Thermal Analysis of a Solar Cooling Adsorption System by a Dynamic Model

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***Abstract*—In this paper is shown the possibilities to implement an energy solar system, without auxiliary elements, made to cool. The new technologies (vacuumpacked tube, tanks of build-up with variable volume, etc.), allow the possibility to obtain easily a stand-alone refrigerating system. Today it is always more and more the case where during the summer season there is a surplus of thermal energy whose use is to be assigned within the energy optimization system. The most immediate solution to this problem is the ability to produce cold by means of simple adsorption solutions, thus contributing to the cooling problem with low COP values. The most beneficial adsorbent both for its thermal/physical and low cost is the silica gel, a polymer of silicon dioxide, commonly used for its dehydrating properties, especially in the preservation of electronic material [1,3,13].**

In this study we have developed a dynamic model with the software trnsys to verify the obtaining of appropriate warm fluid for an innovative cooling system absorption with gel of silica and water and it is tested on a real building as case study.

The dynamic model analyzes the performance thermodynamic balance of a small size system has been made (about 20-50 kW), adequate to cool a Building of 900 sq m. and allow to assess the conformation (surface, storage volume, etc.). of a new generation solar power plant is able to guarantee a continuous operation during the summer period [2].

We have tested a solar cooling system with solar vacuum collectors on a real Building with Meteo data of three Cities as Rome Milan and Tunisi and we have tested the model comparing the results obtained.

The model in fact allows to make a preliminary design of principal part of the plant and to evaluate function cost-benefit of a complex investment for innovative technology The interesting results obtained allow at a later stage to make a prototype validating the theoretical results with experimental measures.

***Index Terms*—Silica gel, Solar Cooling, Building**

I. INTRODUCTION

This study suggests the system here described. It must be considered a first approach based on theoretical calculations to study how much this system is feasible and advantageous. The system is based on the thermophysical properties of some substances (solute = absorbent, and solvent = refrigerant) and on the possible interaction and thermal exchange among the part forming a HT and the part forming an AR system, which are here present in one system. Figure 1 shows the patterns of the solution through: (i) the components that are a HT; and (ii) the components that are the AR system.

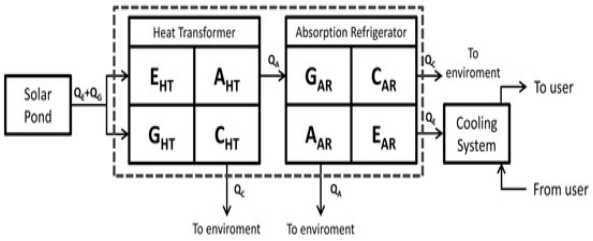


Fig 1. Energetic flux of the system (during the summer) designed for low density residential buildings located in hot climates.

An absorption machine functions thanks to the different pressures between container E (that functions as an evaporator) and container A (that functions as an absorber). In particular, pressure PE inside the evaporator is higher than PA of the absorber.

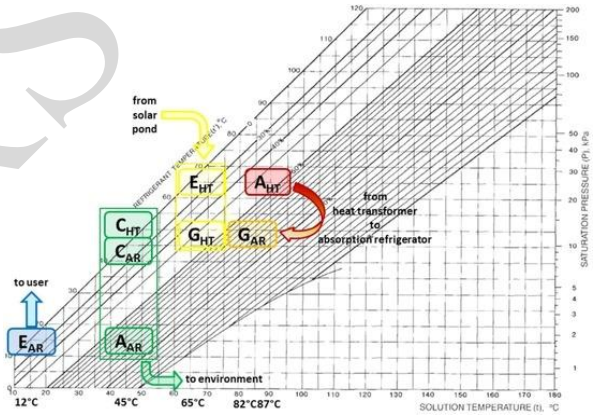


Fig 2. Reports the diagram with the energetic flux of the component of the thermal machine suggested (p, T).

This is because the pressure of the evaporator is affected by the pressure of the substance used as a refrigerant (which in E is pure), whereas the pressure of the absorber is the sum of the partial pressures of the two components (refrigerant, with a high partial pressure; and absorbent, with a lower partial pressure than the one of the refrigerant) multiplied by the substance fraction with respect to the total (oblique lines of the graph, Figure 2). As a matter of fact, the contribution to the total pressure in the absorber depends on the contribution of the pressure of the refrigerant multiplied by its fraction (a number which is lower that one unit). This explains the pressure difference PE–PA characterizing these two containers [8].

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This difference determines a vapor migration of the refrigerant from container E towards container A. The liquid part of the refrigerant present in the evaporator tends to evaporate to reach equilibrium with its own vapor. In order to have this evaporation, the fluid needs latent heat of vaporization taken from the same substance that is cooled (QE). This explains the refrigerating effect that starts thanks to the thermochemical properties of the substances present in the solution. The phenomenon is temporary because the vapor migration towards container A (where it condenses thus heating the fluid and the heat will be released, QA) makes the refrigerant fraction present in the absorber tend to the unit, hence determining a value which is similar to the one of the pressure of container E (with the pure refrigerant). This cancels the pressure difference PE–PA, which is necessary to the system to make the refrigerating effect happen. To maintain this pressure difference, the concentration of container A must be kept constant, though there is a constant arrival of vapor of the refrigerant substance of container E. This is why two more containers are required: the generator G and the condenser C.

Part of the solution is extracted from the absorber, which is taken to the generator. Some heat must be here provided, QG, from the outside (thermal energy that must be introduced into the system, in this way it can function constantly), thus the boiling solution can split (through a distillation process) into pure refrigerant (in the form of vapor migrating towards container C) and a solution that has more absorbent substance sent to container A in order to maintain the right functioning concentration. The vapor of the refrigerant substance, having migrated to container C, condenses (releasing latent heat QC) and is sent to container E to restore the initial level. The system, to function, requires minimum amounts of work that must be provided to the circulator pumps present to transport the pure refrigerant LPRor the solution LPS between the containers.

These are the different functions performed by each container in the system here suggested, both referring to the HT that the absorption refrigerator. While managing the energy fluxes of the entire system, it is possible to have the cooling the users demand (influenced by the needs of the building) through the exertion of the solar heat stored in the solar ponds (at a low temperature).

The system suggested allows the energy flux to have the following pattern [3, 4]:

The solar radiation heats the water in the solar pond, which has a high saline level. Thanks to the geometry of the pond (with low depth values and an insulation layer located towards the surrounding ground) and the covering materials of the bottom, presenting a high absorption coefficient of solar radiation, the solar radiation penetrates the water of the solar pond and the heat is entrapped in the deepest layers. This is possible thanks to the high-salinity of the water forming different layers which inhibits the convective exchanges. In fact, the deepest layers of the pond present higher temperatures and the related higher solubility of salts allows an increase of the salinity level, enhancing the phenomenon. What the phenomenon hence avoids is that the heat might dissipate through the first layer of the pond. A pond which is subject to a high solar radiation for long time intervals during the year, if characterized by hot climates with a low temperature range between day and night where the temperature gradient between the pond and the surrounding air is low, allows the deepest layer to have a temperature ranging between 60 °C and 80 °C [11, 12, 13], with steady conditions over the time thanks to balanced energy fluxes entering and exiting the pond. Therefore, a renewable heat source will be obtained.

The HT (in Figure 1 and Figure 2) is a machine dependent on the chemical-physical properties of some solutions characterized by one absorbent (the solute) and one refrigerant (the solvent). Its functioning is related to the one of a heat pump as the functioning of an AR machine is related to the one of a compression refrigeration machine. The system here suggested has the goal to extract thermal energy from the pond and provide it to its generator “GHT” and evaporator “EHT”, thus having a higher energy quality (hence the temperature) of part of the heat provided by the absorber “AHT” (with negative consequences on the rest of the thermal energy which is degraded during the process and released at lower temperatures in a heat well, to the condenser “CHT”).

In this way, part of the heat of the solar pond is dissipated, though it is possible to extract part of it at higher temperatures than 80 °C, and be able to supply an AR machine which otherwise could not function if supplied directly by the solar pond.The equations governing the heat exchanges among the different parts of the machine and its performances are known [12, 13]. The heat exchanged from every component of the system depends on the behavior of the liquid that characterizes it. The heat exchanged is the sum of the heat related to the phase-change, the sensible heat and the heat solution due to chemical phenomena that can occur. Work provided by the pumps depends on the energy required for pumping the fluids present in the machine [8,9,10]. The coefficient of performance (COP) of a HT, which is the ratio between the thermal output of the absorber and the overall energy provided to the machine, is:

$$COP = \frac{Q_{A_{HT}}}{Q_{G_{HT}} + Q_{E_{HT}} + L_{PS} + L_{PR}} \quad (1)$$

$$Q_{A_{HT}} = r(T_A) + s(x_A, T_A) - m_S c_{PS}(T_A - T_G)(1-\alpha) - c_{PR,v}(T_A - T_E) \quad (2)$$

$$Q_{G_{HT}} = r(T_G) + s(x_G, T_G) - \alpha m_S c_{PS}(T_A - T_G) \quad (3)$$

$$Q_{E_{HT}} = r(T_E) + c_{PR,l}(T_E - T_C) - \alpha m\, c_{PR,v}(T_G - T_C) \quad (4)$$

$$L_{PS} = \frac{m_S \gamma_S (P_A - P_G)}{\eta_P} \quad (5)$$

$$L_{Pr} = \frac{m_r \gamma_{rl}(P_E - P_C)}{\eta_P} \quad (6)$$

The production necessary to the air-conditioning system operating in buildings during the summer depends on an absorption refrigerator (AR in Figure 1, Figure 2). This machine, exploiting the thermophysical properties of an absorbent–refrigerant solution, thus presenting a different configuration of the components with respect to the HT, allows cooling the thermal-vector fluid of the hydronic system of the building. The heat with a high temperature is transferred from the absorber "AHT" of the HT to the generator "GAR" of the refrigerator machine. Thanks to this energy, it is possible to obtain at the evaporator "EAR" cool water at temperatures which are compatible with the cooling of domestic areas, transferring degraded heat at an ambient temperature to the condenser "CAR" and absorber "AAR".

As in the HT, the COP of an AR machine (EAR), which is the ratio between the thermal output of the evaporator and the overall energy provided to the machine, is:

$$COP = \frac{Q_{E\,AR}}{Q_{G\,AR} + L_{PS}} \quad (7)$$

$$Q_{E\,AR} = r\left(T_E\right) + c_{PR,l}\left(T_E - T_C\right) \quad (8)$$

$$Q_{G\,AR} = r\left(T_G\right) + s\left(x_G, T_G\right) - \left[m_S\left(1-\alpha\right)+\alpha\right]c_{PS}\left(T_A - T_G\right) \quad (9)$$

$$L_{PS} = \frac{m_S \gamma_S \left(P_A - P_G\right)}{\eta_P} \quad (10)$$

A hydronic system supplied by chilled water originated by the evaporator of the refrigerator machine provides "cool air" inside the building, guaranteeing air-conditioning when it is hot. It can be noticed how Figure 1, representing the functioning conditions (in terms of pressure, temperature and concentration conditions) of every component of the machine, reports an assumed temperature difference of 5 °C for each heat exchanger used between two components in the system suggested.

The system, to function, requires the heat provided by the solar pond and the electric energy necessary to supply the fluid circulation pumps exerted in the parts forming the system. This type of system can be used where local climates allow a continuous and correct functioning of solar ponds and in urban areas where there are buildings with outdoor areas allowing the realization of solar ponds. Naturally, a building able to minimize heat flux exchange phenomena with outdoor environments, determines a decrease in the thermal loads and thermal power of systems, while taking into consideration the importance of maintaining the internal conditions of comfort for its occupants, which is a goal that an air-conditioning system must consider.

In this study, to make an evaluation of the feasibility of the system here suggested, the focus was on the energy required to cool small one-family buildings located in some urban areas (both of the northern and southern hemisphere) or near the tropics, hence subject to different climatic conditions, though all were characterized by long periods of hot climate during the year. While examining the exertion of these machines in a residential or office environment, the refrigerant–absorbent Silica Gel was used, because they are non-toxic substances, hence they did not represent a danger to human health. Even the ranges of the temperatures for the air-conditioning in civil environments are compatible with the physical-chemical characteristics of these substances put into solution.

II. CASE STUDY SIMULATED WITH TRNSYS MODEL OF THE ABSORPTION SYSTEM POWERED BY SOLAR PANELS.

We have made a dynamic model to test this innovative technology on a real Building with a surface 900 sq meters, frequented by 25-54 persons, purpose as office/school environment, and we have considered a lighting system (18W/m2), open from 8 am to 8 pm[6,7] .

We have analyzed the thermal loads in three cities (Milan, Rome, Tunisi)(fig. 4a,4b,4c) characterized by three different climate conditions; we have made a dynamic model, which allow to find the thermal or cooling demand simply inserting the data listed on the top[5].



Fig 3. Photo of the real Building case test

Analysis of the aforementioned data reported show the thermal loads in the three cities mentioned with the climate conditions data considered by the METEO TYPE oh the model which consider the variations of temperature with a hours time step interval. Fig. 3 shows the building. Therefore we have introduce in the model the solar cooling system to define the operating conditions and to choice the most adequate type of solar panel system to have the system below work at its best.

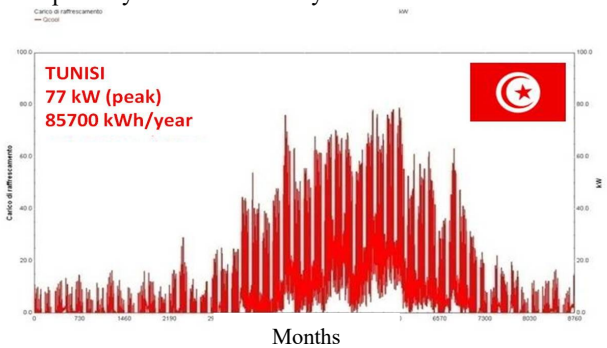


Fig 4. Thermal loads in Tunisi

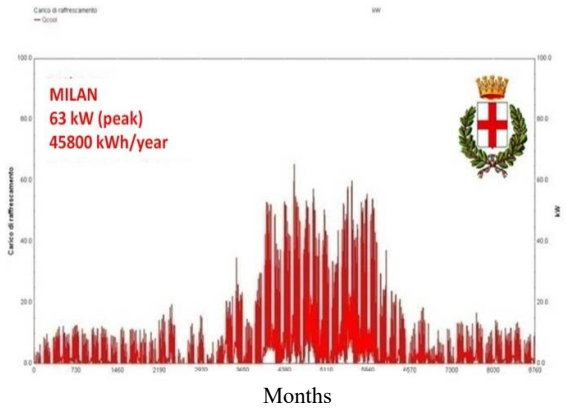


Fig 4.2: Thermal loads in Milan

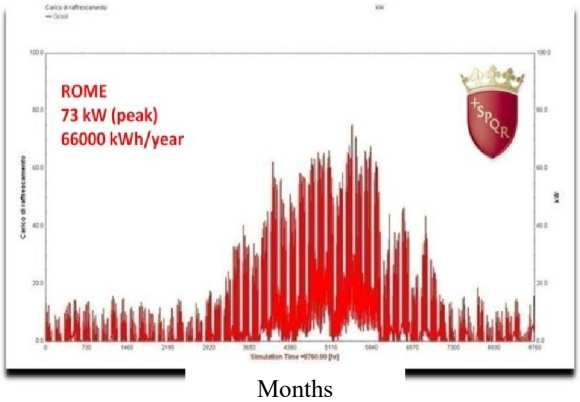


Fig 4.3: Thermal loads in Rome

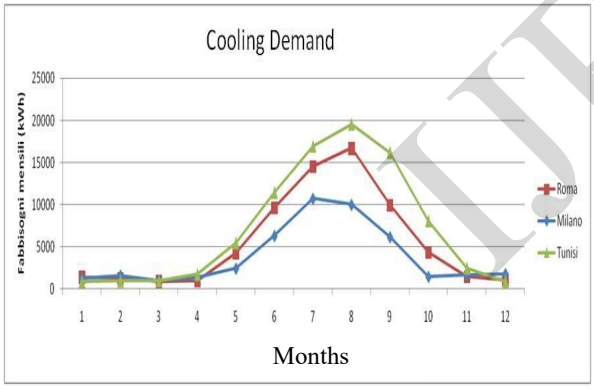


Fig 5. Cooling Demand of the Building case test in three cities (Milan, Tunisi, Rome)

The basic scheme envisages thermal panels with a build-up serving as a buffer: the combinations are numerous and range from those involving accumulations with different volumes to those with the possibility of integration by means of an auxiliary boiler.

For the simulation of the system as a whole, to avoid entering a special type with the risk of overloading the program, the system is viewed as a particular heat exchanger that requires water at a certain temperature and the returns it cold with a constant $\Delta T = 5°C$.

The model also includes a controller to lock the pump of the solar collectors should the temperature of the tank reach 95 ° C, a value that proved to be possible in the simulation as well as another controller to simulate the switching on and off of the users according to preset daily and weekly schedules.

At this point the METEO type which simulates the weather behaviour and its influence on plants and buildings has been included.

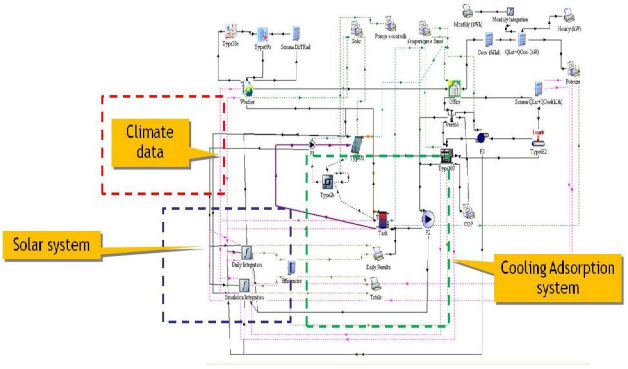


Fig 6. Scheme of the system in Trnsys

The system has basically three degrees of freedom:

1 Panel surface
2 Storage Volumes
3 Inclination of the collectors

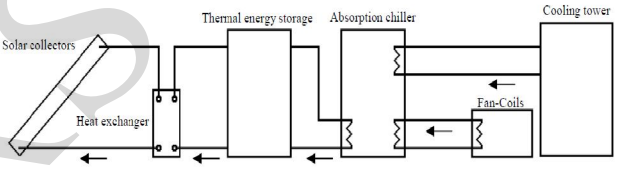


Fig 7. Layout of the solar cooling system with silica gel tested with model

We find two principal indexes to design the cooling system that we have analyzed by the dynamic model as "solar Fraction" ratio between the energy captured by the solar collectors and the energy needed to operate the plant without collectors and the "cooling Index" cooling reaction by solar energy [9,10]

$$F_{sol} = 1 - \frac{Qaux}{Qdhw}$$

$$I_{raff} = 1 - \frac{Qaux}{Qcool} * COP$$

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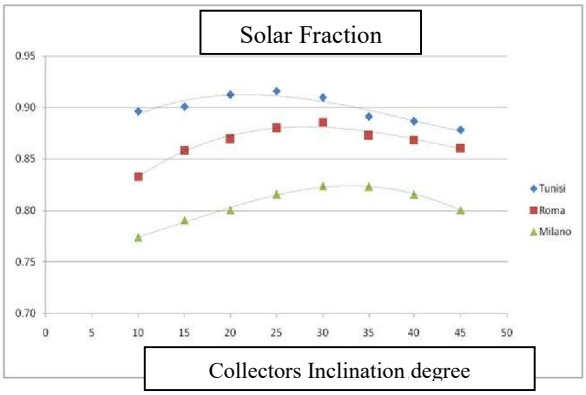


Fig 8. Trend of "solar fraction" respect the inclination degree of the collectors

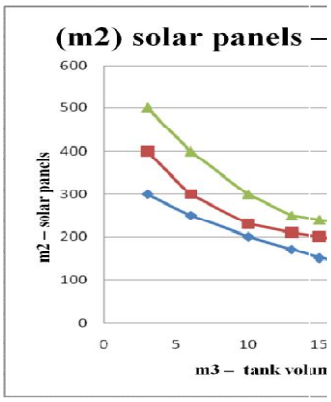


Fig 10.Trends of curve (m2 panels respect m3 volume of tank) of a dimension solar system for a silica gel refrigerator machine

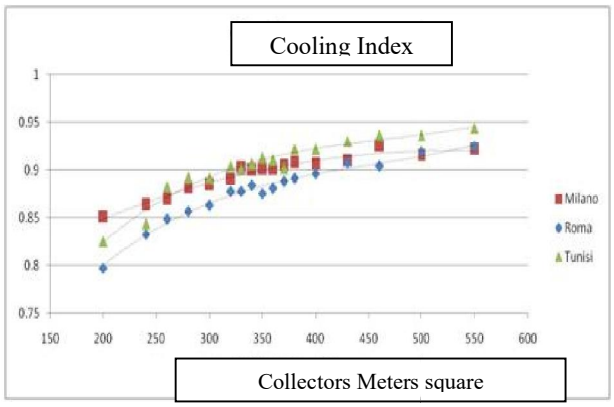


Fig 9. Trend of "cooling index" respect the meters square of the collectors

For the simulation to take place, the system's power on the basis of the considerations being made has been determined (20 to 50 kW refrigerators involving, as we have seen, the use of about 60 to 100 thermal kW);

Under these conditions several coupling possibilities between the surface of the collectors and the storage volume can be obtained, thus providing users with hot water at least at a temperature of 70 ° C and allowing for the operation of a small air conditioning system.

The results of the simulation that has had as a constraint the fact that the temperature inside the storage tank does not exceed 70 ° C, indicates an average temperature of about 85 ° C. In this framework, the results summarized in the curves shown in Fig. 7. have been processed.

III. CONCLUSIONS

The simulation of a small operating system for the production of fluid absorption with silica gel, proves the possibility of practical use in combination with next-generation vacuum solar panels.

In particular, especially in the summer when the surfaces of thermal solar panels for the production of solely hot sanitary water may seem overabundant, the use of an absorption system can help integrate the plant with a consequent increase in the production of cold.

We have analyzed finally the economic and financial aspects of the solar cooling adsorption system in comparison with a tradition chillers conditioning system, considering the output data of our dynamic model and starting from the operational data taken from the preliminary design by the input data, listed on top of ch. and finding the right size of various organs such as the surface of the collectors, the storage tank to vary the requirement that we forcibly made to vary by testing the model in three different weather situations (milan, rome and Tunisi).

We have evaluated for a solar cooling system with a Flat collectors extension 400 m2, a Storage volume 20 m3, considering fixed the investment cost considering the commercial prices for the system tested

$$C_{inv} = C_{coll} + C_{chiller} + C_{acc} + C_{aux}$$

While we have considered Variable costs of electricity and gas, Increased YoY rates (gas: + 6%; electric: + 10%)

$$f_k = C_{var,TRAD} - C_{var,SC} = R$$

VAN Period: 15 years

$$VAN = \sum_{k=0}^{n} \frac{f_k}{(1+i)^k}$$

Discount rate: 1.66%

$$PBP = \frac{C_{inv}}{\overline{f_k}}$$

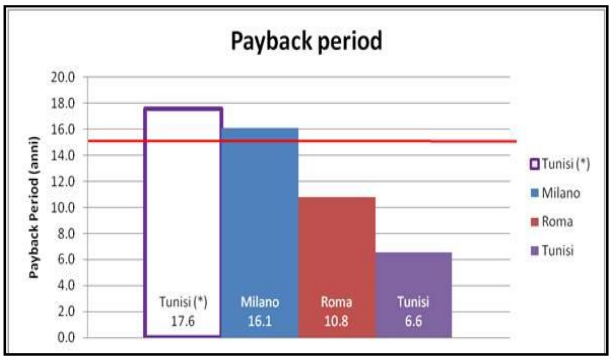


Fig 11.Payback time for the investiment

The solution "solar cooling" can be taken as an alternative to cooling methods "classic" although there are disadvantages associated with:

Strong initial investment (higher by about 4-5 times a traditional chiller)

- Strict dependence Site climate data
- The plant layout and development of the market for small Complexity

The saving is significant when one considers the reduction of variable costs directly related to:

- Annual increase in energy prices
- Advancement of technology both in absorption machines (COP higher in double / triple effect machines) both in the solar collectors (higher efficiency)

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