	SEVILLA	11	13	14	17	21	25	29	29	24	20	16	12	19,3
44	SORIA	4	6	9	11	14	19	22	22	18	13	8	5	12,6
45	TARRAGONA	11	12	14	16	19	22	25	26	23	20	15	12	17,9
46	TERUEL	5	6	9	12	16	20	23	24	19	14	9	6	13,6
47	TOLEDO		9	13	15	19	24	28	27	23	17	12	8	16,9
48	VALENCIA	12	13	15	17	20	23	26	27	24	20	16	13	18,8
49	VALLADOLID	4	6	9	12	17	21	24	23	18	13	8	4	13,3
50	VIZCAYA	10	11	12	13	16	20	22	22	20	16	13	18	15,4
51	ZAMORA	6	7	11	13	16	21	24	23	20	15	10	6	14,3
52	ZARAGOZA	8	10	13	16	19	23	26	26	23	17	12	9	16,8

As I said before, the program will also give us in the report, cooling consumption data, taking into account the above table and the working temperature at which we want to be home.

The following table, table 15, is used for the calculation of Kmes: Depending on the town and inclination of the solar panels, different K will be obtained for each month.

Table 15: Different K depends on the town and the inclination of the solar panels for the calculus of Kmes. (Manual de cálculo de instalaciones de producción de ACS en edificaciones de viviendas mediante energía solar y apoyo individual de gas natural, Grupo gas natural, 2004)

Latitud = 35°	Melilla											
Inclinación	ene	feb	mar	abr	may	jun	jul	ago	sep	oct	nov	dic
30	1,28	1,21	1,13	1,04	0,97	0,94	0,97	1,04	1,15	1,28	1,36	1,35
45	**1,33**	**1,22**	**1,09**	**0,96**	**0,86**	**0,82**	**0,86**	**0,97**	**1,13**	**1,30**	**1,42**	**1,41**
60	1,29	1,16	0,99	0,82	0,70	0,66	0,70	0,83	1,03	1,25	1,41	1,40
90	1,02	0,85	0,64	0,42	0,27	0,21	0,26	0,42	0,66	0,93	1,13	1,15

Latitud = 36°	Ceuta											
Inclinación	ene	feb	mar	abr	may	jun	jul	ago	sep	oct	nov	dic
30	1,29	1,22	1,13	1,04	0,98	0,95	0,98	1,05	1,16	1,29	1,37	1,36
45	**1,34**	**1,23**	**1,10**	**0,97**	**0,87**	**0,84**	**0,87**	**0,98**	**1,14**	**1,32**	**1,44**	**1,43**
60	1,31	1,17	1,01	0,84	0,71	0,67	0,71	0,84	1,05	1,27	1,43	1,42
90	1,05	0,87	0,65	0,44	0,29	0,23	0,28	0,44	0,68	0,96	1,16	1,17

Latitud = 37°	Almería, Cádiz, Granada, Huelva, Málaga, Sevilla											
Inclinación	ene	feb	mar	abr	may	jun	jul	ago	sep	oct	nov	dic
30	1,30	1,23	1,14	1,05	0,98	0,96	0,98	1,06	1,17	1,30	1,38	1,37
45	**1,35**	**1,25**	**1,11**	**0,98**	**0,88**	**0,85**	**0,88**	**0,99**	**1,15**	**1,34**	**1,46**	**1,45**
60	1,33	1,19	1,02	0,85	0,73	0,68	0,73	0,86	1,06	1,30	1,45	1,44
90	1,07	0,89	0,67	0,46	0,30	0,25	0,30	0,45	0,70	0,98	1,19	1,20

Latitud = 38°	Alicante, Córdoba, Jaén, Murcia											
Inclinación	ene	feb	mar	abr	may	jun	jul	ago	sep	oct	nov	dic
30	1,31	1,24	1,15	1,06	0,99	0,97	0,99	1,07	1,18	1,31	1,40	1,38
45	**1,37**	**1,26**	**1,13**	**0,99**	**0,89**	**0,86**	**0,89**	**1,00**	**1,17**	**1,36**	**1,48**	**1,47**
60	1,35	1,21	1,04	0,86	0,74	0,69	0,74	0,87	1,08	1,32	1,48	1,47
90	1,09	0,91	0,69	0,47	0,32	0,26	0,31	0,47	0,72	1,01	1,22	1,23

Latitud = 39°	Albacete, Badajoz, Ciudad Real											
Inclinación	ene	feb	mar	abr	may	jun	jul	ago	sep	oct	nov	dic
30	1,33	1,25	1,16	1,07	1,00	0,97	1,00	1,08	1,19	1,33	1,41	1,40
45	**1,38**	**1,27**	**1,14**	**1,00**	**0,90**	**0,87**	**0,90**	**1,01**	**1,18**	**1,37**	**1,50**	**1,48**
60	1,37	1,22	1,05	0,88	0,75	0,71	0,75	0,89	1,10	1,34	1,51	1,49
90	1,12	0,93	0,71	0,49	0,33	0,28	0,33	0,49	0,74	1,04	1,25	1,26

Latitud = 40°	Baleares, Cáceres, Castellón, Cuenca, Madrid, Teruel, Toledo, Valencia											
Inclinación	ene	feb	mar	abr	may	jun	jul	ago	sep	oct	nov	dic
30	1,34	1,26	1,17	1,07	1,01	0,98	1,01	1,09	1,20	1,34	1,43	1,41
45	**1,40**	**1,29**	**1,15**	**1,01**	**0,91**	**0,88**	**0,92**	**1,03**	**1,20**	**1,39**	**1,52**	**1,50**
60	1,39	1,24	1,07	0,89	0,77	0,72	0,77	0,90	1,12	1,36	1,53	1,51
90	1,14	0,95	0,73	0,50	0,35	0,29	0,34	0,50	0,76	1,07	1,29	1,29

Latitud = 41°	Ávila, Barcelona, Guadalajara, Salamanca, Segovia, Tarragona											
Inclinación	ene	feb	mar	abr	may	jun	jul	ago	sep	oct	nov	dic
30	1,35	1,27	1,18	1,08	1,01	0,99	1,02	1,09	1,21	1,35	1,44	1,42
45	**1,42**	**1,30**	**1,16**	**1,03**	**0,93**	**0,89**	**0,93**	**1,04**	**1,21**	**1,41**	**1,55**	**1,52**
60	1,41	1,26	1,08	0,91	0,78	0,73	0,78	0,92	1,14	1,39	1,56	1,54
90	1,17	0,98	0,74	0,52	0,36	0,31	0,36	0,52	0,78	1,09	1,32	1,32

Latitud = 42º	Burgos, Girona, Huesca, Lleida, Ourense, Palencia, Pontevedra, Soria, Valladolid, Zamora, Zaragoza										
Inclinación	**ene**	**feb**	**mar**	**abr**	**may**	**jun**	**jul**	**ago**	**sep**	**oct**	**nov**	**dic**
30	1,36	1,28	1,19	1,09	1,02	1,00	1,02	1,10	1,23	1,37	1,46	1,44
45	**1,43**	**1,32**	**1,18**	**1,04**	**0,94**	**0,90**	**0,94**	**1,05**	**1,23**	**1,43**	**1,57**	**1,54**
60	1,43	1,28	1,10	0,92	0,79	0,75	0,80	0,93	1,15	1,41	1,59	1,57
90	1,19	1,00	0,76	0,54	0,38	0,32	0,38	0,54	0,81	1,12	1,36	1,35

Latitud = 43º	A Coruña, Álava, Asturias, Guipúzcoa, León, Lugo, Navarra, La Rioja, Vizcaya											
Inclinación	**ene**	**feb**	**mar**	**abr**	**may**	**jun**	**jul**	**ago**	**sep**	**oct**	**nov**	**dic**
30	1,37	1,29	1,20	1,10	1,03	1,00	1,03	1,11	1,24	1,38	1,48	1,45
45	**1,45**	**1,33**	**1,19**	**1,05**	**0,95**	**0,91**	**0,95**	**1,06**	**1,24**	**1,45**	**1,59**	**1,57**
60	1,45	1,30	1,12	0,94	0,81	0,76	0,81	0,95	1,17	1,44	1,62	1,59
90	1,22	1,02	0,78	0,56	0,40	0,34	0,39	0,56	0,83	1,16	1,39	1,38

Latitud = 44º	Cantabria											
Inclinación	**ene**	**feb**	**mar**	**abr**	**may**	**jun**	**jul**	**ago**	**sep**	**oct**	**nov**	**dic**
30	1,38	1,30	1,20	1,11	1,04	1,01	1,04	1,12	1,25	1,40	1,49	1,47
45	**1,47**	**1,35**	**1,20**	**1,06**	**0,96**	**0,92**	**0,96**	**1,08**	**1,26**	**1,48**	**1,62**	**1,59**
60	1,47	1,32	1,13	0,95	0,82	0,78	0,82	0,97	1,19	1,47	1,65	1,62
90	1,25	1,04	0,80	0,57	0,41	0,35	0,41	0,58	0,85	1,19	1,43	1,42

The following table, table 16 is for representing the electricity consumed in each month of the year. Regardless whether it is heating or cooling:

Table 16: Consumed electricity in each month of the year. (Manual de cálculo de instalaciones de producción de ACS en edificaciones de viviendas mediante energía solar y apoyo individual de gas natural, Grupo gas natural, 2004)

Mes	N días/mes	k_{mes}	$H_{día}$ kWh/(m²·día)	El_{mes} kWh/m²
Ene				
Feb				
Mar				
Abr				
May				
Jun				
Jul				
Ago				
Sep				
Oct				
Nov				
Dic				
TOTAL				

This value will be used to calculate the energy due to the cooling and heating which will depend on the location and orientation of the house, i.e. the latitude and tilt it as shown in the table 15.

All these data, are used to calculate the curves drawn (only a general meaning) in the first pages of this section.

Annex B. Solar heating technology

Solar technologies can supply the energy for all of a building's needs without the harmful effects of greenhouse gas emissions created by fossil fuels.

Solar applications can be used almost anywhere in the world and are appropriate for all building types:

- Single-family homes.
- Multi-family residences.
- Office and industrial buildings.
- Schools.
- Hospitals.
- Other public buildings.

In the agriculture sector, solar technology is being used to dry crops ranging from coffee and tea to wool and chicken manure. Companies in Europe, North America, and numerous developing countries see this technology as a cost-effective and environmentally sensitive process.

The majority of the energy used in commercial and industrial processes is below 250°C, a temperature range well suited for solar technologies. Solar technologies are being used for specific industrial processes, such as food processing, textile cleaning and drying, pharmaceutical and biochemical processes, desalination, and heating and cooling of factories.

The most widespread applications of this technology for buildings are: heating, cooling and hot water. Other applications include water heating for indoor or outdoor pools and emerging applications such as air conditioning by absorption cycles, which is used in our project.

Very schematically speaking, the solar thermal system is working as follow: the collector or solar panel captures the solar irradiation and absorbs the energy in the form of heat. Through the solar panel passes a fluid (usually water) which transfers the absorbed heat. The fluid temperature will increase, which will be stored or directly carried to the place of consumption.

B.1. Solar thermal for hot water, pool heating, radiant floor heating

B.1.1. Solar thermal hot water (DHW)

The hot water is typically used at a temperature of 45-60ºC. This temperature is easily reached by a solar system whatever the season. A good percentage of DHW annual coverage is approximately 60%-70%. Indeed, we save that percentage of energy to heat water. We use this percentage, so that in the period of greatest solar radiation there is no excess of energy. The other needs not provided by the sun are obtained from an auxiliary system that usually tends to be oil, gas or electricity. With this rate of solar contribution, payback periods are much more reduced.

The initial investment is higher compared to the conventional system; however, it remains cheap because it has more than 20 years of life expectancy. Thus, the installation of solar energy is more economically advantageous, since all energy obtained from the sun with solar thermal collectors, will not have to be produced. The payback period on investment can fluctuate between 5 and 12 years depending on the size of the facility, on the place where it is installed (more or less radiation) and on the important needs or not, of the user.

Figure 30 shows the schematic of an installation of hot water by solar thermal panels in a single family dwelling.

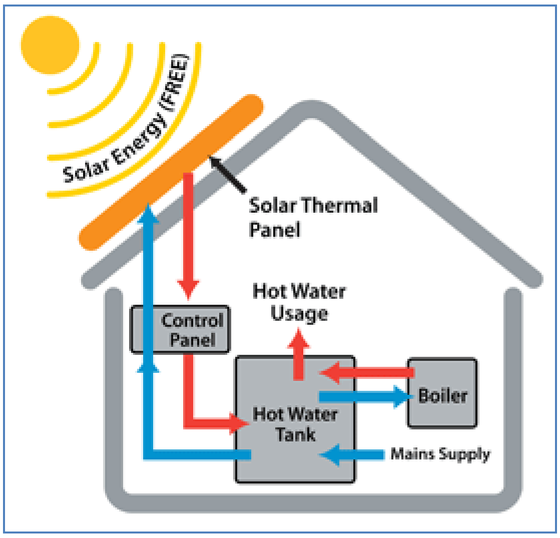


Figure 30: Schematic of an installation of hot water by solar thermal panels in a single family dwelling.

B.1.2. Solar thermal energy for heating swimming pools

For a standard pool of 25m x 12.5m at a temperature of 28°C, the energy consumption can be higher than 300.000 kWh per year, depending on the number of inhabitants.

Solar energy installations for pools are economically advantageous for two main reasons:

- The pool is used as energy storage. Because of it, is not necessary to use accumulators, which makes the installation is more economical.

- The optimum temperature of a swimming pool fluctuates between 23ºC and 30ºC depending on the needs, so the solar collectors are able to work with a lower temperature compared with other applications, they are therefore more efficient.

Outdoor pools using solar collectors can lengthen the period of bath from April to October. In these cases are used collectors of polypropylene, in which can circulate the pool water itself, thus obtaining direct systems, in which the working fluid is water heating.

Figure 31 shows the schematic of a heating installation of pool water with solar thermal combined with DHW.

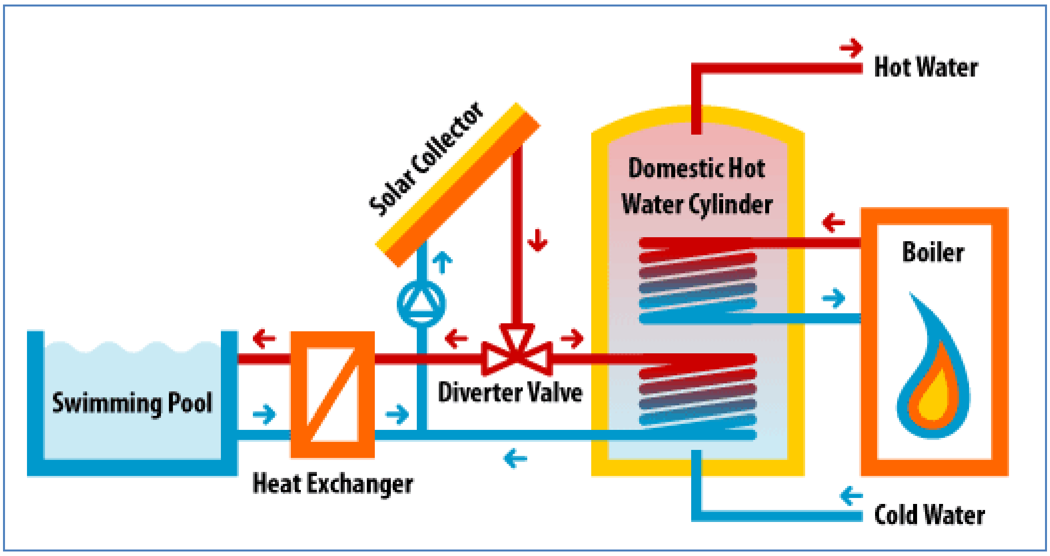


Figure 31: Schematic of a heating installation of pool water with solar thermal combined with DHW.

B.1.3. Solar energy for radiant floor heating

The radiant floor heating is a plastic pipe embedded in the mortar layer that goes heating the room. This piping leads hot water (at low temperature as compared to other heating systems) is usually produced by a boiler which can have a solar support.

Through the pipe, the water transfers heat to the floor, which is then transmitted to the atmosphere of the enclosure. The emergence of cross-linked polyethylene pipes has revolutionized the world of underfloor heating. As a result, it has significantly reduced the installation time, the quality and the performance of the installation.

In addition, solar heating underfloor has several advantages respect to conventional heating radiator:

· The temperature distribution is ideal. It is desirable to achieve a higher temperature in the floor than in the roof since the feeling of getting heat in the floor is much comfortable than receiving it in the head.

· Energy savings: With the usual radiator heating, the circuit carries water at an average temperature of 80ºC. In floor heating, the water temperature is around 40-45°C. If we work with this low temperature, heat losses in pipes are generally minor. This also reduces heat loss through roofs and outside air. With all these factors, it can be assured that energy savings from radiant floor heating is about 15% compared with traditional heating systems.

- Environmentally friendly: it can be combined with alternative energy such as solar or geothermal heat pump due to the low temperature required.

- Uniform temperature: With radiant floor heating, a uniform temperature can be obtained in all the surface of the housing (about 22ºC) disappearing hot and cold areas, characteristics of heating radiators.

The following figure, figure 32, shows the installation of radiant floor heating combined with DHW.

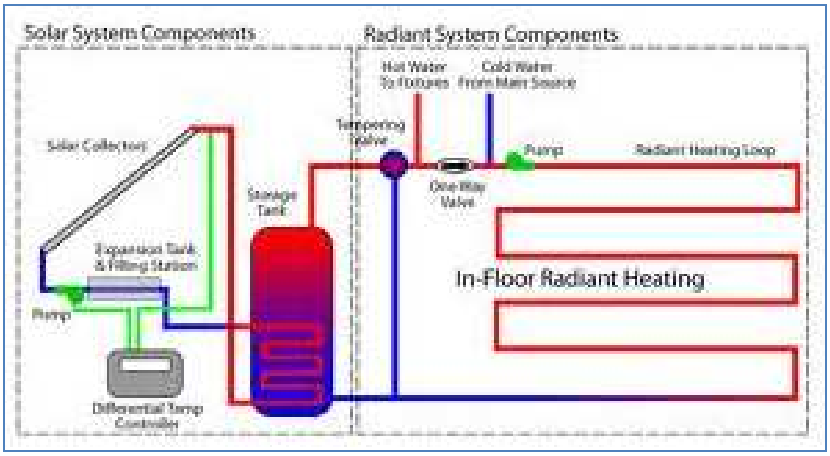


Figure 32: Installation of radiant floor heating combined with DHW.

B.2. Solar collectors

Solar collectors are the heart of most solar energy systems. The collector absorbs the sun's light energy and changes it into heat energy. In this part I will describe the different types of solar collectors used for residences. It also briefly covers the solar heating systems for which they are best suited.

Solar collectors heat a fluid, either air or liquid. This fluid then is used to heat—directly or indirectly—the following:

- Water for household use.
- Indoor spaces.
- Water for swimming pools.
- Water or air for commercial use.
- Air to regenerate desiccant (drying) material in a desiccant cooling system.

There are several types of solar collectors used for residences. These are flat-plate, evacuated-tube, and concentrating collectors.

B.2.1. Flat-plate collectors

Figure 33 shows the flat-plate collectors are the most common collector for residential water-heating and space-heating installations which will be chosen in my project because of the comment after. A typical flat-plate collector is an insulated metal box with a glass or plastic cover—called the glazing—and a dark-colored absorber plate. The glazing can be transparent or translucent. Translucent (transmitting light only), low-iron glass is a common glazing material for flat-plate collectors because low-iron glass transmits a high percentage of the total available solar energy. The glazing allows the light to strike the absorber plate but reduces the amount of heat that can escape. The sides and bottom of the collector are usually insulated, further minimizing heat loss.

The absorber plate is usually black because dark colors absorb more solar energy than light colors. Sunlight passes through the glazing and strikes the absorber plate, which heats up, changing solar radiation into heat energy. The heat is transferred to the air or liquid passing through the collector. Absorber plates are commonly covered with “selective coatings,” which retain the absorbed sunlight better and are more durable than ordinary black paint.

Absorber plates are often made of metal— usually copper or aluminum—because they are both good heat conductors. Copper is more expensive, but is a better conductor and is less prone to corrosion than aluminum.

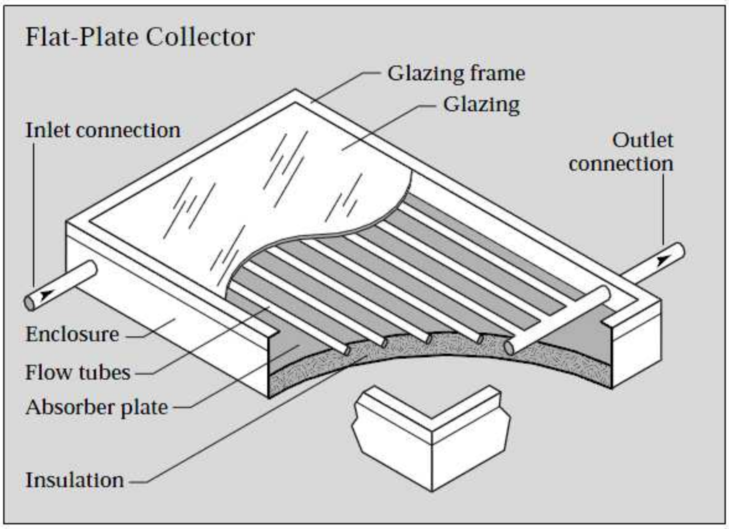


Figure 33: Flat-Plate Collector. (DOE/GO-10096-051, March 1996).

Flat-plate collectors fall into two basic categories: liquid and air. And both types can be either glazed or unglazed.

B.2.1.1. Liquid collectors

In a liquid collector, solar energy heats a liquid as it flows through tubes in or adjacent to the absorber plate. For this type of collector, the flow tubes are attached to the absorber plate so the heat absorbed by the absorber plate is readily conducted to the liquid.

The flow tubes can be routed in parallel, using inlet and outlet headers, or in a serpentine pattern. A serpentine pattern eliminates the possibility of header leaks and ensures uniform flow. A serpentine pattern is not appropriate, however, for systems that must drain for freeze protection because the curved flow passages will not drain completely.

The simplest liquid systems use potable household water, which is heated as it passes directly through the collector and then flows to the house to be used for bathing, laundry, etc. This design is known as an “open-loop” (or “direct”) system. In areas where freezing temperatures are common, however, liquid collectors must either drain the water when the temperature drops or use an antifreeze type of heat-transfer fluid.

In systems with heat-transfer fluids, the transfer fluid absorbs heat from the collector and then passes through a heat exchanger. The heat exchanger, which generally is in the water storage tank inside the house, transfers heat to the water. Such designs are called “closed-loop” (or “indirect”) systems.

Glazed liquid collectors are used for heating household water and sometimes for space heating. Unglazed liquid collectors are commonly used to heat water for swimming pools. Because these collectors need not withstand high temperatures, they can use less expensive materials such as plastic or rubber. They also do not require freeze-proofing because swimming pools are generally used only in warm weather.

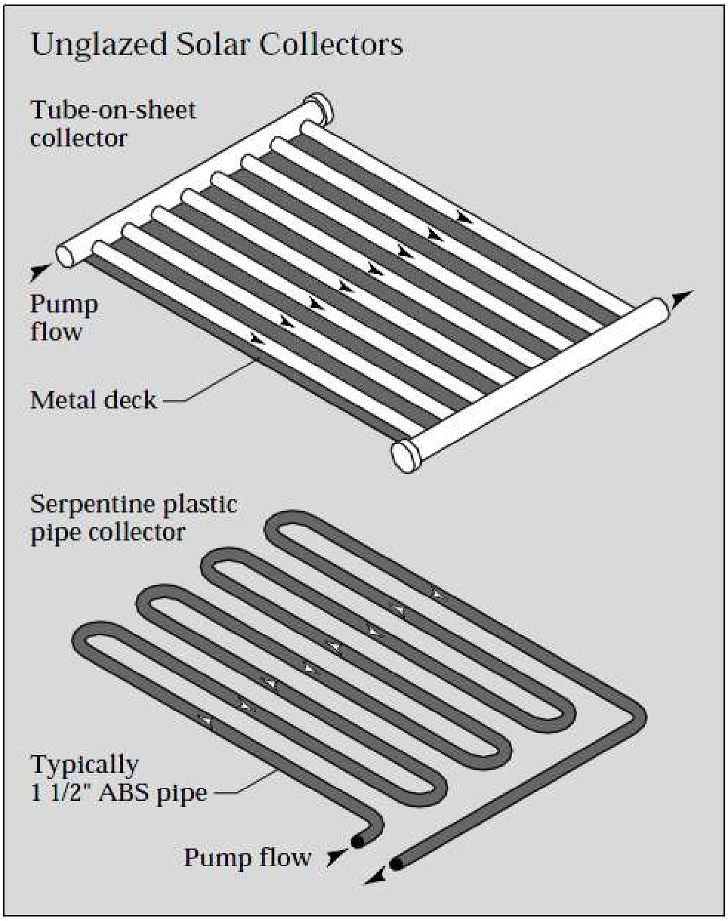


Figure 34: Unglazed Solar Collectors. (DOE/GO-10096-051, March 1996)

B.2.1.2. Air collectors

Figure 35 shows air collectors are simple, flat-plate collectors used primarily for space heating. The absorber plates in air collectors can be metal sheets, layers of screen, or nonmetallic materials. The air flows past the absorber by natural convection or when forced by a fan. Because air conducts heat much less readily than liquid does, less heat is transferred between the air and the absorber than in a liquid collector.

In some solar air-heating systems, fins or corrugations on the absorber are used to increase air turbulence and improve heat transfer. The disadvantage of this strategy is that it can also increase the amount of power needed for fans and, thus, increase the costs of operating the system. In colder climates, the air is routed between the absorber plate and the back insulation to reduce heat loss through the glazing. However, if the air will not be heated more than 17°C above the outdoor temperature, the air can flow on both sides of the absorber plate without sacrificing efficiency.

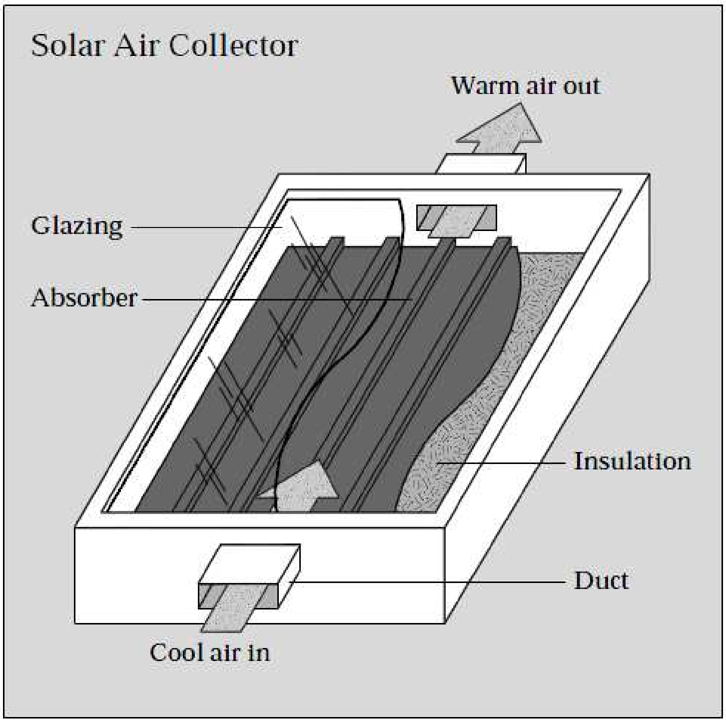


Figure 35: Solar Air Collector. (DOE/GO-10096-051, March 1996)

Air systems have the advantage of eliminating the freezing and boiling problems associated with liquid systems. Although leaks are harder to detect and plug in an air system, they are also less troublesome than leaks in a liquid system. Air systems can often use less expensive materials, such as plastic glazing, because their operating temperatures are usually lower than those of liquid collectors.

B.2.2. Evacuated-tube collectors

Evacuated-tube collectors heat water in residential applications that require higher temperatures. In an evacuated-tube collector, sunlight enters through the outer glass tube, strikes the absorber tube, and changes to heat. The heat is transferred to the liquid flowing through the absorber tube. The collector consists of rows of parallel transparent glass tubes, each of which contains an absorber tube (in place of the absorber plate in a flat-plate collector) covered with a selective coating. Evacuated-tube collectors are modular—tubes can be added or removed as hot-water needs change.

When evacuated tubes are manufactured, air is evacuated from the space between the two tubes, forming a vacuum. Conductive and convective heat losses are eliminated because there is no air to conduct heat or to circulate and cause convective losses. There can still be some radiant heat loss (heat energy will move through space from a warmer to a cooler surface, even across a vacuum). However, this loss is small and of little consequence compared with the amount of heat transferred to the liquid in the absorber tube.

Evacuated-tube collectors are available in a number of designs as we can be shown in the figure 36. Some use a third glass tube inside the absorber tube or other configurations of heat-transfer fins and fluid tubes. One commercially available evacuated-tube collector stores 19 liters of water in each tube, eliminating the need for a separate solar storage tank. Reflectors placed behind the evacuated tubes can help to focus additional sunlight on the collector.

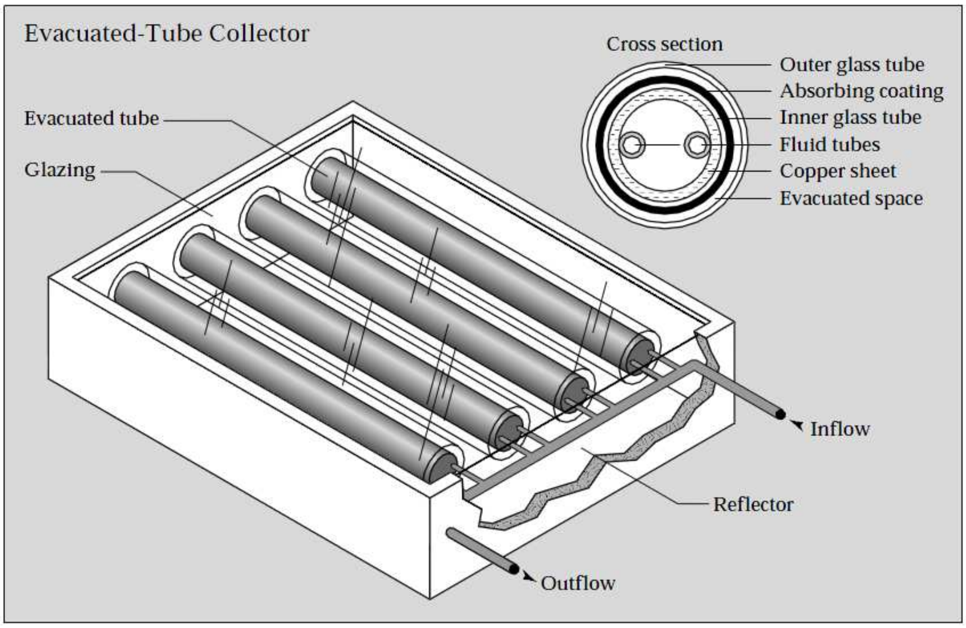


Figure 36: Evacuated-Tube Collector. (DOE/GO-10096-051, March 1996)

These collectors are more efficient than flat-plate collectors for a couple of reasons. First, they perform well in both direct and diffuse solar radiation. This characteristic, combined with the fact that the vacuum minimizes heat losses to the outdoors, makes these collectors particularly useful in areas with cold, cloudy winters. Second, because of the circular shape of the evacuated tube, sunlight is perpendicular to the absorber for most of the day. For comparison, in a flat-plate collector that is in a fixed position, the sun is only perpendicular to the collector at noon. While evacuated-tube collectors achieve both higher temperatures and higher efficiencies than flat-plate collectors, they are also more expensive.

B.2.3. Concentrating collectors

Concentrating collectors use mirrored surfaces to concentrate the sun's energy on an absorber called a receiver. Concentrating collectors also achieve high temperatures, but unlike evacuated-tube collectors, they can do so only when direct sunlight is available. The mirrored surface focuses sunlight collected over a large area onto a smaller absorber area to achieve high temperatures. Some designs concentrate solar energy onto a focal point, while others concentrate the sun's rays along a thin line called the focal line. The receiver is located at the focal point or along the focal line. A heat-transfer fluid flows through the receiver and absorbs heat.

These collectors reach much higher temperatures than flat-plate collectors. However, concentrators can only focus direct solar radiation, with the result being that their performance is poor on hazy or cloudy days. Concentrators are most practical in areas of high insolation (exposure to the sun's rays), such as those close to the equator.

Concentrators perform best when pointed directly at the sun. To do this, these systems use tracking mechanisms to move the collectors during the day to keep them focused on the sun. Single-axis trackers move east to west; dual-axis trackers move east and west and north and south (to follow the sun throughout the year). In addition to these mechanical trackers, there are passive trackers that use Freon to supply the movement. While not widely used, they do provide a low-maintenance alternative to mechanical systems.

Concentrators are used mostly in commercial applications because they are expensive and because the trackers need frequent maintenance. Some residential solar energy systems use parabolic-trough concentrating systems. These installations can provide hot water, space heating, and water purification. Most residential systems use single-axis trackers, which are less expensive and simpler than dual-axis trackers.

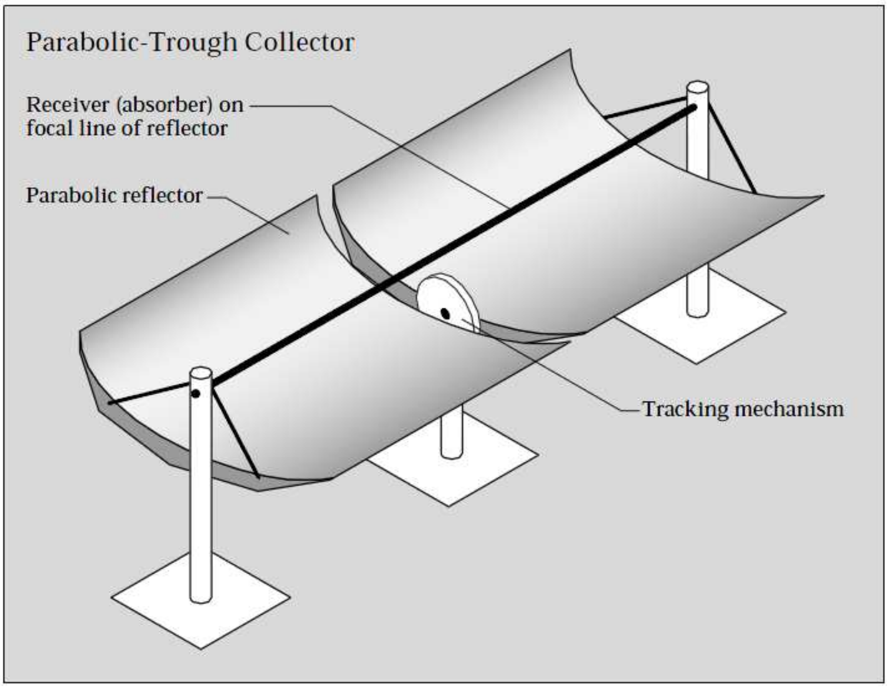


Figure 37: Parabolic-Trough Collector. (DOE/GO-10096-051, March 1996)

B.3. Storage of solar thermal energy

Thermal energy storage can contribute significantly to meeting society's needs for more efficient, environmentally benign energy use in building heating and cooling, space power, and utility applications.

Thermal energy storage (TES) can aid in the efficient use and provision of thermal energy, wherever there is a mismatch between energy generation and use. Three fundamental types of thermal energy storage processes (sensible, latent, and thermochemical) can be used, and many different media are available within each type. Various subsets of these processes are being researched and developed to accelerate TES implementation, focusing on applications in building heating and cooling, industrial energy efficiency, and utility and space power systems. TES can contribute significantly to meeting society's needs for more efficient, environmentally benign energy use in these and other sectors.

Perhaps the major utility of energy storage lies in its ability to couple an energy supply with a demand when the supply and demand vary independently over time. It is convenient to picture a storage system as being functionally located between an energy supply and a load. Ideally, energy is stored during a charging period and released during a subsequent discharge period in such a way that there is no net change in the thermodynamic state of the storage material. During a cycle, it is not necessary that the charge and discharge periods immediately follow one another or be of the same duration.

B.3.1. Thermal energy storage mechanisms

There are three types of thermal energy storage: sensible heat, latent heat, and thermochemical.

With **sensible heat storage**, energy is stored by changing the temperature of a material. The amount of energy stored is a function of the temperature change, the mass of the storage medium, and its specific heat. Most sensible heat systems employ water, rocks, earth, or ceramic bricks as the thermal storage material and water, air, or possibly oil as the heat transfer fluid. The high heat capacity of water (4,18 kJ/KgK) often makes tanks of water a logical choice for TES systems that operate in a temperature range needed for building heating or cooling. The relatively low heat capacity of rocks and ceramics (on the order of 0,84 kJ/KgK) is somewhat offset by the large temperature changes possible with these materials and their relatively high density.

In the case of **latent heat storage**, the storage material changes phase usually between solid and liquid. Thus, if the change in TES temperature includes the melting or freezing point of the storage material, the storage capacity is greatly enhanced by the latent heat contribution. The advantage of latent heat storage in a phase-change material (PCM) is high energy density. The advantage of latent heat storage increases as the difference between the initial and final storage temperatures is narrowed about the melting temperature of the PCM.

Thermochemical energy storage involves chemical reactions. Metal hydrides have been examined for use in chemical heat pumps using hydrogen as the working fluid and as a means for storing hydrogen at pressures substantially lower than the saturation pressure. Metallic salts that combine with ammonia have also been examined as a means of thermochemical energy storage. Temperatures can be lower than for comparable sensible heat systems so that heat losses during long-term cycles can be reduced. Further, thermochemical storage can be useful in energy transport applications where the components can be transferred separately and combined where thermal energy is needed.

B.3.2. Storage applications

TES can be used whenever there is a temporal mismatch between an energy supply and a demand for thermal energy. In addition, TES provides a means for capture, storage, and reuse of thermal energy that would otherwise be wasted or underused. There are many applications of TES; major ones include: building heating/cooling load management, use of solar energy, use of industrial waste heat, and power applications. These applications differ tremendously in their storage capacity, expected thermal flux levels, and charge/discharge periods in building heating and cooling. The fastest-growing application of TES is the use of off-peak electricity to provide building heating or cooling. In large commercial buildings, there is often a need for year-round cooling. This demand is caused by cooling loads from lights, occupants, and equipment and is exacerbated by the growth in air conditioning and an increased thermal load due to computers in the workplace. In growing numbers, electric utilities are promoting the use of TES as a means of reducing peak demand and improving load factors.

A TES system (for heating or cooling) is charged during electrical off-peak periods, typically at night. During subsequent peak periods, the stored heat (or cool) is delivered to meet the space heating (or cooling) load in a building. Stimulated by the desire to avoid demand charges and by utility-sponsored cash incentive programs, building owners are choosing TES as a way to reduce peak electrical demand.

With the above explanation, the storage of solar thermal energy in my case will be made by two different ways. On the one hand, using the latent heat into our ClimateWell machine, and on the other hand, using sensible heat into the heat exchanger. I will not go over in detail, because it will be done in the sixth chapter of the project.

Annex C. Cooling technology

The vapor compression cycle is widely used in refrigeration systems, including refrigerators, refrigeration air conditioning, freezers, and auto air conditioners. R22 and R12 refrigerant are the most commonly used, but are being phased out due to effects on the ozone layer.

In very basic terms, refrigeration systems are used to remove heat from one area and transfer it to another location. This part of the project gives some details about the vapor compression refrigeration cycle, which is very widely used for many types of refrigeration systems, including home refrigerators and freezers, refrigeration air conditioning, and automobile air conditioners.

C.1. Cooling vapor compression machines

Figure 38 shows the components of a vapor-compression refrigeration cycle: a compressor, condenser, expansion valve, and evaporator; and figure 39 the cycle (T-S) of vapor-compression refrigerator.

A low pressure, low temperature liquid is converted to vapor in the evaporator, thus absorbing heat from the refrigerated space and keeping that space cool. The fluid is driven around the cycle by the compressor, which compresses the low temperature, low pressure vapor leaving the evaporator to high pressure, high temperature vapor. That vapor is condensed to liquid in the condenser, thus giving off heat at a high temperature to the surrounding environment. Finally, the high pressure, high temperature liquid leaving the condenser is cooled and reduced in pressure by passing it through an expansion valve. This provides the input to the evaporator which was the first step of the cycle described above.

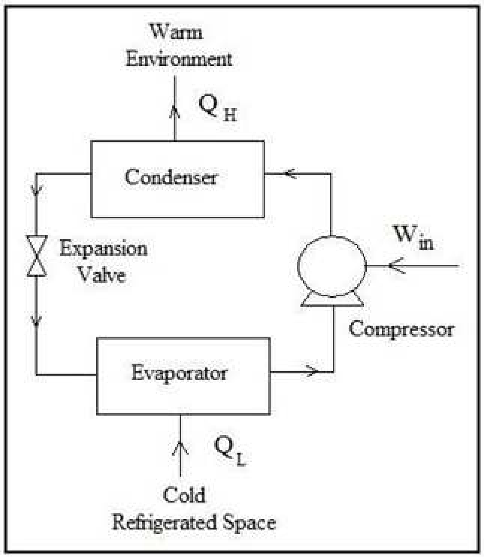


Figure 38: The components of a vapor-compression refrigeration cycle: a compressor, condenser, expansion valve, and evaporator.

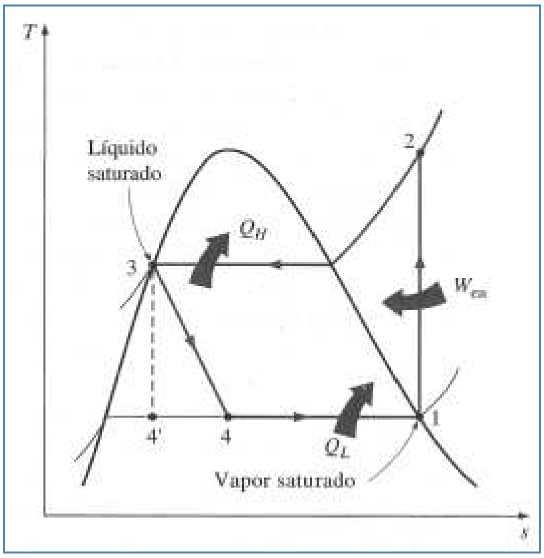


Figure 39: Cycle (T-S) of vapor-compression refrigerator.

The work and heat flows shown in the diagram are W_{in}, Q_H and Q_L. Win is the work input to the compressor. The rate of work input to the compressor is most of the power requirement to run the refrigeration system. In addiction power will probably be needed to drive one or more fans, but their power requirement will be small in comparison with that needed to drive the compressor. Q_H is the high temperature heat rejected to the surroundings by the condenser. Q_L is the low temperature heat absorbed from the cooled space by the evaporator.

The vapor compression refrigeration cycle described in the previous section is widely used for a variety of cooling purposes, such as household refrigerators and freezers; home, industrial and commercial air conditioners; and automobile air conditioners.

In order to improve the efficiency of a refrigeration system, the following guidelines will be useful:

- The refrigerant characteristics should allow for a high condensation temperature for heat rejection to the surroundings and a low evaporation temperature for heat absorption from the cooled space.
- Air filtration through doors and other gaps should be minimized.
- The pressure drop of the refrigerant in suction and discharge lines should be minimumized.
- Good lubrication of moving parts needs to be maintained.
- Pipes of correct size should be used, avoiding unnecessary bends, in order to minimumize the pressure drop.

C.1.1. Phaseout of R22 and R12 refrigerants

Freon 22, also known as R22, is the most common (not anymore) refrigerant in home air conditioning and refrigeration systems. Freon 12, also known as R12, is used in automobile air conditioners. Due to concerns about damage to the earth's ozone layer, the production and use of chlorofluorocarbons like R22 and R12 refrigerants is being phased out around the world and substitute refrigerants are appearing to replace them.

C.1.2. Coefficient of cooling efficiency

The concept of C.O.P. (Coefficient of Performance ") on cooling is similar to Energy Efficiency in the evaporator. The C.O.P. is defined officially as the amount of cooling which is obtained in one machine divided by the amount of energy which you need to provide in order to achieve this cooling.

$$\boxed{COP = Q_L / W_{in}}$$

Where:

Q_L = heat extracted in the evaporator to the load per cycle (kJ).
W_{in} = Mechanical energy used to produce the extraction of heat (kJ).

This coefficient is named depending on how it is being used. In some cases the COP is used only as a factor in heat efficiency and the EER (Energy Efficiency Ratio) as the factor of cooling efficiency. Since in both cases, the coefficient is calculated in the same manner (the calorific kJ extracted by the machine is used in heating and cooling refrigerators) we will only refer to the COP as whether, the cooling efficiency factor, or heat efficiency factor, depending on the case.

Since compression machines are widely studied and sold, the COP values are very high, between 2 and 4. Because of this, the cooling energy produced is between 2 and 4 times greater than the electrical (or mechanical) energy they consume. As a result, compression machines tend to be very competitive and economical. However, the electricity consumed by these machines usually come from conventional power stations (coal, fuel oil or natural gas) or combined cycle power plants that use natural gas which emit CO_2 into the atmosphere causing the greenhouse effect and contributing to global warming. In addition, this type of power plant (mostly conventional thermal power plants) produce nitrogen oxides (NOx) and sulfur oxides (SO_2), which contribute to acid rain phenomenon.

We have to take into account that the COP is the function of process maximum and minimum temperatures. Theoretical limit is given by Carnot efficiency defined as:

$$\boxed{COP_{Carnot} = Tmin / (Tmax-Tmin)}$$

C.2. Absorption refrigeration

Solar cooling consists in cold production from solar radiation. Solar thermal system is coupled with cooling machines to carry out this technology. These machines use a thermal compressor instead of a mechanical compressor, which requires little need of electrical power. The machines used in this process are: the absorption chiller, the adsorption machine, the desiccation machine and the machine of evaporative cooling.

The demand for cold is greater in the moments when solar radiation reaches its maximum (summer). For this reason, the use of solar energy for cooling yields very high performance.

Thanks to this, solar energy installations can be used during the entire year, thus avoiding over-temperatures in summer. In addition, it reduces the payback time of the equipment, energy consumption and emissions of greenhouse gases.

Solar cooling can also be easily combined with other applications, such as hydrogen, evaporation systems, trigeneration (heating, cooling and electric power), etc.

This technology is still developing, so it has not reached sufficient maturity to be applied in a massive way yet. But, due to rising energy prices and fuel costs, this technology has a great future.

Below are listed a number of advantages due to the use of the absorption machine:

- These machines can make the annual consumption of energy more uniformly, and therefore a good payback on expensive gas distribution facilities as mentioned above.

- The use of pump absorption in winter makes the performance higher compared to the production unit of heat. Operating at a suitable temperature range through the absorption cycle, we can be able to obtain a performance ratio higher than one, due to the use of heat pumped from the low-temperature heat reservoir.

- The applicability of solar power and low temperature heat sources from industrial processes like the heat derived from boilers, residual heat of industrial processes or cogeneration, solar power, geothermal, etc.

- Also, high efficiency absorption machines for air conditioning may have applications for transportation vehicles such as trucks, buses and recently in boats, because it can operate using the heat generated by exhaust fumes from these engines.

There are two fundamental differences between the cycle of absorption and vapor compression. On the one hand, the compressor is replaced by an absorber, a pump and a generator. On the other hand, the absorption cooling cycle uses additional fluid, besides the refrigerant, called the absorbent.

The cycle of an absorption chiller is based on two basic principles:

- If pressure drops, the temperature of boiling will decreased due to the relationship between the boiling point and the pressure point.

- Faraday in his laboratory discovered the affinity between specific substances. When a gas is dissolved in a liquid, it is called absorption whereas when the gas is diluted in a solid, it is called adsorption.

Water is an inorganic and harmless substance for the environment (destruction of the ozone) and due to the affinity between certain substances it is high likely to be used as a refrigerant. On the other hand, the absorbing substance is a salt whose effect on the environment is also reduced.

The main criteria for classification of absorption machines are:

- Depending on the number of generators (effect).
  - Single effect: absorption chiller with a single generator.
  - Dual effect: absorption chiller with two generators.
  - Triple effect: absorption chiller with three generators.

- Depending on the couple refrigerant/absorbent used.
  - $H_2O/LiBr$: water is the refrigerant and lithium bromide is the absorbent.
  - NH_3 /H_2O: Ammonia is the refrigerant and water is the absorbent.
  - $LiNO_3/H_2O$: lithium nitrate is the refrigerant and water is the absorbent.
  - $NaSCN/H_2O$: sodium thiocyanate is the refrigerant and water is the absorbent.

- Depending on the number of absorbers (or stages).
  - Single-stage: absorption chiller with an absorber.
  - Dual stage: absorption chiller with two absorbers.
  - Triple stage: absorption machine with three absorbers.

- Depending on the condensing system.
  - Water condensation: the fluid causes the condensation of the refrigerant which is water. This system is associated with a cooling tower.
  - Air condensation: the air is the fluid which causes the condensation of the refrigerant.

- Depending on the heat source which supplies the heating power to the machine.
  - Direct Type or "flame" direct: the heat generated by the products of combustion is used for heating the solution, coming from the absorber, and make it reach the boiling point. The burner used is a fossil fuel (liquid or gas).
  - Type indirect: the heat exchanger receives the necessary amount of heat. The hot fluid may come from a residual source, a solar energy installation, or a gas boiler.

In summary, the simple absorption machine has four interconnected vessels. Two of them are located in the low pressure side (evaporator and absorber) and another two ones in the high pressure side (condenser and generator). The two pressure levels are conditioned by the temperatures of condensation and vaporization of the refrigerant.

The evaporator pressure is low enough to boost the vaporization of the refrigerant. When the water temperature increases, it generates a quantity of steam coming from the cooling circuit. This steam is captured by the absorbent in the absorber, releasing heat which must be evacuated.

The mixture is driven by a pump to the generator where the heat is taken from the heat reservoir. This heat makes the absorbent and the refrigerant separated once again. The refrigerant is released as steam and at a high pressure. The absorbent then returns to the absorber through the expansion valve. On the other hand, the refrigerant enters in the condenser where it is cooled and condensed. It is then expanded through the expansion valve before returning to the evaporator.

An improvement to the basic cycle is to incorporate a heat exchanger between the absorber and the generator so that the concentrated stream that returns to the absorber is preheated.

Figure 40 shows the different components and processes of a simple effect absorption cycle:

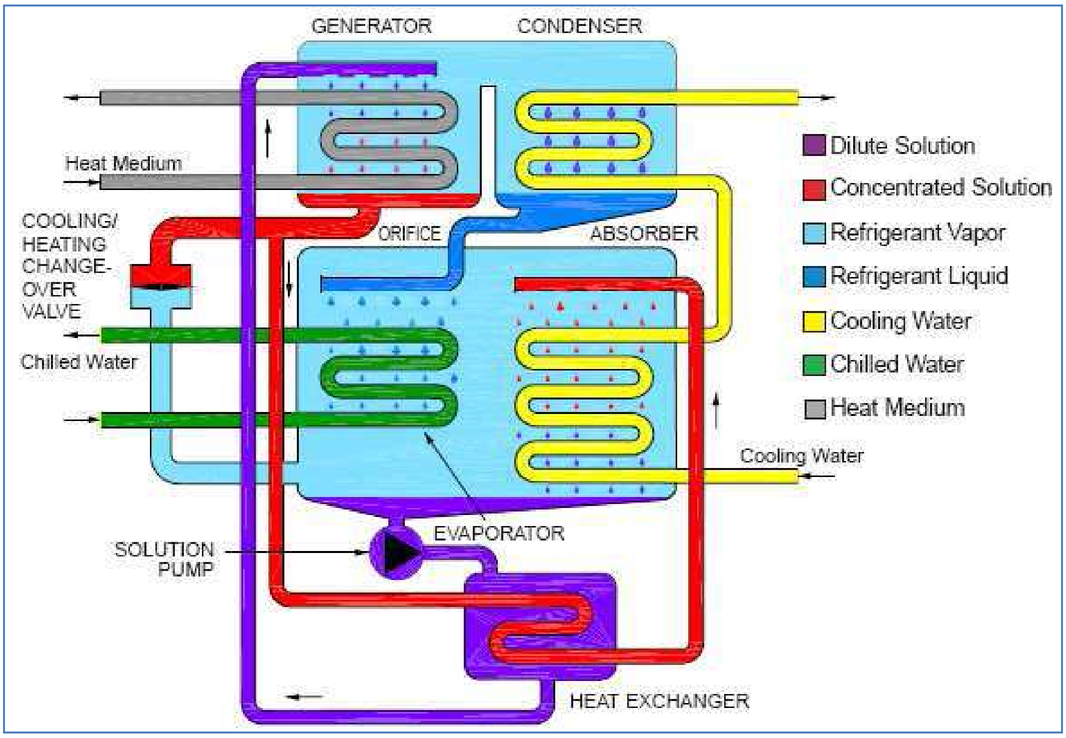


Figure 40: Different components and processes of a simple effect absorption cycle machine.

C.2.1. Simple absorption cycle (More expanded)

In the cycles of absorption, figure 41, you always deal with an absorbing agent (a substance that absorbs the vapors) and a coolant or refrigerant (a substance which is evaporated and it causes the refrigeration production). Water and lithium bromide solution would be absorbents. Ammonia and distilled water, in the cooling-water absorption cycles, and in the lithium bromide-water absorption cycle, are refrigerants.

The entire sequence set out in the absorption cycle will be explained below:

- The high-pressure liquid refrigerant which comes from the condenser passes through an expansion valve. Here, the refrigerant pressure drops to the pressure which is in the evaporator. (Flows 8 and 9)

- The liquid refrigerant is vaporized in the evaporator which absorbs the heat from the place to be cooled (cooling of the wanted environment occurs by the absorption of heat in order to change the phase).

- The low-pressure steam is absorbed by an unrestricted conduit to the absorber where it is mixed with the absorbent. The refrigerant flows from the evaporator to the absorber, because the vapor pressure of the absorbent-refrigerant of the solution in the absorber is less than the vapor pressure of the refrigerant which is in the evaporator. (Flow 10)

- The steam pressure in the absorber (absorbent- refrigerant of the solution) determines the pressure in the low pressure side of the system and consequently, the vaporization temperature of the refrigerant in the evaporator. In the same time, the vapor pressure of the absorbent- refrigerant of the solution depends on the nature, temperature and concentration of the absorber. Decreasing the temperature and increasing the concentration of the absorber will produce low pressure in the solution. (Absorber)

- At the same time that the refrigerant vapor of the evaporator is dissolved in the absorbing solution, the volume of the refrigerant decreases (compression occurs) and heat is released from the absorption. In order to maintain the temperature and the vapor pressure of the absorbing solution at the required level, the heat released in the absorber (whose value is equal to the sum of latent heat of condensation of refrigerant vapor, and heat of dilution of the absorber) shall be evacuated to the surroundings, usually, the same heat sump or means used for condensing heat evacuated by the capacitor. In order to make the transfer of heat from the absorber to the sink, the temperature of the absorber should be higher than the one of the sump. (Flows 13 and 14)

- Since the efficiency of the absorber increases when the temperature of the absorbing solution is decreasing, it results that the efficiency of the absorber depends in part, on the temperature of the available refrigerant. When the refrigerant vapor is dissolved in the absorbent solution, the resistance increases (cooling rate), as well as the vapor pressure in the solution. Therefore, a continuous reconcentration of solution is necessary so that a low level of vapor pressure can occur, to provide low pressure and low temperature that are required in the evaporator. The reconcentration is obtained by eliminating continuously the strong absorbing solution of the absorber, making it recirculation through the generator. Here, most of the refrigerant vapor is boiled through the application of heat. In addition, the resulting weak solution returns to the absorber to absorb more refrigerant vapor from the evaporator. (Flow 6)

- Since the absorber is on the low pressure side and the generator in the high pressure side, strong solution must be pumped from the absorber to the generator and thus, the weak solution will return to the absorber through an expansion valve. The increased pressure of the absorbing solution increases the pressure in the high side in the absorber. The solution is then pumped to the generator. The compression of the refrigerant will not happen in the process because it is done in the absorber chamber. Consequently, the power required by the solution pump is relatively small. (Flows 2 and 5)

- Then is introduced a heat exchanger between the generator and the absorber so that the temperature of the strong solution which goes to the generator is increased while the temperature of the weak solution that goes to the absorber is decreased. On the one hand the heat exchanger will provide a reduction of heat supplied to the generator whereas on the other hand, it will provide the required cold to the absorber, improving the efficiency of the cycle.

- In the generator, the refrigerant is separated from the absorbent by heating and vaporizing the solution in the coolant. The high pressure refrigerant vapor passes by the condenser, where it is condensed, giving up its latent heat to the environment. Because of this, the refrigerant is ready to circulate again in the evaporator. (Generator and flujo7)

- The absorbent solution (weak) which is in the generator returned to the absorber by the return pipe as previously described. The relative strength of the weak solution is controlled by the amount of heat supplied to the generator. (Flows 4 and 5)

- For a maximum efficiency in the system, the pressure differential between high pressure and low pressure sides should be as small as possible, keeping the pressure on the low side as high as possible and cooling as well as pressuring the requirements on the high side (as low as possible with the condensing means available).

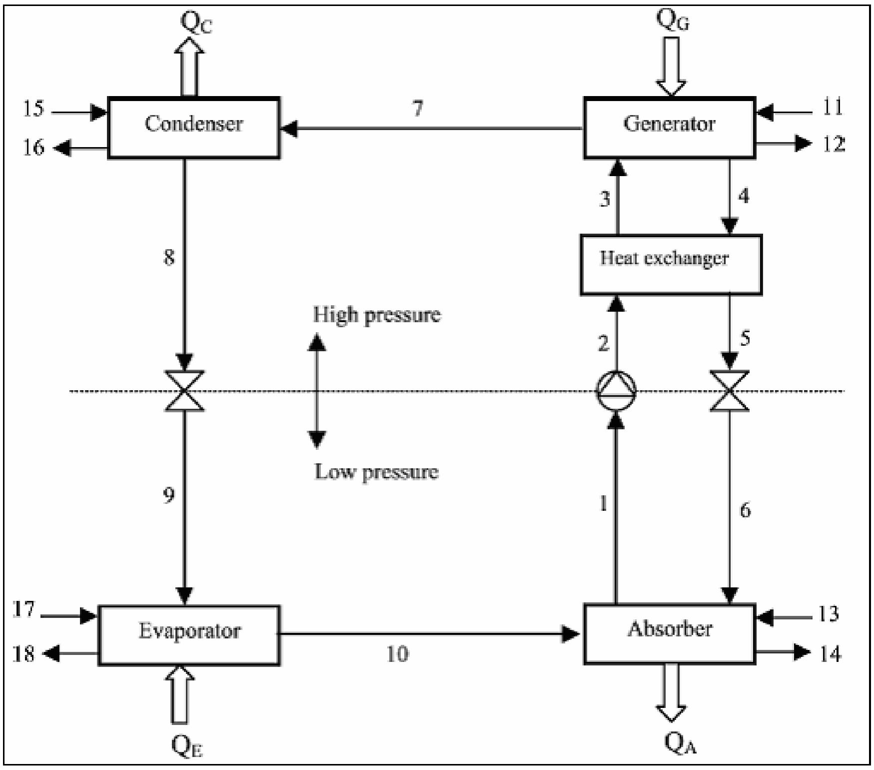


Figure 41: Traditional scheme of an absorption cycle.

The heat extracted from the vapor of water in the absorber and the condenser must be removed by a dissipation circuit of water. The heat from the circuit of dissipation can be removed from one of the following ways:

- Aero-coolers (or heat exchanger cooled by air).
- Evaporative cooling tower with open circuit.
- Evaporative cooling tower with closed circuit.
- Well or river or lake water, through heat exchangers.
- Sea water through the heat exchanger which has appropriate characteristics.

This means, that the three variables to determine its benefits should be:

- The temperature of hot water which enters in the generator.
- The temperature of water in the tower for heat dissipation.
- The temperature of chilled water.

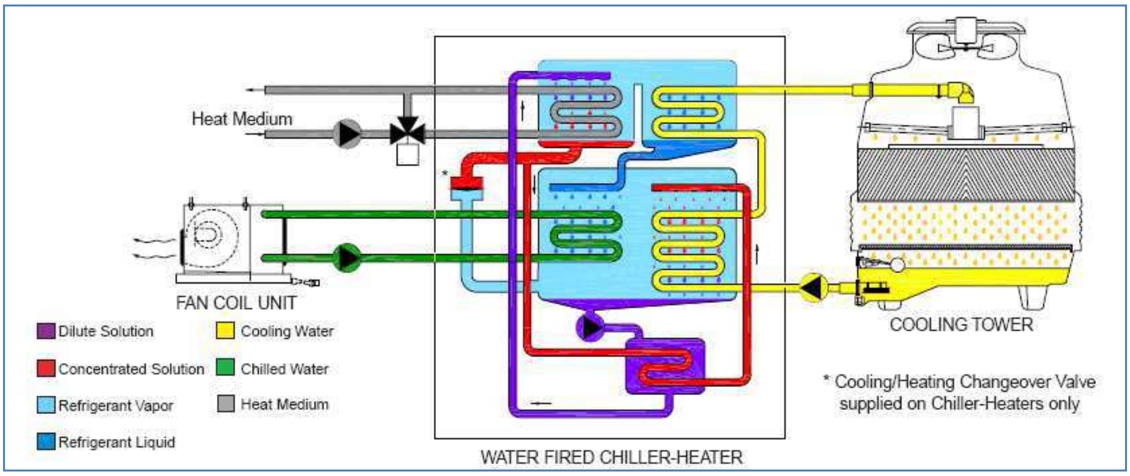


Figure 42: Installation scheme of a simple effect cooling absorption system.

All this makes the absorption refrigeration systems bulky and expensive, especially when these are designed to operate at a low temperature in the generator. This means that it is only profitable when the heat is free or very cheap, and when annual full time operating hours are high.

Absorption machines can function as simple effect or double effect. The simple effect consists in basic elements, while the double effect makes the separation of the refrigerant in two phases (a first generator at high temperature and a second generator at low temperature). The second generator gets the heat from a second capacitor.

The double effect machines need a generator with higher temperatures compared to simple effect machines. Besides, double effect ones are more expensive, but have however higher performance. The COP of an absorption machine of simple effect is between 0,5 and 0,7 while the COP of double effect is between 1 and 1,2. These have been developed between 1970 and 1990 and are now being introduced in the air conditioning market. Because of this, these machines capable of providing a cooling capacity of less than 100 kW are not sold a lot, knowing that this performance would be ideal for a family home.

C.2.2. Couples of fluids used in absorption

The refrigerant and absorbent are the two components which are always required in all cycles of absorption. Although different couples of products can be used, the most common are:

1. Water as coolant and as absorbent of lithium bromide (LiBr).

2. Ammonia as refrigerant and water as absorbent.

Then will be explained with more detail both cycles, making greater emphasis on the couple of Lithium Bromide-Water which is normally used for cooling processes, as in our case, the ClimateWell machine (it does not exactly use BrLi-H_2O but it uses LiCl-H_2O). Finally, it will be shown a summary chart comparing the two processes.

C.2.2.1. Mixture of Lithium Bromide-Water

The couple LiBr-H_2O (always appears as absorbent-coolant) is the most commonly used as mixture of work in absorption machines. It is primarily used for air conditioning although it has limited the working temperature of the evaporator approximately to 5°C because of problems with freezing the water.

The working temperature of the absorber cannot be very high due to the crystallization of salt (figure 43). This makes that the difference between the temperatures of the evaporator and the absorber do not exceed 30ºC, approximately. However, as its enthalpy of vaporization is high and the vapor pressure is low, the machines can be designed with less weight because they require less thickness in the walls.

Because of the crystallization, it is necessary to use heat sumps (cooling towers, pools, aerothermo...) for heat dissipation in the absorber. This makes impossible the heat pump operation mode in winter.

Although Water-BrLi equipments are marketed and can meet both cold and heat needs, the heating process is limited to the transfer of thermal energy directly from the heating circuit to the generator. This doesn't provide any kind of improvement compared to the use of a simple boiler.

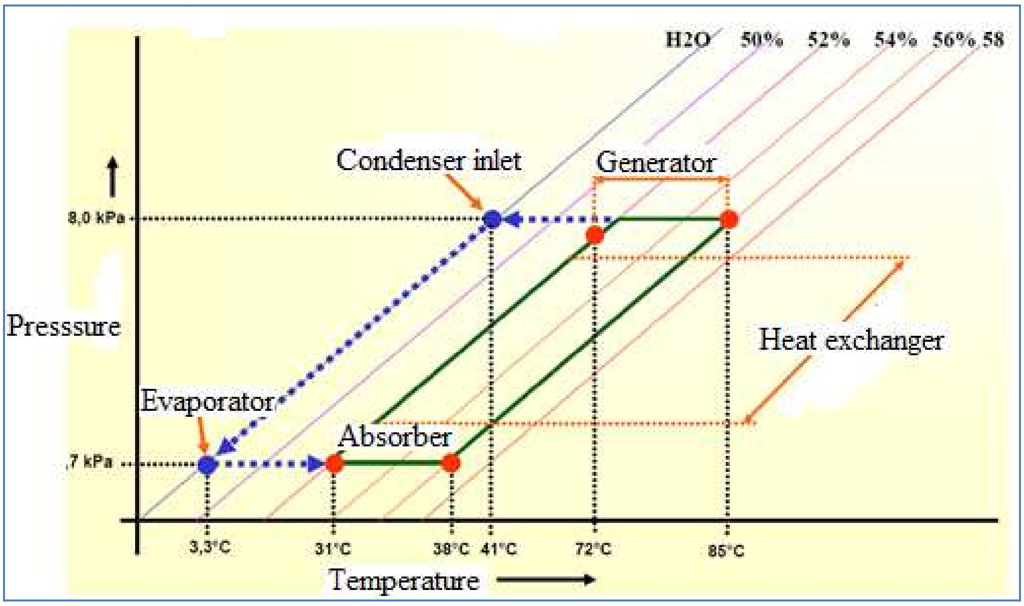


Figure 43: Simple effect absorption cycle H_2O/LiBr

These machines have a good acceptance in the air conditioning market because of their good thermal performance in cooling mode in spite of the low operating margin. In addition, they benefit from a very low toxicity and environmental impact rate. For this reason, numerous researches have been carried out to shift the curve of the crystallization of the dissolution towards points of higher temperature, for instance by adding salt or other substances as we can see in the figure 44.

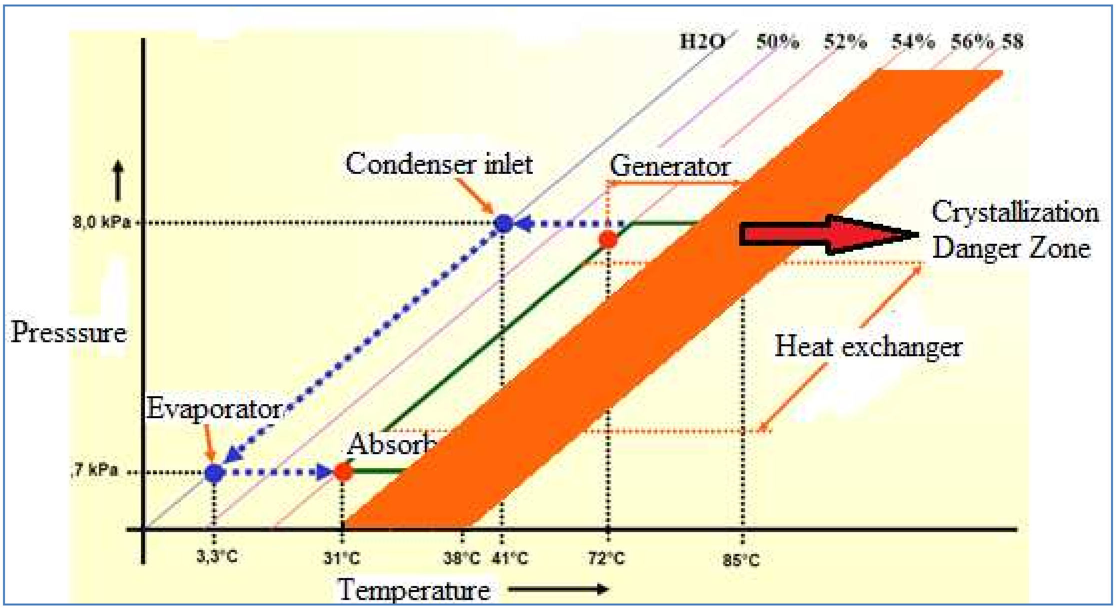


Figure 44: Plot of crystallization of LiBr.

As a result of what has been explained above, some studies are being conducted with quaternary salts and sodium hydroxide, potassium hydroxide and cesium hydride ternary salt as an alternative to water-BrLi couple. The curve of crystallization of this mixture is modified, so that it can operate with a temperature in the absorber of about 50ºC and therefore makes it possible to operate at a high temperature in the generator (about 200ºC). This will provide a thermal performance similar to the previous mixture.

However, its practical implementation has been currently limited due to the corrosion that causes the dissolution. Indeed, with these operating temperatures, there are problems with the materials that are used.

C.2.2.2. Mixture of Water-Ammonia

The Ammonia-Water machines are usually used with industrial refrigeration processes such as: frozen foods or cooling of processes which operate with evaporator temperature of -60ºC. It should be kept in mind that with this range of temperatures, the water-BrLi units are not operating (below 5ºC).

The saline solution in the same operating conditions shows better thermal performance than the ammonia-water mixture because it needs an adjustment system to reduce the content of the absorbent in the evaporator.

These machines work with negative temperatures, it is thus necessary to add a rectifier to the generator output with the objective to remove traces of existing water. If nothing was done, the water into the pipes would freeze and prevent the machines from working correctly.

In addition, since from a security point of view, ammonia is a toxic product whose temperature inside the machine is always higher than the atmospheric pressure, the use of these machines is restricted in some countries like Japan for instance.

As a summary, the following table shows the main differences between the couples used in absorption systems discussed above.

Table 17: Main differences between the couples used in absorption system.

Water/Lithium Bromide (LiBr)	**Ammonia (NH_3)/Water**
• The coolant is water and the absorbent is lithium bromide.	• The coolant is ammonia and the absorbent is water. • Ammonia is a coolant with best thermodynamics properties, commonly used in industrial refrigeration (high specific heat).
•The lithium bromide solution is not toxic, non-flammable and odorless.	• It is a very toxic gas. • Mixtures of, ammonia vapor / air, are flammable and, can be explosive but only in very high concentrations (15,5 to 27% by volume).
• The system cannot cool below the freezing point of water (usually +5°C for safety), so the scope of these systems is the air conditioning of buildings.	• Evaporating temperatures can be obtained until -60°C. • The scope is the industrial cooling (petrochemical, food and chemical industry) at temperatures below 0°C.
• Other advantage of these plants is that the pressure into the exchangers is subatmospheric and for this reason, it is not obligatory that their components are designed according to the rules of pressure vessels.	• The pressures are high and all exchanges must be designed according to the regulation for pressure vessels, so that the pipes which have to be used must be thicker.
• The absorbent (lithium bromide) has no own vapor pressure, making easier the task to separate the refrigerant from the absorbent. • The void means that there is a high impermeability in the system.	• The water absorbent has a high volatility; a distillation tower is thus necessary (or rectification) to separate the refrigerant and the absorbent. • Due to high operating pressures and the necessity of an adjustment system the plants are more expensive than lithium bromide.

C.2.2.3. Coefficient of performance. (C.O.P.)

As mentioned above, the C.O.P. is used to measure the amount of cooling which is obtained from a machine, divided by the amount of energy required to achieve this cooling.

To determine the overall performance of absorption refrigeration system, it shall be taken into consideration the necessity of mechanical energy in pumps and fans (often neglected) as well as the heat input into the generator.

In absorption machines the COP is calculated as following:

COP abs. cycle = (Tcapacitor – Tevaporator) / (Tevaporator – Tabsorber) =

Coolant Effect / Heat input

Where:

- Effect Refrigerant = Cooling capacity of the absorption chiller (kJ or kW).
- Heat input = Heat input in the generator of the absorption chiller (kJ or kW).

The COPs expected in absorption cycles are also very low compared with mechanical compression cycles. In single stage absorption machines that use lithium bromide, the COPs will not exceed the value of 0,7. In two-stage machines, the values can reach until 1,5 times more compared with single-stage machines. This means that two-stage machines make better use of energy than simple stage. The cycles of ammonia/water which work with low temperatures get values of COP around 0,5 and maximum levels of 0,8.

C.2.2.4. Available coolers by absorption

There are different manufacturers of absorption machines. These machines offer a very wide power range. On the one hand the larger are used (around 200 kW) for industrial uses, on the other hand, the smaller ones for single family homes (between 5 and 15 kW).

The following shows different simple effect absorption machines (COP = 0,7, Tª = 85ºC):

- With P> 100 kW: Large number of options
- With 35-100 kW P: Thermax, Yazaki
- With 15-35 kW P: Robur
- With P from 5 to 15 kW: Rotartica, Climate Well (machine used in the project), Phonix, SunInverse, EAW, Pink, AoSol, NEC, SorTech.

Annex D. Description of housing

D.1. Location and site

Since I have to do the evaluation of a specific location, at first thought about a house in Soria, than is where I live, but after analyzing it in more detail, I came to a conclusion that it would be better if I changed the location to Madrid. I have chosen the community of Madrid for different reasons. The main reason is that there is plenty of information available about its regulations and ordinances because it is the capital city. In addition, the majority of the information and examples about the machine of Climawell talk about it. Entering the company website for searching information, I saw that during the past two years the installations of this equipment in this community have increased significantly compared to other region of Spain.

The living area of the dwelling unit will be considered of 200 m^2. There are six people living in the house. In addition, I will consider that all the occupants will live in this house throughout the summer.

What will be taken into consideration is that the detached house has 4 rooms, and 6 inhabitants (according to the Ordinance of Madrid for the calculation of DHW).

The house has a floor heating system to boost water at low or high temperature, depending on the temperature inside the building.

The figure 45 shows a detached house in the Community of Madrid with the characteristics outlined above.

Figure 45: Detached house possible in the Community of Madrid.

An important part of for the implementation of this project is that the detached house has a swimming pool which will be in charge of the dissipation of the installation. This way, the heat is used for heating the pool. If the house wouldn't have had a pool, other dissipation methods would be needed such as a vertical geothermal heat exchanger or a cooling tower.

As also was mentioned in the memory, the dynamic analysis software called "TRNSYS" recognizes any location. It means that you only need to introduce, the place where the project will be carried out, the square meters of the house, the number of people that are living in and the dimensions of the pool to dissipate heat, among other data, to obtain accurate results.

D.2. Characteristics of the closing

Due to the fact that the detached house is a house "invented", the materials used in enclosures are not known, such as exterior and interior walls, windows, doors, and other elements, so that the method of calculation will be explained without enter into detail.

In my case, the exact calculation of losses of heat transfer is not necessary to do, because the program used for the simulation also takes into account the types of enclosures depending on the selected item. Below will be explained the usual method of heat loss calculation.

D.2.1. Coefficients of heat transfer

It is clear that to determinate an air conditioning system, it must be taken into consideration on one hand the amount of heat from outside which enters in summer, and on the other hand the amount of cold from outside which enters in winter, into our detached house.

This way, it can be known the amount of cooling and heating energy that must be provided to meet these demands.

But for knowing the amount of heat/cold which enters inside the enclosure, the so called heat transfer factor of enclosures must be known.

The buildings usually never have a homogeneous, continuous, longitudinal and transverse enclosure. The hollow, the structural elements, the links between forged and walls, the mortar joints and seams, the anchors of the prefabricated panels and bricks and blocks, etc., make that the outside surface of the walls which have some heterogeneities will have a big influence in the features that regulate the thermal balance of exterior-interior system. In these enclosures takes place on one side the heat transfer process and on the other side, the process of diffusion of water vapor between the two separated atmospheres.

Therefore, if the homogeneity of a wall or deck is interrupted by the intersection of another element of higher thermal conductivity as for example pillar or metal beams, the quantity of heat which passes through the section of this material will be greater than the quantity of heat that passes through another section of the rest of the wall or deck. It means that the density of heat flow lines in this section will be higher than the rest of the enclosure.

Weak point of transmission of heat or, thermal bridge (which will not be explained because of its complexity) is called the higher density of heat flow.

Enclosures with thermal bridges define its insulating power through a heat transfer coefficient.

This factor, called "Kc", is tabulated in some books, so that the calculation is almost imminent.
The method to define the thermal needs of a house is determined by the following transfer coefficients Kc:

- Coefficients of heat transfer Kc on interior walls.
- Coefficients of heat transfer Kc in external walls.
- Coefficients of heat transfer Kc in forged.
- Coefficients of heat transfer Kc in terraces.
- Coefficients of heat transfer Kc in decks.
- Coefficients of heat transfer Kc in soils in contact with the ground.
- Coefficients of heat transfer Kc windows.
- Coefficients of heat transfer Kc in various materials.

It should be kept in mind that there are many different types of enclosures, between which the most important are: simple enclosure, composite enclosures, enclosures with an air chamber (vented or unvented), enclosures with variable thickness, enclosures in contact with the ground and the enclosures due to thermal bridges.

What follows will explain the calculation for simple and compound enclosures since they are the most common. The material or materials must be parallel panels, with a thickness equal for all, and the composition of the material must be homogeneous.

"Kc" can be found with the following equation:

$$K = 1 \,/\, [\Sigma\, (\frac{e}{\lambda}) + \Sigma R + (\frac{1}{hi}) + (\frac{1}{he})]$$

Where:

- Kc: overall heat transmission coefficient of enclosure in [W/(m² °C)].
- R = thermal surface resistance [m² ºC/W].
- λ = thermal conductivity of the coating material [W/m °C].
- k: Thermal conductivity of the material of each layer of the enclosure in [W/(m°C)].
- he: surface coefficients of heat transfer inside and outside in [W/(m² °C)].
- hi: surface coefficients of heat transfer inside and inside in [W/(m² °C)].
- e: thickness of each layer of the enclosure, in meters.

In Tables 18 and 19 can be found the thermal conductivity depending on the material and its bulk density. In table 20 can be found the values of the coefficients of surface heat transfer inside and outside.

Table 18: Thermal conductivity of different materials.

Material	Densidad aparente kg/m³	Conductividad térmica λ	
		kcal/hm °C	(W/m °C)
ROCAS Y SUELOS NATURALES			
Rocas y terrenos			
— Rocas compactas	2.500-3.000	3,00	(3,50)
— Rocas porosas	1.700-2.500	2,00	(2,33)
— Arena con humedad natural	1.700	1,20	(1,40)
— Suelo coherente humedad natural	1.800	1,80	(2,10)
Arcilla	2.100	0,80	(0,93)
Materiales suelos de relleno desecados al aire, en forjados, etc.			
— Arena	1.500	0,50	(0,58)
— Grava rodada o de machaqueo	1.700	0,70	(0,81)
— Escoria de carbón	1.200	0,16	(0,19)
— Cascote de ladrillo	1.300	0,35	(0,41)
PASTAS, MORTEROS Y HORMIGONES			
Revestimientos continuos			
— Morteros de cal y bastardos	1.600	0,75	(0,87)
— Mortero de cemento	2.000	1,20	(1,40)
— Enlucido de yeso	800	0,26	(0,30)
— Enlucido de yeso con perlita	570	0,16	(0,18)
Hormigones normales y ligeros			
— Hormigón armado (normal)	2.400	1,40	(1,63)
— Hormigón con áridos ligeros	600	0,15	(0,17)
Hormigón con áridos ligeros	1.000	0,28	(0,33)
Hormigón con áridos ligeros	1.400	0,47	(0,55)
— Hormigón celular con áridos silíceos	600	0,29	(0,34)
Hormigón celular con áridos silíceos	1.000	0,58	(0,67)
Hormigón celular con áridos silíceos	1.400	0,94	(1,09)
Hormigón celular sin áridos	305	0,08	(0,09)
— Hormigón en masa con grava normal:			
• con áridos ligeros	1.600	0,63	(0,73)
• con áridos ordinarios, sin vibrar	2.000	1,00	(1,16)
• con áridos ordinarios, vibrado	2.400	1,40	(1,63)
— Hormigón en masa con arcilla expandida	500	0,10	(0,12)
Hormigón en masa con arcilla expandida	1.500	0,47	(0,55)
Fábrica de bloques de hormigón incluidas juntas (1)			
— Con ladrillos silicocalcáreos macizo	1.600	0,68	(0,79)
— Con ladrillos silicocalcáreos perforado	2.500	0,48	(056)
— Con bloques huecos de hormigón	1.000	0,38	(0,44)
Con bloques huecos de hormigón	1.200	0,42	(0,49)
Con bloques huecos de hormigón	1.400	0,48	(0,56)
— Con bloques hormigón celular curado vapor	600	0,30	(0,35)
Con bloques hormigón celular curado vapor	800	0,35	(0,41)
Con bloques hormigón celular curado vapor	1.000	0,40	(0,47)
— Con bloques hormigón celular curado aire	800	0,38	(0,44)
Con bloques hormigón celular curado aire	1.000	0,48	(0,56)
Con bloques hormigón celular curado aire	1.200	0,60	(0,70)
Placas o panales			
— Cartón-yeso	900	0,16	(0,18)
— Hormigón con fibra de madera	450	0,07	(0,08)
— Placas de escayola	800	0,26	(0,30)
LADRILLOS Y PLAQUETAS			
— Fábrica de ladrillo macizo	1.800	0,75	(0,87)
Fábrica de ladrillo perforado	1.600	0,65	(0,76)
Fábrica de ladrillo hueco	1.200	0,42	(0,49)
— Plaquetas	2.000	0,90	(1,05)

Table 19: Thermal conductivity of different materials.

Material	Densidad aparente kg/m³	Conductividad térmica λ	
		kcal/hm °C	(W/m °C)
VÍDRIO (2)			
— Vidrio plano para acristalar	2.500	0,82	(0,95)
METALES			
— Fundición y acero	7.850	50	(58)
— Cobre	8.900	330	(384)
— Bronce	8.500	55	(64)
— Aluminio	2.700	175	(204)
MADERA			
— Maderas frondosas	800	0,18	(0,21)
— Maderas de coniferas	600	0,12	(0,14)
— Contrachapado	600	0,12	(0,14)
— Tablero aglomerado de partículas	650	0,07	(0,08)
PLÁSTICOS Y REVESTIMIENTOS DE SUELOS			
— Linóleo	1.200	0,16	(0,19)
— Moquetas, alfombras	1.000	0,04	(0,05)
MATERIALES BITUMINOSOS			
— Asfalto	2.100	0,60	(0,70)
— Betún	1.050	0,15	(0,17)
— Láminas bituminosas	1.100	0,16	(0,19)
MATERIALES AISLANTES TÉRMICOS			
— Arcilla expandida	300	0,073	(0,085)
Arcilla expandida	450	0,098	(0,114)
— Aglomerado de corcho UNE 5.690	110	0,034	(0,039)
— Espuma elastomérica	60	0,029	(0,034)
— Lana de vidrio:			
• Tipo I	10-18	0,038	(0,044)
• Tipo II	19-30	0,032	(0,037)
• Tipo III	31-45	0,029	(0,034)
• Tipo IV	46-65	0,028	(0,033)
• Tipo V	66-90	0,028	(0,033)
• Tipo VI	91	0,031	(0,036)
— Lana mineral:			
• Tipo I	30-50	0,036	(0,042)
• Tipo II	51-70	0,034	(0,040)
• Tipo III	71-90	0,033	(0,038)
• Tipo IV	91-120	0,033	(0,038)
• Tipo V	121-150	0,033	(0,038)
— Perlita expandida	130	0,040	(0,047)
— Poilestireno expandido UNE 53.310:			
• Tipo I	10	0,049	(0,057)
• Tipo II	12	0,038	(0,044)
• Tipo III	15	0,032	(0,037)
• Tipo IV	20	0,029	(0,034)
• Tipo V	25	0,028	(0,033)
— Poliestireno extrusionado	33	0,028	(0,033)
— Polietileno reticulado	30	0,033	(0,038)
— Polisocianurato, espuma de	35	0,022	(0,026)
— Poliuretano conformado, espuma de			
• Tipo I	32	0,020	(0,023)
• Tipo II	35	0,020	(0,023)
• Tipo III	40	0,020	(0,023)
• Tipo IV	80	0,034	(0,040)
— Poliuretano aplicado *in situ*, espuma de			
• Tipo I	35	0,020	(0,023)
• Tipo II	40	0,020	(0,023)
— Urea formol, espuma de	10-12	0,029	(0,034)
— Urea formol, espuma de	12-14	0,030	(0,035)
— Vermiculita expandida	120	0,030	(0,035)
— Vidrio celular	160	0,038	(0,044)

Table 20: Surfaces coefficients of heat transfer inside and outside.

Posición del cerramiento y sentido del flujo de calor	Situación del cerramiento					
	De separación con espacio exterior o local abierto			De separación con otro local, desván o cámara de aire		
Cerramientos verticales o con pendiente sobre la horizontal > 60° y flujo horizontal.	0,13 (0,11)	0,07 (0,06)	0,20 (0,17)	0,13 (0,11)	0,13 (0,11)	0,26 (0,22)
Cerramientos horizontales o con pendiente sobre la horizontal ≤ 60° y flujo ascendente.	0,11 (0,09)	0,06 (0,05)	0,17 (0,14)	0,11 (0,09)	0,11 (0,09)	0,22 (0,18)
Cerramientos horizontales y flujo descendente.	0,20 (0,17)	0,06 (0,05)	0,26 (0,22)	0,20 (0,17)	0,20 (0,17)	0,40 (0,34)

In case of vertical enclosures the heat flow is horizontal, therefore:

$$[(1/hi) + (1/he)]^{-1} = 0,17 \text{ W} / (m^2 * {}^{o}C)$$

Then the values of heat transfer coefficients which are applied to exterior walls, interior walls, windows, desks and floors will be explained briefly, because these are the most typical dealing with calculations of enclosures for a house.

D.2.2. External enclosures

Usually the exterior walls, figure 46, have different layers (double bricks, bovedillas, foam, air layers, layers of insulating ...) to make the heat transfer not too high (7 layers in the picture shown).

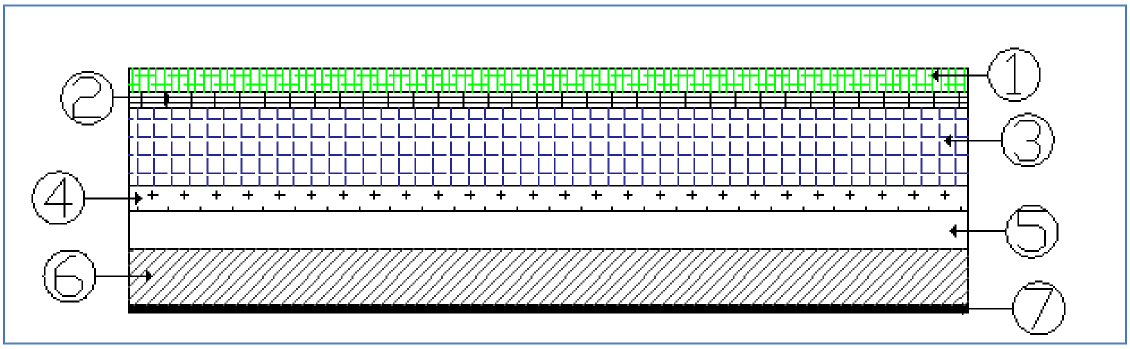
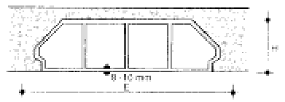
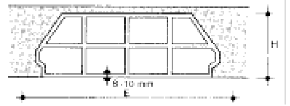
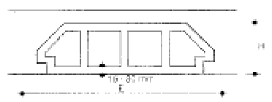
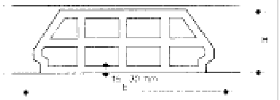


Figure 46: Exterior walls.

As mentioned before, the K values are usually quite low and are usually between 0,4 and 0,7.

In Table 21 are given the values of thermal resistance, useful for some types of unidirectional forged, depending if they are ceramic or concrete bovedillas.

Table 21: Thermal resistance R in m^2 h°C/Kcal [m^2 °C/W].

Tipo de forjado		Distancia de entrevigado E en cm	Altura H en la bovedilla, en cm				
			8	12	16	20	25
Bovedilla cerámica		< 45	0,09 (0,08)	0,13 (0,11)			
		45 a 65	0,13 (0,11)	0,16 (0,14)			
		> 65	0,14 (0,12	0,19 (0,16)			
Bovedilla cerámica		< 45		0,15 (0,13)	0,20 (0,17)	0,24 (0,21)	0,29 (0,25)
		45 a 65		0,22 (0,19)	0,27 (0,23)	0,30 (0,26)	0,36 (0,31)
		> 65		0,27 (0,23)	0,31 (0,27)	0,35 (0,30)	0,40 (0,34)
Bovedilla de hormigón		< 65		0,13 (0,11)	0,15 (0,13)	0,17 (0,15)	0,21 (0,18)
		≥ 65		0,14 (0,12)	0,16 (0,14)	0,19 (0,16)	0,22 (0,19)
Bovedilla de hormigón		< 65				0,26 (0,22)	0,29 (0,25)
		≥ 65				0,27 (0,23)	0,31 (0,27)

The glasses of windows and doors have a high heat transfer coefficient, on the one hand because of the material itself and on the other hand because of the fact that there is only one layer for heat transfer (if the windows are not double). These K values are usually between 2 and 7 depending on the type of windows and doors. The best is still, as mentioned before, to look at the tables and get the value depending on the type of glass.

Table 22: Heat transmission coefficient of enclosure for windows. [Kcal/m^2 °C (W/m^2 °C)]

Tipo de acristalamiento	Espesor nominal de la cámara de aire, en mm	Tipo de carpintería	Inclinación del hueco con respecto a la horizontal	
			≥ 60°	< 60°
Sencillo		Madera	4,3 (5,0)	4,7 (5,5)
		Metálica	5,0 (5,8)	5,6 (6,5)
Doble	6	Madera	2,8 (3,3)	3,0 (3,5)
		Metálica	3,4 (4,0)	3,7 (4,3)
	9	Madera	2,7 (3,1)	2,8 (3,3)
		Metálica	3,4 (3,9)	3,6 (4,2)
	12	Madera	2,5 (2,9)	2,7 (3,1)
		Metálica	3,2 (3,7)	3,4 (4,0)
Doble ventana	≥ 30	Madera	2,2 (2,6)	2,3 (2,7)
		Metálica	2,6 (3,0)	2,8 (3,2)
Hormigón traslúcido	—	—	3,0 (3,5)	3,2 (3,7)

Table 23: Heat transmission coefficient of enclosure for doors. [Kcal/m^2 °C (W/m^2 °C)]

Tipo de puerta		Separación con: Exterior	Separación con: Local no calefactado
Madera	Opaca	3,0 (3,5)	1,7 (2,0)
	Acristalamiento simple en < 30% Acristalamiento simple en 30 a 60%	3,4 (4,0) 3,9 (4,5)	
	Acristalamiento doble	2,8 (3,3)	
Metálica	Opaca	5,0 (5,8)	3,9 (4,5)
	Acristalamiento simple	5,0 (5,8)	
	Acristalamiento doble con cámara de 6 mm en < 30% Acristalamiento doble con cámara de 6 mm en 30 a 70%	4,7 (5,5) 4,1 (4,8)	
Vidrio sin carpintería		5,0 (5,8)	3,9 (4,5)

D.2.3. Interior partitions

Usually, the interior partition is doubled hollow brick and is then coated with gypsum. As was mentioned, these values will be high due to the fact that the heat transfer is big. These K values are usually around 3 for internal partitions; since heat transfer between rooms of the same house doesn't matter contrary to the thickness and the saving of money that really do matter. As a result, all the available square meters (as wider walls occupy big interior space) will be used.

The following figure, figure 47, displays a typical interior partition.

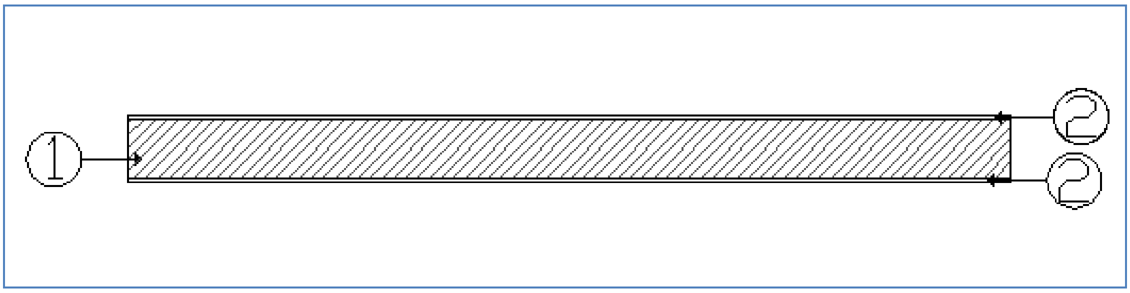


Figure 47: Typical interior partition.

In Table 24 are given the thermal resistance values of a brick enclosure of one sheet, according to the type of brick: hollow, perforated or solid, and the thickness of the enclosure, excluding coatings that could be added.

Table 24: Thermal resistance R, in m^2 h°C/Kcal [m^2 °C/W]

Formato métrico		Espesor E, en cm, del cerramiento						
Tipo de ladrillo	Peso especifico en kg/m^3	4,0	5,3	9,0	11,5	24,0	36,0	49,0
Hueco	1.200	0,09 (0,07)	0,13 (0,11)	0,21 (0,18)	0,27 (0,23)	0,57 (0,49)	0,86 (0,74)	1,17 (1,00)
Perforado	1.600	0,06 (0,05)	0,08 (0,07)	0,14 (0,12)	0,18 (0,15)	0,37 (0,32)	0,55 (0,47)	0,75 (0,65)
Macizo	1.800	0,05 (0,04)	0,07 (0,06)	0,12 (0,10)	0,15 (0,13)	0,32 (0,27)	0,48 (0,41)	0,65 (0,60)
		Resistencia térmica R en m^2 h °C/kcal (m^2 °C/W)						

D.2.4. Deck enclosures

In this section, we will focus on differentiating the interior floors of the house, roofs and deck enclosures.

- Interior floors and roofs will have K values around the unity (very low).
- Deck enclosure will have K values similar to the vertical enclosures.

In summary I would emphasize that internal partitions, doors and windows usually have high values regarding the heat transfer coefficient. Lower values of K (in order the heat transfer to be as low as possible and without losses) are usually set in the enclosures that separate the exterior and interior of the house.

As can be noticed, all the values given in the tables above are in kcal, they will thus have to be converted into W for the calculation of K.

All the tables can be found in NBE-CT -79 (Basic Rules of Construction), (Technical Code).

The result of K must be less or equal to 0,91 according to Standard NBE-CT-79 for the considered air conditioning area.

Annex E. Calculation of thermal loads

E.1. Technical burdens in housing

When speaking of thermal load in air conditioning, this refers to all perturbation which is capable of altering the energy in air-conditioned spaces. The perturbations are caused on the one hand, in energy sources located inside the spaces, and on the other hand, in the climatic conditions of outside space that surrounds the venue.

Thermal loads are associated with determined spaces and are variable over time. The objective of the air conditioning is to cancel these loads at all times and in all spaces, so it is necessary to know how the thermal loads vary, in space and in time.

There are two different ways to manifest the energy in a room which is cooled. On the one hand by convective heat fractions and on the other hand by radiant fractions of load type each. The convective fraction is transmitted instantaneously to the air of the place by convective transfer; however, the radiant fraction does not directly affect local air. It has an impact on the walls and the contents of space. Also, it is absorbed by all materials that are part of local, home or area which is air-conditioned, making the temperature increase. Then, this absorption is transferred to the air temperature by a convective mechanism.

It is called **gain**, the energy that affects the control volume (space which is air-conditioner), and **load**, the energy that is manifested in the air of the local. The difference between them is linked to the inertia of the enclosures and the contents of the local. In addition it is also linked to the different origins of convective and radiant fractions of thermal excitations.

Then will be defined a serial of elements of buildings that are needed to know and thus be able to dimension the installations:

- *External load* (outdoor conditions) is primarily the effect of the outside on the interior, which is modified by the enclosures of the building (which will attenuate to a greater or lesser extent the signal). It also depends on the level of isolation, because it will be responsible for slowing the signal, depending on its density or its capacity to store the conditions which separate the outside from the inside. You have to get information about the inertia and load level from outdoor for modeling the outside load.

- Enclosure: as noted in the previous paragraph, it is responsible for the transmission from outside to inside. It allows different models.

- *The Internal loads (Internal conditions)* are the elements that together with external actions will be responsible for stating the amount of energy needed by air conditioning systems to maintain comfort conditions for occupants. They are characterized by a high level of randomness, being therefore the most independent part (depending on persons, activity, internal lighting, machinery from the inside...).

- *Installations*: are responsible for the transit of heat/cold and the humidity in order to maintain comfort conditions inside of the place independently from the outside. The configuration and the system which are chosen will condition the control system installation.

E.1.1. Indoor conditions

These conditions are important for the comfort of users, i.e. the climatic conditions that satisfy their requirements when they are in a heated room.

The RITE (Regulation of Thermal Installations in Buildings - 2007) tells us in the ITE 1.1, that the comfortable temperatures in summer are between 23ºC and 25ºC. In winter the comfort temperatures are between 20ºC and 22ºC.

We will select in the program of simulation a comfortable **temperature in the interior of 24ºC in summer and 21ºC in winter**, thinking that the energy efficiency and comfort inside the home will be successful.

To make the calculation, the simulation program assumed a constant occupation of the rooms, providing a constant air flow ventilation and internal heat. Due to the fact that it is a home, we can assume that these conditions are variables, but are considered as the most common that can be given, in each of the rooms.

E.1.2. Outdoor conditions

RITE tells us to consult the external conditions in technical articles or books that collect information from the National Institute of Meteorology (INM) for getting the external conditions which are necessary to dimension the equipment. The data are tabulated, according to the Spanish province. The data which have to be considered are: the number of hours of sunlight during the day, the nominal temperature, the thermal daily extrusion (average of daily temperature variation), altitude and latitude. These data should be considered for winter and for summer, depending on the situation of the zone where is located the house which will be heated.

E.2. Calculating loads of cooling [Qc].

The formula used in the calculation is:

$$\mathbf{Q_c = Q_{sens} + Q_{lat}}$$

Where:

- Qc: cooling global heat load [W].
- Qsens: cooling sensible heat load [W].
- Qlat: cooling latent heat load [W].

E.2.1. Sensible load

$$Q_{sens} = Q_{solar} + Q_{trans} + Q_{inf} + Q_{ints} + Q_{Vsrn}$$

E.2.1.1. Solar gain due to the glass (Qsolar) (W)

The energy that comes to the house from solar radiation and passes through transparent elements such as windows is of two types: heat transfer by convection and by solar radiation.

To know the solar radiation which incidents on a surface like a window, you have to determine a month of calculation. For this calculation, it is always chosen or July 23 or August 24 because those are the moments of the year with the more solar radiation.

The last indispensable factor for finding the incident radiation is the orientation of the window, which will vary depending on the room of calculation, i.e. the percentage of energy transmitted through the glass and the existence or not of blinds or curtains (Transmission of heat by solar radiation). Must be taken into consideration that the transmitted energy is converted to load and it is stored on the floors and on the walls.

$$Q_{solar} = A_{glass} \cdot K_g \cdot f_c \cdot f_t$$

Where:

- Qsolar: solar gain due to radiation in windows [W].
- Aglass: glass area of a room in a specific orientation [m^2].
- Kg: coefficient of solar contribution through the single glass (*Tables*) [W/m^2]
- fc: weighting. For example, for metal frame windows is 1.17.
- ft: solar gain total factor through glass. For example, for double glazing with exterior blinds is 0,2 (*Tables*)

E.2.1.2. Solar gain through the transmission of decks, interior walls and exterior walls (Qtrans) (W)

The heat gains through the exterior walls, floors and decks are calculated at the time of maximum flow thermal. They are due not only to the difference between outside air temperatures and inside faces, but also to the solar heat absorbed by the outside walls, sunstroke which receives the house and the difference of temperatures inside and outside. All these variables change throughout the day, making that the intensity of the flow will be unstable.

Therefore, we have used the empirical concept of "equivalent temperature difference”, which is defined as the difference between the temperatures of indoor and outdoor air, resulting from the total heat flow through the analyzed structure, which depends on variable solar radiation and on the outside temperature. This equivalent temperature difference through the structure will depend on: the different types of structures and orientations, exterior wall color, location of the building, sunstroke on it and the conditions of the project. Because of this, we will then explain on the one hand, calculation method for external walls and decks and on the other hand the calculation method for interior walls.

Solar gain by transmission of exterior walls and deck (Qtrans1) (W)

When talking about radiation in walls, this refers to radiation from the sun which heats the outside walls of the local which is air-conditioned. The radiation heat is transferred by conduction through the walls and deck, generating the heating of the interior of the building.

The calculation will be done by the following equation:

$$Q_{trans1} = A_{wall} \cdot \ (DTE) \ \ Kc$$

Where:

- Qtrans1: solar gain transmitted on exterior walls and deck [W]
- Awall: area of the outside wall of a room depending on the orientation [m^2] and also area of the deck in the case of the room is in contact with the outer cover.
- Kc: transmission coefficient of the wall or deck (*calculated in the ANNEX D of the project*) [$W/m^2 \cdot °C$]
- DTE: equivalent difference of temperatures in °C.

The equivalent difference of temperature (DTE) is referring to a jump of thermal temperature in order to take into account the effect of solar radiation (*Tables*).

The following three parameters will be needed to find the equivalent difference of temperature of a wall:

- The orientation of the wall.
- The weight per square meter of the wall.
- The solar time when the project takes place.

To find the DTE of a deck, the parameters that must be known are:

- If the deck is shaded or not.
- The weight per square meter of the deck.
- The solar time to which the project takes place.

Solar gain by transmission (except exterior walls and deck) (Qtrans2) (W)

In this part of the project, we have to consider the areas such as windows (in this case, to know the heat produced by transmission) and interior walls, provided that they are not in contact with another air-conditioned room, since in this case it would be valueless.

The interior doors should not be considered. Its surface is considered as if it were a piece of wall to which it belongs. In this case the equation is:

$$Q_{trans2} = A \cdot \Delta T \cdot Kc$$

Where:

- Qtrans2: Gain transmission in inside walls and floors [W].
- A: Area of inside wall, floor or roof of a room [m^2].
- Kc: global transmission coefficient of the wall, etc. (*calculated in the ANNEX D of the project*) [W/m^2 •°C].
- ΔT: It is the difference of temperature between outside and inside [ºC]. For the surfaces (walls, ceilings, etc.) in contact with an unheated room it is usually taken $\Delta T/2$.

E.2.1.3. Sensible heat due to infiltrations

This part is referring to, on the one hand the heat that enters when the doors or windows are opened and on the other hand, to the heat that enters through the fissures. The calculation of this contribution is only compulsory if the doors or windows are frequently opened, like in the case of public places.

E.2.1.4. Sensible internal heat (Qint sen) (W) (Internal loads)

$$Q_{int\ sen} = Q_{ocsen} + Q_{el}$$

- $Qint_{sen}$: sensible interior heat [W].
- Coc_{sen}: sensible thermal load of the occupants [W].
- Qel: thermal load of lighting and machines [W].

All humans give off a certain amount of heat because our body temperature is approximately 37ºC. This heat makes the room being more or less hot, depending on the activity and the number of people that are in the room.

Sensible or latent heat that a person gives off depends on the task that you are doing and the temperature of the local. These values are tabulated in tables. Multiplying the heat produced by an individual per the number of individuals, we will get the total power [W] generated local occupants. It is usually used a simultaneity factor of the people situated in the local which, as an approximation, can be taken equal to 0,75.

$$Q_{ocsen} = N_p \cdot Q_{sp}$$

Where:

- N_p: Number of people in the same room.
- Q_{sp}: Unity gain of sensible heat due to occupant (*Tables*) [W/pers]

Like people, the lighting and the machines (oven, heater ...) also produce heat that will heat the local atmosphere. The heat from lighting is sensible heat, but a part of this load is due to radiation and another part due to convection, depending on the type of lighting. Again, for the instantaneous cooling load, the effect of storage will be taken into consideration in order to accurately assess their contribution to the total load.

The heat produced by lighting depends on whether it is incandescent light or if it comes from a fluorescent light. In the case of incandescent lighting, it is equal to the power of illumination. But if the lighting is fluorescent, the power of illumination has to be multiplied by a zoom factor of 1,25.

Fluorescent light

$$Q_{el} = 1{,}25 \cdot I$$

Incandescent light

$$Q_{el} = I$$

Where:

- I: Electrical power of illumination [W]

E.2.1.5. Sensible heat of ventilation (Qv sen) (W)

In the air conditioning installations, it is necessary to forecast the renewal of the air (for removing odors, etc ...) as well as the introduction of a sufficient amount of oxygen to ensure the quality of the air inside the air-conditioned room.

The outside air introduced must be compensated by the same flow of air extracted or expelled through the windows and doors. Doing it, the same amount of dry air will be maintained in the enclosure.

To find the amount of air that we will have to introduce inside the air-conditioned room, it is necessary to look in the tables, and depending of the activity performed in the local, we will get the air flow required for the ventilation.

The ventilation could be mechanical (by conduits that bring outside air) or natural (through windows or doors). With the following formula, we obtain the sensitive load of ventilation:

$$Qv_{sen} = q \cdot 0{,}3 \cdot (4{,}18 / 3{,}6) \cdot (To - Ti) \cdot f$$

Where:

- Qv^{sen}: sensible heat of ventilation [W].
- q: outside air flow set for the room [m^3/h].
- To and Ti: air temperature respectively outside and inside [ºC].
- f : By-pass factor (depending on the system of distribution (*tables*))

E.2.2. Latent load

$$Qlat = Q_{OC1} + Qv1at$$

$$Q_{OC1} = N_P \cdot Q_{lp}$$

Where:

- Qlat: Latent load of the occupants (Q^{OC1}) (en W).
- Q^{OC1}: Latent thermal load of the occupants of the room [W].
- N^{p}: Number of people who occupy the room or local.
- Q^{lp}: Unity load of latent heat due to occupants (*Tables*) [W/per].

Latent heat of ventilation (Qv_{lat})

$$Q_{V\,lat} = q \cdot 0{,}7 \quad \frac{4{,}18}{3{,}6} \cdot (w_0 - w_i) \cdot f$$

Where:

- Qv lat: sensible heat of ventilation [W].
- q: outside air flow set for the room [m^3/h].
- wo y wi: Specific humidity of respectively outside and inside air, (*Tables*) [g/Kg].
- f : By-pass factor (depending on the system of distribution (*Tables*)).

You can find below a summary of the three main equations for obtaining the total load of the room or stay (Q_R).

$$Q_C = Q_{sens} + Q_{lat}$$

$$Q_{sens} = Q_{solar} + Q_{trans} + Q_{inf} + Q_{int\ sens} + Q_{vsens}$$

$$Q_{lat} = Q_{OC1} + Q\ V_{lat}$$

E.3. Calculating loads of heating [Qh]

The estimation of the maximum thermal power in the case of heating is calculated in the same way as in the case of cooling, taking into account the worst possible case (minimum temperature, zero solar radiation, minimal presence of persons, and minimum light). In the case of heating, we must take into account that the loads are heat losses, to maintain an ambient temperature higher that the outside temperature, except for internal loads.

I would emphasize that for this part of the project, it is necessary to use different tabulated tables. Since I have not done mathematical calculations, I thought it would be better not to put them, however, it can be found in NTE.

ANNEX F. REPORT

1. Introduction, Objectives of the project and methodology

1.1. Introduction and motivation of the project

The evolution of the European market of energy in recent years is marked by the progressive liberalization of different sectors and the growing concern of the impact of energy activity on the **environment**. The mass consumption of hydrocarbons is already producing the known **greenhouse effect**, which is already causing an increase in global average temperatures (+ 0,17°C per year). In addition, they are the cause of the **acid rain.**

Currently, and despite being the air conditioning sector an emerging market in our territory (Spain), it is already considered that 12% of the electricity demand is intended for air conditioning of buildings and houses and is the main cause of the annual **demand peaks** in the months of July and August. Which made the electricity networks of transportation and distribution in some areas of Spain (especially in the south) to reach its limits and caused increases in the price of electricity in the market. With these teams virtually zero power consumption could be reduced and stabilize the demand.

The **Kyoto Protocol** - drafted in the 1997 although it was not ratified until 2005 – calls upon developed countries to reduce their emissions by 5,2% in 2012 in comparison with 1990 levels. As a solution to these environmental is important to carry out efforts aimed at the replacement of conventional energy sources, such as coal or oil, for **clean and renewable energy** to maintain a sustainable economic growth to ensure energy supply.

Currently, in Spain, due to the coming into force of **Building Technical Code** (CTE, 2006) the solar thermal energy is experimenting a greater implementation. According to the Basic Document HE of Energy Savings in the section "HE 4 Contribution minimum solar of sanitary hot water" (HE 4, 2004), both the new buildings and the renovated buildings must cover a part of the demand of sanitary hot water, as well as the incorporation of feedback systems, storage and utilization of low-temperature solar energy. Likewise, also, the obligation extends to the swimming pool heating.

Current cooling systems, mainly based on **compression**, are a technical irony. Because they radiate more heat into the atmosphere than they produce cold needed for the people. This means that if we continue to use conventional cooling systems, we will continue accelerating the spiral of global warming.

System for many years offered this possibility is based on the so-called refrigeration cycle of **absorption**, in which the movement of fluids is achieved using heat from the combustion of any fuel, waste sources as cogeneration equipment or free as it is the case that we study the collected solar radiation (collector solar thermal).

1.2. Objective of the project

To solve this problem, of demand peaks and to reduce CO_2 emissions to the environment there is another system for small powers of air conditioning (both for cold to heat) which is an alternative to lithium bromide-water absorption machine that exists in the market. It will be responsible for air conditioning of the house, i.e., the heat for winter heating, sanitary hot water (DHW) throughout the year, and the cold in summer.

In this project, I intend to design a solar cooling system for a house located in the **Community of Madrid**, in which 6 people live throughout the year using a thermal solar power plant that supplies an absorption refrigeration machine (ClimateWell_10). In addition, there will be installed an auxiliary boiler and a water storage tank to provide sanitary hot water and heating demand if necessary.

The objective which is pursued with this installation is to achieve a model of building more sustainable, showing the potential of renewable energy and encouraging greater application in society.

The technical conditions of the installation to work properly the all of the circuit are also specified.

1.3. Methodology

The first thing to develop is a current assessment of thermal solar energy both in Spain as in Europe, commenting the current and future potential of it to achieve the target of 20% triple imposed by the European Community in the field of renewable energy. The economic and environmental benefits that this would produce to short and long term will be commented. Regional and annual variations of solar thermal energy will also be explored, more specifically in Spain, and finally the calculation method for estimating the demands. All of this is mentioned in **ANNEX A.**

Next, in the **ANNEX B**, the heating technology will be explained, i.e. the use of solar energy for DHW, pool and underfloor heating. In this Annex, will be commented the different types of solar collectors that exist in the market, their differences and their uses, and finally a brief explanation of thermal energy storage.

In the **ANNEX C** will be made a study of compression and absorption refrigeration systems, developing the major differences between them, besides, commenting the different types and cycles of absorption and a comparison between them.

Next, in the **ANNEX D** will be done a brief description of house location and then will be explained the calculation method for heat transfer coefficients of the different enclosures.

To calculate the thermal demands of Annex B, must be taken into account the different thermal loads of the building, so in the **ANNEX E**, the different existing thermal loads in a house will be explained, and the method of calculating of them.

In this report shall be calculated terminal units for the installation to be developed, taking into account the different circuits needed for the proper functioning of it. All of this, taking into account the advices followed by the manufacturer of absorption machine. Then a hydraulic diagram of the circuit made with AutoCad will be presented with their corresponding control.

By the dynamic calculation software called **"TRNSYS"** will be made a calculation both economic as environmental of the project, making a comparison with conventional systems used until now.

Will be studied possible grants to local and regional level (City and Community of Madrid) and State (Institute for Diversification Energy and Saving of Energy -IDAE-) because it is a novel system that uses solar energy as a main source of energy. Study regional and state existences for financing the installation.

In this report, is referred to a series of appendices, which range from **ANNEX 1** to **ANNEX 10**, in which are lists of characteristics of different components, the equation mains component of the project, the hydraulic circuit diagram, the election of radiant floor, an Excel spreadsheet for economic profitability calculation and the report provided by the simulation of the system after to do the corresponding calculations.

2. Global description of the installation

Obtaining energy for our project will be done through solar collector's planes of low temperature, which will be connected to a heat exchanger. It will also have a storage tank for domestic hot water production, an auxiliary boiler for backup heating, an absorption machine which will provide heating or cooling to the house depending of the needs of it, a circuit for heat dissipation (pool) which is separated from the absorption machine through a second heat exchanger and a hydraulic circuit using radiant floor both for heating the house in winter as for cooling in summer.

The basic scheme to develop in our solar thermal power system is shown in the figure 1:

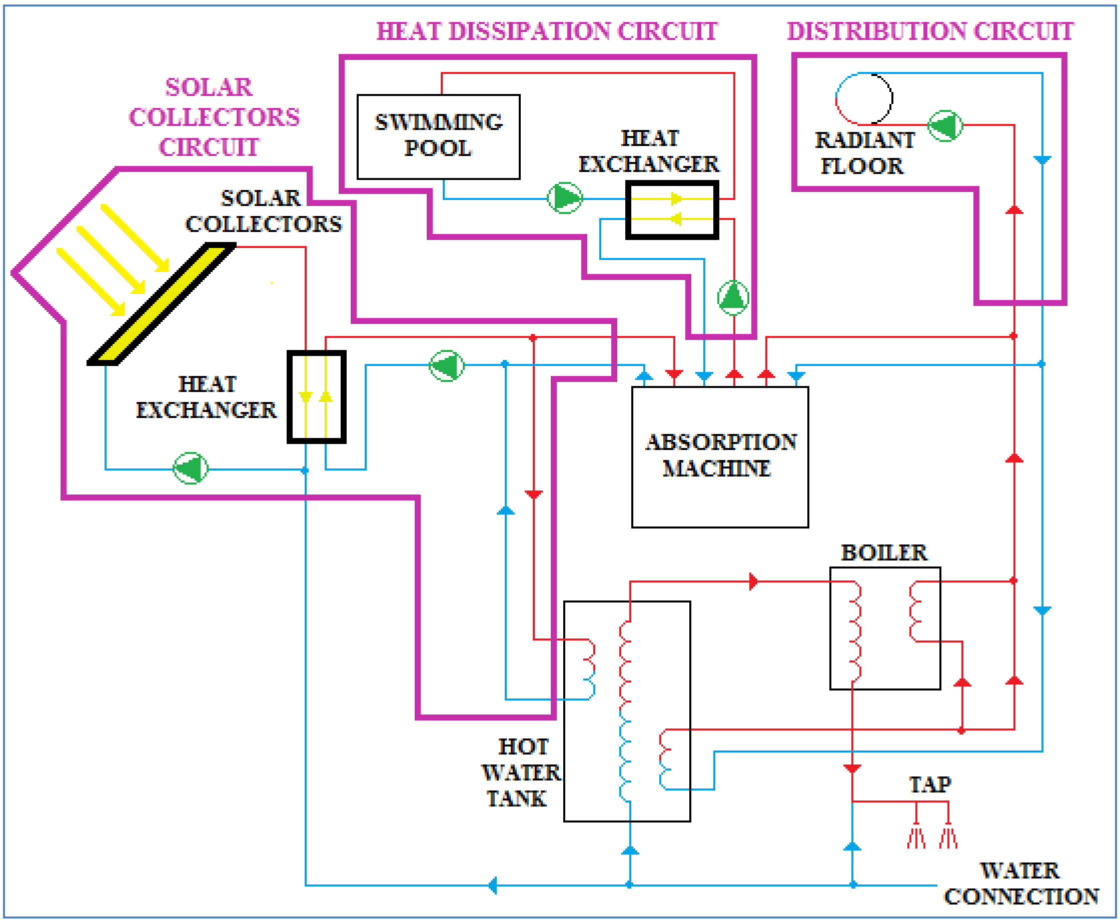


Figure 1: Simplified schematic of the installation.

The main components of the system are:

- **Solar capture system**: It is composed of several interconnected solar collectors in order to achieve the desired temperature in the fluid.

- **Absorption machine**: In our case, the chosen machine is called ClimateWell_10 (CW_10), which provides the needed demands of the home, for hot water (DHW), heating and cooling.

- **Accumulation system**: It is also known by the name of accumulator, and consists in one or more storage tanks of hot water. It also serves to support the absorption machine on cloudy days, when the energy from the solar collectors is not sufficient for the production of energy in the absorption machine.

- **Dissipation system:** It will be responsible for heat dissipation, both in the loading process, as in the download process, making the absorption machine working properly.

- **Distribution system:** Set of equipment and devices that are responsible for transporting the produced hot water to the points of consumption. It is formed by heat exchangers, pipes, pumps and safety features, among others.

- **Auxiliary system**: Usually, it is whether a conventional boiler or an electrical heater, which is triggered when the temperature of hot water at the outlet of the accumulator is less than the defendant temperature, and also, to provide cover if necessary to the absorption machine during the winter.

Both in winter as summer, the priority of the circuit will be the heating of DHW, if there is a need of demand. Because of this, the heat flow from heat exchanger of primary circuit will affect first in the heat exchanger of hot water tank, and only if this need is covered, the hot water of primary circuit will arrive to the machine absorption.

If for consumption, the water temperature that is inside of tank is not high enough, this water will enter the boiler so as to increase its temperature until the required outlet temperature.

As will be explained later and in greater detail, the boiler will also provide the heating water that is inside of the tank, if the water that is inside of this does not have a sufficiently high temperature to provide the radiant floor heating in winter; in case of the absorption machine cannot provide heated.

In summer, cooling necessary and in winter, heating necessary will be provided by the absorption machine which as will be explained in paragraph 5 of this report, requires the use of a dissipation circuit, producing in this case an increase water temperature of the pool.

In addition, as shown in the previous figure, all the circuits have a water inlet from general connection in order to produce the filling them and provide coverage for cold water needs that are demanded at home.

In the following paragraphs are explained in more detail the circuits appointed so far, with its different components so that the whole the circuit works properly.

3. Solar capture circuit

3.1. Solar capture system

As mentioned in the **ANNEX B**, the more appropriated capture systems are the solar selective flat collectors or vacuum tube. These will do that the absorption machine works correctly thanks to a water inlet temperature around 90ºC. The other option would be to use solar collectors of parabolic tracking, but this option has been discarded in the project due to the fact that it would increase the cost.

So, whether flat collectors or tube collectors will be chosen, because both use low temperatures of work (T <100°C).

In general, with the vacuum tube collector, less capture area is required to cover the same demand of heat. In Spain, as can be observed in figure 2, for applications of low temperature, there is not a big difference of performance between flat collectors and vacuum tube collector. Therefore, if we work with low temperatures, as it is our case, the extra cost of vacuum tube collector is not compensated. However, for higher temperature applications, its use becomes more important.

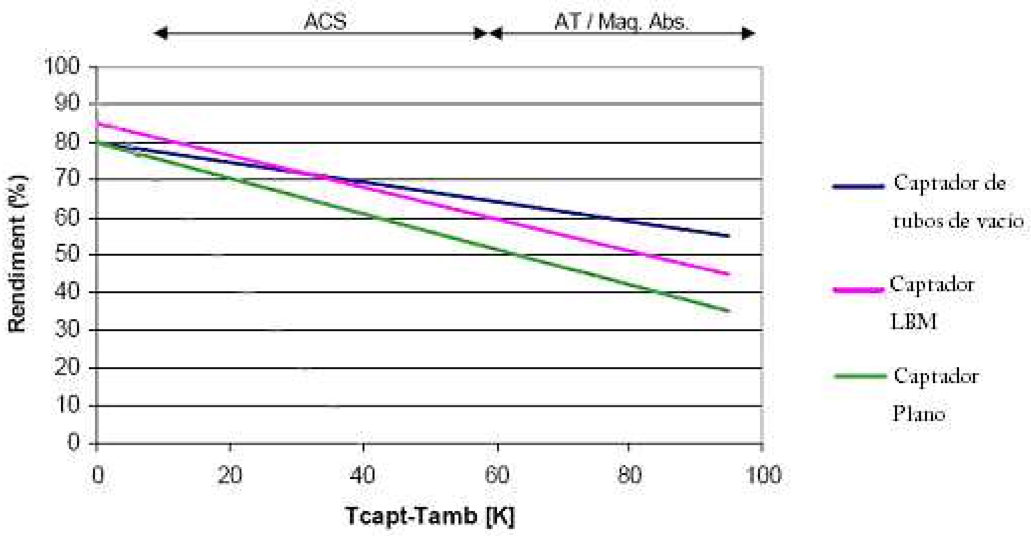


Figure 2: Efficiency curves of different types of solar collectors, depending on the difference of temperature between the collector and the ambient (radiation of 800 W/m^2).

The table 1 draws a comparison between the vacuum tube collector, selective flat collector and a standard flat collector, taking into account the efficiencies and cost.

Table 1: Summary table of the solar collector's characteristics.

Type of solar collector	Commercial models	Optimal performance	Loss coefficient [W/m^2*K]	Instant performance at 90°C	Area collector [m^2 useful surf.]	Price per unit [€/m^2 useful surf.]
Solar collector	EURO-C20HTF	0,81	3,47	30-35%	2,39	304
Selective flat collector	LBM 100 AR	0,83	2,43	45-50%	9,1	415
Vacuum tube collector	Vitosol 300 H30	0,825	1,19	55-60%	3,21	1.036

In **ANNEX 1** can be seen the formulas that rule the behavior of elected collector, i.e. a flat solar collector.

As can be seen in the technical data of the machine offered by the manufacturer (**ANNEX 2**), the capture solar primary circuit requires a flow between 15 and 20 l/min in order it to work in optimum designed conditions. Because of this, the primary circuit flow will be of **17,5 l/min**. This way, the transfer in the heat exchanger will be done properly.

In the same way, it will needed a heat transfer fluid flow into each solar collector of 1.25 l/min, making that it will be required a total of **14 collectors** to ensure a flow of 17.5 l/min in the secondary circuit, so that heat transfer in the heat exchanger will be correct.

In the table 2, it can be observed the approximate requirements in m^2 of solar collectors depending on the number of refrigerating machines used and recommended by the manufacturer:

Table 2: Total solar capture area based on the number of used ClimateWell_10 machines. (*Data provided by the manufacturer)*

Numbers of machines CW_10	Size of solar panels[m^2]	Power of solar panels [kW]
1	30	15-20
2	60	30-40
10	300	150-200

As mentioned earlier, the solar panels used in our project will be of Wagner brand, in particular the solar collector model **C2/HTF EURO**. In the **ANNEX 3**, is shown the solar collector technical specifications, in which can be seen that it has a surface area of 2.39 m^2 per each solar collector, that, when multiplied by the 14 solar collectors obtained previously, results in a total gross capture area of **33.46 m^2**. If we compare this value, with the recommendations of the manufacturer, as can be seen in table 2, we can conclude that the calculation was correct.

The connection of the solar panels will be made using the technique of invert return to ensure that the same pressure drop into each battery of collectors, independently from the flow that circulates through them. And for this, the inlet connection to each line of collectors will be carried out by the bottom connection tube of the first collector, and the outlet will be carried out by the top connection tube of the last line collector. This is a necessary requirement when working with variables flows.

In addition to the general specifications that the manufacturer provides us in the technical specifications of the solar collectors, should be known the maximum number of solar collectors that can be connected in parallel. This number is six.

As shown the figure 3, the 14 solar collectors will be connected in parallel in two identical rows of 5 collectors and a one of 4 collectors, each one along the south part of the roof, because this part receives more solar radiation.

An immersion temperature sensor will be used in the last collector of the last series of collectors, and a second sensor near ClimateWell_10, but in the primary circuit, which will control the solar pump of the primary circuit in the side of the solar collectors if the collector temperature is more than 120ºC. In addition, it must be ensured that the sensor is measuring the temperature of the collector and not the flow of the pipes. The temperature sensor located on a pipe cannot be used to control the pump, and because of this, it should measure the temperature of the collector even when the solar pump is turned off.

At the end of each group of solar panels will be installed an automatic purger of buoy to allow the air to get out of the collectors. In addition, a safety valve will be put at the entrance and exit of each row of collectors for the replacement or repairing, in case of failure.

In the figure 3, we can see a drawing of the hydraulic configuration of the solar panels which will take place in our project, with the necessary sensors presented in the previous paragraph.

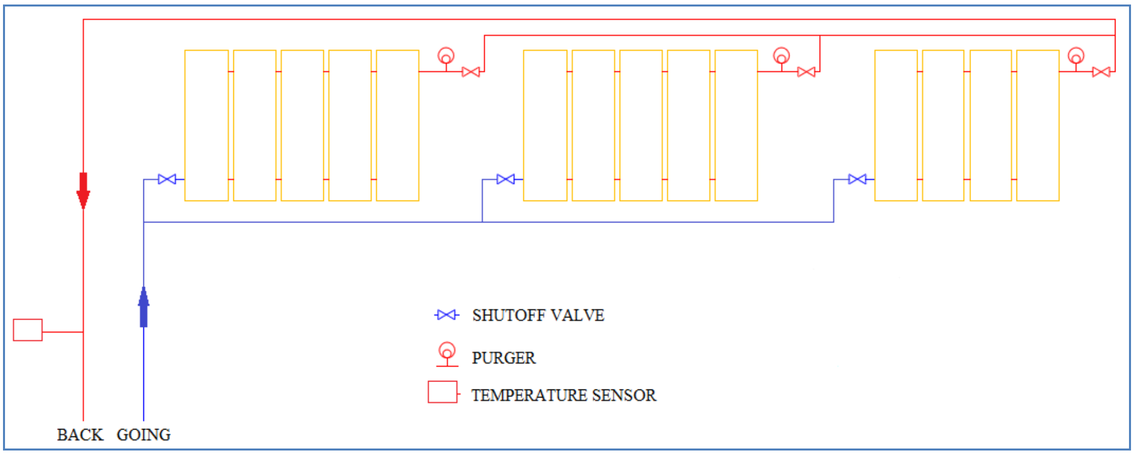


Figure 3: Hydraulic configuration connection of the solar collectors with valves, purgers and sensor of needed temperature.

These will be installed directly on the south roof deck, where the solar radiation is high if it is approximately tilted of 30º (optimum angle tilt in the peninsula) If the deck does not have this inclination, metallic structures will be placed, that will hold the solar panels with a inclination of 30º. It will be assumed in the project that there are no overlaps or leftovers.

3.2. Heat transfer fluid

The fluid of heat transfer which flows through the primary circuit and through the heat exchanger is the one that transfer heat to the secondary circuit. The fluid consists in a blend of antifreeze and water, to prevent water from freezing. The fluid will have a series of none toxic legionella and corrosion inhibitors to buffer the PH, making that, with 20ºC, the PH will be maintained between 5 and 9 (as stated in technical specifications for installations of low temperature solar thermal).

The antifreeze recommended by the manufacturer is **propyleneglycol**. This one doesn't have toxic corrosion inhibitors and buffer the capacity of PH. In addition, the antifreeze must bear more than 170°C without being altered. After looking at the manufacturer's data which are attached in **ANNEX 4**, the antifreeze can bear between 184 and 189°C before boiling, meaning that it is the appropriated one.

To determine the percentage of propyleneglycol that the heat transfer fluid of solar collector's circuit should contain, it must be taken into account the registered minimum temperature in recent years in Madrid. After searching for information about minimum temperatures I have found that the lowest one for the Community of Madrid was recorded in 1963, reaching -14,8°C.

Knowing the minimum temperature recorded in the site, we can determine the percentage by mass of propyleneglycol using on the table 3, which indicates the freezing temperature of heat transfer fluid according to the percentage in weight. Due to this, we will take a **30% of antifreeze**, which corresponds to a freezing temperature of -15ºC.

Table 3: Blend depending on the freezing point of propyleneglycol with water.

PROPILENGLICOL % DEL PESO	PUNTO DE CONGELACIÓN EN ºC
10	-3,5
16	-6,3
20	-8
26	-12
30	-15
36	-20
40	-24
45	-30
50	-36
80	-47

3.3. Heat exchanger of primary circuit

The use of a heat exchanger is due to the fact that the fluid flowing through the solar collector (primary circuit), cannot be used directly in the cooling system, neither for consumption (secondary circuit) due to the presence of antifreeze in the heat transfer fluid.

There are two different types of heat exchangers, depending on whether the exchange of heat in the exchanger is produced through external plates out of the tank, or inside the tank with serpentine, both being with very similar thermal behavior.

The heat exchanger selected is the plate. Moreover, this will connect thermally, without mixture of fluids, the primary circuit (collector) and the secondary circuit (which feeds the hot water storage tank and the boiler). This has been chosen because the heating of DWH has to be provided in our circuit, as well as the circulation of hot water for heating, as recommended by the manufacturer.

In **ANNEX 1** is shown the equations for calculating of heat exchanger and for calculating its power. For this, is used the following formula:

$$\mathbf{P_{exchanger}} = \dot{m}_1 \text{ [Kg/s]} * Cp_1 \text{ [kJ/Kg*ºC]} * (Ti_1 - To_1) = \dot{m}_2 * Cp_2 * (Ti_2 - To_2)$$

The hot water mass flow ($\dot{m}$), is obtained with the volumetric flow rate (Q), and its density (ρ), at the working temperature.

Since the power of the heat exchanger can be calculated using the primary circuit or secondary circuit, we will use the secondary circuit, although the same liters per second will be circulated, as recommended by the manufacturer, the secondary circuit will be used because in this circuit there is only water, and the finding of its physical properties will be obtained more easily. However, if we use the primary circuit, the water is mixed with antifreeze.

According to the manufacturer's recommendations, the difference of temperature between primary and secondary circuit, must be 3°C. Due to this, the temperature of the liquid in the secondary circuit is designed for 80ºC, making that the temperature of the liquid of the primary circuit will be 83ºC. (The manufacturer of Climatewell recommended that the Tª in the secondary should be between 75 and 95ºC, always 50ºC higher than the source of heat dissipation. In addition, the mass flows in the primary and secondary circuits have to be the same).

To apply the equation, it is necessary to know the specific data of the fluid that flows through the secondary circuit. The table 4 shows the thermophysical properties of water at operating temperature of the fluid in the secondary circuit of the exchanger.

Table 4: Water thermophysical properties at 80ºC. (*METCALF & EDDY, INC. Ingeniería de aguas residuales. Mc Graw Hill. 3ª Edición (1995)*)

Working temperature (ºC)	80
Density ρ(kg/m^3)	971,8
Specific heat *Cp*(kJ/Kg·ºC)	4,205

Pexchanger = 17,5 [l/min] * 1/60 [min/s] * 971,8 [Kg/m^3] * 1/1000 [m^3/l] * 4,205 [kJ/KgºC] * 20 [ºC] = **23,84 kW**

The difference of temperature between inlet and outlet of the heat exchanger is 20ºC (manufacturer recommendation after doing the appropriate tests).

The heat exchanger used is **S1-9TLA** of the Pilan Company. As can be seen in **ANNEX 5**, it can operate with a power of 26.7 kW and a maximum working volume of 26 l/min, which fits according to our design needs (17.5 l/min.)

As specified by the manufacturer of ClimateWell, the heat exchanger selected should be between 20 and 30 kW and due to this, it can be said that the sizing is correct.

4. Absorption refrigeration machine (ClimateWell_10)

ClimateWell_10 is an air conditioning machine that works with higher efficiency if the energy used is solar energy. It has the ability to store energy (as a chemical cell) and it provides both cooling and heating. In addition, it provides the heating of domestic hot water during winter and summer.

ClimateWell 10 achieves the storage and the integration of energy-efficient, thanks to its triple technology absorption phase. It has three states of aggregation - solid, liquid and gas - allowing a continuous cooling or heating depending on the user's needs. Also, it can operate through three modes - charging, heating and cooling.

It is important to emphasize that due to the availability of two similar tanks the machine can load and unload simultaneously. Because of this, it can always get heat and simultaneously supplying heat or cold (heating or cooling). The system can also simultaneously heat hot water (DHW) or a pool depending on the connection and programming or mode of operation of it.

In the table 5, we can see the most important features of ClimateWell_10. It can be seen that the thermal COP is very stable; both for the supply of cold and heat, and finally, that the maximum power of cold can be doubled if the two barrels are connected in parallel, changing the operating mode (dual mode).

Table 5: Technical dates of CW_10. (*ClimateWell_10 producto.pdf*)

Mode	Storage capacity(with 2 barrels)	Maximum power	Thermal COP
Cold	60 kWh	10/20 kW	0,68
Heat	76 kWh	25 kW	0,85

As can be seen in the figure 4, the machine is formed by 3 parts: two twin barrels, each one with a reactor and condenser/evaporator that work independently. It also has a piece of plumbing that connects the two barrels with the external circuits.

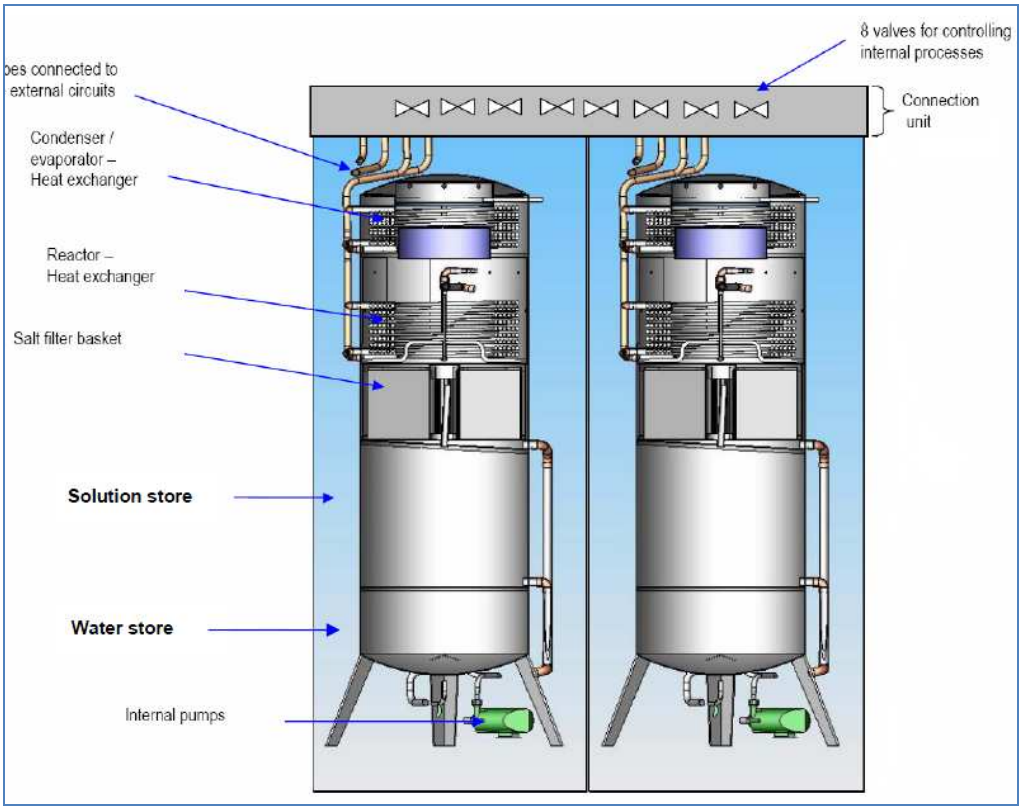


Figure 4: ClimateWell_10. It is making up by two identical barrels. (*Thermo Chemical accumulator. pdf*)

Table 6 shows the electrical properties of the ClimateWell_10 machine, in which should be noted.

Table 6: Electrical properties of CW_10. (*Thermo Chemical accumulator. pdf*)

ClimateWell 10 internal components	Power Each [W]	Percentage operating hours	Average energy consumption [kWh/year]
Internal water pumps	80	20%	140
Internal LiCl pumps	80	100%	701
Internal control system	10	100%	88
Total	170 W		931 kWh/year

4.1. Operation and characterizes

Three external circuits are connected to the ClimateWell_10:

- Thermal heat source (solar collectors).
- Air conditioning distribution system for cooling and heating (e.g. radiant floor, fan-coil units).
- Heat sink for charging and discharging (swimming pool).

The main features of ClimateWell_10 are:

- It has internal storage in each of the two accumulators. This allows the machine to store chemical energy with a very high density. This energy can subsequently be used both for cooling and heating. It is important to emphasize that it is chemical energy, not thermal energy that is stored.
- It works intermittently with two parallel accumulators (Barrel A and Barrel B).
- It is designed to use relatively low temperatures and is hence optimized for usage with solar thermal collectors. It also works with a stable temperature inside the accumulators, which in turn allows for an effective use of solar thermal collectors.
- Each barrel is composed of two tanks. A tank, reactor, containing lithium chloride, and another tank, condenser/evaporator, containing water.
- To facilitate the process of condensation and evaporation both tanks will be empty.
- It is important to emphasize that, as can be seen in the figure 5, the main difference between the use of LiCl as an absorbent and non BrLi, is that the vapor pressure in LiCl is higher, so the difference of temperature to overcome is lower (T^{a}).

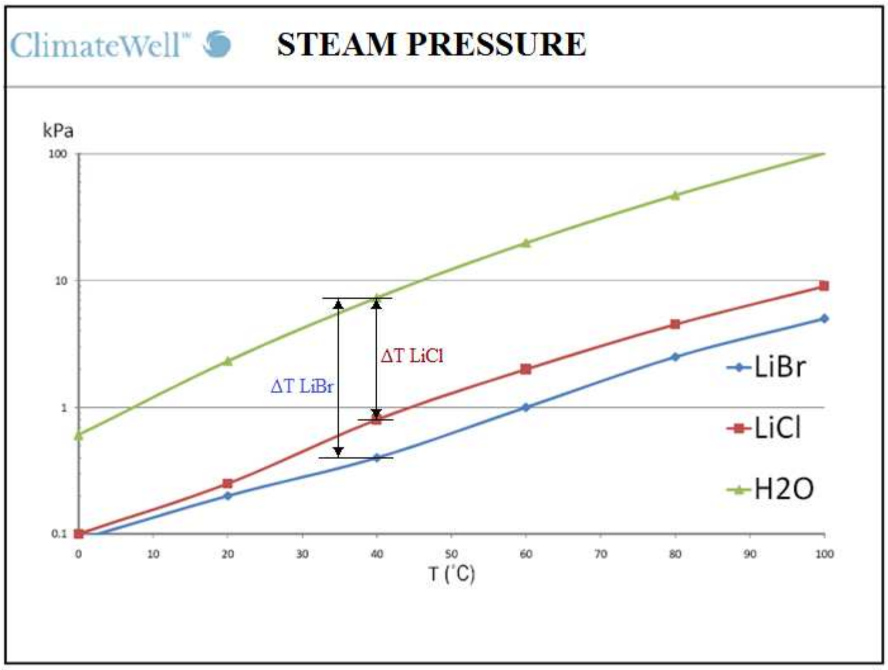


Figure 5: Stream pressure of LiBr, LiCl and H_2O depend on the temperature.

The two barrels can work in two different ways: charging and discharged. When a barrel is charging, it is connected to the heat source and to the dissipation system, while if it is discharged, it is connected to the distribution and dissipation system. The normal operating mode means that when a barrel is discharged, the other is charging and vice versa. As a result, the machine can always receive heat, while providing heat or cold to the distribution system.

4.1.1. Charging

Hot liquid from the thermal source enters the reactor heat exchanger. The manufacturer tells us that the liquid from the thermal source needs to be at least 50ºC above the heat sink temperature for charging. If the thermal source is solar collectors, then this temperature will depend on the power delivered by the solar collectors, which in turn depends on the solar irradiation, flow rate and the size and efficiency of the collectors.

The figure 6 shows that when the entering heat reaches the reactor heat exchanger, it causes the LiCl solution in the reactor to boil. When boiling the LiCl returns to crystalline form. At the same time the water evaporates and steam is released to the condenser/evaporator where it condenses on the heat exchanger with the relatively lower temperature.

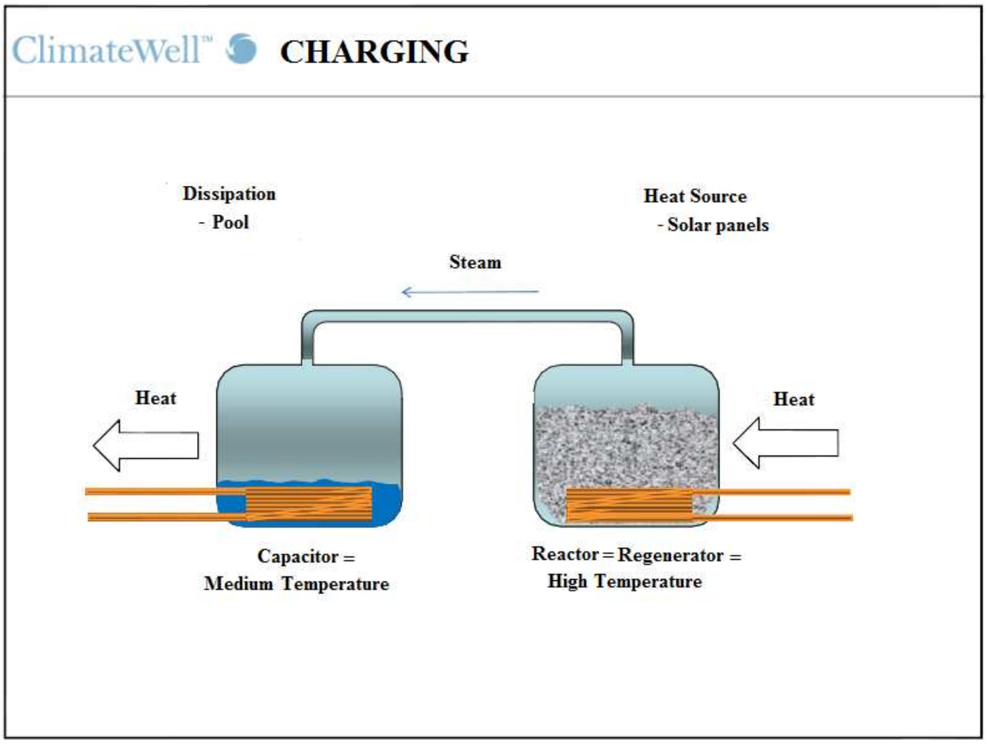


Figure 6: Charging process of absorption machine. (*Tecnología absorción ClimateWell.pdf*)

The figure 7 shows the energy balance during charging. Some 44 kWh are required to charge both barrels, giving the heat sink 33 kWh of energy. In winter, this energy can be sent directly to the building distribution system.

Figure 7: Charging process. (*ClimateWell_10 producto.pdf*)

Dimensioning data

The maximum continuous charging temperature is 95ºC, but shorter periods (minutes) of higher temperatures, up to 120ºC are possible. Because of this, it is very important that the solar thermal panels are well dimensioned, this should not occur. If the charging power is higher than the recommended maximum power, the return temperature to the panels will increase and in consequence, the charging temperature. The two barrels can be charged in parallel, thus doubling the charging power.

The typical flow rate for the solar thermal panel circuit is 15 l/min (17,5 l/min in our case).

The figure 8 shows charging power (15 l/min) per barrel at 30% charging level (100% meaning fully charged) as a function of:

- Hot water temperature from the thermal source.
- Liquid (water) temperature from the heat sink (Ths)

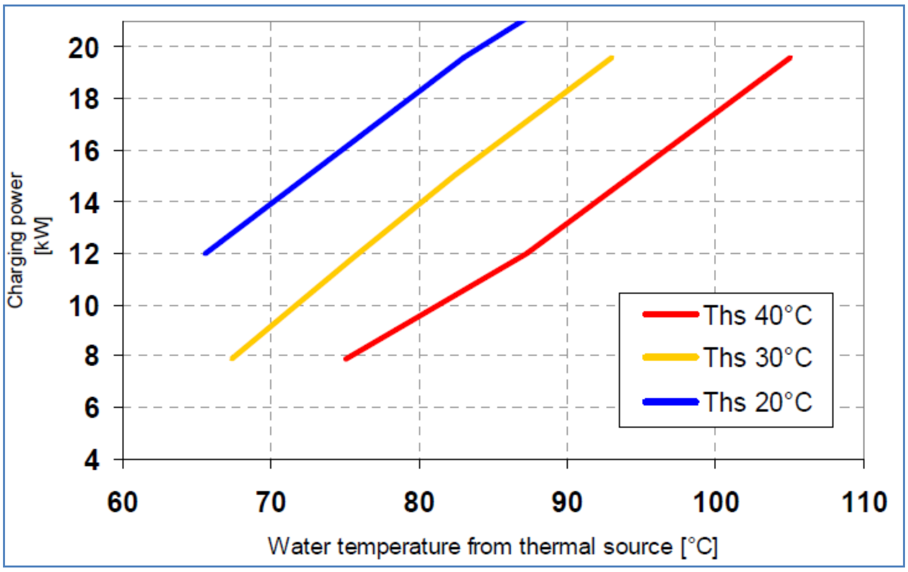


Figure 8: ClimateWell_10 charging performance. (*ClimateWell_10 producto.pdf*)

We have to take in account that the maximum power is 26 kW per barrel resulting in 52 kW total if charging both barrels at the same time.

For example:

- If we have 80ºC from the thermal source and 30ºC from the heat sink, then the charging capacity would be 14 kW per barrel.
- In terms of energy, 88 kWh is required to fully charge both barrels, thus fully charging one empty barrel would take 44 / 14 = 3 hours and 9 min.
- When reaching fully charged level, typically 5ºC higher temperature is required to achieve the same charging power.

4.1.2. Discharging

The discharging process can be of two types: on the one hand, the cooling to produce cold, and on the other hand, the heating to produce heat. In figure 9, it can be seen the discharging process, which will be discussed more fully below, depending on whether it is cooling or heating.

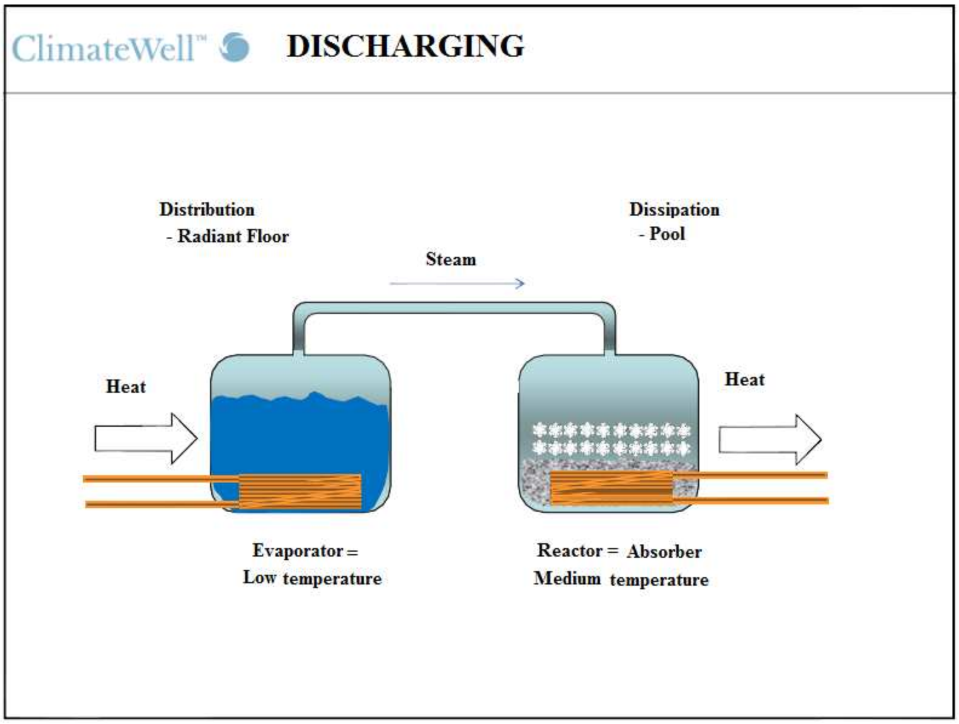


Figure 9: Discharging process of absorption machine. (*Tecnología absorción ClimateWell.pdf*)

4.1.2.1. COOLING

The water returns from the distribution system at a higher temperature than when it left the condenser / evaporator (the building has been cooled). This heat causes the water in the evaporator to boil and the steam passes down to the reactor, where it condenses, since the reactor is relatively cooler. Steam that condenses into water in the reactor will dilute the LiCl solution. The diluted LiCl solution is then pumped through the filter basket, where it mixes with the salt and regains its saturation. The saturation is needed to continuously provide a temperature difference between the condenser/evaporator and the reactor.

The figure 10 below shows the energy balance during cooling.

Figure 10: Energy balance during cooling. (*ClimateWell_10 producto.pdf*)

Dimensioning data

It is important to note that low temperatures from the heat sink improve the ClimateWell_10's cooling capacity, so selection of the type and size of heat sink is important to optimizing performance and minimizing costs. Temperature from the heat sink will depend on ambient conditions and the size and efficiency of the heat sink.

If the cooling load increases in the building to a point where the maximum power of the machine is reached, the distribution circuit temperature will start to increase slowly, but still cool the building. The indoor temperature will increase, but still be lower than the outdoors. Due to, the manufacturer not recommended to have a great difference between indoor and outdoor temperature when it is very hot outside.

The typical flow rate for the building distribution circuit is between 15 l/min and 20 l/min. (17,5 l/min in our case).

The figure 11 shows cooling capacity (15 l/min) per barrel when fully charged as a function of:

- Chilled water temperature from the machine
- Liquid (water) temperature from the heat sink (Ths)

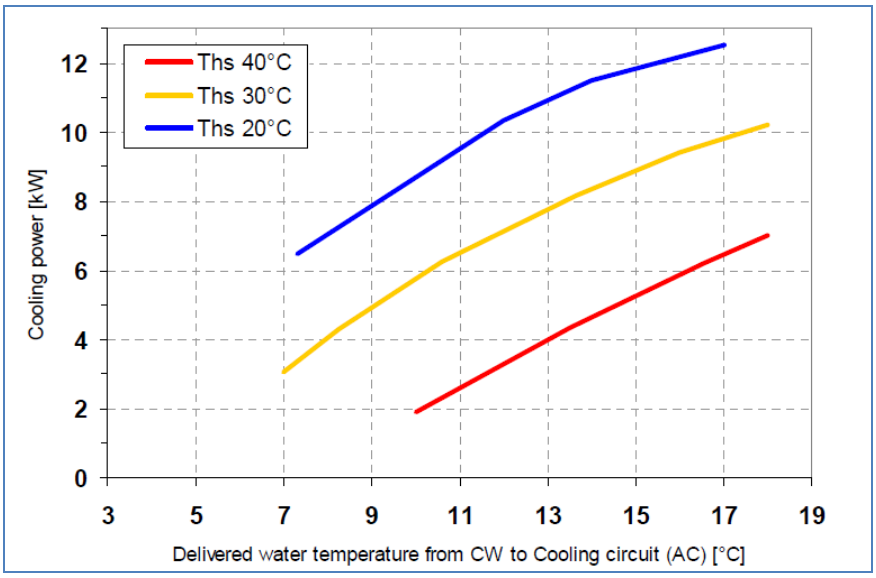


Figure 11: ClimateWell_10 cooling performance. (*ClimateWell_10 producto.pdf*)

We can see in the figure 9 that the higher the temperature to the distribution system, the more effectively the machine works in cooling mode. It is thus ideal for radiant floor applications, where flow temperatures up to 17ºC are used.

If we have 30ºC from the heat sink and deliver 15ºC to the (radiant floor) cooling circuit, then the cooling power per barrel would be 9 kW. If both barrels are discharged at the same time, the cooling power would be 18 kW.

4.1.2.2. HEATING

Heating is just cooling in reverse, meaning that the charged energy is extracted as heating by connecting the condenser/evaporator to the heat sink and the reactor to the distribution system.

Water returns from the distribution system at a lower temperature than when it left the reactor (we have heated the building). This water causes the water in the condenser/evaporator to boil and the steam passes down to the reactor, where it condenses. Steam that condenses into water in the reactor will dilute the LiCl solution. The diluted LiCl solution is pumped through the salt filter basket, where it mixes with the salt and regains its saturation. The saturation is needed to continuously provide a temperature difference between the condenser/evaporator and the reactor.

During discharging, the heating energy is extracted as by connecting the evaporator to the heat sink and the reactor to the distribution system. During charging, heat can also be extracted by connecting the condenser to the distribution system during charging mode.

The figure 12 shows one of the two barrels commencing and completing heating.

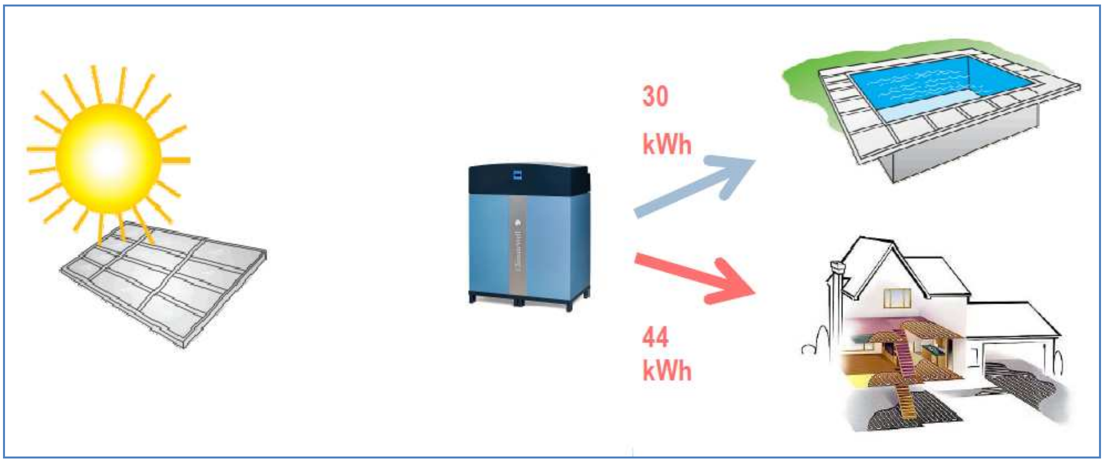


Figure 12: Energy balance during heating. (*ClimateWell_10 producto.pdf)*

Dimensioning data (Heating)

It is important to note that to use the ClimateWell_10 as a heat pump in winter it is very important to have a source from where energy can be extracted during discharging like in our case a swimming pool. The temperature from the heat sink must never be below 0ºC as this may cause the water in the evaporator to freeze. With a well dimensioned heat sink in winter it is possible to reach the efficiency of a burner up to 160% and still use the solar collectors for domestic hot water.

The typical flow rate for the building distribution circuit is between 15 l/min and 20 l/min (17,5 l/min in our case).

Figure 11 shows discharging heating capacity (15 l/min) for both barrels when fully charged as a function of:

- Hot water temperature from the machine
- Liquid (water) temperature from the heat sink (Ths)

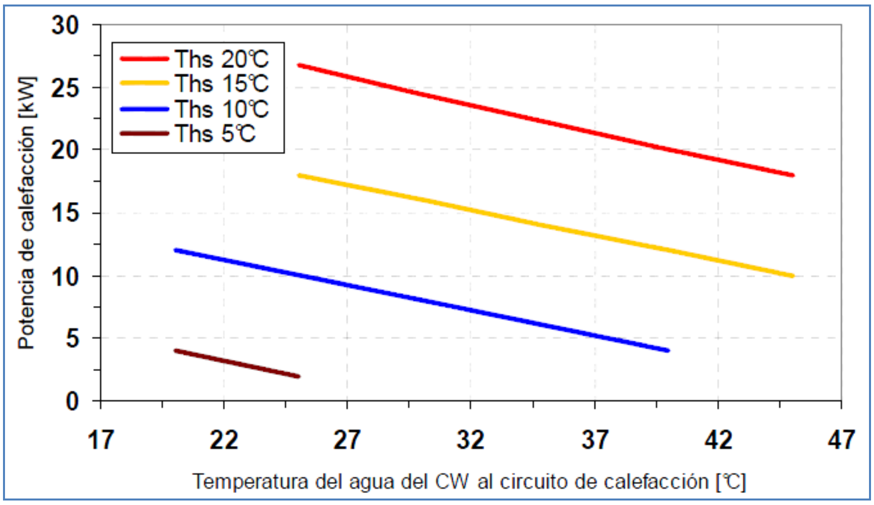


Figure 11: ClimateWell_10 heating performance. (*ClimateWell_10 producto.pdf*)

As we can see, the lower the temperature to the distribution system, the more effectively the ClimateWell_10 works in heating mode.

The back-up thermal heat source (boiler) can be used to add heating capacity on extremely cold days or if solar collector power is insufficient.

For example, if we have 15ºC from the heat sink and deliver 32ºC to the (radiant floor) heating circuit, then the heating power would be 15 kW.

To summarize what had been explained in this section about the operation of charging and discharging of ClimateWell_10, I put the figure 14 that illustrates a tank of CW_10. It clearly shows the two parts of it (reactor and condenser/evaporator) and the inputs and outputs to the machine, depending on whether the process is charging or discharging or depending on the operating mode.

When a barrel is fully charged until it cannot consume more energy or if the other barrel cannot contribute with more cold/heat for lack of load, the machine automatically changes its state. The loaded barrel start to discharge and the 'empty' begins to charge, this change is called "swap".

The machine has its own control system that makes all the "swaps", i.e. change of charge to discharge and vice versa. The control system also sends signals to the plumbing in order to control the valves and to send the necessary flows. The control system of the machine will be commented in another section later in the project. It makes the machine operate automatically and autonomously.

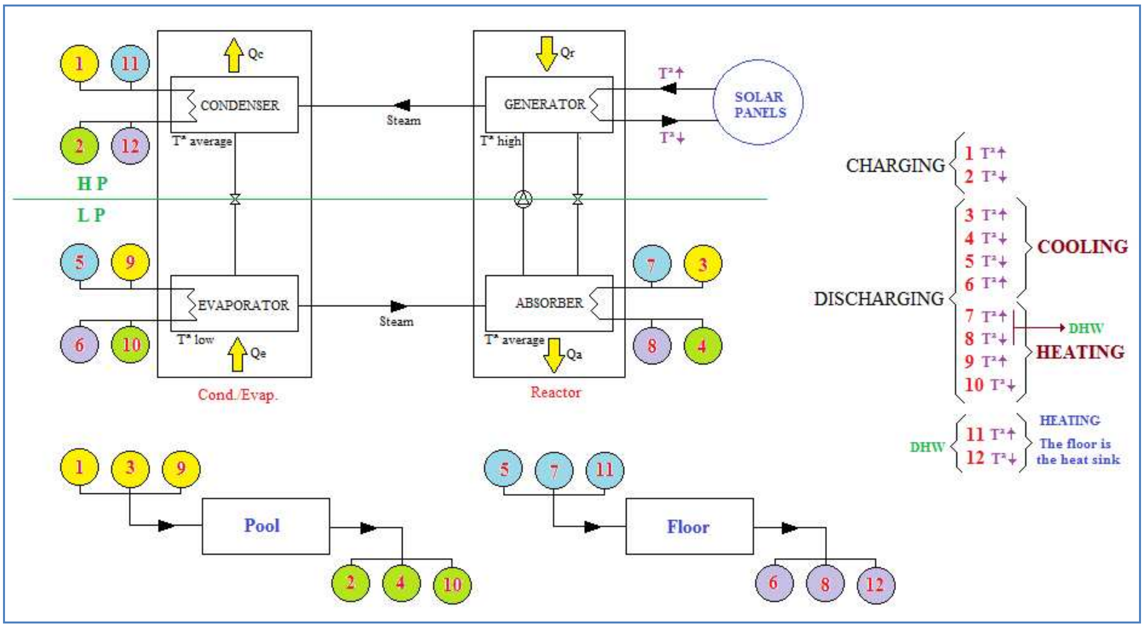


Figure 14: One of the two tanks which make up CW_10. Internal connections depend on if the machine is charging/discharging, or if it is cooling/heating the floor. Both depend on its mode of operation.

5. Heat dissipation circuit

The dissipation circuit that had been chosen is a pool, since we assume that our house has one. This way, it provides dissipation at low cost. Also, bathing periods are extended, especially during spring and autumn. The minimum required surface area of the pool recommended by the manufacturer is 30 m^2, so we assume that our pool has **40 m^2**.

In the same way that it has been described in the primary circuit, the dissipation water from the ClimateWell_10 machine must be physically separated from the pool water. It is thus necessary to install a heat exchanger.

In the table 7, provided by the manufacturer, we can see the typical power which required by the sink, for a typical flow of 30 l/min. If lower than 30 liters/minute, the turbulent flow becomes laminar flow and thus, the power of the machine decreases considerably. The recommended flow is 30 liters per minute.

Table 7: Data to calculate the necessary parameters of the heat sink. (*Design Guidelines ClimateWell 10*)

Nº. CW_10	Flow [liters /minute]	CW_10 pressure loss [kPA]	UA value of heat exchanger [W/K]	Power heat sink [kW]
1	30	50	~8 000	30
2	60	50	~14 000	60
10	300	50	~60 000	300

We have to take in account that the specified power sink in the table above, is the sum of the charge power due to solar panels (≈ 20 kW) and discharge power (≈ 10 kW cooling demand).

After having a look on different catalogs of ClimateWell for different models, and as can be seen in the table above, we can say that usually, the dissipation flow is twice the flow of the primary circuit. Since the flow in the primary circuit is 17.5 l/min, the flow in the circuit dissipation will be **35 l/min.**

5.1. Heat exchanger in the dissipation circuit

The chosen heat exchanger must bear the corrosion due to the additives used in pool maintenance. In addition, the heat exchanger will be chosen depending on the chemical products which are used in the pool water and depending on the power necessary for an adequate heat exchange.

As displayed in the calculation of the heat exchanger in the primary circuit, the dissipation power exchanged in the dissipation circuit, under ideal conditions (no losses) for the calculation of the heat exchanger is:

$$\mathbf{Pexchanger = \dot{m}_1 * Cp_1 * (Ti_1 - To_1) = \dot{m}_2 * Cp_2 * (Ti_2 - To_2)}$$

The ClimateWel_10 manufacturer recommends that the output temperature of the ClimateWell machine to be between 30 and 45ºC, while the input to it, must be less than 30ºC.

To apply the equation, it is necessary to know the specificities of the fluid that circulates in the secondary circuit. The table 8 shows the thermophysical properties of the fluid in operating temperature in the secondary circuit of the heat exchanger.

Table 8: Water thermophysical properties at 40ºC. (*METCALF & EDDY, INC. Ingeniería de aguas residuales. Mc Graw Hill. 3ª Edición (1995)*)

Working temperature (ºC)	40
Density ρ(kg/m^3)	973
Specific heat Cp(kJ/Kg·ºC)	4,205

Pexchanger = 35 [l/min] * 1/60 [min/s] * 973 [Kg/m^3] * 1/1000 [m^3/l] * 4,205 [kJ/KgºC] * (15ºC) **= 35,8 kW**

The heat exchanger used is **S1-12TLA** manufactured by Pilan Company. As can be seen in **ANNEX 5**, it can operate with a power of 40,47 kW and a maximum working volume of 39,7 l/min, which fits with our design needs (35 l/min.)

As specified by the manufacturer of ClimateWell, the selected heat exchanger should be around 30 kW with a flow of 30 l/min, meaning that the sizing was correct.

6. Distribution circuit

Distribution systems of our home can be: underfloor heating/cooling, fan coils, roof cooling, or heating/cooling central driving.

It must be taken into account that, for the running of ClimateWell_10 in cooling mode, the higher the temperature going to the distribution system, the more efficient the system. As a result, it is ideal for floor/ceiling heating that use temperatures up to 18ºC. Regarding the functioning of ClimateWell_10 in heating mode, the lower the temperature going to the distribution system, the more effective the system. Consequently, it is ideal for floor or ceiling heating that use temperatures below 27ºC. However, if we use radiators, the temperature of the water should be around 70ºC, and if we use fan-coils for cooling, the temperature of the water should be around 7ºC.

Our system will be radiant floor or ceiling. The table 9 shows advantages and disadvantages of both systems.

Table 9: Advantages and disadvantages of using floor/ceiling systems.

SISTEM	Advantages	Disadvantages
Radiant floor	* Excellent temperature distribution in the occupied space. * Low operation and maintenance costs. * It does not cause air movement. * It does not require floor space.	* The ventilation must be provided separately. * System dependent on water temperature. * It is difficult to implement once the building is constructed. * It requires less floor insulation.
Radiant ceiling	* The required water temperature allows better performance of the system. * It does not require floor space. * Low maintenance. * The cooling effect of radiation allows higher local temperatures.	* The primary air must be supplied separately. * Risk of condensation on the ceiling. * It requires insulation in the roof top. * Must provide an alternative method of heating.

After analyzing the optimal temperature profile of the human body, the radiant floor system is best suited to it. This profile assumes that the air temperature at the height of the feet is slightly higher than the air temperature, at the level of the head.

Because of the comments in the preceding paragraph and looking at the table 9, in which the main disadvantage of the use of radiant ceiling, is the absence of heat, or heat that doesn't provide comfort but headaches to the occupants, we conclude by saying that the elected system will be the **radiant floor**.

The elected system of distribution is called **ClimaDeck**. This is explained with more details in the **ANNEX 6**, where can be observed the advantages, the form and the installation constraints.

7. Other Elements

7.1. Water storage system

The accumulation system or storage tank is responsible for storing the hot water (DHW).

There are basically two different methods for the preparation of sanitary hot water. One is to prepare and store the water for consumption in DHW tanks before to use it, and another, is to heat the water immediately when it is necessary. The main advantage of the first solution is that peak demands can be covered with heat exchangers of small capacity, but implies hygienic problems resulting from the hot water storage. The second solution provides high hygienic conditions, because cold water is heated instantly, but it requires that heat exchangers are adapted to meet peak power demands.

Due to what was commented in the preceding paragraph, if part of the design of our system would not depend on heating by solar panels, the heating would be direct. However, in order not to waste the hot water coming from the tank, our system of accumulation will be designed to take the hot water directly from the tank when it will be necessary. To avoid too much increase of the temperature of the water inside the tank (resulting in problems of hygienic conditions as mentioned above) the tank will have a temperature sensor in order it not to exceed 60-70°C.

For this type of facilities, Technical Specifications of the Building Technical Code (CTE) obliges the use of the following formula for the calculation of the accumulator volume of DHW:

$$\mathbf{25} \leq \frac{V\ tank\ (liters)}{S\ solar\ panels\ (m2)} \leq \mathbf{50}$$

Our system has been designed with a total solar collector's area of 33,34 m^2. Because of this, and according to the formula above, the volume of accumulation should be between 833,5 liters and 1.667 liters. Due to the fact that the implementation of the storage tank will be for a house with only 6 occupants, an accumulator of 1250 liters will be enough.

It will use a tank or accumulator to be able to generate hot water (DHW) and heating in the same tank. Thereby a lot of money is saved because, the installation of two separate deposits for the production of hot water (DHW) and for heating, is not required.

As far as the use in winter is concerned, as the cooling demand coincides with the availability of hot water, the obtained heat is consumed almost instantaneously.

The heat accumulator which is selected is **GASOKOL HyGenio** (Tank in Tank) of 1.250 liters from a manufacturer of Zaragoza, whose datasheets are attached in the **ANNEX 7**.

7.2. Auxiliary power system

As has been explained above, the installation must have an auxiliary power system in parallel to support our of ClimateWell_10 machine. Its dimensioning must be calculated for it to be able to supply the energy demand consumed in the home, in case of prolonged rainy days, without excessive light or very cold times.

The chosen system will be a condensing boiler by natural gas. For the calculation of the boiler, we must consider the hypothesis that all the heat needed to heat the soil, can only be provided by the auxiliary boiler. Because the maximum heating power of our boiler is 25 kW, the chosen condensing boiler is **ISOFAST 21 CONDENS F30** of the brand Dual Sauna which is attached in **ANNEX 8**. This condensing boiler will provide 25,7 kW of heating and 30,6 kW of DHW if necessary.

7.3. Pipes

The pipe diameter is determined according to the flow requirement in each section of the circuit. In our case, we have three different circuits and because of this, three values of pipes diameters must be calculated. However, since the solar collector circuit and the distribution circuit have both the same flow, we only will calculate two different diameters.

To size the pipe, we must calculate a flow rate which is between 0,5-1,5 m/s, since if it is more than 1.5 m/s, it will cause a high pressure drop in the solar circuit. If the speed is less than 0.5 m/s, it will prevent the air bubbles from arriving to the unit purged, resulting in higher heat losses. Due to this, the sizes of the pipes will be designed for a speed of 1m/s.

For a pipe diameter (m) and a flow (m^3/s) the flow velocity (m/s) is provided by the following expression:

$$V = \frac{Q}{\Pi \frac{D^2}{4}} \rightarrow D = \sqrt{\frac{Q}{4 \Pi V}}$$

D (solar collector and distribution circuit) (17,5 l / min) = 4,82 mm ≈ **5mm**
D (dissipation circuit) (35 l / min) = 6,81 mm ≈ **7mm**

The piping material used will be **stainless steel** because it offers efficient and reliable performance, especially in high-temperature circuits, as it is the case of solar circuit.

The **thickness** of pipe insulation depends if the pipes are outside or inside and on the temperature of the fluid flowing through them.

7.4. Circulation pumps

The pumps will be responsible for the fluid circulation inside the pipes. In our circuit 5 pumps will be installed:

- Solar collector primary circuit (solar collector).
- Solar collector secondary circuit (on the side of ClimateWell_10).
- Dissipation circuit (on the side of the pool).
- Dissipation circuit (on the side of the machine ClimateWell_10).
- Distribution circuit.

Circulation pumps will be installed in the coldest areas of the circuit, and between two shut-off valves. Also, these will have sufficient space to allow their possible replacement or repair without having to drain the system.

The functioning of a circulation pump is determined by its characteristic curve, which represents the relation between the manometric height H which provides the pump and the circulation flow Q.

Due to the design of our circuit, in order the pumps to be very efficient, it is important to have high effectiveness at partial load. This is the reason why variable speed pumps will be installed.

For the design of each pump, it must be taken into account the losses occurring in the circuit that depend on the circuit itself and on the quadratically flow.

The calculation of all pumps will be made the same way. The only differences are the losses depending on the circuit where it is placed, and the flow circulating through them. Since our project does not reflect the distribution of pipes, we cannot calculate the losses. Nevertheless, as an explanation, we will indicate the different losses in each circuit to be able to choose the right pump.

After making the balance in w.c.m. and after knowing the values of Q and H, we will choose a pump whose curve feature will be selected depending on the operating point where we want the circuit to work.

Pump of solar primary circuit (solar collector)

$$\mathbf{H_1 = HL\ pipes + HL\ exchanger_1 + HL\ solar\ panels}$$

Pump of solar primary circuit (on the side of ClimateWell_10)

$$\mathbf{H_2 = HL\ pipes + HL\ exchanger_1 + HL\ ClimateWell\_10}$$

Pump of dissipation circuit (on the side of the pool)

$$\mathbf{H_3 = HL\ pipes + HL\ exchanger_2 + HL\ (exchanger = pool)}$$

Pump of dissipation circuit (on the side of CW_10)

$$H_4 = \text{HL pipes} + \text{HL exchanger}_2 + \text{HL ClimateWell\_10}$$

Pump of distribution circuit

$$H_5 = \text{HL pipes} + \text{HL ClimateWell\_10}$$

- **$H_{1,2,3,4,5}$:** Manometric height of the pumps (water column meters) (w.c.m.).
- **HL pipes:** Head losses in the pipes (may be lineal or singular. The first are produced in straight sections in the pipes, while the second are produced in the opposite direction.) (w.c.m.).
- **HL $exchanger_{1,2}$:** Head loss produced by the heat exchanger (it is provided by the manufacturer.) (w.c.m.).
- **HL solar panels**: Head loss by the solar panels (it is provided by the manufacturer) (w.c.m.).
- **HL (exchanger = pool):** Head losses in the pool (It is the exchanger) (w.c.m.).
- **HL ClimateWell_10:** Head losses produced by the ClimateWell_10 machine (w.c.m.).

7.5. "Small" elements

7.5.1. Automatic air purgers

In order the fluid flow not to be interrupted by the formation of air bags that prevents the correct circulation of fluid due to corrosion and high temperature points, automatic air purgers will be installed in the highest points of the circuit, one in each circuit.

7.5.2. Automatic filling valve

When the circuit is discharged due to unwanted water evaporation, these elements will make the needed cold water enter automatically into the circuit to compensate the operating pressure of the circuit where it will be placed.

7.5.3. Pressure relieving valve

Due to accidental causes, to prevent a sharp increase of water pressure inside the hot water tank, this valve will be installed. It acts when the pressure inside the tank exceeds 6 bars, to avoid damages to the equipment, increasing its lifetime and avoiding the possibility of accidents.

7.5.4. Pressure reduction valve

In the entrance of cold water to storage tank, this valve will be installed to allow the system to work with a stable water pressure. It is necessary to ensure a sufficient flow and pressure distribution to each consumer. This way, it will avoid violent fluctuations which may cause damages to equipment components repeatedly and randomly.

7.5.5. Anti waterhammer expander vessel

It is vital and will be installed in the cold water inlet to the tank. Its main function is to absorb waterhammer caused by differences in density between the hot water tank and cold water entering. This installation will prevent unwanted noise in the pipes, vibration and eventual damages.

7.5.6. Non-return valve

It is placed to prevent the flow of water from circulating into unwanted places. This will be installed after the pump of heat transfer circuit, so that during the stagnation, the steam does not arrive to the pump and damage it.

7.5.7. Cut-off valves

These valves, usually of ball type, will be connected to all major equipment of the installation to carry out repairs or maintenance actions without emptying the rest of the circuit.

7.5.8. Expansion tank

Due to changes of temperature in the working fluid, an expansion tank will be installed to absorb its dilations in all circuits in which water circulates at high temperature. To protect it, it should be installed in the coldest point of each circuit.

7.5.9. Drain valves

The drain valves will enable to eliminate the water from the system to facilitate the repair or replacement processes in the circuit. These will be placed at the lowest points of the installation, in the bottom of storage tank and solar panels circuit.

7.5.10. Safety valves

The main objective of the safety valves is to prevent excessive overpressure into the circuits that could damage the elements of the installation or people who manipulate it.

A safety valve will be installed in the primary circuit, in the tank and in front of the expansion tank for its maintenance operations.

7.5.11. Filters

The filters are placed in the automatic valves and inputs of the pumps to retain the impurities that may exist inside the installation pipes. For a complete safety, another filter is placed in the main entrance of the general water distribution of the town.

7.5.12. Expansion joint

This component prevents deformations of the pipes due to dimensional differences in the tubes or other elements due to thermals causes.

7.5.13. Measurement and monitoring

In the solar installation, a series of measure elements are included. They have no effect on the performance of the installation but are very useful to evaluate and monitor it. In addition, it enables to quantify the real services of the installation.

- Manometer: It will measure the pressure of each circuit, and will be placed in the 5 pumps of the circuit.
- Temperature sensor: It will be placed at the output of solar collectors, at the input of the collectors (to see the temperature difference), at the output of solar tank (2), and a temperature probe in the return pipe of the distribution to help controlling the circuit.

8. Control and operation

8.1. Monitoring system and internal control

The ClimateWell_10 control system is fully integrated with the barrels and the LCD display is situated on the front of the left barrel. The control system is based on three 8-bit microcontrollers.

The system measures 7 internal temperatures, the incoming and outgoing temperatures of the 4 heat exchangers and the temperature of the charging circuit, giving in total 16 temperatures upon which all control is based.

To change between heating and cooling there is a switch on the front of the control box. This procedure is not controlled by the system itself, but by the user when appropriate.

ClimateWell_10 does not control the auxiliary units such as solar panels, boiler or radiant floor. Because of this, these elements must be controlled in a different way, as it will be explained later.

If energy is provided to a full barrel, it will be received, processed internally by the full barrel and will be released through a heat sink. This energy is not used, but is received, thus avoiding problems with excessive heat in the solar collectors.

Depending on the control strategy, ClimateWell_10 can be adjusted in different manners depending on the specific requirements of the installation. The manufacturer recommends establishing the operational strategy of ClimateWell_10 during the sizing and planning of the installation. In addition, he tells us that depending on the region of Spain where the project is implemented, the control strategies will differ. For example, in southern Spain where the cooling demand is higher, he recommends the control strategy to follow to be in dual mode. However, if the machine is installed in the central or northern of Spain, it is recommended to choose the strategy of simple mode. Because of this, and knowing that the location of our project is in the center of Spain, we will manage that our ClimateWell_10 machine work in **single mode**.

The following paragraphs will describe the two modes of operation which have been previously mentioned.

8.1.1. Single mode

In normal operation the control strategy is set to charge one barrel and discharge the other at the same time. In this way we can deliver and charge energy continuously. As soon as one barrel is fully charged the control system automatically switches over to the second barrel and starts charging it.

In order to prevent the ClimateWell_10 from switching too often, for example when both barrels are full or if we have a very high cooling demand, it has been programmed to always charge each barrel for a minimum period of 1 hour.

8.1.2. Dual mode

There are situations where the single mode strategy is not optimal. By running the barrels in double mode both barrels are charged at the same time, and then discharged at the same time. This strategy is interesting when using a radiant floor system for cooling with a large inertia at a location with great difference between night time and day time outdoor temperature.

8.2. Monitoring system and externat control

The temperature sensors, the motorized valves, the auxiliary system, the temperature of solar collectors and hot water tank will be united to a system of regulation, control and monitoring by a wire. This will collect information for managing the equipments and to gather significant data about the performance and energetic efficiency of the circuit.

All these signals are wired to a **PLC** (programmable logic controller) which, after programming it, will be in charge of the acquisition and control operations of the system, deciding the opening of the valves and running or not, of the rest of the components, such as pumps.

8.3. Complete system operation

Our system is designed to take in to account the following priorities:

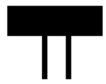
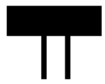
- In Winter:
  1º DHW
  2º CW_10 (Heating)

- In Summer:
  1º DHW
  2º CW_10 (Cooling)
  3º Pool

For a better explanation, a hydraulic circuit diagram of all the installation has been drawn with AutoCad 2010, which is shown in the **figure 15** of the Spanish report.

Below is explained the system operation, depending on the needs of the consumer (necessity or not of DHW) and on the system (heating or cooling). For this explanation, will be considered the position of all motorized valves, using the following table 10:

Table 10: Motorized valve positioning.

	V1	**V2**	**V3**	**V4**	**V5**	**V6**
ON						
OFF						

X: The position of the valve doesn't matter.

<u>NOT NECESSITY OF DHW (T1 ≥ 60°C)</u>

❖ <u>WINTER</u>

- Heating (Provides by CW_10).

V1	**V2**	**V3**	**V4**	**V5**	**V6**
OFF	X	ON	X	ON	OFF

- Heating (Provides by the tank and/or boiler).
    - ♦ T2 > 45ºC (The water provided by the tank does not go into the boiler to heat the floor).

V1	**V2**	**V3**	**V4**	**V5**	**V6**
ON	ON	ON	X	ON	ON

- ♦ T2 < 45ºC (The water that comes from the tank enters in the boiler to increase its temperature and to be able to heat the floor). Depending on whether the return of hot water after heating the floor is higher than the output water of the tank or not, the system is the following.

    - ➢ T3 < T2 (The water temperature of the tank is higher than the water that comes to heat the floor).

V1	**V2**	**V3**	**V4**	**V5**	**V6**
OFF	ON	OFF	OFF	ON	ON

- T3 > T2 (The water that comes to heat the floor is higher than the water temperature of the tank).

V1	V2	V3	V4	V5	V6
OFF	OFF	X	ON	ON	ON

- SUMMER
  - Cooling.

V1	V2	V3	V4	V5	V6
OFF	X	ON	X	ON	OFF

NECESSITY OF DHW (T1 < 60ºC) In this point, it depends if one of the two tanks is charged or not, ie if CW_10 can provide the required demand or not, because the priority is always supplying heat to DHW.

- WINTER
  - Heating.
    - Tank charged (Provides by CW_10).

V1	V2	V3	V4	V5	V6
OFF	OFF	ON	OFF	OFF	OFF

- Tank discharged (Provides by the tank and/or boiler).
  - T2 > 45º (The water provided by the tank does not go into the boiler to heat the floor).

V1	V2	V3	V4	V5	V6
ON	ON	ON	X	OFF	ON

- T2 < 45ºC (The water that comes from the tank enters in the boiler to increase its temperature and to be able to heat the floor). Depending on whether the return of hot water after heating the floor is higher than the output water of the tank or not, the system is the following.
  - T3 < T2 (The water temperature of the tank is higher than the water that comes to heat the floor).

V1	V2	V3	V4	V5	V6
OFF	ON	OFF	OFF	OFF	ON

➢ T3 > T2 (The water that comes to heat the floor is higher than the water temperature of the tank).

V1	V2	V3	V4	V5	V6
OFF	OFF	X	ON	OFF	ON

❖ SUMMER

- Cooling (It will depend on whether the tank is changed or discharged). In this case, being in summer or winter doesn't matter since the boiler only provides heat and not cold).

V1	V2	V3	V4	V5	V6
OFF	X	ON	X	OFF	OFF

9. Simulation of the system

TRNSYS is a dynamic analysis tool which is used worldwide for the calculation of solar systems, energy saving systems in buildings, air conditioning systems with advanced features, renewable energy systems, cogeneration ... in conclusion, systems which require a dynamics simulation.

Using the interface TRNSED (simulation software for DHW by solar energy) for TRNSYS, we will introduce the parameters of our system, to obtain the necessary results both economic and environmental.

TRNSED has a database from Meteonormo. This database has all the information related to the different temperatures and climates, depending on where the project is installed. This way, the program can determine the energy to use in our system.

By introducing all the values commented previously in the simulation program we will obtain a simulation report, as can be seen in the **ANNEX 9**.

You can see that most of the parameters entered into the simulation program are included in the report. In the project we didn't place auxiliary cooling equipment, but the program needs to know its COP value in order to be able to make the economic analysis and the corresponding comparison with the cost of fuel. After checking with the program that the variation of this value had a great repercussion on the variation of annual cost savings, we sought information about different suppliers of these devices. The chosen COP has been 2 because an average value has been selected in comparison with refrigeration equipment currently on the market.

As the program does not have the option to choose the solar collector chosen in our project, we chose one of the same brand but of smaller size. This makes that the final result varies a little bit in comparison with the reality since the performance of the solar collector will be higher, as it is larger. As a result, if after calculating the project's profitability we obtain profitable results, it would even be a little more. In the graphic provided in the report, the different temperatures of solar collectors can be seen as well as the temperature inside and outside of the home, and the dissipation temperature of the pool.

The pool temperature has a constant value around 23°C. As it is not more than 30ºC at any time, we can conclude that the dimensioning was appropriate. This factor is extremely important in order the machine to operate with its optimal conditions of design, especially for cooling. The temperature of the solar panels never exceeds 90ºC. Consequently, the sizing was also correct, making that, added to the sink one, both values of temperature are the two most important control parameters of the system.

The temperature to the house fixed in our system is very similar to the temperature provided in the report. In addition, it offers us the different coverages both of DHW, as well as heating and cooling that are provided by the machine. The coverage of heating is only 8,1% since, as it has been commented earlier in the project; the priority is focused on DHW, making its coverage of 85,4%. Cooling coverage is 41,6%. This can be increased if the solar panels are changed by vacuum tube collectors, because of its higher performance. It should also be bear in mind that the price of vacuum tube collectors is much higher, so that the profitability of the project should be recalculated.

The report provides us an annual saving which is derived from the use of this equipment. It will help us below for calculating the profitability of the project. It also offers us a series of environmental data, which will be exposed in the next paragraph.

10. Environmental Analysis

The report provides us a series of environmental data to take into account. As can be seen, the consumption of 4,5 tons of CO_2 is avoided with the use of this system. This is equivalent to an area of 0.5 hectares of forest and to the emission of CO_2 when travelling around 30.000 Km with a car.

To compare different buildings, we have to take into account its energy certification. It refers to a building energy qualification that reflects its energy independence. Thus it takes into account the energy savings, making a comparison with a conventional system.

In order to make this comparison, the same report provides us a comparison between the energy certification of the used system and a conventional system. You can notice that the energy certification with CW_10 has improved considerably. This is especially true regarding DHW due to its high coverage providing by the system, as it has been commented previously.

11. Economic Analysis

To make the economic analysis of the installation and be able to compare our system with a conventional installation, I considered the fact that not all the elements previously commented are different from a conventional hydraulic circuit. We will thus only consider the elements that are added to our solar system with CW_10. In the table 11 are reflected the components that are added with respect to a conventional installation. For example, the boiler, underfloor heating, different elements of the system would be needed for both systems.

Table 11: Cost of installation.

ELEMENTS	PRICE (€)
Solar collectors	$14\text{ cap.} \cdot 304\,\frac{€}{m^2\,s.util} \cdot 2{,}39\,\frac{m^2\,s.util}{cap.} = \mathbf{10.171{,}84}$
CW_10 machine	**15.000**
Tank of DHW	**780**
Heat exchanger of 25kW	**376**
Heat exchanger of 35kW	**428**
"Small" elements	**3992**
Mounting	**+ 15%**
TOTAL	**35.360,016 €**

To know the prices of the table above I researched in internet the sale prices of the different manufacturers for the selected components. After searching a wealth of information about the cost of "small" components (valves, sensors ...) and comparing it with other existing installations similar to mine, the average price is the one reflected in the table. Also, I have taken into account that the price of assembling is about 15% of all the elements.

Looking at online prices concerning the price of installations like ours, the general trend is estimated around 30.000 €; the price of our project is thus quite similar.

For the calculation of economic analysis, we will assume that a loan is not required. Regarding the maintenance of the installation, we will not consider it since every installation also requires maintenance and, as it has been commented earlier, CW_10 doesn't need it.

The grants for this type of installations depend on each Autonomous Community, the State and especially the type of building in which the system is installed. The grants are not accumulative and it must thus be asked to the Community itself, the grant for each type of particular installation. The grant provided by the State depends on the square meters of solar panels installed, and the grant provided is 375 € per square meter of useful area installed. Since 33.46 m^2 have been installed, the grant would be 12.547,5 €. The grant provided by the Community of Madrid, for single family homes (particular) is from 30% to 70% of the total cost of the installation. This is determined by sending the project to the Community that assesses and defines the given amount.

To determine the profitability of the project we will calculate the NPV (net added value). To calculate the NPV, it is taken into account that ClimateWell_10 life is 15 years (data provided by the manufacturer) and that for the rest of elements, its lifetime is higher.

As can be seen in **ANNEX 10** to calculate the NPV, I have considered the annual savings provided by the simulation program and also, the annual price rise of both gas as electricity.

We will calculate the average of the increase in electricity and natural gas during the last years in order to be able to estimate the price for the next few years which is around 10,75%.

You can see below a series of figure 16, in which the NPV varies considerably depending on the existence of grants or not (whether from the Community of Madrid or from the State) and taking into account that the annual savings determined by the simulation program is **781,3 €/year**.

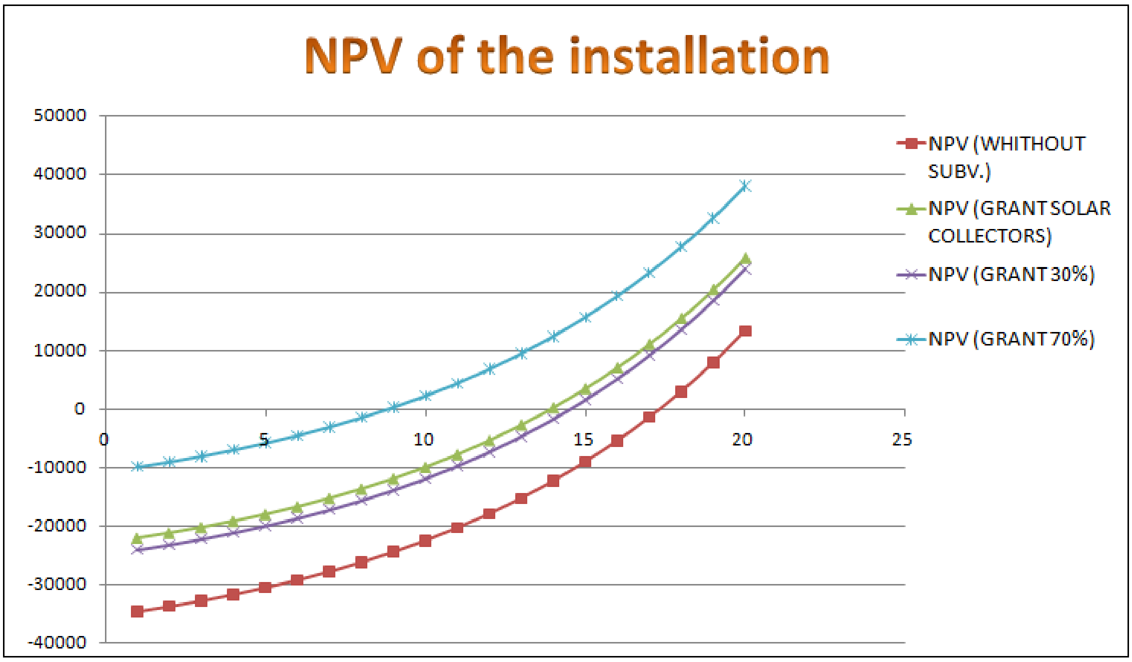


Figure 16: NPV of the installation depending on the grants.

As can be seen, without grant, the NPV is positive only 17 years after the installation of the project, so that the installation of our system is not economically viable.

The NPV, with grant from the State for solar collectors is approximately the same that the NPV calculated with a grant of 30% provided by the Community of Madrid. This is positive after about 13 years, and consequently, the installation is economically profitable.

The NPV, with a grant of 70% provided by the Community of Madrid is positive after about 9 years. Because of this the economic profitability would be more than shown.

As it has been mentioned, the grants will vary between 30% and 70%. Regardless of the grant provided by the Autonomous Community of Madrid, or the State, the profitability of the project is more than evident.

12. Conclusions

As presented in the memory exposed above, we can definitively say that the implementation of this air conditioning system in our single family home has a lot of advantages.

The first advantage I would like to emphasize is that our system is very environmentally friendly. Indeed it considerably reduces the CO_2 emissions to the atmosphere. In addition, the fact to use solar panels for energy generation, clean energy, makes that the energy requirements as water, heat, and cooling, are not dependent on the price of fuel and on its utilization. This provides more sustainability to the construction.

The peaks of energy consumption for winter and especially the peaks in summer, which produce overloads in networks and general electrical power substations, will be removed if everyone implements this system in their homes and buildings in which they work or live in.

In addition such factors like the convenience of the system, lack of noise and economic profitability, must be taken into account since it really contributes to the National Action Plan 2011-2020 of Renewable Energy (PANER).

After analyzing again the project as well as the memory, I have seen that we could implement a possible improvement in the hydraulic circuit of the installation, i.e. placing a by-pass in the distribution system, making the boiler consume less energy. When the boiler starts heating the water that feeds the underfloor, the pipes from the boiler to the floor are cold, so the boiler has to provide not only the energy for heating the floor, but also for heating the pipes until the floor.

If we put a by-pass in the input/output of the floor, with a valve that controls the flow and a sensor that controls the temperature of the water that circulates, we can do that when the boiler is starting to work, some flow that comes to heat the floor, re-enter into its inception and another part of flow fence towards the boiler to heat the cold pipes. As the pipes get hot, the water recirculation will be reduced to a point zero, making the boiler consume less natural gas at the beginning.

This will require the placement of an additional flow meter and a temperature sensor that controls the temperature of the return pipe, making the system procedure change a little bit regarding what was said in the control and operation part.

Another improvement for the project that could be done is the programming of all the valves, sensors, pumps ... in a PLC, according to the comments addressed in the control and operation part of the system. It would result in a fully integrated control system of the circuit.

Even taking into account the hours spent in the preparation of the project, in my opinion, to carry out the project in Finland has really helped me, especially for my self-development. Indeed, before I came abroad, when I had a problem or doubt, it was easy to find someone to help me, but here, the philosophy of study and work is totally different. Here, you have to fend for yourself and solve your own problems, and this, added to my limited knowledge of the language when I left Spain, have done that at first, I had troubles not only with talking to my project director but also with the simple fact of looking for the necessary information in the library. For all these reasons, I am now more independent and truly believe that to be able to trust more in me was a necessary prerequisite before finding a job.