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PREPRINT

UTILISATION DE L'ÉNERGIE SOLAIRE POUR LA RÉFRIGÉRATION ET LE CONDITIONNEMENT D'AIR

UTILISATION OF SOLAR ENERGY FOR REFRIGERATION AND AIR CONDITIONING

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SOLAR POWERED AIR CONDITIONING DEMONSTRATION PROJECT IN ISRAEL :

SYSTEM AND CONTROL DESIGN OPTIMIZATION

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ABSTRACT

Unique solar powered air conditioning systems were developed and have been demonstrated. Development included solar powered absorption chiller, flate plate collectors to operate the chiller, systems engineering and control strategies and systems.

During the last two years a large demonstration system has been designed and installed in the Haim Sheba Medical Center at Tel Hashomer, Israel. 200 ton chiller (at nominal conditions) which was developed by TADIRAN/ASD*, 3,000 square meter flate plate collectors, and microprocessor based control systems were designed and installed. The system has been integrated with the conventional based chillers central machine room in order to supply chilled water to the medical center. The system is considered to be one of the largest in the world.

The purpose of this paper is to present system and control optimization strategies, which lead to maximizing in energy cost saving versus capital investment.

1. INTRODUCTION

The purpose of the project is to demonstrate the operation of the technologies - machines and collectors - and the overall system concept.

Special effort was directed to the development of overall system integration.

The purpose was to come with concepts which define the overall system configuration and control methodology in order to use the system at high efficiency.

Existing projects and literature surveys and case studies showed that solar powered air conditioning systems integration have a great effect on the economical efficiency of the the systems. These surveys also showed that in many cases very sophisticated systems were applied in order to use each main equipment (cooling machine, collectors etc.) in the most efficient way in short periods of time.

*TADIRAN/ASD (Israel Electronic Industries/Applied Solar Devices Group).

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However, these approaches have led to an increase in the initial cost. On the other hand, utilizing advanced equipment (cooling machine and collectors) which have relatively high efficiency in over simplified approaches, misses the potential of utilizing the technologies in a high efficient way from an economical point of view.

In the said project, and based on the development effort, investigations into many alternatives and cases were done. As a result, a relatively simplified system integration approach has been implemented. According to this approach the potential to achieve economical benefit as a goal is great.

The purpose of this paper is to present systems and control optimization strategies which were considered in the project in order to achieve this goal.

The optimization strategies were related to the following subjects :

* Overall system configuration concept;
* Determination of the solar system collector array size.
* Determination system control and operation.

It has to be emphasized that an optimization approach in this project was not based on pure analytical systems (static and dynamic) optimization techniques, but on practical engineering approaches which were based on practical systems experience, systems investigation, engineering judgement and basic calculations and system analysis, and intuition. So, there is a place to extend this project and to do more analysis work in order to find the optimal system based on pure analytical systems optimization, (static and dynamic) and to compare the results of the two approaches.

2. OVERALL SYSTEMS CONFIGURATION CONCEPT

Typical central large size solar powered air conditioning concepts are shown in Figure No. 1.

This type of configuration is popular due to the fact that it enables use of several modes of operation and also because it applies to several piping loops based on primary/secondary looping approaches which make the hydronic system design relatively simple.

However, this type of configuration requires a lot of accessories such as pumps and control valves which increases the complexity of the system and its cost, thus reducing the potential economic benefit.

In addition, when the backup boiler operation is required, due to relatively low temperature of water coming from collectors, the efficiency of collectors reduces significantly because the backup boiler raises the hot water temperature coming into the collectors.

In order to achieve maximum potential econimical benefits, several basic concepts have been developed. These concepts are defined in a simplified system configuration approach, with a high degree of flexibility and additional modes of operation.

Figure No. 2 describes schematicaly this configuration.

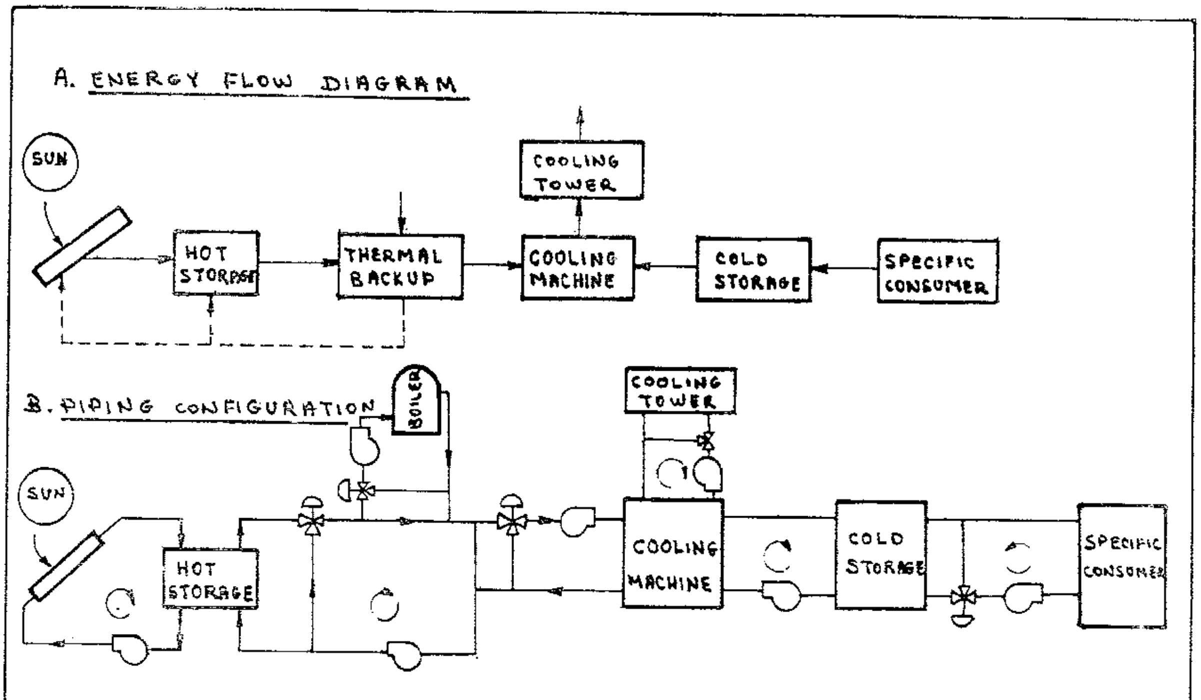


FIG. 1 – TYPICAL SOLAR POWERED AIR CONDITIONING SYSTEM

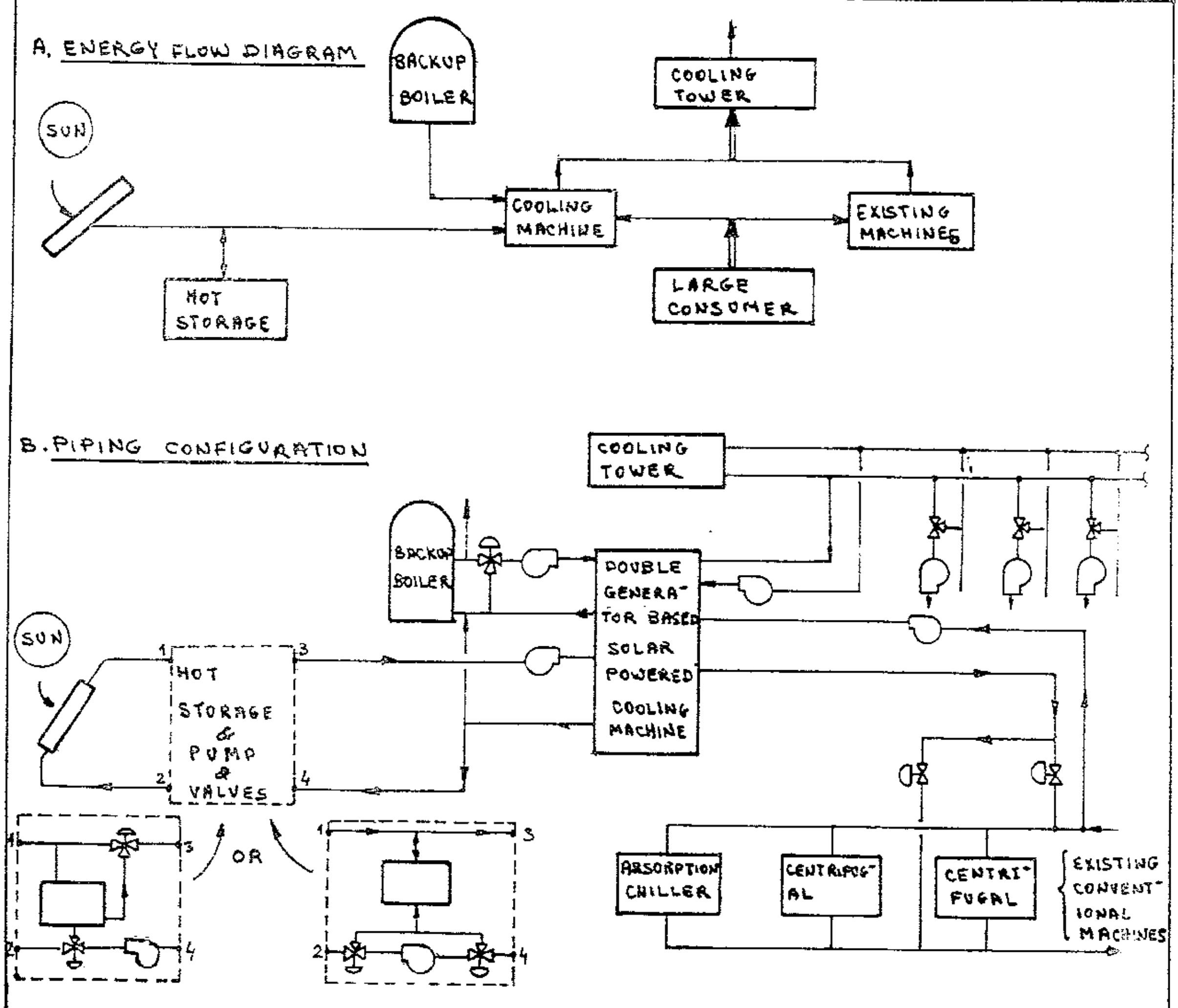


FIG. 2 – DEMONSTRATED SOLAR POWER AIR CONDITIONING SYSTEM

The advantages of this configuration is :

* Less accessories (such as automatic valves and pumps);
* Higher efficiency due to the following fact :

  Additional modes of operation such as :

  * Supplying of hot water from collectors directly to the cooling machine when it is preffered, and not through the storage tank as usual. This connection enables simultaneously adjusting the storage charging and required hot water temperature to the cooling machine.
  * Integration of additional backup generator in the cooling machine enables a supply of hot water from the backup boiler with minor effect on the hot water loop connected to the solar collectors system.

3. DETERMINATION OF ENERGY AND ECONOMIC FEASIBILITY

Determination of energy capacity of the solar collectors arrayes were based on the performance of :

* TADIRAN/ASD collectors;
* Cooling load;
* Weather conditions(radiation, temperature etc.);
* The performance of TADIRAN/ASD collectors was achieved due to calculations and standard experiments (according to ASHRAE, Weizmann Institute, etc.)
* The cooling load was estimated as 200 tons of refrigeration approximately. This assumption was based on the fact that the total cooling load of the medical center has become greater with time to a relatively high level, thus large variations in the total cooling load would cause minor variations in the cooling load of the solar machine.

Three stages were considered in the determination process :

First Stage - Calculations of the tilted angle in order to achieve the maximum energy capacity from the collectors. The calculations were based also on the outside air temperature profile, collector inlet temperature profile and solar radiation profile.

Calculations of the general procedure is represented in Figure No. 3.Results are represented in Figure No. 4. The selected tilted angle was 16^{o}.

Second Stage - Determination of the size of the collectors array based on 16^{o} (tilted angle) and on the 200 ton cooling capacity.

The determination process includes calculations of solar energy collected by 2,000 sq. metres; 3,000 sq. metres; 4,000 sq. metres; 5,000 sq. metres; 6,000 sq. metres and 8,000 sq. metres solar collectors array.

Figure 5 presents hourly average energy collected on a typical day.

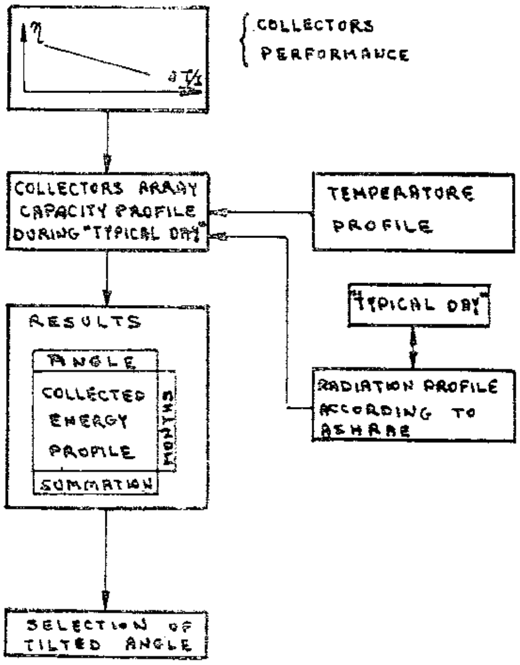


FIG. 3 – CALCULATIONS PROCEEDURE OF COLLECTORS TILTED ANGLE

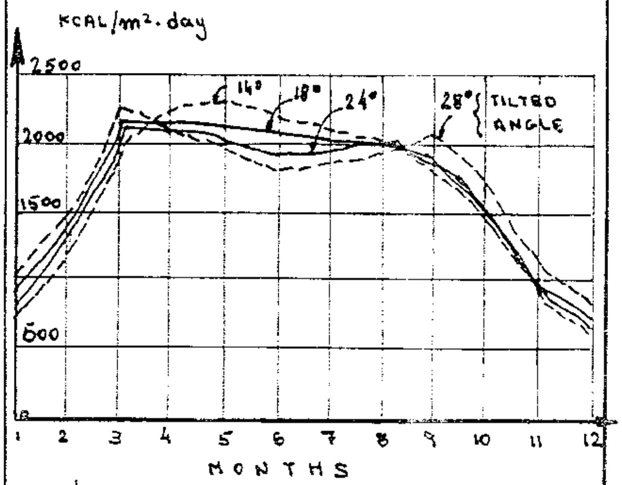
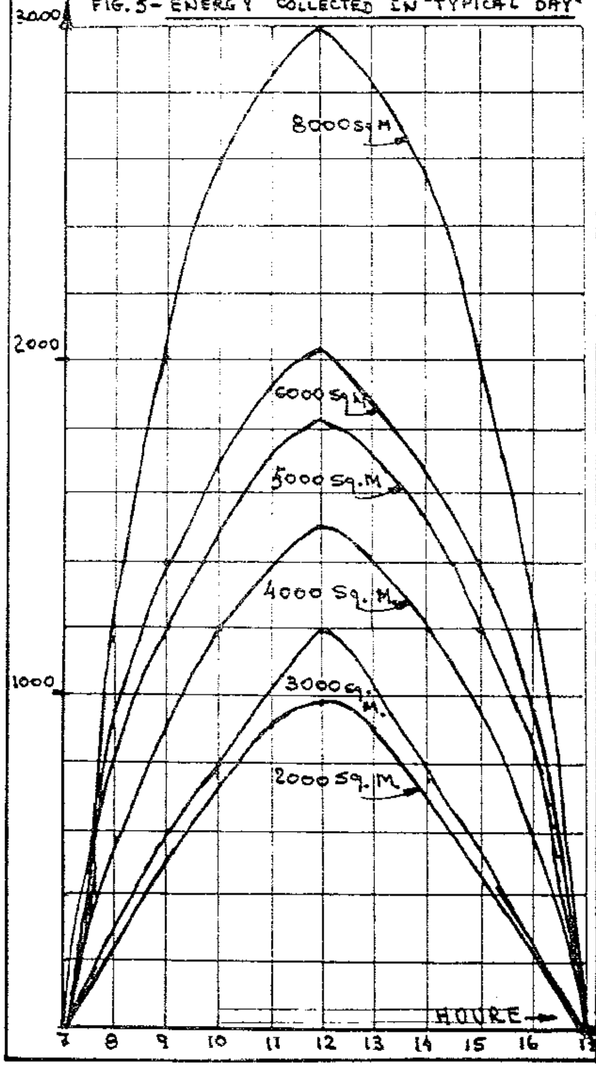


FIG. 4 – COLLECTED ENERGY PROFILE

FIG. 5 – ENERGY COLLECTED IN "TYPICAL DAY"



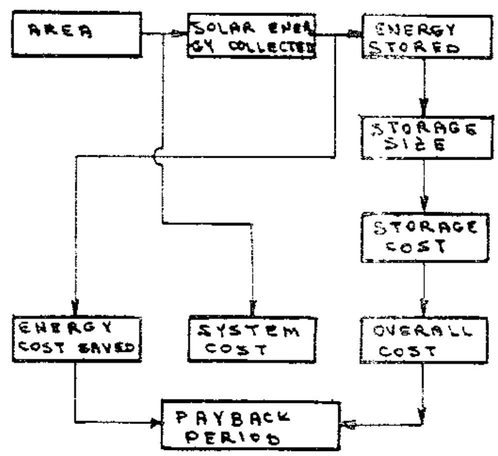
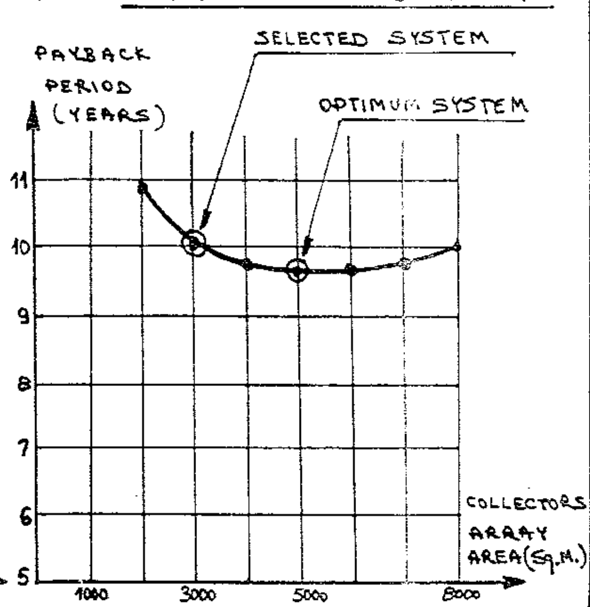


FIG. 6 – ECONOMIC CALCULATIONS PROCEEDURE

FIG. 7 – ECONOMIC CALCULATIONS RESULTS



Third Stage - At this stage economic calculations were done in order to define the optimum collectors area and to select the proper area. The calculations were based on the energy cost saved by the collector array on one side, and on the system cost on the other side (including collectors, cooling machines, storage, pipes, pumps, valves, infrastructure electrical control, and instrumentations). Energy saving calculations were done for each area defined above (2,000 to 8,000 sq. metre). The procedure is described in Figure No. 6.

The results are presented in the graph in Figure No. 7. The graph shows that the optimum area is between 4,000 and 5,000 sq. metres. This is based on the assumption of constant cooling load (200 ton). Since to-day the cooling load is not constant, a sub-optimal size was selected with the option to be extended in the future.

The size of the storage is used now mainly for dumping and testing. Increasing the collector arrayes size will increase the capacity of storage, and to lower payback periods.

4. SYSTEM CONTROL AND OPERATION OPTIMIZATION

Practical system control and optimization approach was based on the following steps in which the schedule of activities is shown in Figure 8, and which includes :

* Evaluation of component performance maps.
* System operation research.
* Classification and selection of proper control system (modes of operation; specification of hardware and software; installation; experimentation and modification).

Evaluation of Components Performance Maps

Typical performance maps of the solar system components are shown qualitatively in Figure No. 9. It is shown that the capacity of the collectors decreases with the increasing of the heated water temperature, but the capacity of the cooling machine and of the charging rate of the hot storage, increase. Matching of these performance maps lead to the conclusion that dynamic control optimization exist. The integrated map shows that a specific required cooling capacity defines a required hot water temperature and energy collected by the collectors. In the case where storage temperature is lower, the optimal control problem is : to define the policy in which charging of storage is existing at a lower hot water temperature, but with a higher level of energy collected by collectors. At the same time, the backup boiler will supply the cooling machine with an additional amount of required energy to keep the temperature of the hot water at the inlet of the cooling machine.

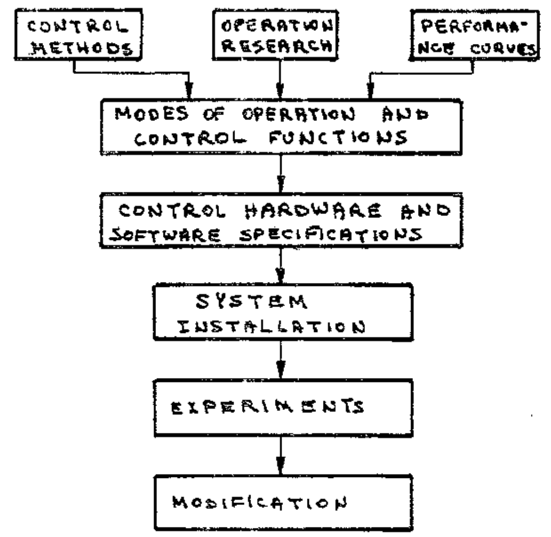


FIG. 8 – CONTROL SYSTEM PROJECT SCHEDULE

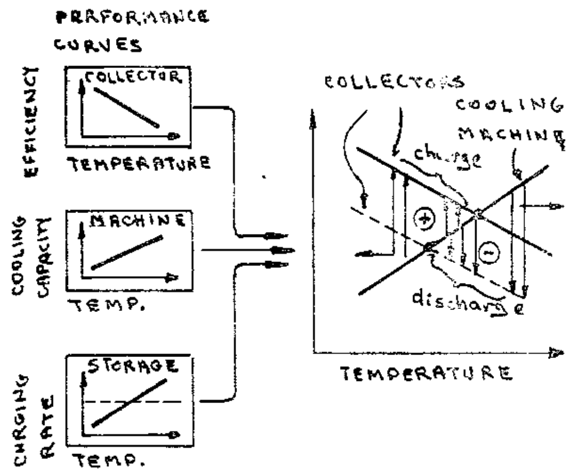


FIG. 9 – PERFORMANCE CURVES EVALUATION IN THE SOLAR SYSTEM

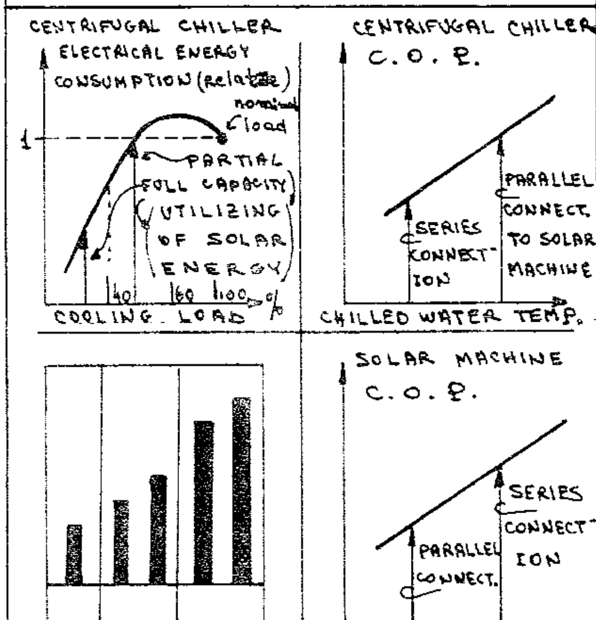


FIG. 10 – COOLING SYSTEM PERFORMANCE CURVES

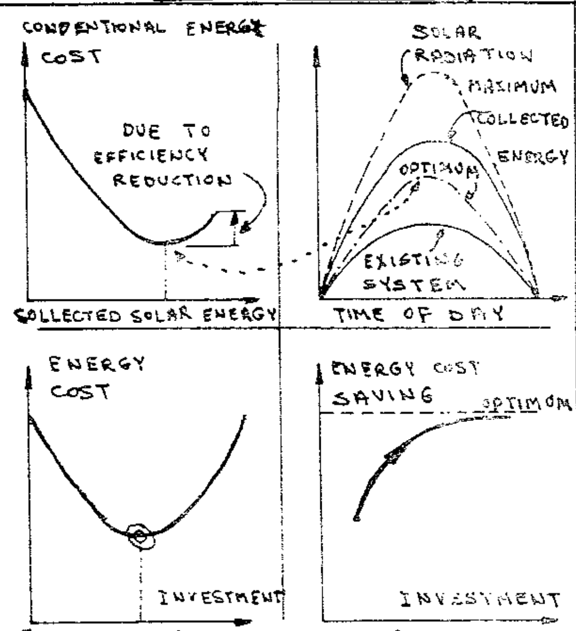


FIG. 11 – OPERATION RESEARCH

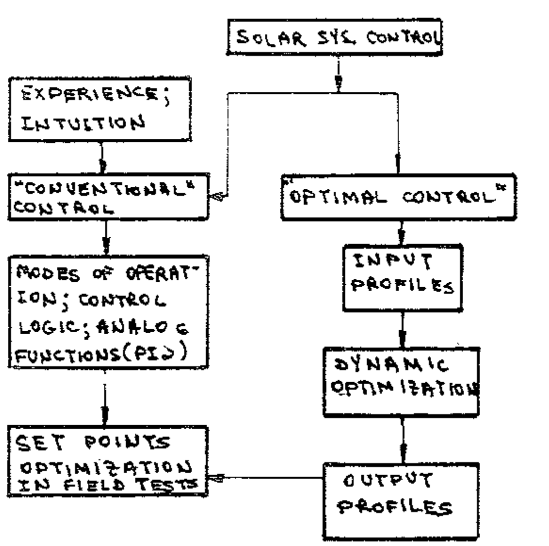


FIG. 12 – CONTROL CLASSIFICATION & SELECTION

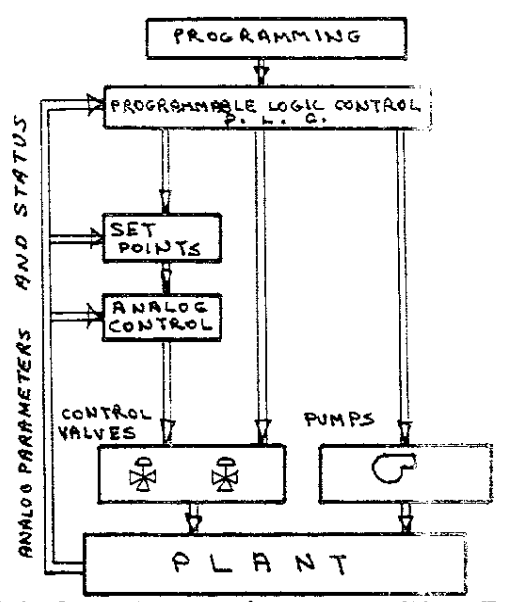


FIG. 13 – CONTROL SYSTEM CONFIGURATION

Figure No. 10 presents arguments in the cooling system which affect also the optimal Control problem.

The performance curves of the conventional type centrifugal cooling machine which was installed in the cooling system in the medical center, shows that in the case of both machines,when they are operated simultanously, the efficiency of the conventional cooling machine may decrease when all the energy collected by the collectors is suppliedto the solar powered cooling machine, and may increase, if part of the collected solar energy is supplied to the storage. In this case, more electrical energy is required which is consumed at a higher efficiency.

Other optimal control problems exist due to the connection of a solar powered machine to another machine in the chilled water loop, i.e. parallel or series, and due to the effects of electrical energy consumed by the pumps.

Preliminary Operation Research

Preliminary operation research is presented in Figure No. 11. The figures shows that control optimization based on energy cost saving, may lead to maximizing of economical benefit rather than maximization of solar energy collected.

Classification and Selection of Proper Control Systems

Figure No. 12 presents classification of control systems - conventional based and optimal.

Due to the time limitation of the project, conventional control functions were selected. However, since maximum modes of operation have been integrated, and since microprocessor based programmable logic control system has been applied, it is possible to modify the control according to accummulated test results. This is according to the flexibility of the logical systems which enable also to adjust automaticaly temperatures set points. General system diagram is shown in Figure No. 13.

Currently a multipoint data acquisition and recording systems are being installed and calibrated. According to the data which will be accummulated during the following years, required activities will be defined later which may improve and optimize the overall integrated system control.

The development program was sponsored by the Israeli Ministry of Energy and Infrastructure.

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PROJET DE DEMONSTRATION DE CONDITIONNEMENT D'AIR SOLAIRE EN ISRAEL : OPTIMISATION DE LA CONCEPTION DE L'INSTALLATION ET DE LA REGULATION

RESUME : Des systèmes de conditionnement d'air solaire originaux ont été réalisés et testés. La réalisation portait sur un refroidisseur à absorption à énergie solaire, des capteurs plans pour faire fonctionner le refroidisseur, l'ingénierie des systèmes et des stratégies et systèmes de régulation.

Au cours des deux dernières années on a conçu un grand système de démonstration et on l'a installé au centre médical de Haim Sheba à Tel Hashomer, Israël. On a réalisé et installé un refroidisseur d'une puissance nominale de 696 kW mis au point par TADIRAN/ASD, des capteurs plans de 3 000 m2 et un système de régulation par microprocesseur. Le système a été intégré dans la salle des machines centrale habituelle pour les refroidisseurs afin de fournir de l'eau glacée au centre médical. Ce système est considéré comme l'un des plus grands du monde.

Ce rapport a pour but de présenter les stratégies d'optimisation des systèmes et régulations actuels permettant d'économiser le plus possible sur le coût de l'énergie en fonction du coût d'investissement.