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WORKSHOP PROCEEDINGS*

VOLUME I

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I. NEW AND RENEWABLE SOURCES OF ENERGY AND THE ACTIVITIES OF UNIDO IN THIS FIELD

Energy crises, generated among others through a heavy dependence on fossil fuel energy, albeit periodical, and the uneven distribution of effective conventional sources of energy, have been instrumental in fostering research and development in alternative sources of energy. New and renewable sources of energy (NRSE), although easily accessible in most cases, are not fully exploited usually owing to economic rather than technical constraints.

In principle, non-conventional and renewable sources of energy should be used or are already used complementary to conventional sources. In order for new and renewable sources of energy to be fully integrated into the economy, however, a number of obstacles must be overcome and certain conditions must be established.

Only infrequently can a solution to an energy source problem be found that would meet the following criteria:

Improving environmental quality
Conserving energy
Conserving conventional energy resources
Making obvious economic sense
Solving socio-economic problems

NRSE can meet these criteria under certain circumstances. In light of the mounting energy shortage, an increasing demand for environmental pollution control and quality as well as the need to prevent an increase of CO_2 in the atmosphere on a long-term basis, the so-called "clean" alternatives of wind, water, solar, tidal and geothermal energy have been given particular attention world-wide. The long-term future demand of energy supplies could be met by a combination of these sources.

Without intending to oversimplify a complex subject such as NRSE, the following issues constitute some of the broad characteristics of a NRSE:

(a) Deficiencies exist at the national and international level in the statistical assessment of the reserves and resource potential of NRSE, and it is still difficult to assess the role of various NRSE in national and international energy statistics;

(b) The major economic impediments to a more dynamic growth of NRSE are presently both external (world oil prices, budgetary policies) and internal (apparent high capital costs, lack of standardization/mass production, unsatisfactory producer/user dialogue);

(c) NRSE can play an important role in attenuating the effects of energy deficiencies, particularly in rural areas, remote areas, isolated systems etc. Therefore, NRSE are a valuable substitute for conventional energy sources, and their utilization prevents an uncontrolled use of fossil fuel energy;

(d) Hydropower (including small-scale), conventional geothermal energy, peat, some types of biomass, solar thermal energy for hot water production and wind systems are economic in many applications. Solar photovoltaic (PV) systems has proven competitive in isolated circumstances;

(e) Additional NRSE options are at various stages of R&D. A number of these technologies offer the promise of technical feasibility and economic viability under conditions of higher energy prices, environmental regulations, mass production, technical refinement and an innovative marketing effort and/or governmental support;

(f) The storage of energy (also in the case of NRSE), for later consumption is necessary for instance when there is an imbalance between consumption and demand at the regional or sectoral level, the availability of energy sources is irregular, or during long maintenance periods at the plant level etc.;

(g) By storing energy for later consumption, it is possible to use machines more effectively . In addition, if suitable energy storage systems could be made available for renewable energy sources, this would have a considerable beneficial effect on the development and use of these sources which would result in a far less detrimental environmental impact than the use of conventional sources. On a global scale, this has a two-fold effect on the environment: on the one hand, it will reduce the amount of emissions (CO_2, SO_2 and NO_2) associated with the burning of conventional fuels and, on the other hand, it will reduce the amount of energy produced from terrestrial sources;

(h) Most NRSE produce "clean" energy;

(i) NRSE need a wide range of equipment, special material, accurate assessment of siting and distribution. A large contribution from NRSE would entail economies of scale in the production of equipment and intermediate product and, subsequently, the rise of a new dynamic industrial branch;

(j) The increased utilization of NRSE on a long-term basis presupposes further efforts at cost reduction, energy storage, reduced energy and material intensity, and higher energy conversion efficiency;

(k) Attention has also to be paid to the price differential between conventional sources of energy (CSE), and NRSE; since most of the ongoing industrial activities depend on CSE, it is expected that an assessment of demand elasticities will reveal that the demand for NRSE is more elastic. Therefore, R&D costs could militate against NRSE unless government intervention in the form of incentives and disincentives could make NRSE development more attractive;

(l) The adaptation of mature technologies to varying user needs is of great importance compared with further technical refinement. The sharing of costs and risks through internal co-operative R&D has proven beneficial;

(m) The availability of comparative data on conventional energy sources and NRSE concerning investment cost as well as data about the amortisation time within the limits of a facility's serviceable life can help people to create important criteria for the economic viability of NRSE;

(n) There is a role of social responsibility in connection with NRSE for all segments of society in developing an effective power supply system; in this connection, Governments or authorities have an important role to play in creating the relevant infrastructure;

(o) A number of factors are instrumental in providing a development framework for NRSE. These include: the stability of monetary policies; continuity of R&D funding; neutral tax regimes; the simplification of building regulations; the harmonization of standards, test certifications and quality requirements; and the internalization of externalities in the prices of all fuels.

II. UTILIZATION OF NRSE IN THE DEVELOPING COUNTRIES AND THE ROLE OF UNIDO

The level of primary energy consumption in developing countries is low compared to world consumption or consumption in the industrialized countries. Primary energy consumption in the world, in the industrialized countries and in the developing countries is shown in figure I. Various scenarios for future primary energy consumption are illustrated in figure II. A breakdown of energy consumption by type of energy for the world during the period 1966-1986 is shown in figure III.

The constraints encountered by developing countries in developing their energy resources to the optimum and in improving the efficiency of their industrial energy consumption are numerous, but they can be grouped under five main headings:

Lack of finance
Lack of know-how
Lack of skilled human resources
Lack of equipment
Lack of plans and specific proposals

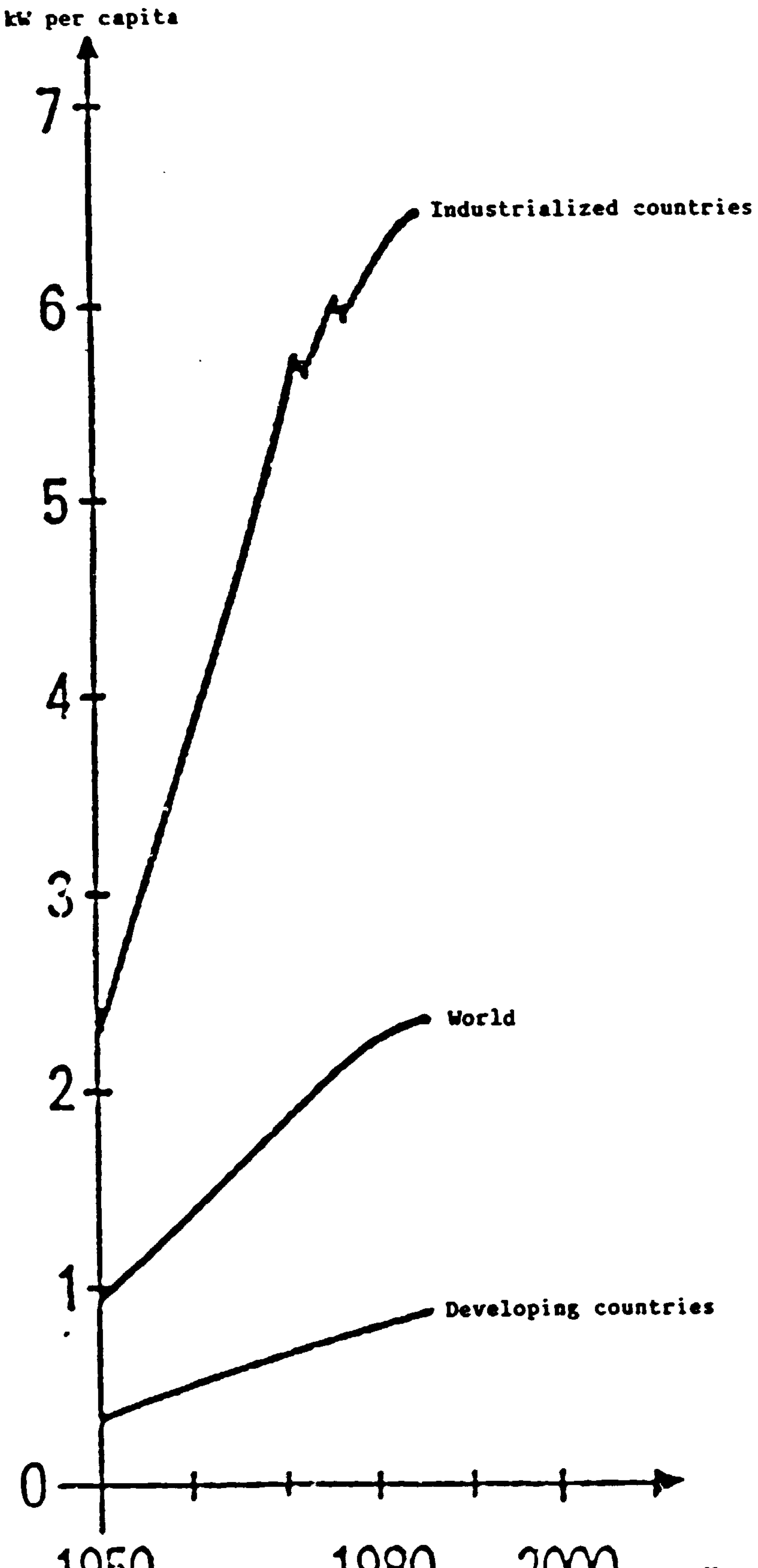
These constraints are interconnected. In spite of the great potential for satisfying their energy needs, several developing countries for instance countries of West Africa[1/], are not mastering technologies for renewable sources of energy owing to the above-mentioned constraints. Most of the potential resources either have not been developed at all or are being used in inefficient ways.

NRSE, are especially important for developing countries for at least two main reasons: (a) they constitute a respectable amount of total energy input of developing countries (see table 1) and (b) important NRSE, such as solar and water, are practically inexhaustible and they have the greatest potential for improvement, expansion and increased effectiveness, through new technologies. It is difficult to estimate the total energy produced from renewable sources in developing countries. Annual energy production in some countries are shown in table 2. The figures given are not comparable, because solar energy may include both heat and electricity generation. Minihydro and biogas energy in many countries and solar heat production in some countries are already in commercial use, as can be seen in table 2. A word of caution is necessary, however: it is important that developing countries take into consideration the fact that some of the new sources are highly dependent on "frontier technology" and might lead the developing countries into new forms of dependence, unless they take the appropriate institutional and technological action, to ensure that they can take decisions autonomously. The proportions of different types of energy sources harnessed in 47 developing countries are shown in table 3.

In dealing with industrial development, it is essential for UNIDO to consider further the role of NRSE: their potential contribution and the interdependence between the development of such sources of energy and industrialization. Attention should be focused on the industrial energy requirements of developing countries, since in these countries energy demand will expand at a faster rate and NRSE are likely to contribute most towards the overall and/or industrial energy supply. (Scenario A in Figure II represents an optimistic variant of this trend.)

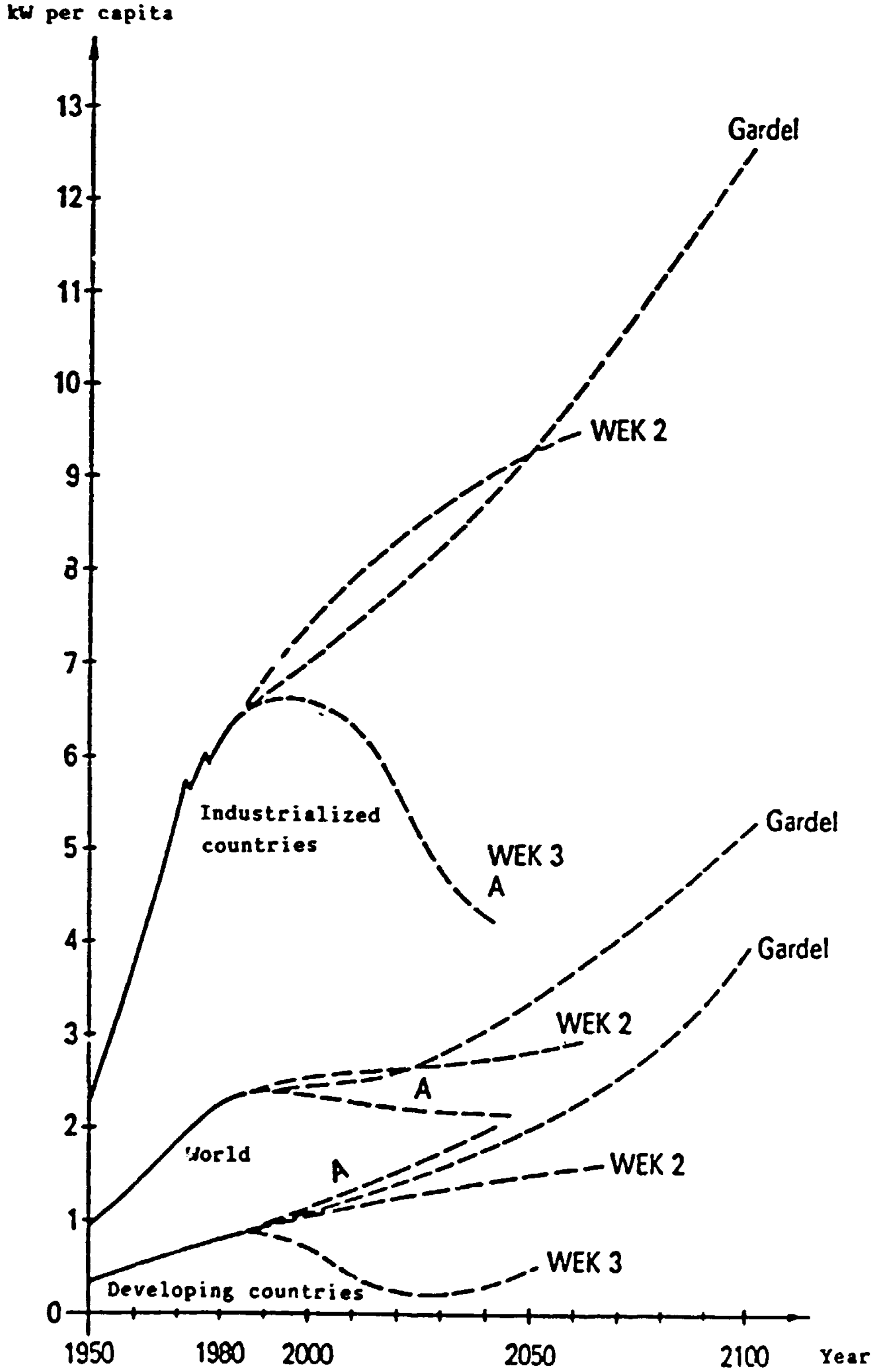
It is important to recognize that the pattern of energy availability and use in developing countries is changing especially with regard to NRSE. In fact, it is in the developing countries that some of the most original and significant departures from conventional energy use can be found at present. Necessity and ingenuity have led to non-conventional solutions (based on NRSE) that are remarkable for their pragmatism and, in certain cases, for their originality and sophistication, in terms of processes and fuels used, equipment produced and national planning involved.

Figure I. Per capita consumption of primary energy



Source: Technische Rundschau, March 1988.

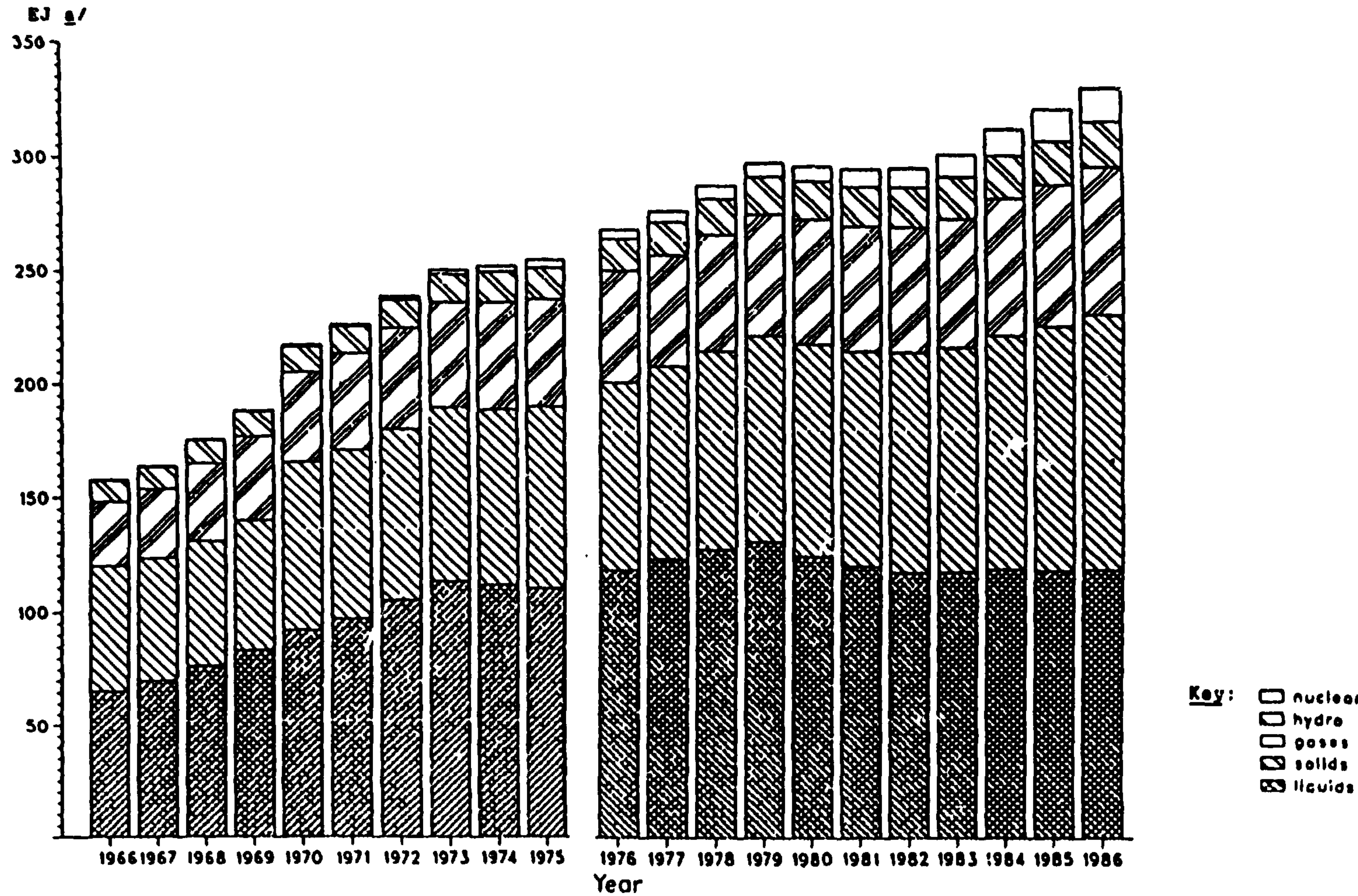
Figure II. Per capita consumption of primary energy to the year 2100, various scenarios



Source: Technische Rundschau, March 1988.

Note: An explanation of the various scenarios is contained in the source.

Figure III. Breakdown of total energy consumption for the world, 1966-1986



Source: International Atomic Energy Agency, Energy, Electricity and Nuclear Power Estimates for the Period up to 2000 (Vienna, 1987).

Note: Data for the period 1966-1969 do not include the contribution from fuel wood, which in 1970 contributed 7.4 per cent to the total energy consumption.

a/ 1 EJ = 104.17 TWh.
b/ All 1986 values excluding nuclear are extrapolations.

Table 1. Total world energy consumption a/ by type of fuel, 1986
(Percentage)

Region or group	Solids b/	Liquids	Gases	Hydro	Nuclear	Geotherm	Total
North America	25.21	38.41	23.81	6.86	5.55	0.16	100
Western Europe	23.36	42.19	16.10	7.78	10.53	0.05	100
Industrialized Pacific	22.42	50.50	12.58	6.17	8.18	0.16	100
Eastern Europe	32.97	29.29	31.96	3.31	2.43	0.04	100
Asia	66.11	22.77	5.34	4.61	1.05	0.13	100
Latin America	21.13	44.03	19.17	15.26	0.26	0.16	100
Africa and Middle East	43.07	42.37	11.55	2.59	0.39	0.03	100
World average	33.99	35.72	19.78	6.02	4.40	0.10	100
Developed countries	26.30	37.39	24.10	5.93	6.19	0.09	100
Developing countries:							
Centrally planned economies, Europe c/	52.65	23.34	20.06	1.70	2.24	0.00	100
Other developing countries	48.65	33.79	9.88	6.88	0.66	0.14	100
Total developing countries	49.18	32.41	11.23	6.20	0.87	0.12	100

Source: International Atomic Energy Agency, Energy, Electricity and Nuclear Power Estimates for the Period up to 2000 (Vienna, 1987).

a/ Total energy consumption = consumption of primary energy plus net imports (imports minus exports) of secondary energy.

b/ Solids include commercial wood.

c/ Albania, Bulgaria, Czechoslovakia, Hungary, Poland and Romania.

Table 2. Annual energy production from renewable energy sources in selected developing countries ($kWh/a \times 10^3$)

Country	Solar	Wind	Minihydro	Biomass	Biogas	Total
Pakistan	15 000 a/	--	484×10^6	--	1 800 a/	484×10^6
Panama	28 000	3 000	88×10^3	--	9 100	128.1×10^3
Philippines	480 000	--	1.5×10^6	--	180 000	2.16×10^6
Senegal	537 a/	14	--	--	204	755
Sri Lanka	4 000 a/	8 000	500 000	--	29 000	541 000

Source: Yehia El Maghary and Seppo Kaerkkaeinen, eds., Energy Storage Systems in Developing Countries (London, Cassell Tycooly, 1988).

a/ Electricity generation.

Table 3. Present and anticipated use of renewable energy sources in 47 developing countries
(Percentage of countries that have harnessed or plan to harness each energy source)

	Harnessed	Planned	Total
Solar	55	17	72
Wind	30	9	39
Minihydro	47	9	56
Biomass	28	13	41
Biogas	36	13	49
Tidal or wave	4	--	4
Other	9	--	9

Source: Yehia El Maghary and Seppo Kaerkkaeinen, eds., Energy Storage Systems in Developing Countries (London, Cassell Tycooly, 1988).

III. UNIDO ACTIVITIES IN THE AREA OF NRSE

The mandate of UNIDO in the energy-related aspects of industrialization, including especially new and renewable sources of energy, was established by the Second and Third General Conferences of UNIDO and was also reflected in the report of the Secretary-General to the General Assembly at its thirty-fifth session.

UNIDO, in its approach to the development of NRSE, is opting to support developing countries in the following areas:

Transfer and application of technology
Strengthening institutional infrastructure appropriate for the further development and infrastructure of NRSE
Identification of financial resources
Continuous training of technical and managerial personnel
Elaboration of relevant legislative and regulatory framework

An outline of the current and planned activities in connection with new and renewable sources of energy is contained in the annex.

UNIDO activities in the field of energy cover a wide range of energy issues, such as energy conservation, energy management as well as new and renewable sources of energy. Within this area, UNIDO functions in two ways, namely through: (a) technical assistance activities, which are a response to requests from Governments; and (b) promotion of industrial development.

A. Technical assistance

UNIDO delivers yearly some $US 100 million of technical assistance, of which ten percent is in energy in 1987. In the year 1980 it was only five per cent. The annual disbursements on energy for the years 1980-1987 are shown on figure IV. The increase in the technical assistance delivery on NRSE can be seen in figure V: in the year 1980, the share for NRSE amounted to 0.5 per cent of UNIDO technical assistance; by the end of 1987, an almost constant share of three per cent can be recorded. UNIDO technical assistance in NRSE compared to that for total energy for the period 1980-1987 is shown in figure VI.

Requests from developing countries for UNIDO technical assistance in the field of NRSE are mainly in the following areas: biomass; hydropower; solar; and wind (to a much smaller extent than the other areas). The trends in percentages of technical assistance requests with respect to these sources of energy are illustrated comparatively in figure VII.

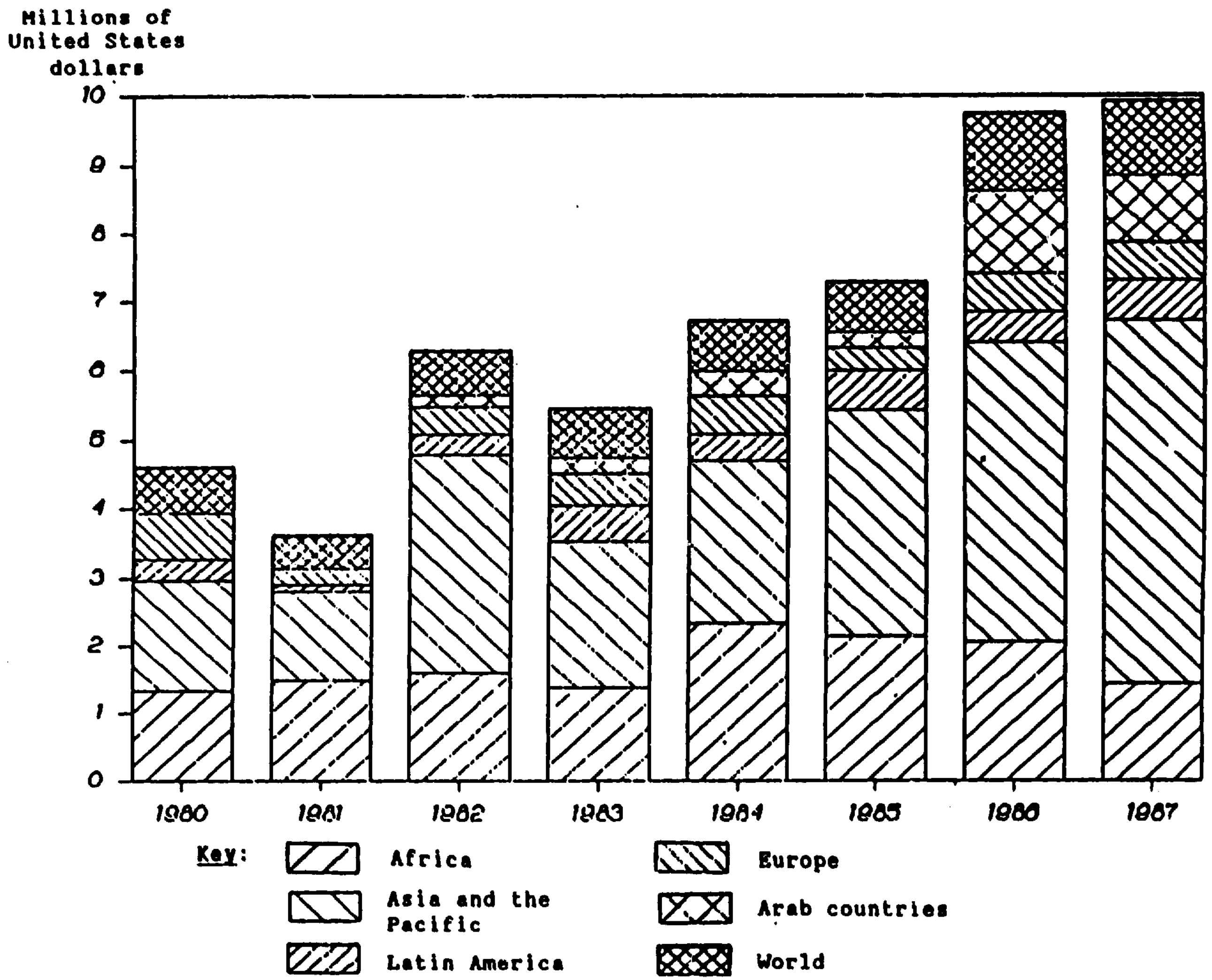
The assistance delivered in the various regions by type of energy is shown in figure VIII.

As mentioned in above, the developing countries as a whole are well endowed with, and have the potential for developing, new and renewable sources of energy, such as biomass, hydropower, solar and wind. These sources of energy and UNIDO activities relating to each of them are discussed below.

1. Biomass

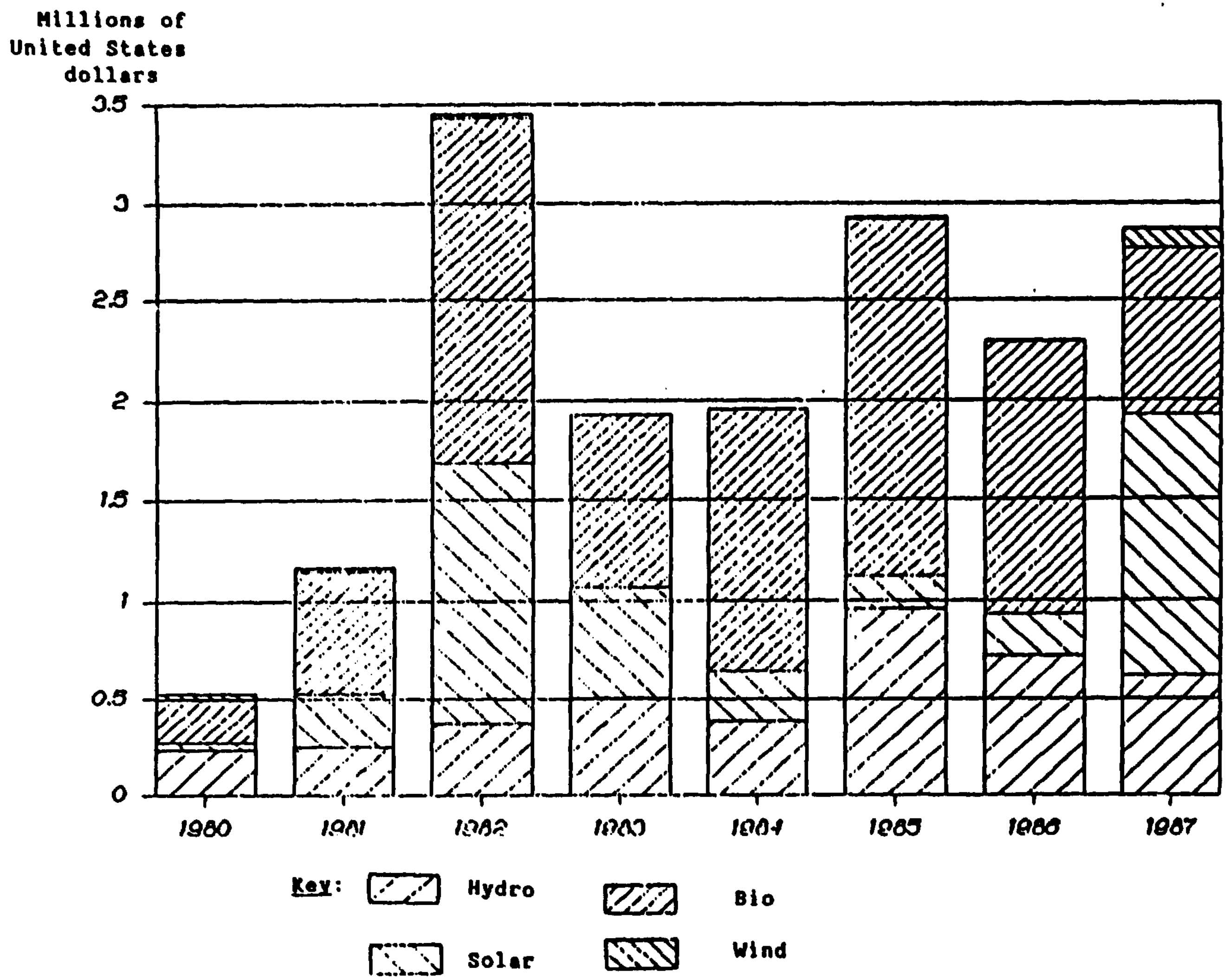
It has been estimated [2/] that biomass provides between 6 and 13 per cent of total world energy needs. But such estimates can only be regarded as best guesses, because much of the biomass used for energy production is not recorded in any commercial energy statistics. It is clear, however, that biomass provides the major source of energy in many developing countries. This is to a large extent in the form of wood for fuel. Typical biomass materials, conversion processes and biomass-derived fuels and energy products are shown in figure IX.

Figure IV. Yearly regional disbursement on energy, 1980-1987



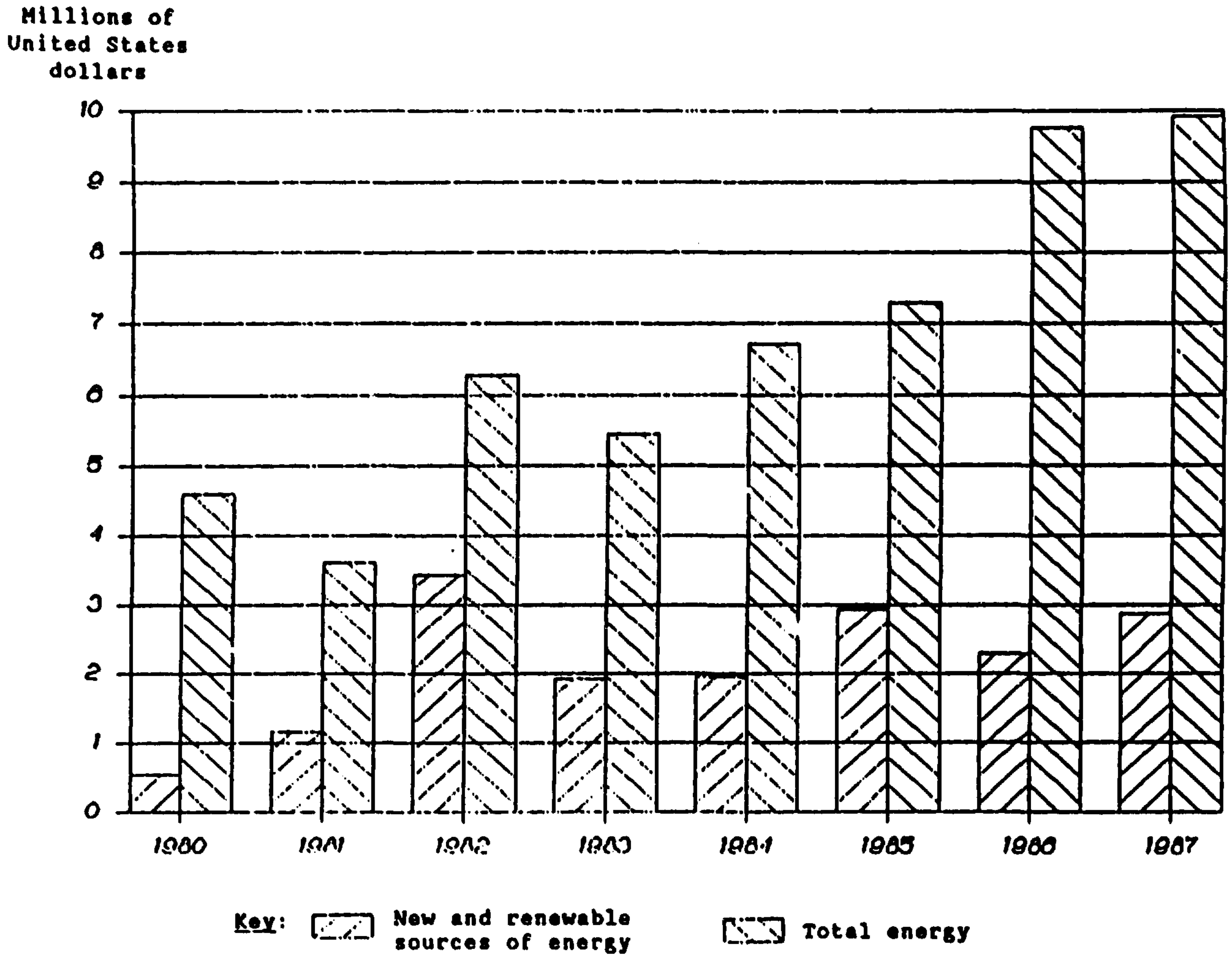
Source: IPCT/DTT/INF.

Figure 7. UNIDO disbursements for new and renewable sources of energy by type of energy, 1980-1987



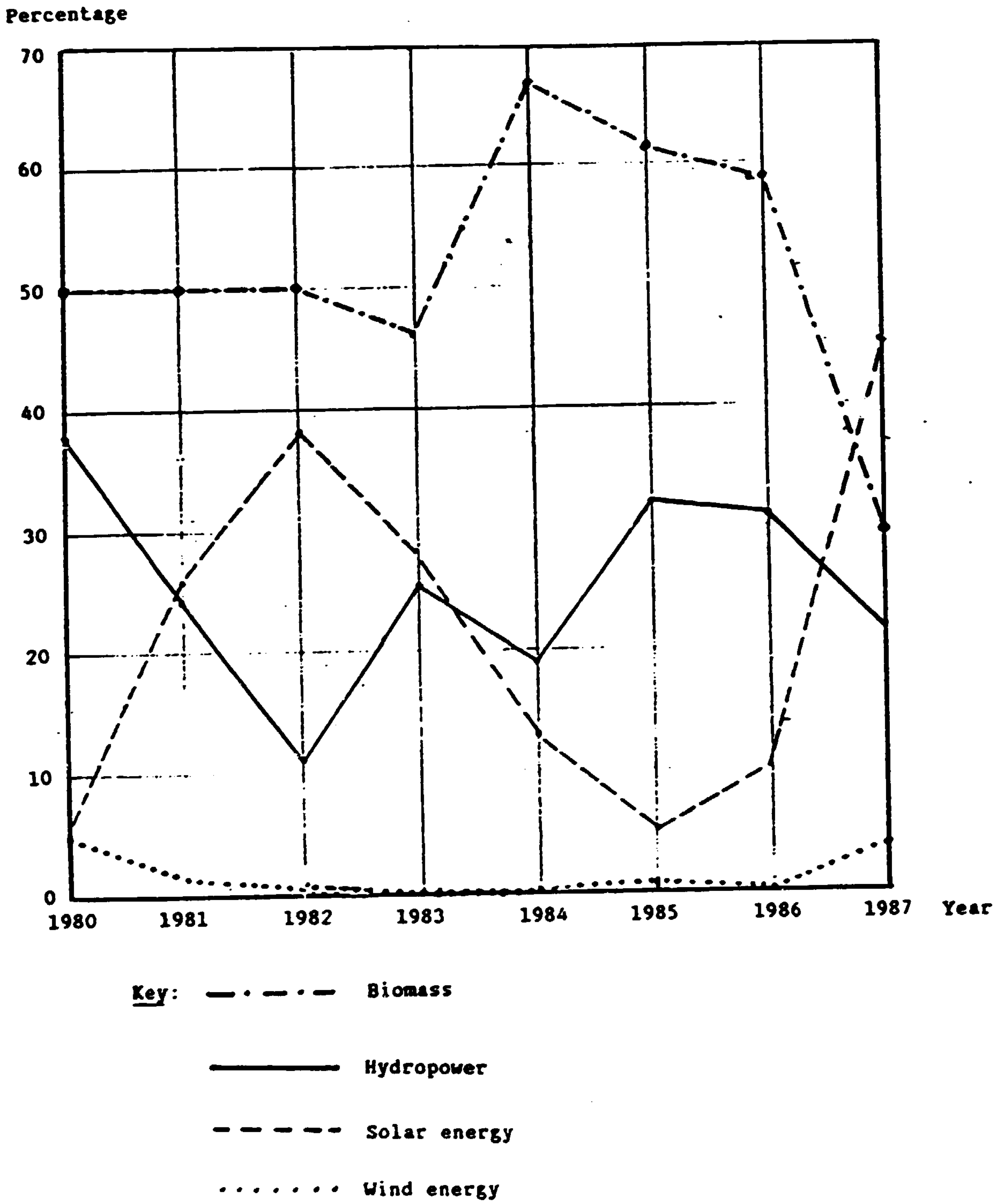
Source: IPCT/DTT/INF.

Figure VI. UNIDO disbursement in new and renewable sources of energy compared with total energy, 1980-1987



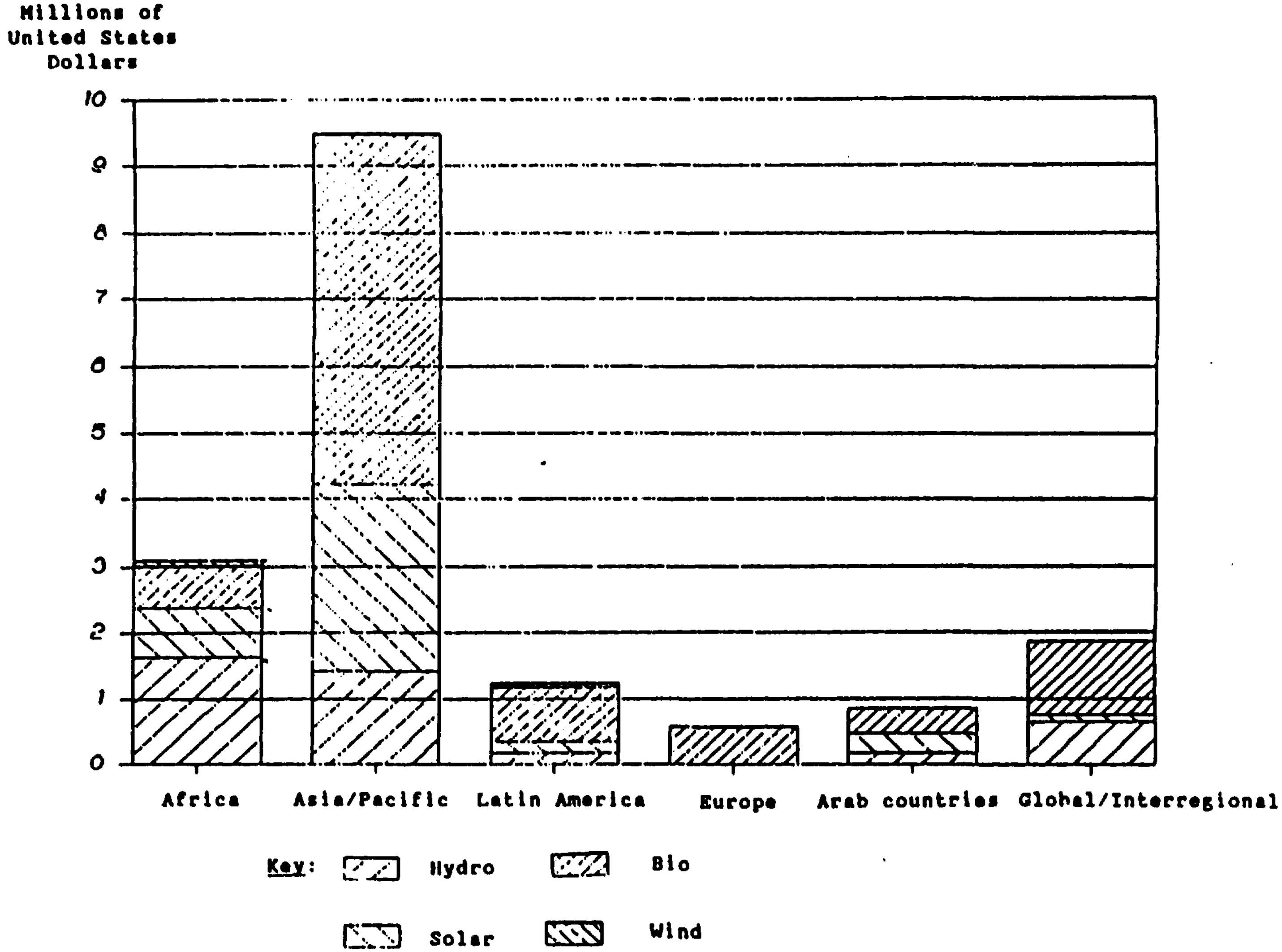
Source: IPCT/DTT/INF.

Figure VII. Requests for technical assistance, by type of energy, 1980-1987



Source: IPCT/DTT/INF.

Figure VIII. UNIDO disbursement on new and renewable sources of energy, by region and type of energy, 1980-1987



Source: IPCT/DTT/INF.

Figure IX. Biomass conversion processes and fuels/energy products

	Biomass resource	Conversion process		Fuels/energy products
Energy Crops	o Agriculture – sugar	fermentation		ethanol
	– starch	hydrolysis	fermentation	ethanol
	– cellulose	hydrolysis	fermentation	ethanol
		anaerobic digestion		biogas
	o Wood	hydrolysis	fermentation	ethanol
		combustion		steam/electricity
		pyrolysis		pyrolytic oil, pyrolytic gas, solid fuel (char)
		gasification		low-heat-value gas (producer) gas, medium-heat-value (synthesis gas)
	o Aquatic plants	anaerobic digestion		biogas
	o Marine plants	anaerobic digestion		biogas
Resources	o Crops	anaerobic digestion		biogas
	o Wood	hydrolysis	fermentation	ethanol
		combustion		steam/electricity
		pyrolysis		pyrolytic oil, pyrolytic gas, solid fuel (char)
	o Manures/sewage	anaerobic digestion		biogas
	o Refuse (urban solid waste)	gasification		low-heat-value gas, medium heat-value gas
		anaerobic digestion		biogas
		combustion		steam/electricity
		pyrolysis		pyrolytic oil, pyrolytic gas, solid fuel (char)
		hydrolysis	fermentation	ethanol

Source: Handbook of Biomass Conversion Technologies for Developing Countries (UNIDO/IO.580).

Biomass, and its conversion to a usable energy form, represents a major resource for the developing countries. It provides them with the possibility of obtaining large quantities of indigenously produced energy from a wide variety of feedstocks and processes and is a renewable energy form. It is, or can be, produced in a wide variety of form to meet a range of needs, as can be seen in figure IX. It is therefore possible with planning to provide the right quantity and type of energy or fuel.

In keeping with its mandate of promoting industrialization, the UNIDO biomass energy programme targets primarily the agro- and forest-industry subsectors. Food processing industries, including breweries, distilleries, dairies and abattoirs, are usual counterparts for anaerobic digestion (biogas) projects. In charcoal production and thermochemical gasification, UNIDO provides technical assistance to agricultural and logging/sawmilling organizations with activities such as charcoal production from sawmill waste and crop residues and the gasification of waste for shaft power generation. Priority is given to processes and techniques for which equipment can be locally fabricated.

UNIDO continues to support the fermentation alcohol industry with projects that address a wide range of problems, from improved process engineering-immobilized yeast cell processes to the use of surfactants with diesel fuel/ethanol blends for the production of stable emulsions of up to 25 per cent alcohol requiring no engine modifications.

For full advantage to be gained from biomass energy, developing countries need to undertake and strengthen R&D on all aspects of the subject, from improved biomass resource management through conversion technology to more efficient end-uses. At the same time account must be taken of the fact that biomass resources have many competing uses. It is therefore necessary to adopt an integrated and balanced approach in line with the particular needs and resources of developing countries. The conversion of biomass has to be carefully assessed in order not to disturb natural balances and to fully assess environmental impacts.

2. Hydropower

The hydropower potential of the developing countries is vast; Africa alone is estimated to have some 30 per cent of the world's potential. It was noted that currently only about 9 per cent of the hp potential in the developing countries had been exploited. Electric power is a universal energy form and can be used to satisfy many industrial energy needs. Although the major part of electric power will be supplied from large -scale projects, there is an important role for small and mini-hydropower plants, especially in rural areas and in decentralized industrial applications.

The estimated world's potential hp capacity is about 2.2 x 10**6 MW. Approximately 60 per cent of this potential exists in the less developed countries of Latin America, Africa and Asia and the Pacific. Compared with the requirements and potential resources, however, the utilization of hp, especially the portion below 5 MW capacity, is largely underdeveloped. Only about 16 per cent of the total technically usable hydropotential in Asia and about 13 per cent of the corresponding rate of utilization in South America have so far been harnessed. For Africa, the corresponding proportion is only 4 per cent compared to 94 per cent in Europe. Mini-hydro projects (under 1 MW) might comprise 5 - 10 per cent of the world's total hydro-resources. Small-scale hydro power plants are gaining growing importance and are being widely used in the range from 10 kW to approximately 5,000 kW at heads from 2 m to 500 m.

UNIDO has paid special attention to this area and particularly to small-scale hydropower and has established a strong reputation in the field of NRSE. In that connection, attention is drawn to the most recent UNIDO Workshop on Mini Hydropower Development, held in Vienna in June 1987.

3. Solar energy

The developing countries, owing to their geographical locations, have abundant solar radiation. There is a wide area of industrial application for solar energy in the form of low-temperature water (30-70° C) produced in simple thermosyphons with flat-plate collectors. Using concentrating collectors, high temperatures (up to 150° C) can be generated. This range of temperatures fits a variety of industrial uses such as bottle washing, sanitary uses or boiling.

Another solar energy route being developed is the direct production of electric power through photovoltaic cells. This is a new technology. In the future, energy through PV systems could be an important renewable source of energy, particularly for developing countries.

In general, UNIDO has already accumulated some valuable experience in the introduction and application of PV systems in developing countries and quite good connections have been established with a number of R&D institutions and firms in industrialized countries dealing with promising solar energy projects and related technologies including PV.

UNIDO technical assistance activities are mainly concentrated, where possible, on the establishment of facilities for detailed design, system engineering, prototype development, testing and pilot plant production of complete PV systems or components tailored to the needs of developing countries.

4. Wind energy

With regard to wind power, UNIDO has realized wind pump pilot schemes and technical assistance activities in African and Latin American countries aimed at establishing local capabilities for the production and installation of wind mill systems on the medium or long term for water-pumping and/or electricity generation.

B. Promotion of technology and information exchange

The promotion of energy and NRSE technologies is a clearly defined programme component of UNIDO. Solar energy, particularly is considered by UNIDO to be one of the promising sectors deserving promotion through international co-operation It is infinitely renewable, abundant and widely available in both developed and developing countries.

In connection with the establishment of a Consultative Group on Solar Energy, Research and Application (COSERA)3/ the following activities have been undertaken by UNIDO:

(a) Background reports and publications related to solar energy research and application;

(b) A workshop on COSERA, 8 - 14 December 1986;

(c) Donor agencies, international organizations and research institutions were canvassed for their view of and support for COSERA, the result being generally strong favourable reaction;

(d) Consultant's reports on solar energy research institutions in Latin America and Asia; a third consultancy covering North African countries will be undertaken this April;

(e) Preparation of a portfolio of solar R&D projects from various sources to be reviewed and considered for implementation by COSERA.

UNIDO acts as a clearing house for appropriate technologies and also promotes information transfer.

Information is one of the three factors constituting the physical plane of the production function, as detailed in figure X . The appropriate information results in energy conservation or/and optimal energy generation or utilization.

UNIDO has a strong mandate in the field of industrial information and has, for over 20 years, been active in providing computerized information packages and in establishing information networks on specific topics, including NRSE.

The exchange of technological information plays a growing role and UNIDO is aware of the necessity to contribute in closing the technology gaps between countries and to assist in avoiding duplication of responsibilities and efforts. Therefore, the UNIDO Energy Information System (EIS) has been created in order to provide support for the Organization's energy programme and to record its energy activities.

The System's key components are described below.

PRAD DATA BASE

The necessity for reporting on UNIDO activities in the energy sector led to the creation of a computerized information system covering project and other energy-related activities, which has been expanded over the years and has gained in complexity and coverage. Almost 500 energy projects have been under implementation since 1980 and form a part of the PRAD computer programme (one component of EIS). This data base provides information on project activities, giving standard data on project number, title, financial aspects, counterpart agencies as well as an abstract on each project's scope and coverage.

IDA DATA BASE

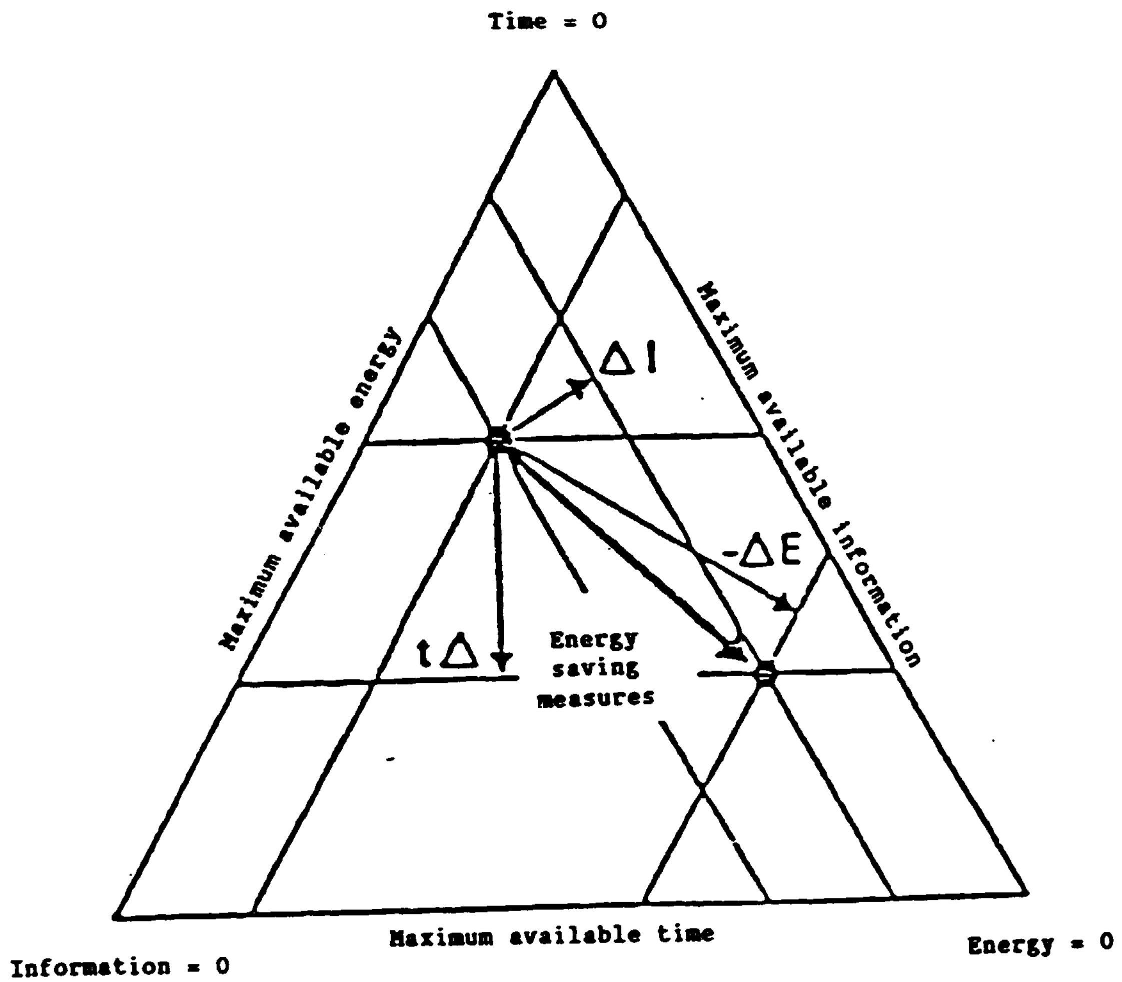
The Industrial Development Abstracts data base records, inter alia, technical and final reports that stem from projects, thereby providing a complementary source of information on energy project activities. This data base is also utilized for providing information on what UNIDO has been doing in the energy sector.

ENER DATA BASE

The ENER data base system primarily provides support for the Industrial Energy Conservation Abstracts, which cover information on several activities related to energy conservation in industry, namely:

Abstracts of technical papers
Energy efficient technologies/equipment
Training opportunities
Research and development
Planned meetings
Consultants/experts

Figure X. Time/information/energy triangle



P = f (T, I, E)

Conventional economic point of view:

P = f (work, capital, country)

Where: P = production
T = time
I = information
E = energy

Source: D. T. Spreng, Substitution von Energie durch Information, NFP 44 (Swiss National Fond for the Promotion of Scientific Research).

The data base will also be available in micro form by mid-1988.

The sectoral focal points of the Industrial Energy Conservation Abstracts are:

Energy auditing
Iron and steel
Chemicals
Building materials
Food processing
Waste heat recovery
Energy conservation policy.

The Industrial Energy Conservation Abstracts data base is the core of an initiative for creating an information network on industrial energy conservation.

Resulting from a supported project by the United Nations Development Programme (UNDP) in the European region, the network concept has found an echo in other regions, initially the Association of South-East Asian Nations (ASEAN) and the Caribbean, and with other organizations. Activities will include the utilization of electronic mail for information exchange and the initiation of information exchange modalities between interested parties/nodes within each region and between regions. The envisaged output of the Industrial Energy Conservation Abstracts network information structure are:

(a) Manuals/guides on energy technologies and activities related to them - e.g. solar energy and energy conservation in specific sectors;
(b) Information on UNIDO energy activities;
(c) An Industrial Energy Conservation Abstracts newsletter;;
(d) Information packages on selected aspects of energy/industry.

Notes

1/ "Involvement of NGOs in the development of renewable sources of energy in Africa" (ID/WG.444/4).

2/ "Energy and industrialization", background paper presented to the Fourth General Conference of the United Nations Industrial Development Organization, Vienna, August 1984.

3/ "Workshop on the establishment of COSERA: Report" (ID/WG.464/4).

Annex

CURRENT AND PLANNED ACTIVITIES OF UNIDO IN CONNECTION WITH NEW AND RENEWABLE SOURCES OF ENERGY

The mandate of UNIDO in the NRSE-related aspects of industrialization finds response in the following:

(a) Implementation of comprehensive NRSE programmes at the national, subregional and regional levels to support the industrialization process;

(b) Intensification of research and development activities at the national, subregional and regional levels;

(c) Analysis of current uses of NRSE with a view to ascertaining the efficiency of their uses as well as the potential and possibilities for conservation;

(d) Assessment of energy, machinery and equipment needed for the generation, transmission etc. of NRSE, taking into account existing and future requirements;

(e) Assessment of the cost-effectiveness of the various available types of NRSE and end-uses of energy generated with a view to selecting the most effective renewable source of energy and systems for particular end-uses;

(f) Preparation of various profiles for the NRSE Sector;

(g) Intergovernmental consultations on policies for the development of NRSE within the overall industrialization framework;

(h) Energy study groups to advise Governments on national energy needs, supply policies, conservation measures and R&D efforts required to ensure the development and application of technology in the sector of NRSE;

(i) Enterprises for the development, reliability, production and marketing of new and renewable enrgy resources;

(j) Research, development and training centers, with emphasis on non-conventional energy;

(k) Enterprises for the manufacture and marketing of equipment and devices for the generation, storage, transport, transmission and utilization of NRSE;

(l) Subregional and regional energy boards, consisting of the national energy boards, to foster the integration and interconnection of energy networks as well as the standardization of energy equipment with respect to NRSE;

(m) Identification of resource requirements for the development of potential new and renewable resources in relation to present and future energy needs (preparation of inventories on a country and/or regional basis);

(n) Identification of existing capabilities in developing countries in the various activities related to NRSE such as planning, R&D, training, capital equipment manufacturing, consultancy services;

(o) Establishment of close working relationships between national institutions and regional/national, and international organizations, in all phases of exploration and development of NRSE;

(p) Co-operation in the area of capital equipment supply for the production and utilization of NRSE;

(q) Mobilization of financial resources for the exploration and development of NRSE through existing international, regional and other financial institutions, whose facilities should be fully utilized;

(r) Identification of existing training institutes in the developing countries and promotion of national training and research centres of multinational scope;

(s) Encouragement of co-operation between countries in the conservation of energy resources, the utilization of NRSE, storage of energy, regulations and environmental protection;

(t) Promotion of information exchange by strengthening or setting up energy information systems and liaising with on-going activities. Co-operation for the development of a world-wide network with other international, national and regional organizations. Information may also be exchanged through direct contracts, meetings of experts and other channels;

(u) Support or establishment of repair and maintenance capacities for existing NRSE facilities;

(v) Assistance to countries to enhance their activities in the NRSE area;

(w) Assistance to developing countries to evaluate their NRSE potential;

(x) Monitoring and assessing NRSE technologies for the benefit of developing countries.

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ACTIVITIES IN THE AREA OF SOLAR AND WIND ENERGY

MALEK A. KABARITI

ABSTRACT

This paper presents in brief the solar and wind energy activities of the Royal Scientific Society (RSS) in particular and the activities of other Jordanian Organizations' in the field of renewable energy in general. The activities carried out in Jordan in this field may be classified into three main categories namely : basic research, applied research and finally application. The current research and development work carried out in Jordan has been selected in such a manner so as to match Jordan's resources with energy demand and that the equipments utilizing such resources should have high possibilities for local production given Jordan's manufacturing constraints.

INTRODUCTION

Jordan is one of the few countries in the world that lack indigenous sources of energy readily available in the commercial sense using the current technology. It also has experienced in the last five years a great development in the energy sector, whereas the energy demand has increased by approximately 9% annually.

Jordan imports all its energy needs whereas its total oil imports have reached more that 120% of its total exports earning in the last few years. On the other hand. Jordan possesses a good solar resources, a good oil shale resources and an accepted wind energy resource. Thus, it is understandable that research and development activities are directed to explore, develop and utilize these resources.

The activities carried out in Jordan in This field may be classified into three categories namely :

i) Basic research, which is being performed at the Jordanian universities in the field of solar thermal and photovoltaics.

ii) The applied research, development and demonstration which is being carried out by the RSS in the field of solar water heating, space heating, water pumping utilizing Wind Energy Converting System (WECS) and photovoltaics.

iii) The application in the field of solar water heater for domestic and industrial utilization, agricultural green houses and potash recovery from evaporating ponds.

It is worth mentioning here that among numerous organizational measures taken in the past five year plan, the energy sector has been organized to cope with its fast development through the establishment of the Ministry of Energy and Natural Resources (MENR) so as to take on its behalf the planning and the general policy actions required for the sector. The newly established ministry is giving renewable energy and conservation of energy a high consideration whereas a separate department to deal with this matter has been put in its organizational structure.

A brief presentation of Jordan renewable energy activities is presented hereafter.

PAST ACTIVITIES

The RSS had conducted several projects in the field of solar and wind energy research, development and demonstration. Leading among such projects were :

Sea Water Desalination Using Heat Pipe Principle

This project, supported by the Government of the Federal Republic of Germany and conducted jointly by RSS and the German Agency for Technical Cooperation (GTZ), aimed at studying the possibility of utilizing solar energy in water desalination.

As a result, a pilot research plant was constructed at the solar energy experimental station in Aqaba for studying the behavior and performance of the system and for modifying its various components.

The findings were presented in a final report on the project under RSS publication No. (3)80/23 Dec. 1980. In addition, the RSS had compared the above mentioned method of water desalination with that of the solar stills which is a widely accepted and known method in the world. It had constructed 20 sq.m of such stills with different designs for this comparison process. The results led us to conclude that the output of those stills was much higher than of the original heat pipe system design.

Design and Installation of Mini Photovoltaic System

This joint project was conducted by RSS, the Public Security Department, Civil Defense Department, and Jordan Meteorological Department. The RSS carried out a survey on several types and brands of solar cells available in the international market. It had chosen two types for field testing and experimentation on the behavior of the system together with other system controls and storage. The findings were distributed to the concerned departments with the recommendations for the utilization of Jordanian-made batteries for storage.

Study on The Potential of Solar and Wind Energy Applications in Jordan

The project aimed at identifying the potential applications of solar and wind energy technologies according to Jordan's current and future needs. It was supported by the Government of the Federal Republic of Germany and conducted jointly by the RSS and the German Agency for Technical Cooperation (GTZ). The information pertaining to the subject were collected from various ministries and agencies, and thus programmed, evaluated and presented in the following volumes:

- Energy situation in Jordan.
- Assessment and analysis of basic energy needs to be supplied by solar energy.
- Assessment and analysis of available energy resources.

- State of the art survey on solar and wind energy related to Jordan's needs.

- Possible applications of solar energy in Jordan.

The volumes and annexes were published by RSS under publication No's(3)83/29, (3)83/30, (3)83/31, (3)83/32, (3)83/33, in May 1983.

THE SOLAR HOUSE

This project, which was carried out jointly by RSS and Kuwait Institute for Scientific Research (KISR), aimed at conducting research and experiments on solar space and water heating, and studying the various solar heating systems, solar collectors, storage systems and media and auxiliary systems. In addition to the technical study, the project aimed at studying the economic feasibility of the house. The outcome of the first year of operation of the solar house has been evaluated and presented in a technical report published by RSS under publication No.(3)83/33.

The first year results showed that the thermal load was considerably high and that the storage tank efficiency was low.

Measures were taken to remedy these weak points. The house was subjected to a second year testing period. In the second testing year period new heating devices, namely the fan coil units were used to replace the underfloor heating system that was used in the first testing year. The results demonstrated that the thermal load was reduced to about 46% and that the collector array integrated efficiency was maintained at approximately 22%.

ON-GOINING ACTIVITIES

Flat Plate Collectors

In the area of flat plate collectors (which was one of the first activities carried out by RSS) the RSS worked on the development of domestic solar water heaters according to the criteria that guarantee a low cost of unit, ease of installations and maintenance and the utilization of materials normally available in the country.

The RSS had designed and produced pilot systems in its workshop and signed three agreements with local manufacturers for mass production for the local market and for export.

In its continuous effort to develop flat plate collectors for medium and high temperature requirements the RSS is currently conducting a project that aims at upgrading its preciously designed flat plate collector with the aid of GTZ. The project involves the establishment of an Indoor-Outdoor test facility of a total area of 4 sq.m allowing the testing of such collectors according to international standard and consequently speeding up their development.

In parallel to the above mentioned project and in cooperation with the United Nations Industrial Development Organization (UNIDO), the RSS currently experimenting with large solar water-heater systems manufactured in its workshop and installed at one of the leading diary factory in Jordan and a hotel in Aqaba.

Wind Energy

The RSS has designed and conducted two prototype windmills (a mechanical and and electrical one) for demonstration and testing purposes. In cooperation with the Water Supply Corporation and Natural Resources Authority it has ordered a 12 KW WECS for water pumping purposes and installed it on a deep well (60m) at the site of Jurf El-Darawish in Ma'an district. The system was tested for two years. The weak points of the system, which were mainly in the control system were determined and remedied. The modified and developed system was then transferred to Al-Kharana Station, since the water demand in Jurf was drastically increased due to the direct connection of the well with the water network.

The RSS signed an agreement with GTZ to perform a project in the field of wind energy utilization for water pumping. The main aim of the project is to strengthen the RSS capabilities in wind energy technology so as to enable it to develop such technology in accordance with Jordan's wind resources and energy demands for water pumping and ultimately to produce such WECS locally. In the frame-work of this project different wells with dynamic levels varying between 30 m and 190 m and water demands between 30 m^3/d and 150 m^3/d will be equipped with various types of WECS. Mechanical, medium technology, and advanced technology electrical wind mills will be applied to pump water from the deepest well, where the maximum water supply is required. In parallel 16 measuring stations including advanced data logger are used to determine the wind energy potential in different parts cf Jordan.

Photovoltaic

The major research, development and demonstration activities in this field are being carried out by the SERC at RSS. In 1983 and in cooperation with European Community (EEC), an outdoor testing facility capable of testing photovoltaic systems and their components was established. This testing facility has contributed a great deal to the RSS activities concerning the proper selection of PV components and the design of the hereafter mentioned project.

In the field of water pumping the RSS under a contract with the Jordan Authority has completed the design and the erection of several pumping systems. Each photovoltaic system consists of photovoltaic cells, AC submersible pump and the necessary inverters.

In the field of remote-site electrification, a location has been supplied with 1.5 KW peak of photovoltaic to supply the basic energy needs of that location. The generated electrical energy will be utilized by a small refrigerator for the clinic, lighting of main streets, educational television and an emergency telephone. The project has been contracted to RSS by the Jordan Valley Authority.

In cooperation between RSS and GTZ a project that aims at designing mini photovoltaic systems to supply minimum electrical requirements for remote areas and for selected purposes is being planned. The project will involve the design, installation and testing of three different photovoltaic systems in three different locations. These tests will determine the technical and economic feasibility.

Geothermal

The Natural Resources Authority (NRA) had started in the last few years a survey to determine the availability of geothermal resources in Jordan. (NRA) was able in 1985 to determine the sites of 2 geothermal wells and is currently preparing for the drilling of these locations to an approximate depth of 1500 m. Based on the technical and economic feasibility of these wells as related to their utilization for electrical power generation, other sites will be explored.

Wind-Photovoltaic Hybrid System

The development objectives of this project is to enhance the social and economic development in remote and rural locations in Jordan by providing such locations with the basic energy needs and the associate opportunities resulting from the local manufacturing of simple energy producing equipments and energy requiring activities.

The project, which will be implemented by RSS under a grant from the Arab Gulf Fund, the UNDP and other Jordanian authorities involves installation of WECS and photovoltaic systems to be used in providing electrical power for water pumping, and electrical energy for the location. The project would lead to acquiring local skills in system design and evaluation of performance, in addition to its impact to widen the scale of application of Renewable Energy Technology in Jordan and other countries.

Thermal Insulation

The project aims at studying the possibility of utilizing thermal insulation in building and the consequent possibilities of local production from local available raw materials. In the scope of this project it is proposed to establish a laboratory to test water tightness materials and insulations.

RENEWABLE ENERGY APPLICATION IN JORDAN

Radio Telephone System Powered by Photovoltaic Cells

Jordan has installed 88 units of such a system in rural and remote desert locations. These units were acquired to satisfy the great number of villages and long desert roads in Jordan. The system is providing an efficient, reliable and cheap method of communication.

Solar Evaporation Ponds for Potash Recovery

The Jordanian Potash project is utilizing both the brine reserves of the Dead Sea and the solar energy to recover about 1.2 million tons per year of potash and other by-products. Three evaporation ponds have been constructed with a total area of 76 sq.km. The Dead Sea water is pumped into these ponds where the brine concentration and precipitation of salts take place. The total solar energy utilized in this process is estimated to be 3.73 x 10" KWh per year. This energy is equivalent to the energy available in 3.25 million tons of crude petroleum at the cost of 749.1 million U.S. Dollars.

Solar Water Heaters

The technology of solar water heater could be considered as a new one. The utilization of solar energy for domestic hot water began in Jordan after the oil crises in 1973. Two Jordanian workshops began in 1973 producing solar water heaters with an annual output of 50 units. In the following years the solar water heaters became popular and widely accepted and utilized. The number of workshops for local production increased in 1984 to a total of 37 workshops with a real production rate of 12284 units/year (consisting of 3 collectors with an area of approximately 3.2 sq.m.storage tank and the required piping) and a rated production capacity of 43924 units (the utilized part of the production currently 28%). The total aggregate investment in this industry as of 1985 is 1.63 mill JD.

The number of houses utilizing solar water heaters in Jordan by the end of 1984 was estimated to be 44700 (approx.13% of the total houses in Jordan).

Agriculture Green Houses

Jordan's utilizing of solar energy for agriculture application started late in 1970. The area cultivated by green houses in Jordan started with 50 Acres in 1970 and is estimated by 25000 Acres in the beginning of 1985. The main cultivated area was concentrated in the Jordan Valley, but with the improvement of technology and the validation of the economic feasibility of such application, the green houses is now spreading all over the country. Many manufacturers are currently producing the plastic cover needed for the agricultural houses and the irrigation pipes with a capacity sufficient for local use.

The RSS conducted with the Iraqi Solar Energy Research Center a joint project in this field. In the framework of this project a complete station consisting of 48 houses, with advanced measuring capacity has been established.

CONCLUSION

This paper has covered some of the main lines of activities concerning renewable energy in Jordan. It is hoped that these activities will pick up momentum in the near future. RSS program is flexible in its approach and is kept amenable to revision as new results or understandings are developed. The emphasis on R & D by RSS has been on its highest priorities.

DOMESTIC SWH APPLICATIONS; JORDAN EXPERIENCE

ENG. KHALED TOUQAN

ABSTRACT

This paper summerizes the Jordan experience in Domestic and Industrial Solar Water Heater (SWH) Applications; starting from the solar energy situation in Jordan, especially SWH first applications; passing through SWH industry in prospective, ending with the role of the Royal Scientific Society (RSS) in this field such as the research and development work conducted on flat plate collectors (FPC) & SWHs in cooperation with different local and foreign organizations, and the construction of pilot plants for testing and evaluating SWH systems in small and large scale applications.

INTRODUCTION

Jordan imports all its energy needs whereas its total oil imports have reached more than 90 % of its total exports earning in the last few years, until 1986 where this number dropped to 47 % because of the drastic decrease in oil prices. On the other hand, Jordan is blessed with a good renewable energy resources, an important one being the solar energy with an average daily radiation of about 5.5 KWh/m2 and a sunshine duration of about 3300 hour/year. Thus, it is understandable that research and development activities are directed to explore, develop and utilize the solar energy resource.

Since the very begining of the development programme the RSS had devoted extensive efforts towards the development and optimization of SWHs for domestic and industrial uses. Many prototypes were manufactured and tested and the results were very promising.

The basic criteria for developing the local know-how in the field of SWH applications in Jordan are the following:

- Strengthening of local manpower capabilities in this field.
- Development of equipment and systems to the most optimum potential adequate enough for application and use in Jordan.
- Promotion of local manufacturing of components and systems through appropriate design suitable for local conditions.
- Involvement of relevant institutions in all major stages of research projects.
- Testing of products and applications with emphasis on the end-user's needs and involvement.

HISTORICAL BACKGROUND

The utilization of solar energy for domestic hot water began in Jordan after the oil crises in 1973, while the RSS work in solar energy research started at the Mechanical Engineering Department (MED) early in 1972. The RSS designed simple solar water heaters according to the following criteria:

- Low cost of units.
- Ease of installation to existing structures.
- Ease of maintenance.
- Use of materials normally available in the country.
- Ease of production using simple machine shop equipment and moderately skilled labor.

The workshop of the MED produced SWH units that were installed at different locations in Jordan. The experience gained in this process lead to lots of changes and final designs.

The RSS collector is composed of the following parts:

- Cover made of 4mm single white glass.
- Fitted fins absorber made of steel plate 0.9 mm, treated with flat black paint.
- Galvanized steel pipes of ½ " diameter as risers connected to 1" galvanized steel pipes as headers.
- Fiberglass insulation.
- Casing made of 0.7 mm galvanized steel plates.

The basic unit commonly used consists of three collectors (1.2 m^2 each) with 150 liters storage tank, and 1 m^3 cold water tank as seen in figure (1):

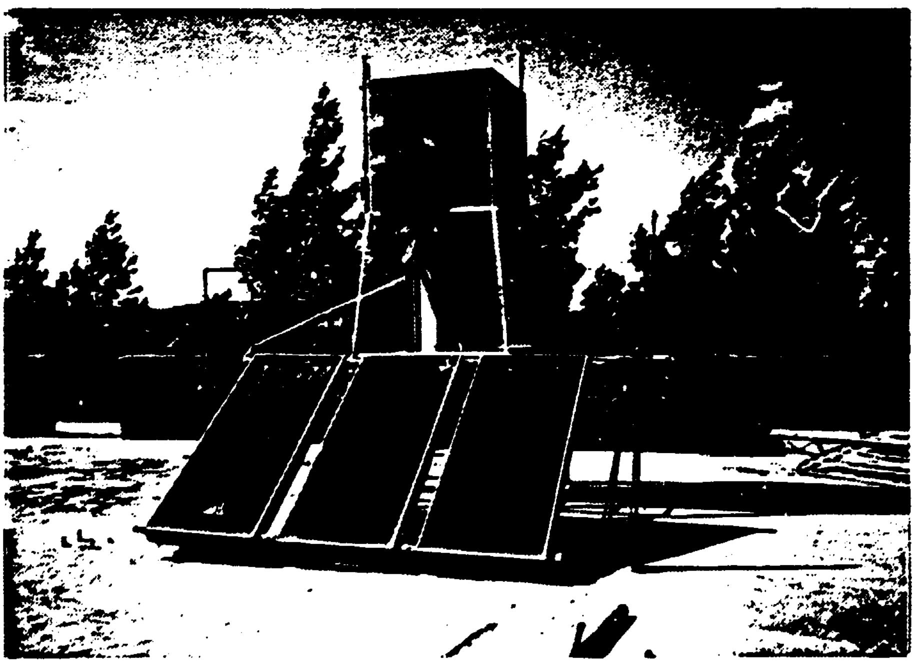

Fig. (1): RSS design of thermosyphon SWH

SWH INDUSTRY IN PROSPECTIVE

It was not until 1979 that people started to accept solar energy utilization as a form for heating water. The last survey shows that by the end of 1988 more than 40 manufacturers of solar water heaters were existing in Jordan, 3 of which are large factories while the rest are normal workshops. The total production rate of these manufacturers is around 15,000 unit / year, while the rated production capacity is around 50,000 unit / year, (the utilized part of the production capacity is currently 30 %).

A statistical survey made by the Jordan Electrical Authority shows that 25 % of the total no. of houses in Jordan utilizes SWH for domestic use, which means about 100,000 unit; while this number is expected to reach 250,000 unit by the year 2000, which means about 50 % of the total number of houses in Jordan at that year.

The convensional energy savings using the data at the end of 1986, (if all the houses were to use SWH for heating 150 liter at 55 °C with 50 % electrical auxiliary heating) would have been approximately equal to 27,3 million J.D / year with reference to the cost of production, and 34 million J.D / year reference to the selling cost.

It is important to mention here that the pay-back time of SWH (3 collectors, 150 liter storage and 1 m^3 cold water supply including racks, insulation and piping) is about 5 years while the expected life of the SWH is at least 15 years when providing needed simple maintenance.

ROLE OF THE RSS IN THIS FIELD

Considering the importance of energy, and as a result of the remarkable success in developing the use of solar energy for different purposes, the RSS formaly established the Solar Energy Research Center (SERC) on November 1983 with the objective of placing more emphasis on the research & development work in the field of renewable energy.

A main section of the SERC is the solar collector application section which has the following aims and functions:

1. Conducting research and studies related to the equipment and instruments used in solar collector applications and designing solar collector application equipment applicable in Jordan;

   Different local and imported SWH are put under testing at the RSS field with respect to Jordan's weather conditions. All the results of these research and studies are published and given to whom it may concern.

Fig (2): SWH testing field at RSS site.

2. Developing solar collector applications equipment and instruments;

The RSS is currently conducting a project that aims at upgrading its previously designed FPC and SWH with the aid of the German Federal Ministry for Economic Cooperation (BMZ) through the German Agency for Technical Cooperation (GTZ). The RSS had successfully developed FPCs for different applications taking into consideration low cost and high efficiency, and signed three agreements with local manufacturers for mass production for local market and exports under the supervision and control of the RSS.

3. Constructing pilot testing stations for evaluating solar collector applications equipments;

In parallel to the previously mentioned project with GTZ, the RSS has conducted a project in cooperation with the United Nations Industrial Development Organization (UNIDO), aiming for the design and manufacturing of SWH systems for Industrial and Large Applications. The first part of this project which consists of 128 m^2 of collectors, i.e. 96 FPC, and $5m^3$ storage tank was installed and tested at a dairy factory located in a small industrial town called Ruseifa, north of Jordan, where hot water quality 40 - 45°C temperature is needed for dissolving powder milk to produce reconstituted milk, also hot water of 60 °C temperature is needed for container washing purposes.

The second part of this project which consists of 180 m^2 of collectors, i.e 90 FPC, and a 12 m^3 storage volume was installed and tested at a hotel in Aqaba, south of Jordan. The system was installed as a preheater to the existing boiler system where a thermostat controls the temperature of hot water inside the existing cylinder, which is connected to the boiler through a heat exchanger.

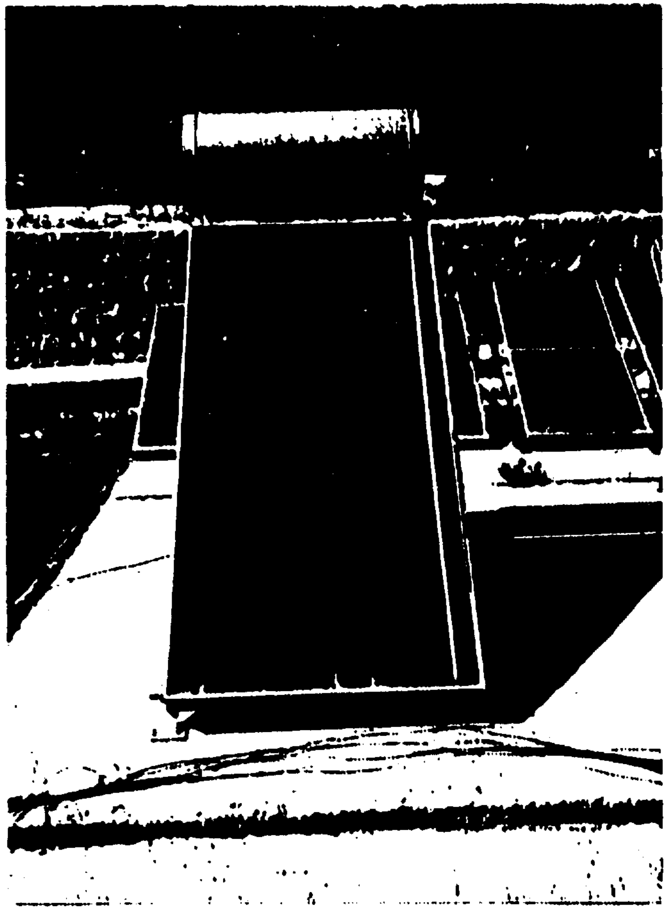

Fig. (3): 100 liters unit developed at RSS.

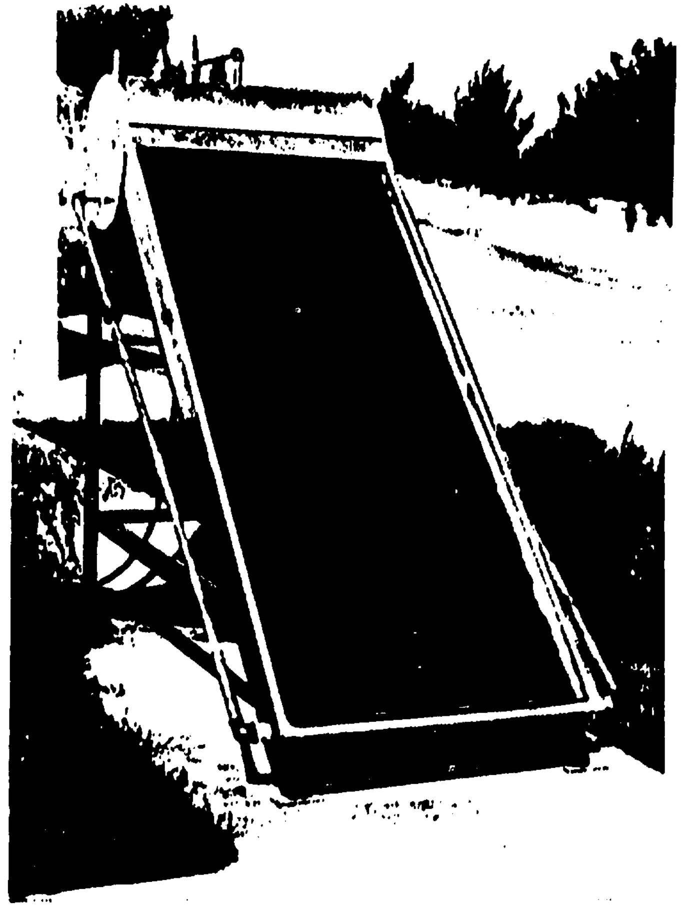

Fig. (4) 60 liters unit deveoped at RSS.

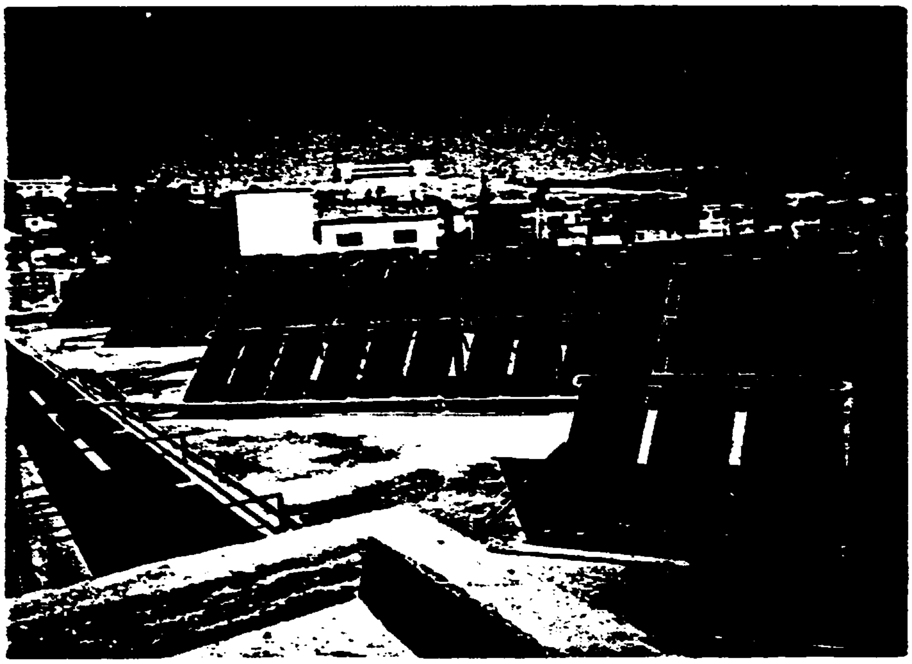

Fig (5): Jordan Dairy Factory SWH system.

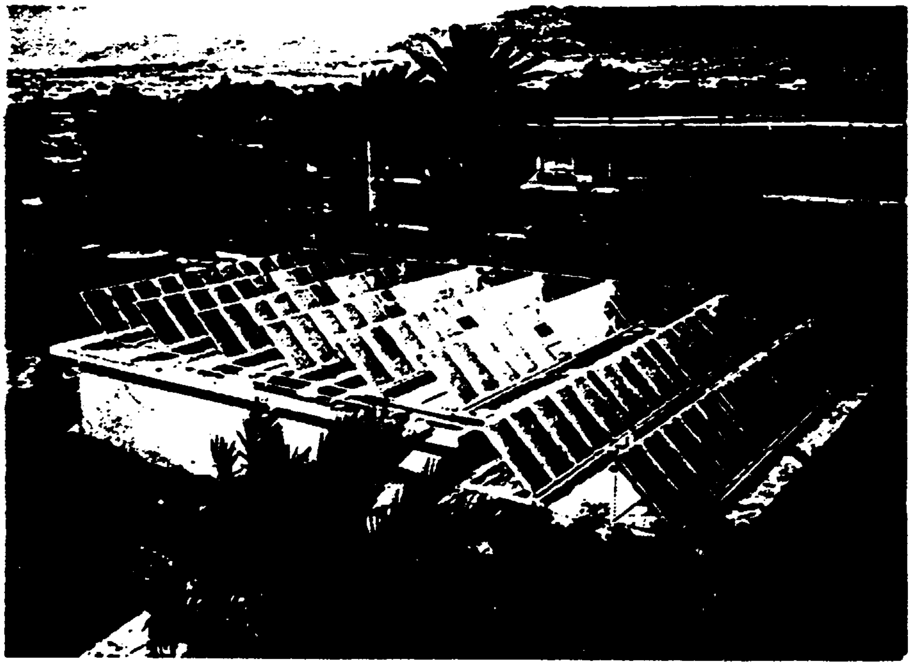

Fig. (6): Coral Beach Hotel SWH system.

The analysis of the measured and calculated data of the two SWH systems showed that both systems are operating with good effeciences and performance, achieving significant energy savings; for the hotel more than for the factory because of the higher and continuous consumption of hot water, which aslo allow for more energy collection and higher system effeciency.

4. Testing and issuing special certificates of solar collector efficiency according to the national and international standards;

As the simpilicity of producing the FPCs has made many workshops indulge in manufacturing them without regard to the minimum specifications requirements, which had negatively affected the economic feasibility of the utilization of collectors at the consumer's level, the RSS has erected an Indoor - Outdoor Collector Test Facility equipped with the latest instrumentation and data evaluation systems, which is used to determine FPCs effeciency under specified conditions, and to evaluate the energy output of these collectors at different inlet temperatures.

The Test Facility is composed of the collector test rack, which is automatically oriented towards the sun by the azimuth and elevation drives, controlled by electronic sun-tracking system; and the solar simulator (1.75m x 2.25m) that is used for indoor testing, where the daily radiation profiles of the sun are programmable and computer controlled, with irradiation data adjustable from 0 to 1100 W/m^2.

5. Cooperation with Arab Countries and others;

The RSS has many cooperation agreements with other Arab countries. A solar house project was carried out jointly by RSS and Kuwait Institute for Scienitific Research (KISR), aimed at conducting research and experiments on solar space and water heating, and studying the various solar heating systems, solar collectors, storage systems and media and auxiliary systems. In addition, to the technical study, the project aimed at studying the economic feasibility of the house.

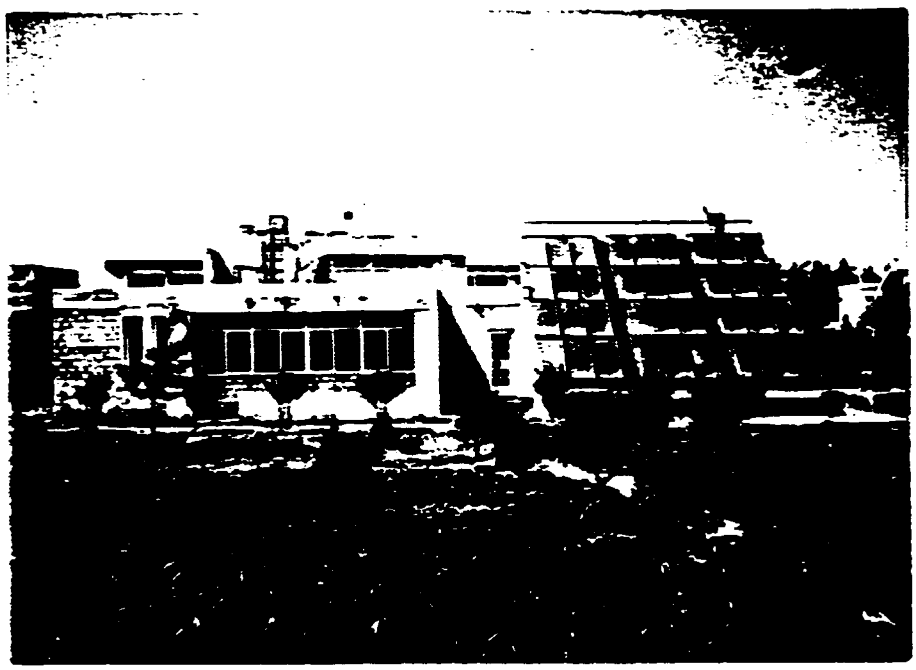

Fig. (7): Jordan Solar House

Another ongoing project in cooperation with the Academy of Scientific Research & Technology in Egypt, aims at developing SWH for domestic use according to the available equipments and materials in both countries.

A third project is now conducted in cooperation with the Solar Energy Research Center in Iraq. A main part of this project will be building a solar house taking into consideration the passive and active features.

6. Participating in the training of local manpower working in local industries related to solar collector applications equipments and instruments;

A continuous back up is provided by RSS to local manufacturing of SWHs. Training courses and seminars are always held for both engineers and technicians in cooperation with national and international authorities to help in the improvement of their products, designs, and installations.

7. Providing specialized technical consultation and services for both private and public sectors;

Whenever is needed, design studies and consultation are provided for different sectors for all solar collector applications covering water heating, space heating, and swimming pool heating.

CONCLUSION

The paper has covered some of the main lines of the situation concerning SWHs in Jordan, where due to the fact of high solar radiation in Jordan, SWHs commonly used in heating water for domestic and industrial purposes were found to be economically feasible, and can be considered from the point of energy saving. The paper also described in brief the RSS activities in the field of solar energy applications where the development of SWH applications both in Jordan and other developing countries showed a good example of the RSS success in this field.

Nowadays, Jordan has passed the stage of prototype production and can offer commercial, technically well-designed and tested SWH systems for both domestic and industrial applications based on its own experience and local know-how. An important feature is that the past and current research and development work carried out in Jordan has been selected and organized in such a manner so that the equipments utilizing energy resources (like SWH) should have high possibilities for local production given Jordan's manufacturing constraints.

UTILIZATION OF SOLAR WATER HEATERS FOR INDUSTRIAL APPLICATIONS (PART I)

JORDAN DAIRY COMPANY SOLAR WATER HEATING SYSTEM

ENG. KHALED TOUQAN

ABSTRACT

This paper presents in brief a description of the first experimental large solar water heating system that was designed, manufactured, installed, and tested by the Royal Scientific Society in Jordan with the aid of the United Nations Industrial Development Organization. This system which is considered as a logical follow-up of the activities carried out during recent years in the field of domestic solar water heaters was installed as a direct hot water system for the Jordan Dairy Factory to be utilized in manufacturing processes. This system illustrates a practical example of a low cost useful utilization of solar water heaters in industrial applications.

INTRODUCTION

The following is a description of the first large Solar Water Heating (SWH) system installed for the Jordan Dairy Factory in Ruseifa, north-east of Jordan. The system is to provide hot water for milk production.

This system is considered as the first part of the project "Manufacturing of Solar Water Heater for Industrial Applications", being executed by the Royal Scientific Society (RSS) in Amman - Jordan. with all equipment and materials funded by the United Nations Industrial Development Organization (UNIDO).

SITE SELECTION

A survey was made to identify the possible candidate factory for this pilot project that will utilize the SWH system for its needs. Jordan Dairy Factory was chosen for many reasons :

- Its suitable consumption of hot water.
- The need for hot water in certain processes.
- Its suitable location and the available area for the installation of the flat plate collectors required in the design.

To give a quick description of the factory we can say that Jordan Dairy Factory is located in a small industrial town named Ruseifa. It produces milk, cheese, yogurt, ice cream and various juice drinks.

SYSTEM DESIGN

The solar heating of water was an improvement to the process of dissolving the imported powder milk that produce reconstituted milk. Cold water was used for this process, however in order to reduce process time and consequently reduce electrical consumption of blenders, hot water quality of 40-45° C temperature is needed. The hot water is also needed for container washing purposes with water quality of 60° C. The solar system is thus used to provide these two requirements.

According to the above requirement, a complete design was made based on the f-chart method and based on the factory estimated hot water consumption. The solar collector area was found to be 128 m^2; i.e. 96 RSS Flat Plate Collectors, and the storage volume was found to be 5 m^3 (40 liter/m^2 of collectors), in order to get the optimum value of (f) which represents the SWH system contribution in the total hot water load.

The piping system was designed according to the reverse-return method to assure balanced flowrate . The piping diameters were all found based on a water flowrate of 0.02 Liter/m^2.sec, also the circulating pumps capacity was found to give the required flowrate and head. Figure-1 presents a schematic diagram of the system, showing its components and operation.

SYSTEM MANUFACTURING

Manufacturing of collectors, Racks, storage tank, and make up water tank was carried out at the mechanical engineering workshop at the Royal Scientific Society as follows:

1. Flat plate collectors

- Cover: Normal window glass has been used. In addition, and to protect glass from breakage and to protect the collector from air and rain, rubber seals between glass and case have been used.

- Case : The case was made of 0.7 mm galvanized steel sheets.

- Risers, headers, and absorber plate: Risers and headers were made of ½" and 1" galvanized seam welded pipes, while the absorber plate was made of 0.9 mm black steel sheets.

- Insulation: Fiberglass (rolls) were used to insulate the bottom and sides of the case to decrease amount of heat losses.

- Paint: Simple flat black paint was applied to treat absorber plates and risers.

2. Racks

Racks were made of 45 x 45 x 3 mm iron angle. They had a 45° tilt angle.

3. Storage tank

The 5 m^3 cylindrical storage tank was made of 3 mm thickness galvanized steel sheet metal. Rolled sheets were arc welded to form the sleeve of the tank. The top and bottom of the tank

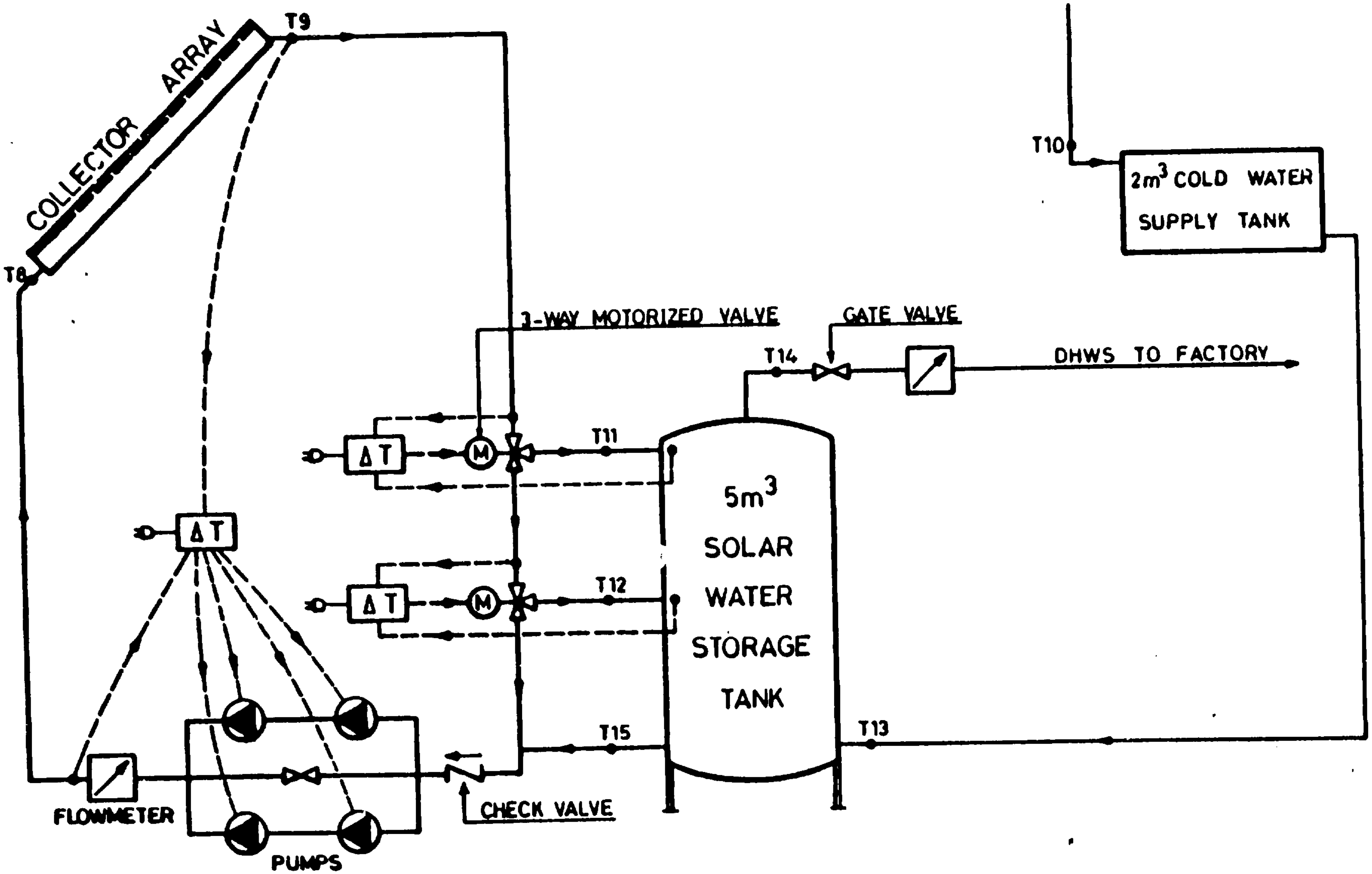

FIG. (1): SCHEMATIC DIAGRAM. OF THE JORDAN DAIRY FACTORY SWH SYSTEM.

are of the concave type so as to give more rigidity to the tank; stiffeners were welded inside the tank for the same purpose. Internally threaded nipples were welded on the sides bottom and top of the tank. A manhole was put on the side of the tank to allow serviceability. Three legs at the bottom of the tank were provided for stability and the desired spacing for insulation. The tank was 2.5 m in hight.

4. **Cold water supply tank**

A 2 m^3 tank was made of 1.5 mm galvanized steel sheet. It has three nipples, two on the side (inlet and outlet), and one at the bottom for the purposes of draining and cleaning. The tank was painted with a glossy black paint.

SYSTEM INSTALLATION

The installation of system components took place as follows:

1. **Racks**

For convienence 30 % of Racks were welded on site. Racks were directed towards the south and were split into four sets, so that each set would hold 24 collectors.

2. **Collector array and piping**

The collectors were mounted in a diagonal position, facing south. The basic unit consists of 3 panels. In order to avoid excessive temperature and therefore an increase in heat loss, a maximum of two units were connected in series. This gives a sub-module of 6 panels. Every two of these sub-modules share the inlet and outlet connection.

Given the lattitude of Ruseifa at 32 deg N, the collector set had been tittled at an angle of lattitude + 10 deg = 42 deg, for better winter utilization of the system.

Outlets of all sets of collectors drop into one line in which water goes to the storage tank through two 3 - way valves depending on temperature difference; or back through 4 pumps (each 2 in series) to the collectors again. An automatic air vent were installed at each drop point to prevent air block in the system. All pipes were insulated with Aramflex insulation and covered by an adhesive aluminum foil to protect it from adverse weather conditions. The pipes were also supported to prevent any possible bending.

3. **Storage tank**

The 5 m^3 storage tank which has a cylindrical shape was installed vertically to achieve better temperature stratification. To prevent overnight cooling, a good tank insulation was applied using 15 cm of polyurethane foam. The thermocouples for temperature measuring were all put in places before insulation took place.

4. **Cold water supply tank**

The 2 m^3 supply tank was installed at a higher level above the system such as the bottom of the cold water supply tank was almost as high as the top of the hot water storage tank, in order to keep it completely filled during factory consumption. The cold water supply tank was connected to main water supply of the factory through a pressure pump.

5. **Pumps and controls**

Two 3-way valves controlled by two temperature differential controllers were installed to allow the water coming from the collector array to enter the storage tank through either the top or mid inlets; if it is sufficiently warmer than the water at the corresponding level of the tank, or return back to the collectors again. The locations of their sensors are shown in figure-1.

Four stainless steel pumps (two in series and two in parallel) controlled by a temperature differential controller were installed at the water line going to the collectors, and operate according to the temperature difference between inlet and outlet of the collectors array.

6. Instrumentation

A magnatic flowmeter was installed after the pumps to measure the water flowrate through the collector loop, while another flowmeter was installed on the water pipe going to the factory to measure the factory consumption of hot water, from which we could calculate the energy supplied to the factory by the solar system.

Two solarimeters with and without a shielding ring were installed to measure diffused and global radiation. These two solarimeters were installed at the same tilt angle of the collectors.

TESTING AND EVALUATION

In order to determine the performance of the system, the system was tested for one year. Different parameters were monitored and recorded, while other parameters were calculated.

The measured parameters include the following:

- Temperature at different locations on the wall and ports of the storage tank.
- Temperature difference across the collector loop.
- Temperature of cold supply water.
- Water flowrate in the collector loop and the pipeline going to the factory.
- Radiation measurement which includes global and diffused radiation.
- Ambient temperature.
- Percentage of time during which any of the two 3-way valves was open.
- Percentage of time during which pumps were in operation.

While the calculated quantities are:

1. Rate of energy collected in the solar collector array.

2. Rate of energy to storage tank through each one of the two electric valves.

3. Rate of energy supplied from the storage tank to the factory.

The monitoring system was based on an HP - 3497A data acquisition unit, controlled by an HP - 85 microcomputer. Copper/constantan thermocouples were used to measure temperatures at different parts of the system. All sensors were scanned over 10 seconds and the data was integrated at hourly intervals. The hourly values were stored on flopy disks, which are then removed for data analysis and evaluation.

The tables shown in Appendix - A presents an example of the data recorded and calculated for each day during the year of testing.

CONCLUSIONS

The following are some general conclusions that could be obtained from this pilot plant on large SWH systems.

1. The system is capable of producing hot water of quality more than 50°C throughout the year eventhough no high radiation would occur for several days.

2. An inspection of the long term test reading shows the following general results concerning the performance of the system :

   a) the net daily energy collection varies from about 100 to 250 kWh, averaging some 150 kWh,

   b) the daily amount of energy supplied to the factory varies between about 0 and 200 kWh,

   c) the collection efficiency at the time of peak irradiance can reach 0.4 and often exceeds 0.3, while the long term average is about 0.24,

d) tne daily average storage tank efficiency is about 0.79,

e) the daily average efficiency of the whole system is about 0.15.

3. It is always more feasible to have high consumption of hot water so as to get better efficiency of both collector and storage subsystems. A main result would be a decrease in losses, where system will be operating at lower temperature, which will result on a temperatu~e difference on the collector loop that allows the electric valves to open and this will result in an increase in energy entering the storage tank and higher collector efficiency.

4. As for the two electric 3-way valves, it is always better to have mid. valve open (always open or operating by a temperature differential controller) and upper is closed but not the reverse. The mid. valve will allow 2/3 of tank to be at high temperature while the upper will only allow 1/3 of the tank to be at high temperature. This conclusion is directly affected by the irregular and low hot water consumption by the factory.

5. The collector have shown good performance even after one year of operation, with the existance of very small problems:

   a) some outgassing occurs from the fiberglass insulation,

   b) some condensation occurs in the inner face of the glass due to humidity effects,

   c) no corrosion problems occured on the absorber plates,

   d) the area of installation is very dusty which requires cleaning of glass every while to asure good collector performance.

6. Better load matching and higher water consumption will improve the system efficiency which is expected to be acheived by the second prototype system.

7. In fact, this experimental installation of the first large solar water heater in Jordan forms a starting point for better and more efficient systems which will be installed in the future.

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COLLECTOR APPLICATION SECTION
JORDAN DAIRY COMPANY SOLAR HOT WATER SYSTEM

HOURLY AVERAGE DATA

DATE: 27/05/86

HOUR	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
00	-	-	-	-	-	-	0	0	0	17	0	0	0	-	0	57	57
01	-	-	-	-	-	-	0	0	0	15	0	0	0	-	0	57	57
02	-	-	-	-	-	-	0	0	0	14	0	0	0	-	0	57	57
03	-	-	-	-	-	-	0	0	0	13	0	0	0	-	0	57	57
04	-	-	-	-	-	-	0	0	0	13	0	0	0	-	0	57	57
05	-	-	-	-	-	-	0	6	0	12	0	0	0	-	0	57	57
06	-	-	-	-	-	-	0	57	37	14	0	0	0	-	0	57	57
07	-	-	-	-	-	-	0	209	68	17	0	0	0	-	0	57	57
08	19	26	-	-	-	-	41.17	420	92	19	.02	0	0	-	0	57	57
09	29	45	-	-	-	24	40.68	628	108	22	.07	0	0	67	594	57	50
10	41	61	27	70	64	25	46.23	799	118	25	.34	.06	.1	62	412	50	51
11	49	72	28	78	66	-	45.16	864	133	27	.33	.1	.15	-	0	51	57
12	48	68	40	79	71	-	45.9	870	148	27	.48	.07	.19	-	0	57	61
13	52	69	36	79	73	26	45.71	871	144	27	.45	.09	.09	68	392	61	65
14	57	68	-	-	-	-	47.63	802	136	27	.11	0	0	-	0	65	65
15	68	77	-	-	-	-	46.34	642	125	27	.06	0	0	-	0	65	65
16	64	71	-	-	-	-	33.01	437	112	27	.01	0	0	-	0	65	65
17	-	-	-	-	-	-	0	212	86	25	0	0	0	-	0	65	65
18	-	-	-	-	-	-	0	51	46	23	0	0	0	-	0	65	64
19	-	-	-	-	-	-	0	7	0	21	0	0	0	-	0	64	64
20	-	-	-	-	-	-	0	0	0	19	0	0	0	-	0	64	64
21	-	-	-	-	-	-	0	0	0	18	0	0	0	-	0	64	64
22	-	-	-	-	-	-	0	0	0	18	0	0	0	-	0	64	64
23	-	-	-	-	-	-	0	0	0	17	0	0	0	-	0	64	64
TOTAL								6875	1352						1398		

1) COLLECTOR INLET TEMPERATURE
2) COLLECTOR OUTLET TEMPERATURE
3) BOTTOM STORAGE OUTLET
4) TOP STORAGE INLET
5) MID STORAGE INLET
6) BOTTOM STORAGE INLET FROM COLD WATER SUPPLY
7) COLLECTOR FLOW RATE (LPM)
8) TOTAL RADIATION (WATT/sq. m)
9) DIFFUSE RADIATION (WATT/sq. m)
10) AMBIENT TEMPERATURE
11) PERCENTAGE OF TIME DURING WHICH PUMPS WERE ON
12) PERCENTAGE OF TIME DURING WHICH UPPER VALVE WAS OPEN
13) PERCENTAGE OF TIME DURING WHICH LOWER VALVE WAS OPEN
14) TEMPERATURE OF HOT WATER TO FACTORY
15) FACTORY CONSUMPTION OF WATER (LITER)
16) INITIAL AVE. TEMP. OF STORAGE TANK
17) FINAL AVE. TEMP. OF STORAGE TANK

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COLLECTOR APPLICATION SECTION
JORDAN DAIRY COMPANY SOLAR HOT WATER SYSTEM

HOURLY AVERAGE DATA & ENERGY

DATE: 27/05/86

HOUR	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)
00	30	47	54	57	58	58	60	69	75	57	-	0	0	0	0
01	30	46	54	57	58	58	60	69	74	57	-	0	0	0	0
02	30	46	54	57	58	58	60	68	74	57	-	0	0	0	0
03	30	46	54	57	58	58	60	68	74	57	-	0	0	0	0
04	31	46	54	57	58	58	60	68	73	57	-	0	0	0	0
05	31	46	54	57	58	58	60	68	73	57	-	0	0	0	0
06	31	45	53	57	58	58	60	68	73	57	-	0	0	0	0
07	31	45	53	57	58	58	60	68	73	57	-	0	0	0	0
08	31	45	53	57	58	58	60	68	72	57	-	495	0	0	0
09	29	37	49	55	57	58	59	65	70	54	29	3509	0	0	30068
10	27	27	36	50	56	58	59	59	63	49	20	21301	7796	11687	14452
11	27	32	48	55	59	60	60	61	67	53	-	34802	14906	18239	0
12	34	51	56	60	62	64	64	64	71	59	-	30637	7801	17597	0
13	35	54	59	61	65	67	68	68	70	62	31	23313	13284	8967	2348
14	43	58	60	64	67	69	69	69	73	65	-	4157	0	0	0
15	43	58	60	64	67	69	69	69	73	65	-	1883	0	0	0
16	43	58	61	64	67	69	69	69	72	65	-	187	0	0	0
17	43	58	61	64	67	69	69	69	72	65	-	0	0	0	0
18	43	58	60	64	67	69	69	69	72	64	-	0	0	0	0
19	43	58	60	64	67	69	69	69	71	64	-	0	0	0	0
20	42	58	60	64	67	69	69	69	71	64	-	0	0	0	0
21	42	57	60	64	67	69	69	69	71	64	-	0	0	0	0
22	42	57	60	64	67	69	69	69	71	64	-	0	0	0	0
23	42	57	60	64	67	69	69	69	70	64	-	0	0	0	0
TOTAL												120284	43787	56490	46868

18-26) WALL TEMPS. OF STORAGE TANK AT 9 POINTS EQUALLY SPACED ALONG A VERTICAL LINE, WITH 18 IS TEMP. AT THE LOWEST POINT AND 26 IS TEMP. AT THE HIGHEST
27) AVE. TEMP. OF STORAGE TANK
28) TEMP. OF COLD WATER TO SUPPLY TANK
29) SOLAR ENERGY COLLECTED (WATT.HR)
30) ENERGY TO STORAGE THROUGH UPPER VALVE (WATT.HR)
31) ENERGY TO STORAGE THROUGH LOWER VALVE (WATT.HR)
32) ENERGY FROM STORAGE TO USER (WATT.HR)

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COLLECTOR APPLICATION SECTION
JORDAN DAIRY COMPANY SOLAR HOT WATER SYSTEM

DATA EVALUATION

DATE: 27/05/86

HOUR	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
00	0	0	-	-	0	0	0	0	331646	-243	243	-
01	0	0	-	-	0	0	0	0	331403	0	0	-
02	0	0	-	-	0	0	0	0	331403	-563	563	-
03	0	0	-	-	0	0	0	0	330840	-286	286	-
04	0	0	-	-	0	0	0	0	330554	-575	575	-
05	6	6	-	-	0	0	0	0	329979	0	0	-
06	57	20	-	-	0	0	0	0	329979	-243	243	-
07	209	141	-	-	0	0	0	0	329736	-594	594	-
08	420	328	3	417	0	0	0	0	329142	-8	8	.01
09	628	520	27	601	0	0	0	30068	329134	-36495	6427	.04
10	799	681	166	633	7796	11687	19483	14452	292639	5031	0	.21
11	864	731	272	592	14906	18239	33145	0	297670	33145	0	.32
12	870	722	239	631	7801	17597	25398	0	330815	25398	0	.28
13	871	727	182	689	13284	8967	22251	2348	356213	19903	0	.21
14	802	666	32	770	0	0	0	0	376116	-391	391	.04
15	642	518	14	628	0	0	0	0	375725	0	0	.02
16	437	325	1	436	0	0	0	0	375725	-570	570	-
17	212	126	-	-	0	0	0	0	375155	0	0	-
18	51	5	-	-	0	0	0	0	375155	-904	904	-
19	7	7	-	-	0	0	0	0	374251	-582	582	-
20	0	0	-	-	0	0	0	0	373669	-214	214	-
21	0	0	-	-	0	0	0	0	373455	-233	233	-
22	0	0	-	-	0	0	0	0	373222	-628	628	-
23	0	0	-	-	0	0	0	0	372594	-136	136	-
TOTAL	6875	5523	936	5397	43787	56490	100277	46868		40812	12597	

1) TOTAL SOLAR INCIDENT (WATT.HR/sq.m)
2) DIRECT SOLAR INCIDENT (WATT.HR/sq.m)
3) SOLAR ENERGY COLLECTED (WATT.HR/sq.m)
4) COLLECTOR HEAT LOSS [1-3] (WATT.HR/sq.m)
5) ENERGY TO STORAGE THROUGH UPPER VALVE (WATT.HR)
6) ENERGY TO STORAGE THROUGH LOWER VALVE (WATT.HR)
7) ENERGY TO STORAGE [5+6] (WATT.HR)
8) ENERGY FROM STORAGE TO USER (WATT.HR)
9) INITIAL STORAGE TANK STATUS (WATT.HR)
10) HOURLY INCREASE IN STORED ENERGY (WATT.HR)
11) STORAGE HEAT LOSS [7-8-10] (WATT.HR)
12) HOURLY INTEGRATED COLLECTOR EFFECIENCY [3/1]

A) DAILY EFF. OF SOLAR COLLECTOR SYSTEM = .11

B) DAILY EFF. OF STORAGE TANK = .87

C) DAILY SOLAR RADIATION (WATT.HR) = 877800

D) DAILY COLLECTED ENERGY (WATT.HR) = 119508

UTILIZATION OF SOLAR WATER HEATERS FOR INDUSTRIAL APPLICATIONS (PART II)

CORAL BEACH HOTEL SOLAR WATER HEATING SYSTEM

ENG. KHALED TOUQAN

ABSTRACT

This paper describes in brief the second experimental large solar water heating system that was designed, manufactured, installed, and tested by the Royal Scientific Society in Jordan, with the aid of the United Nations Industrial Development Organization. This system was installed as a preheater to the existing boiler system used for domestic water heating for a hotel. This system consists of a second practical example of low cost useful utilization of solar water heaters for industrial and large applications.

INTRODUCTION

The following presents a description of the second large Solar Water Heateing (SWH) system installed as a preheater at the Coral Beach Hotel in Aqaba, south of Jordan. The system is to provide hot water for domestic use of the hotel rooms, kitchen, and laundry.

This system is a second part of the project "Manufacturing of Solar Water Heater for Industrial Applications", being executed at the Royal Scientific Society (RSS) in Amman - Jordan, with all equipment and materials funded by the United Nations Industrial Development Organization (UNIDO).

SITE SELECTION

First a decision was made to install a second SWH system for a hotel, the Coral Beach Hotel was chosen for many reasons :

- Its location in one of the hotest areas in Jordan.

- A reasonable quantity of oil is used for water heating. Therefor a significant oil saving could be acheived by installing the solar system.

- There is a space for the collector array with area as required in the design on the roof of the single-storey boiler house and service building.

- There is adequate space for the storage tank (6 m^3) near the boiler room.

The Coral Beach Hotel is located at the sea side in Aqaba, south of Jordan. It has 95 rooms, it is low-rise (3-storey) building. It has a boiler that uses 4900 liters of deisel oil per month to produce the needed hot water for hotel uses.

SYSTEM DESIGN

A complete design was made based on the f-chart method, and based on the hotel's estimated hot water consumption which was calculated from the deisel consumption, assuming a boiler efficiency of about 0.50. The solar collector area was found to be 180 m^2, i.e. 90 RSS new design Flat Plate Collectors, and a storage tank volume of 6 m^3 taking into consideration the available 6 m^3 hot water cylinder, so this will give a total storage volume of 12 m^3, in order to give the optimum value of (f = 0.77) which represents the SWH system contribution of the total hot water load.

The piping system was designed according to the reverse-return method and based on water flowrate of 0.02 liters/m^2.sec. The pumps capacity was also calculated to give the required flowrate and head. Figure-1 illutrates a schematic diagram of the system, showing its components and operation.

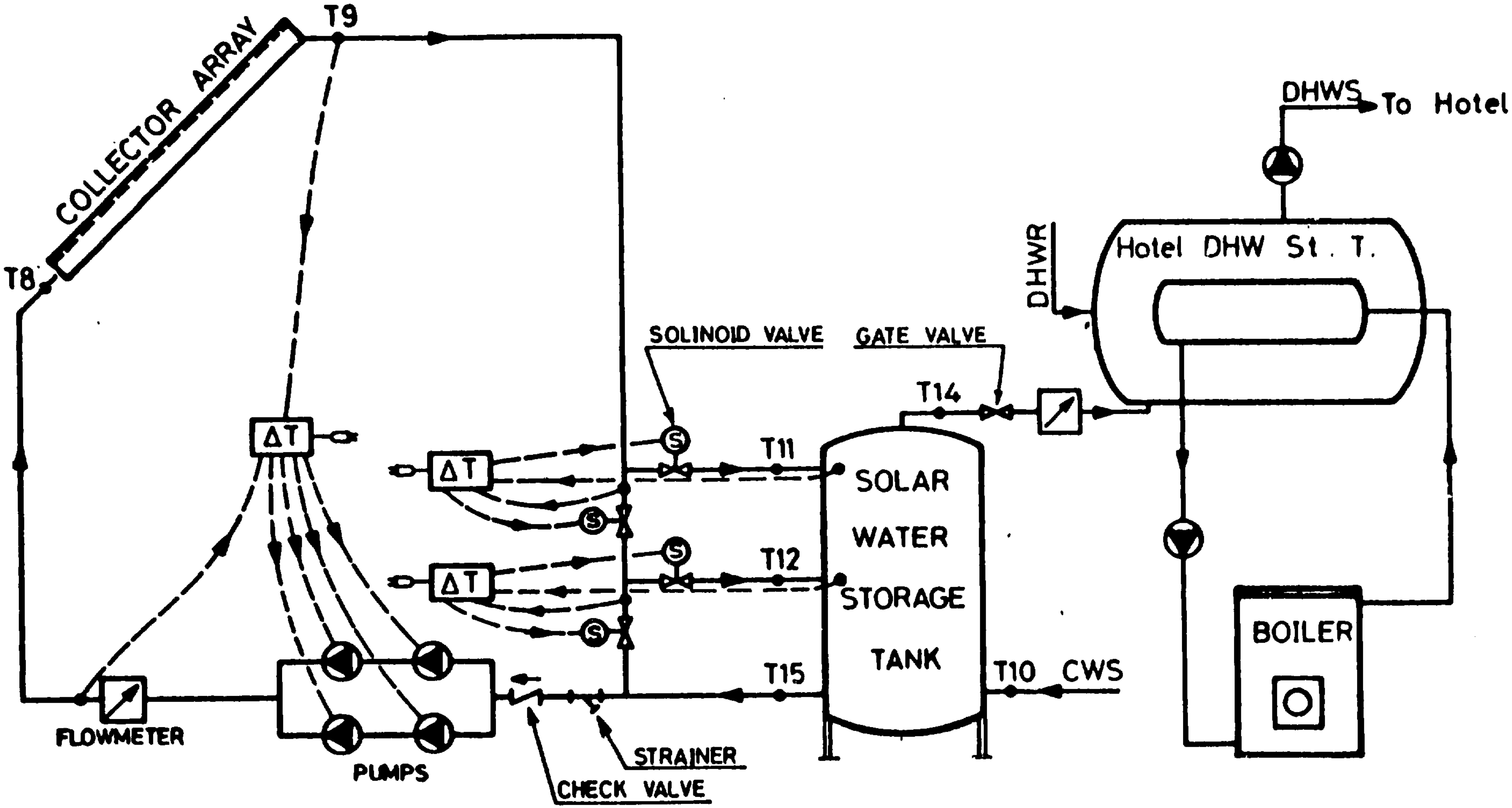


FIG. (1): SCHEMATIC DIAGRAM OF THE CORAL BEACH HOTEL SWH SYSTEM.

The solar water heater system will be a preheater to the existing boiler system, where a thermostat controls the temperature of hot water inside the existing cylinder which is connected to the boiler through a heat exchanger. The solar system is to provide the hot water from the storage tank (6 m^3) to the hotel hot water cylinder (also 6 m^3) at a temperature quality of more than 50 °C, otherwise the boiler will operate until reaching that temperature which could only occur in the early mornings and in winter time.

SYSTEM MANUFACTURING

Manufacturing of collectors, Racks, and storage tank was carried out at the mechanical engineering workshop of the Royal Scientific Society as follows:

1. Flat plate collectors

- Cover: Normal 4 mm glass has been used. In addition, and to protect glass from breakage and to protect the collector from air and rain, rubber seals between glass and case have been used.

- Case : The case was made of Aluminum profiles to form the sides, while the bottom made of 0.7 mm galvanized steel sheets.

- Risers, headers, and absorber plate: Risers and headers were made of galvanized seam welded pipes with a diameter of ½" and 1" respectively, while the absorber plates were made of 0.9 mm black steel sheets.

- Insulation: Fiberglass (rolls) were used to insulate the bottom and sides of the case to decrease amount of heat losses.

- Paint: Simple flat black paint was applied to treat absorber plates and risers.

2. **Racks**

Racks were made of 45 x 45 x 3 mm iron angle. They had a 45° tilt angle. The racks were all painted with silver protection paint. The racks were fabricated in a way to be welded on site, so that each rack will hold 5 collectors.

3. **Storage tank**

The 6 m^3 cylindrical storage tank of was made of 3 mm galvanized sheet metal. Rolled sheets were arc welded to form the sleeve of the tank. The top and bottom of the tank are of the concave type so as to give more rigidity to the tank; stiffeners were welded inside the tank for the same purpose. Internally threaded nipples were welded on the sides bottom and top of the tank. A manhole was put on the side of the tank to allow serviceability. Three legs at the bottom of the tank were provided for stability and the desired spacing for insulation. The tank height was 3.0 meters while it's diameter was 1.6 meter.

SYSTEM INSTALLATION

The installation of system components took place as follows:

1. **Racks**

All racks were welded on site. Racks were directed towards the south and were split into 18 sets, so that each set would hold 5 collectors.

2. **Collector array and piping**

The collectors were mounted in 8 rows facing south. The basic unit consists of 5 panels. Each of the first two rows consists of 3 units (15 collectors) while each of the other six rows consists of 2 units (10 collectors). Every two of these units share the inlet and outlet connection.

Given the latitude of Aqaba at 29 deg N; the collector set had been tilted at an angle of latitude + 15 deg which gives approximately 45, deg which is better for winter utilization of the system, when the sun is in its lowest positions.

Outlets of all sets of collectors drop into one line in which water goes to the storage tank through 4 selenoid valves (two are normally open which goes to the pumps and two are normally closed which goes to top and mid. inlets of storage tank) which operates depending on temperature difference; or back through 4 pumps (each 2 in series) to the collectors again. An automatic air vents were installed at the outlet of each basic unit and at each drop point to prevent air block in the system.

All pipes were insulated with "climax" insulation and painted by ultra-violet resistant white paint, so as to protect it from adverse weather conditions. The pipes were also supported to prevent any possible bending.

3. <u>Storage tank</u>

The 6 m^3 storage tank which has a cylindrical shape was installed near the boiler room vertically to acheive a better temperature stratification. To prevent overnight cooling, the tank was insulated with 100 mm of polyurethane. The thermocouples for temperature measuring of storage tank wall temperatures were all put in places before insulation took place. The cold water supply to the storage tank comes from tanks at the hotel's roof (about 10 meters high).

4. <u>Pumps and Controls</u>

The water coming from the collector array may enter the storage tank through the top inlet or the mid inlet, if it is sufficiently warmer than water at the corresponding level of the tank. Four seleniod valves (two normally open and two normally closed) were installed to control the top and mid. entering of water to storage according to the temperature difference.

Four bronze pumps were installed to circulate the water through the collector loop, which operates according to the temperature difference between the inlet and outlet of the collectors.

5. Instrumentation

A magnatic flowmeter was installed after the pumps to measure the water flowrate through the collector loop, while another flowmeter was installed on the water pipe going from the top of the storage tank to the boiler's cylinder to measure the hotel consumption of hot water, from which we could calculate the energy given to the hotel from the solar system.

Two solarimeters with and without a shielding ring are used to measure the diffused and total radiation. They are held to their bases by screws, and the two bases which are made of angle iron are welded to the collectors rack.

TESTING AND EVALUATION

In order to determine the performance of the system, different parameters were monitored and recorded while other parameters were calculated. The measured parameters include the following:

- Temperature at different locations on the wall, inlets, and outlets of the storage tank.
- Temperature difference across the collector loop.
- Temperature of the cold supply water.
- Water flowrate in the collector loop and the pipeline going to the existing boiler system.
- Global radiation and ambient temperature.
- Percentage of time during which seleniod valves were open allowing hot water to enter the storage.
- Percentage of time during which pumps were in operation.
- Percentage of time during which hotel's boiler was operating.

The calculated parameters are the following:

1. Rate of energy collected in the solar collectors array.

2. Rate of energy to storage tank through each one of the two electric valves.

3. Rate of energy supplied from the solar system storage tank to user.

The monitoring system was based on an HP-3497A data acquisition unit, controlled by an HP-85 microcomputer. Copper/constantan thermocouples were used to measure temperatures at different parts of the system. All sensors were scanned over about 10 seconds and the data was integrated at hourly intervals. The hourly values were stored on flopy disks, which are then removed for data analysis and evaluation.

The tables shown in Appendix-A presents an example of the data recorded and calculated for each day during the year of testing.

CONCLUSIONS

The following are some general conclusions that could be obtained from this pilot plant on large SWH systems.

1. The system is operating with good efficiency, capable of producing hot water of quality more than 50°C throughout the year.

2. An inspection of the available test readings shows the following general results concerning the performance of the system:

    a) the net daily energy collection varies from about 250 to 400 kWh,

    b) the daily amount of energy supplied to the hotel from the solar system varies between about 100 and 400 kWh,

c) the collection efficiency at the time of peak irradiance can reach 0.50 and often exceeds 0.30, while the long term average is about 0.31,

d) the daily average storage tank efficiency is about 0.76,

e) the daily average efficiency of the whole system is about 0.18,

3. It is always more feasible to have high consumption of hot water so as to get better efficiency of both collector and storage subsystems. A main result would be a decrease in losses, where system will be operating at lower temperature difference on the collector loop that allows the electric valves to open and this will result in an increase in energy entering the storage tank and higher collector efficiency.

4. The performance of the system in general is better than that installed at the Dairy Factory which may be due to the higher consumption of hot water (5 m^3/day - 20 m^3/day), in addition to the improvement made in the solar collectors and type of insulation used.

5. For a preheater system where there is no need for high levels of temperature, hot water can be fed continously to the storage when the pumps are in operation without any control valves. This would allow full utilization of the collected energy and will reduce the energy loss through collector array subsystems.

6. The storage tank have shown good efficiency and performance with no problems eventhough its installation vertically to inhance startification was not needed because of the continouse consumption from the storage through the whole day.

7. The improved collectors used have shown good performance throughout the period of testing, with no corrosion problems and no water leakage and are expected to have lifetime not less than 10-15 years given the simple required maintenance.

8. The system provided a significant energy saving and this means that it is economically feasible and the expected payback time is about 5-6 years depending on the yearly energy consumption from the system.

9. In fact, one of the main benefits of this expermintal installation of the second large solar water heating systems in the "hands on" experience gained by all the people involved from engineers, technicians, workers, and monitoring perosnnel. These experiences will be put to good use in the next future projects.

ROYAL SCIENTIFIC SOCIETY
SOLAR ENERGY RESEARCH CENTER
COLLECTOR APPLICATION SECTION
AQABA CORAL BEACH HOTEL SOLAR HOT WATER SYSTEM

HOURLY AVERAGE DATA

DATE: 27/05/88

HOUR	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
00	-	-	-	-	-	27	0	0	26	0	0	0	51	160	32	31
01	-	-	-	-	-	-	0	0	24	0	0	0	-	0	31	31
02	-	-	-	-	-	25	0	0	24	0	0	0	49	2	31	31
03	-	-	-	-	-	-	0	0	22	0	0	0	-	0	31	31
04	-	-	-	-	-	25	0	0	22	0	0	0	50	71	31	31
05	-	-	-	-	-	25	0	0	21	0	0	0	50	391	31	30
06	-	-	-	-	-	26	0	33	22	0	0	0	42	1455	30	27
07	-	-	-	-	-	-	0	86	23	0	0	0	-	0	27	27
08	-	-	-	-	-	-	0	170	24	0	0	0	-	0	27	27
09	27	38	27	37	34	28	151	340	26	.1	.09	0	28	689	27	28
10	29	35	28	43	34	-	89	520	28	.33	.16	.08	-	0	28	33
11	35	40	36	41	41	-	151	666	29	1	.33	.31	-	0	33	38
12	41	47	42	47	-	-	147	766	30	1	1	0	-	0	38	45
13	48	54	49	54	-	-	146	828	32	1	1	0	-	0	45	52
14	54	59	55	59	60	-	147	822	32	1	.33	.52	-	0	52	57
15	58	62	-	-	-	-	156	752	30	1	0	0	-	0	57	57
16	57	61	-	-	-	-	156	622	31	1	0	0	..	0	57	57
17	51	53	-	-	-	29	154	426	33	.83	0	0	61	1160	57	57
18	39	43	-	-	-	29	149	149	32	.17	0	0	60	1055	57	53
19	-	-	-	-	-	29	0	6	30	0	0	0	59	613	53	51
20	-	-	-	-	-	28	0	0	28	0	0	0	57	789	51	49
21	-	-	-	-	-	28	0	0	27	0	0	0	54	336	45	44
22	-	-	-	-	-	27	0	0	25	0	0	0	53	261	44	42
23	-	-	-	-	-	27	0	0	24	0	0	0	52	387	42	40
TOTAL								6186						7369		

1) COLLECTOR INLET TEMPERATURE
2) COLLECTOR OUTLET TEMPERATURE
3) BOTTOM STORAGE OUTLET
4) TOP STORAGE INLET
5) MID STORAGE INLET
6) BOTTOM STORAGE INLET FROM COLD WATER SUPPLY
7) COLLECTOR FLOW RATE (LPM)
8) TOTAL RADIATION (WATT/sq. m)
9) AMBIENT TEMPERATURE
10) PERCENTAGE OF TIME DURING WHICH PUMPS WERE ON
11) PERCENTAGE OF TIME DURING WHICH UPPER VALVE WAS OPEN
12) PERCENTAGE OF TIME DURING WHICH LOWER VALVE WAS OPEN
13) TEMPERATURE OF HOT WATER TO HOTEL
14) HOTEL CONSUMPTION OF HOT WATER (LITER)
15) INITIAL AVE. TEMP. OF STORAGE TANK
16) FINAL AVE. TEMP. OF STORAGE TANK

ROYAL SCIENTIFIC SOCIETY
SOLAR ENERGY RESEARCH CENTER
COLLECTOR APPLICATION SECTION
AQABA CORAL BEACH HOTEL SOLAR HOT WATER SYSTEM

HOURLY AVERAGE DATA & ENERGY

DATE: 27/05/88

HOUR	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)
00	28	28	29	29	29	30	30	39	53	32	0	0	0	0	4459
01	28	29	29	29	29	30	30	36	52	31	0	0	0	0	0
02	28	29	29	29	29	30	30	36	52	31	0	0	0	0	45
03	28	29	29	29	29	30	30	36	51	31	0	0	0	0	0
04	28	29	29	29	29	30	30	35	50	31	0	0	0	0	2034
05	28	29	29	29	29	30	30	32	45	30	0	0	0	0	7919
06	26	28	28	29	29	29	29	30	33	29	.04	0	0	0	16154
07	27	27	27	27	28	29	29	29	29	28	.28	0	0	0	0
08	27	27	27	27	27	27	28	29	29	28	0	0	0	0	0
09	27	27	27	27	27	27	27	28	29	27	.33	10962	9990	238	448
10	28	28	29	30	31	31	31	31	31	30	0	33330	25218	5283	0
11	34	36	36	36	37	37	37	37	37	36	.12	50793	19652	14944	0
12	42	43	43	43	43	43	43	43	43	43	.14	63626	51064	0	0
13	49	50	50	51	51	50	50	50	50	50	0	62762	51362	0	0
14	56	56	56	57	57	57	57	57	57	57	0	58771	14532	20273	0
15	58	59	59	60	60	60	60	60	60	60	0	45604	0	0	0
16	61	61	61	62	62	62	62	62	62	62	0	38698	0	0	0
17	57	57	57	57	58	59	61	62	62	59	0	20472	0	0	2476
18	46	53	54	54	54	56	57	60	61	55	0	8773	0	0	24820
19	38	50	50	51	51	53	55	56	58	52	0	0	0	0	17666
20	29	36	48	50	51	51	53	55	56	48	0	0	0	0	26208
21	28	29	32	49	50	51	51	52	55	45	0	0	0	0	10262
22	28	29	29	39	50	51	51	51	56	43	0	0	0	0	7889
23	28	28	29	31	46	50	51	51	52	41	0	0	0	0	11541
TOTAL												393791	171818	40738	131921

17-25) WALL TEMPS. OF STORAGE TANK AT 9 POINTS EQUALLY SPACED ALONG A VERTICAL LINE, WITH 17 IS TEMP. AT THE LOWEST POINT AND 25 IS TEMP. AT THE HIGHEST
26) AVE. TEMP. OF STORAGE TANK
27) PERCENTAGE OF TIME DURING WHICH BOILER WAS ON
28) SOLAR ENERGY COLLECTED (WATT.HR)
29) ENERGY TO STORAGE THROUGH UPPER VALVE (WATT.HR)
30) ENERGY TO STORAGE THROUGH LOWER VALVE (WATT.HR)
31) ENERGY FROM STORAGE TO USER (WATT.HR)

ROYAL SCIENTIFIC SOCIETY
SOLAR ENERGY RESEARCH CENTER
COLLECTOR APPLICATION SECTION
AQABA CORAL BEACH HOTEL SOLAR HOT WATER SYSTEM

DATA EVALUATION

DATE: 27/05/88

HOUR	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
00	0	-	-	0	0	0	4459	-8986	4527	-	0
01	0	-	-	0	0	0	0	0	0	-	0
02	0	-	-	0	0	0	45	-745	700	-	0
03	0	-	-	0	0	0	0	0	0	-	0
04	0	-	-	0	0	0	2034	-2114	80	-	0
05	0	-	-	0	0	0	7919	-7919	0	-	0
06	33	-	-	0	0	0	16154	-16154	0	-	.04
07	86	-	-	0	0	0	0	0	0	-	.28
08	170	-	-	0	0	0	0	0	0	-	0
09	340	58	282	[illegible]	238	10228	448	7142	2638	.17	.33
10	520	178	342	25218	5283	30501	0	30501	0	.34	0
11	666	272	394	19652	14944	34596	0	34596	0	.41	.12
12	766	341	425	51064	0	51064	0	51064	0	.45	.14
13	828	336	492	51362	0	51362	0	51362	0	.41	0
14	822	315	507	14532	20273	34805	0	34805	0	.38	0
15	752	244	508	0	0	0	0	0	0	.33	0
16	622	207	415	0	0	0	0	0	0	.33	0
17	426	109	317	0	0	0	2476	-2476	0	.26	0
18	149	47	102	0	0	0	24820	-24820	0	.31	0
19	6	-	-	0	0	0	17666	-17666	0	-	0
20	0	-	-	0	0	0	26208	-37692	11484	-	0
21	0	-	-	0	0	0	10262	-10713	451	-	0
22	0	-	-	0	0	0	7889	-16285	8396	-	0
23	0	-	-	0	0	0	11541	-12093	552	-	0
TOTAL	6186	2107	3784	171818	40738	212556	131921	51807	28828		.91

1) TOTAL SOLAR INCIDENT (WATT.HR/sq.m)
2) SOLAR ENERGY COLLECTED (WATT.HR/sq.m)
3) COLLECTOR HEAT LOSS [1-2] (WATT.HR/sq.m)
4) ENERGY TO STORAGE THROUGH UPPER VALUE (WATT.HR)
5) ENERGY TO STORAGE THROUGH LOWER VALUE (WATT.HR)
6) ENERGY TO STORAGE [4+5] (WATT.HR)
7) ENERGY FROM STORAGE TO USER (WATT.HR)
8) HOURLY INCREASE IN STORED ENERGY (WATT.HR)
9) STORAGE HEAT LOSS [6-7-8] (WATT.HR)
10) HOURLY INTEGRATED COLLECTOR EFFECIENCY [2/1]
11) PERCENTAGE OF TIME DURING WHICH AUXILIARY BOILER WAS ON

A) DAILY EFF. OF SOLAR COLLECTOR STORAGE SYSTEM = .16

B) DAILY EFF. OF STORAGE TANK = .86

C) DAILY SOLAR RADIATION (WATT.HR) = 1152451

D) DAILY COLLECTED ENERGY (WATT.HR) = 392534

DEVELOPMENT OF FLAT PLATE COLLECTORS AND SOLAR WATER HEATERS AT THE ROYAL SCIENTIFIC SOCIETY IN JORDAN

Eng. Ammar Taher

ABSTRACT

The paper discusses the development of flat plate collectors at the RSS in Jordan. A computer program was developed and used to optimize flat plate collectors at the RSS. Furthermore, experimental development was conducted towards improving the absorber plate design. Several models were designed, constructed, and tested. An attemp to use a selective surface for the absorber plate and the transparent cover was conducted and its economical feasibility was examined.

Five solar water heaters were designed ,constructed, and tested. All test results are included in this paper .The test is conducted four times for each system. The design criteria of the different developed system was to reduce heat losses and to increase the thermosyphon flow rate while the material selection criteria was to reduce cost and to increase expected life.

INTRODUCTION

Solar energy conversion into thermal energy has been and will continue to be one of the most economic and attractive ways of utilizing this type of renewable energy. This is due to the regular daily demand on such energy at moderate temperatures and because the equipment required for this conversion are simple to produce and install.

Much of the research in solar collector technology is directed to increase the efficiency. Several high - efficiency collectors are available in the international market. Unfortunately these collectors may not be cost effective when used for domestic water heating. It may be better financially to install an increased area using ordinary collectors than utilizing the expensive but efficient collectors.

In the development of flat plate collectors conducted at the RSS in Jordan, only financially verified improvements such as increased collector efficiency and increased collector life were attempted in this work.

ANALYTICAL DEVELOPEENT

In selecting the absorber material, a cost estimate was made for steel absorber, copper absorber, and aluminum plate with copper piping absorber. Aluminum piping was not considered due to severe corrosion problems encountered when used for open system. The absorber have the groved plate and welded pipes design as shown in the next page. The tube spacing and plate thickness of the different absorbers were selected according to the thermal conductivities of each material so that all the absorbers have the same effici¬ncy.The cost was estimated according to the local market. Fig.1 shows the estimated cost for the different absorber material.

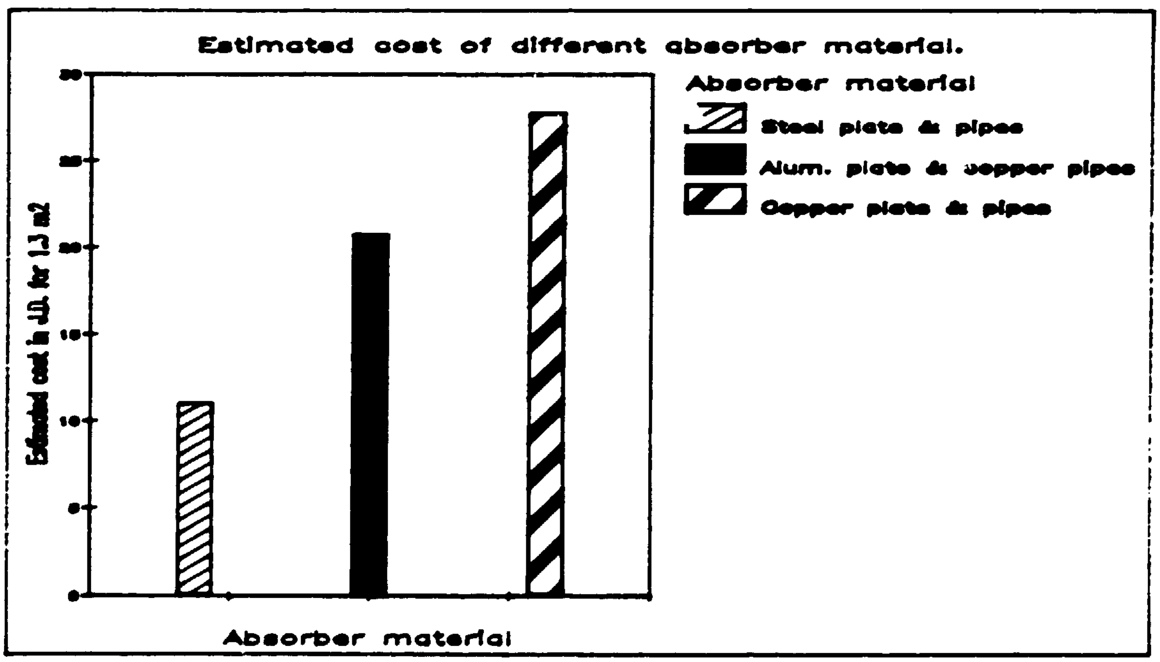


Fig.1 Estimated cost of different absorber materials

The choice between steel, copper, or aluminum is made purely on the basis of corrosion resistance and cost. Steel absorbers were found favorable for the following reasons:

1. Cost effective.
2. No severe internal corrosion problems which may be due to:
   - Compatibility with existing pluming in Jordan.
   - Hardness range and PH range encountered in Jordan are 16-22 GPG and 7.4-8.5 respectively.
3. No severe external corrosion problems when the casing is properly assembled except some minor crevice corrosion which occurs mainly at welded joints (Fig.2) and at points where the risers are welded to the absorber plate (Fig.3).

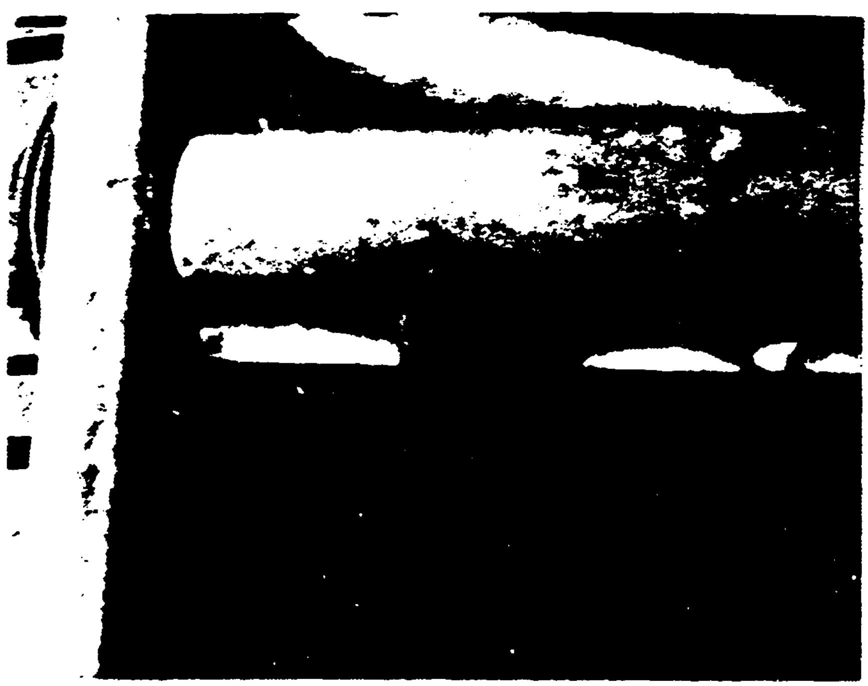


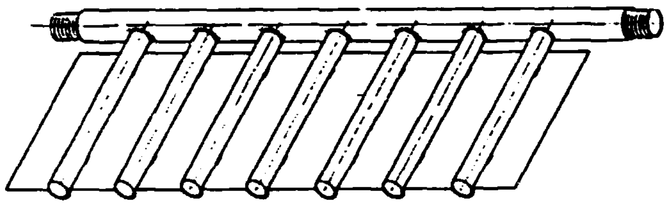
Figure-2 Crevice corrosion at welded joints between pipes

Figure-3 Crevice corrosion at welded points between the risers and the absorber plate.

The starting point of the collector development was the steel collector manufactured at many local companies. The collector design was optimized analytically using a special computer program developed for this purpose which resulted the RSS collector that is composed of the following parts:

- Single 4 mm regular glass.
- Groved steel absorber plate 0.9 mm thick, surface treated with flat black paint.
- Seven 1/2" galvanized steel risers & two 1" galvanized steel headers, welded together and are welded at several points to the absorber plate. Riser spacing is 100 mm.
- 50 mm of fiberglas insulation.
- 0.7 mm galvanized steel casing.

The collector has an area of 1750 x 750 mm. It was tested at the Solar Collector Testing Facility at the RSS. The first and second order efficiency curves are represented by the following equations:



$$n = 62.8 - 6.3\,x \quad \ldots\ldots (1)$$
$$n = 62.8 - 6.73\,x + 0.092\,x^2 \quad \ldots\ldots (2)$$

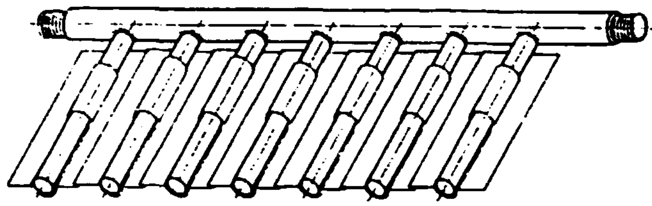
where n = Efficiency
x = 100 (ti - ta)/It
ti = Inlet water temperature (°C)
ta = Ambient temperature (°C)
It = Solar intensity (W/m^2)

EXPERIMENTAL DEVELOPMENT

The development of the steel absorbers discussed in the previous section was carried out experimentally in the direction of increasing the efficiency by improving the contact and increasing the heat transfer area between the risers and the plate. This task was not easy to do analytically since their would be considerable variation between "as designed " and " as built " regarding such matter. Also it was desirable to reduce or eliminate welding if possible to reduce corrosion therefore to extend the useful life of the collector .

Four different absorbers where designed constructed and tested utilizing the same standard steel casing , tube spacing , and absorber plate thickness discussed in the previous section .

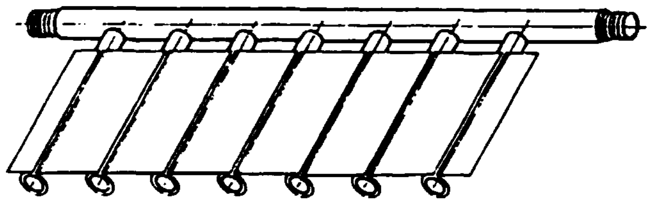
The first improved design shown below is made out of separate pieces of fins. Each has a number of groves along its center line, with these semicircular cross sectional groves alternating. The new design was tested where the test results are:



$n = 71.5 - 6.1\ x$ .... (3)
$n = 71.5 - 5.5\ x - 0.086\ x^2$ .... (4)

The test results have shown an increased collector efficiency when compared with the groved absorber design.

An attempt to increase the heat transfer area between the risers and the absorber plate is shown below. A collector was constructed and tested using this absorber. The efficiency of this collector, which are represented by equation 5 & 6, showed an improvement over the original groved plate design. Even though this absorber design was expected to have higher efficiency than

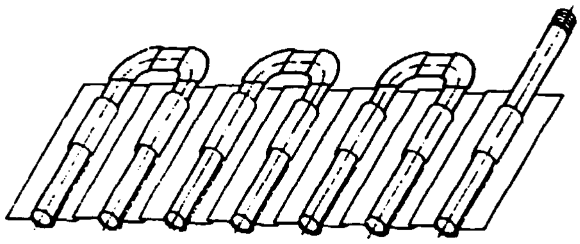


$n = 63.4 - 4.9\ x$ .... (5)
$n = 63.4 - 1.84\ x - 0.635\ x^2$ .... (6)

the fitted separate fin design due to increased heat transfer area between the risers and the plate. Both absorber designs are expected to reduce potential corrosion problems due to welding elimination between the risers and the plate.

In an effort to increase the useful life of the absorber by eliminating welding between the risers and the headers , a serpentine tube arrangement absorber were developed.

The first model was constructed using the fitted separate fins discussed earlier with pipes elbows. The test results are represented by the following equation:

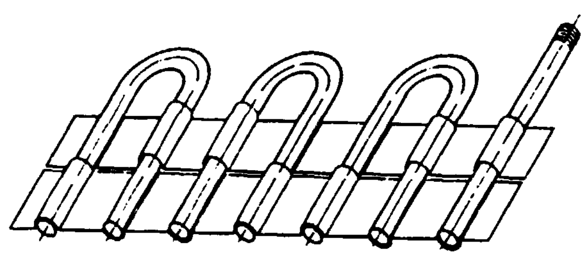


$n = 74.3 - 6.6x$ ....(7)

$n = 74.3 - 5.4x - 0.17\ x^2$ ....(8)

The test results show better efficiency than all the developed collectors, which may be due to the separate fitted fins, and to the increased heat transfer coefficient as a result of increased velocity because the water have to flow through each pipe.

To avoid the possible problems of water leakage at the fittings , another absorber was designed, constructed and tested. This absorber used bended pipes. The separate fitted fins were not used due to inherited manufacturing limitations . The groved alternating absorber used for this absorber was introduced. The test results of this collector is given by the following equations



$n = 69.1 - 5.3x$ ....(9)

$n = 69.1 - 3.03x - 0.398x^2$ ....(10)

The last two absorbers have the following disadvantages:
- Not suitable to thermosyphon operation.
- May have erosion corrosion problems due to the high velocity.
- Have high pressure drop when used in forced circulation sytems.

Fig.4 shows the daily energy output for the above developed collectors at three different inlet water temperatures calculated according to the national standard, while Fig.5 plots the first order efficiency curves.

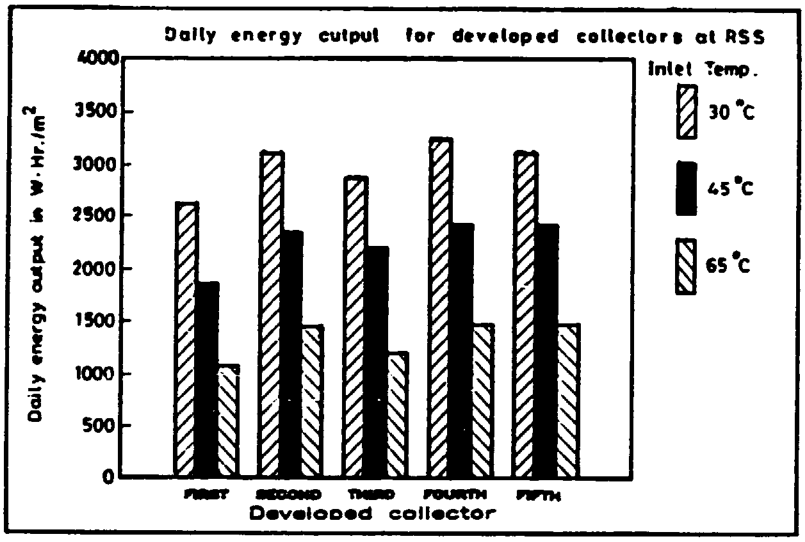


Fig.4 Daily energy output for the developed collectors

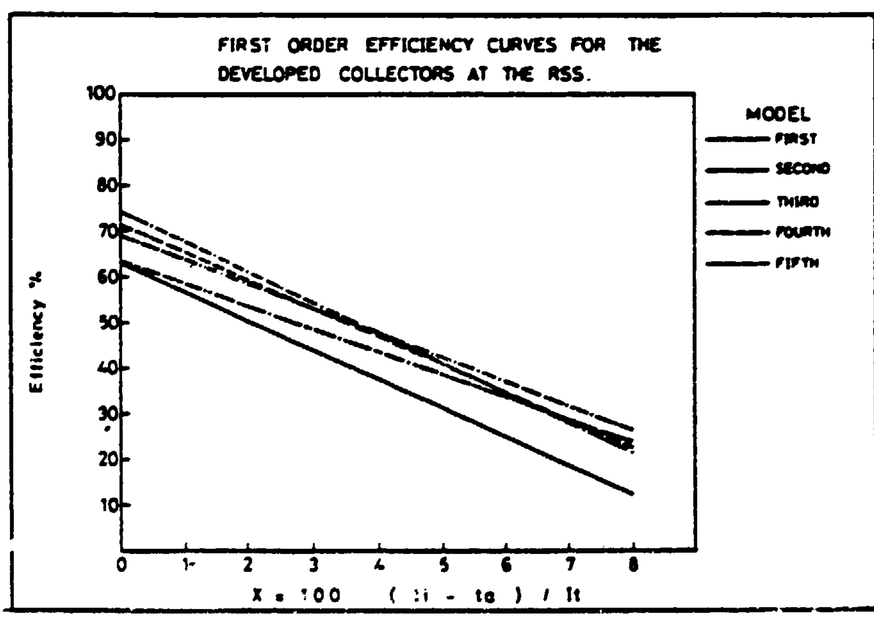


Fig.5 The first order efficiency curves

Furthermore, a survey of the available selective coatings for the collector cover and absorber plate was made to learn about new commercial products in the international market.

One product of each type was selected. A spray type selective absorber coating was selected due to its ease of application and moderate cost. A collector was built and tested utilizing this selective absorber plate coating which increased the collector cost of about 1%. The collector showed an increase of the daily collected energy of 2%, 7%, and 23% for inlet water temperature of 30, 45, 65°c.

For the collector cover, a transparent 100 µm film was selected due to its superior characteristic, light weight and good weather resistance. Such film was not justified due to the drop of collecter efficiency and its high price.

DEVELOPMENT OF SOLAR WATER HEATERS

The starting point of this work was the thermosyphon solar water heaters manufactured at many local companies which have three collectors and 150 liter storage tank. The collectors and the storage tanks have different dimensions and material thicknesses.

Five different solar water heaters were designed, constructed at the Solar Energy Research Center at the Royal Scientific Society, and tested at the Solar Collector Testing Facility utilizing the indoor solar simulator.

The following sub-sections will discuss the five developed solar water heating systems including detailed description of system components, pictures, and test results.

8.1 RSS-SWH :

The first developed system called RSS-SWH shown in Fig.6 consists of the following :

1. Three RSS analytically optimized flat plate collectors as discussed earlier in the paper with a total area equals to 4 m2(1.33 m2 each) tilted at 45 degree angle. Each collector is composed of the following parts :

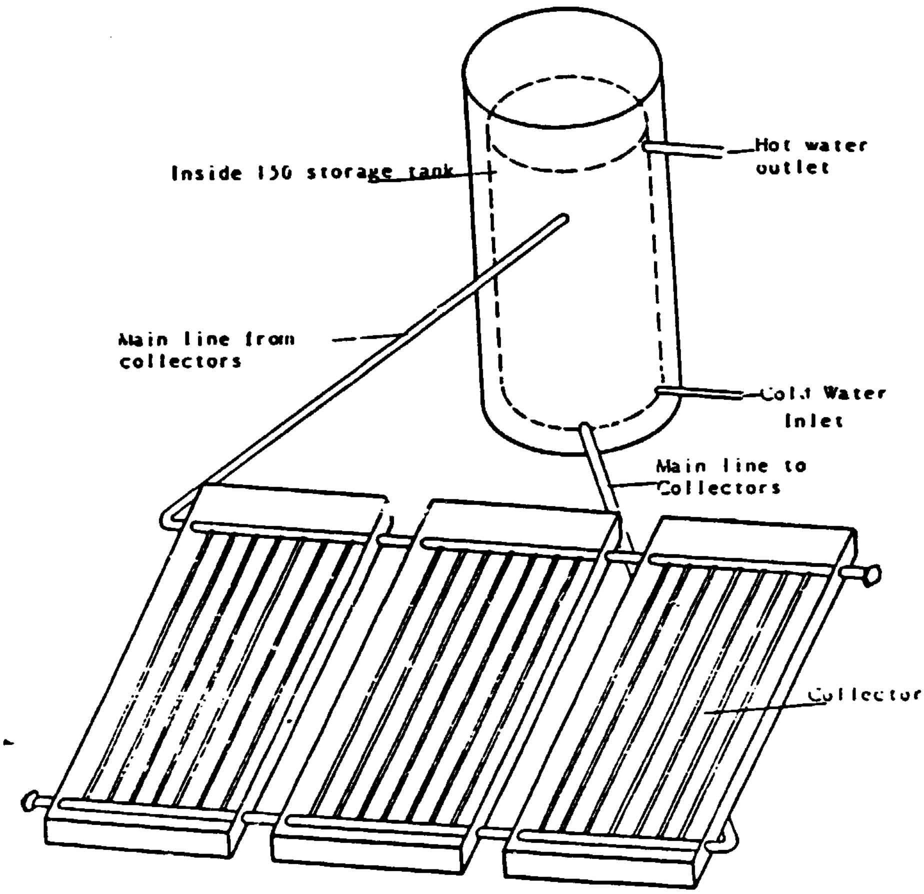


Fig.6 RSS-SWH

- Single 4 mm regular glass.
- Grooved steel absorber plate 0.9 mm thick, surface treated with flat black paint.
- Seven 1/2" galvanized steel risers and tow 1" galvanized steel headers, welded together and are welded at several points to the absorber plate.
- 50 mm of fiberglas insulation.
- 0.7 mm galvanized steel casing.

2. 150 liter vertical storage tank composed of the following parts:

- Inner tank made from 2 mm galvanized steel sheet.
- Outer tank made from 0.7 mm galvanized steel sheet.
- 50 mm of fiberglas insulation.

8.2 RSS-IMPROVED :

In an effort to decrease piping losses and to decrease absorber temperature, hence to increase the efficiency of solar water heaters the second system was designed, constructed, and tested.

As shown in Fig.7 the system consists of the following parts:

1. One flat plate collector with an area of 2 m2 tilted at 45 degree angle which is composed of the following parts:

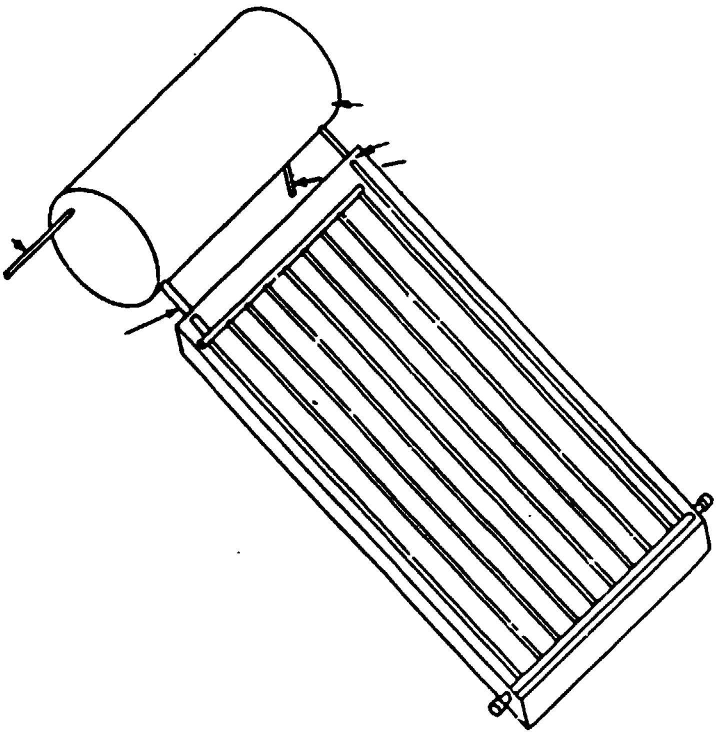


Fig.7 RSS-Improved

- -Single 4 mm regular glass.
- -Grooved steel absorber plate 0.9 mm thick, surface treated with flat black paint.
- -Nine 1/2" galvanized steel risers and two 1" galvanized steel headers, welded together and are welded at several points to the absorber plate.
- -One 1/2" unpainted galvanized steel pipe welded to the bottom header, internally laid inside the collector, and connected to the storage tank as the water inlet to the collector from the storage tank.
- -50 mm fiberglas insulation.
- -0.7 mm galvanized steel casing.

2. 150 liter horizontal storage tank composed of the following parts:

- -Inner tank made from 2 mm galvanized steel sheet.
- -Outer tank made from 0.7 mm galvanized steel sheet.
- -50 mm of fiberglas insulation.

8.3 RSS-F-1M-53L :

Another system, RSS-F-1M-53L, was constructed and tested that have the same design criteria as the previous one, RSS-IMPROVED, with a collector area of 1 m2 and a storage capacity of 53 liters. Fig.8 show a picture of the system. The system is composed of the following parts:

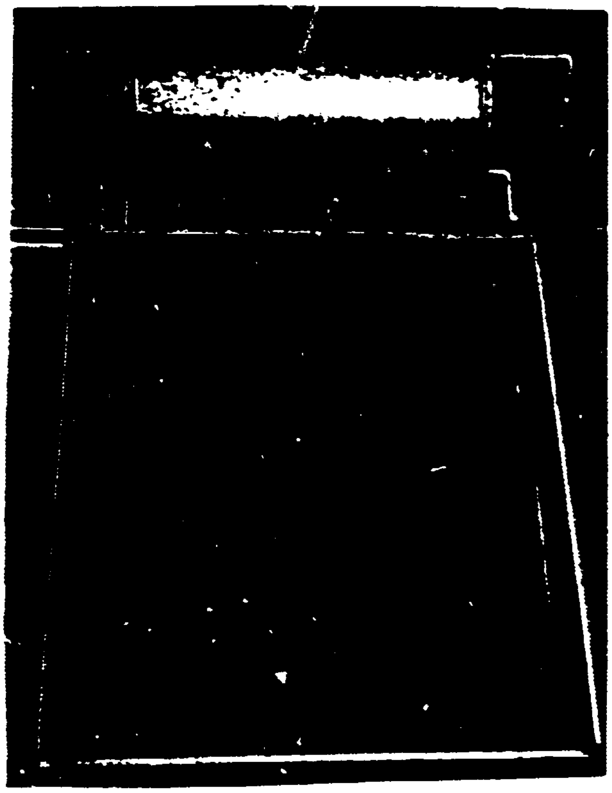


Fig.8 RSS-F-1M-53L

1. One flat plate collector with an area of 1 m2 tilted at 45 degree angle which is composed of the following parts:

-Single 4 mm regular glass.
-Grooved steel absorber plate 0.9 mm thick, surface treated with flat black paint.
-Eight 1/2" galvanized steel risers and two 1" galvanized steel headers, welded together and are welded at several points to theabsorber plate.
-One 1/2" unpainted galvanized steel pipe welded to the bottom header, internally laid inside the collector, and connected to the storage tank as the water inlet to the collector from the storage tank.
-50 mm fiberglas insulation.
-0.7 mm galvanized steel casing.

2. 53 liter horizontal storage tank composed of the following parts:

-Inner tank made from 2 mm galvanized steel sheet.
-Outer tank made from 0.7 mm galvanized steel sheet.
-50 mm of fiberglas insulation.

8.4 <u>RSS-TURBO</u> :

As shown in Fig.9 the system consists of the following parts:

1. One flat plate collector with an area of 1.358 m2 tilted at 45 degree angle which is composed of the following parts:

-Single 4 mm regular glass.
-Absorber plate made of separate pieces of fins. This design was developed at the RSS and was discussed earlier in the paper.
-Seven 1/2" galvanized steel risers fitted into separate fins and 1" galvanized steel header welded together. The other ends of the risers are welded directly to the storage tank. The absorber is treated with flat black paint.
-50 mm fiberglas insulation.
-0.7 mm galvanized steel casing.

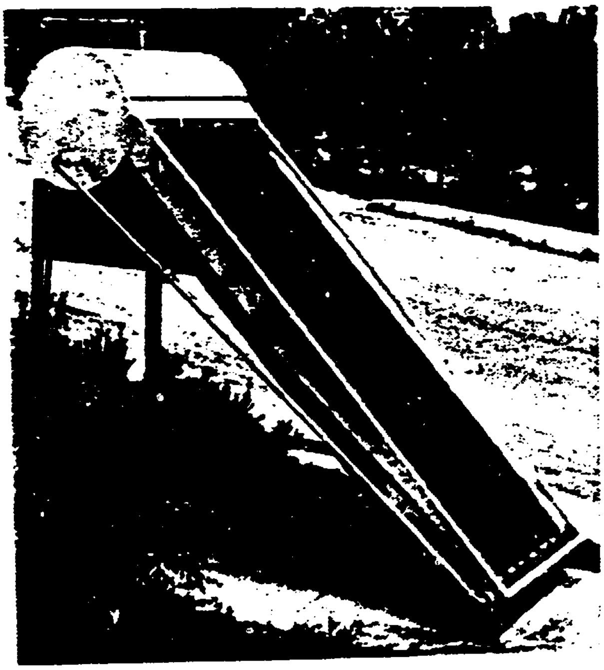


Fig.9 RSS-urbo

2. Horizontal storage tank of 59 liter capacity composed of the following parts:

-Inner tank made from 2 mm galvanized steel sheet.
-Outer tank made from 0.7 mm galvanized steel sheet.
-50 mm of fiberglas insulation.

The design criteria for this system was to minimize frictional head losses in order to accelerate the thermosyphon flow, thus providing better absorber cooling which results in higher efficiency. Also it was desirable to reduce edge and piping losses.

8.5 RSS-TURBO-R-HE :

Fig.10

Another system was designed, constructed, and tested which have the same design criteria as the previous one (RSS-TURBO) with the same collector area and storage capacity, except that the absorber in this model is constructed from the special shaped tubes shown in Fig.10 imported by Metal Industries Co. Amman-Jordan for their use for manufacturing space heating radiators. The cross section of the tube as shown is 70 x 11 mm made from 1.2 mm thick black steel.

Ten of the tubes are welded together, welded to bottom header, and the other end welded directly to the storage tank to form the absorber. The use of a heat exchanger was essential for the storage tank since it is an open system.

The RSS-TURBO-R-HE system is composed of the following parts:

1. One flat plate collector with area of 1.355 m2 tilted at 45 degree angle which is composed of the following parts:

-Single 4 mm regular glass.
-Absorber made of ten tubes welded together as mentioned earlier and treated with flat black paint.
- 50 mm fiberglas insulation.
-0.7 mm galvanized steel casing.

2. 59 liter horizontal storage tank:

-Outer tank made from 0.7 mm galvanized steel sheet.
-50 mm of fiberglas insulation.
-Inner tank made from 2 mm galvanized steel sheet composed of two cylinders having the same length. The inner cylinder is the domestic hot water storage of 59 liter. The outer cylinder is connected in closed loop from and to the collector. The expansion of the water in the closed loop is accounted for by incorporating a 5 liter expansion tank.

Discussion of SWH tsest results

Fig.11 & 12 present the mixing draw-off profiles for the systems under simulated summer conditions. Fig.13 & 14 present the profiles under simulated winter conditions. The five develcped solar water heaters have different collector areas, storage capacities, collector area to storage capacity ratios, and different costs. To be able to compare the results of the developed solar water heaters, the following were calculated and presented in Fig.15 for each system :

- System efficiency.
- Average temperature of discharged water of storage capacity.
- Average storage water temperature before discharge.
- Daily energy output in watt.hour per J.D. system cost.

The average storage water temperature before discharge was not calculated for the RSS-Turbo-R-HE system, because the total energy collected as calculated does not include the energy collected and stored in the closed collector tc storage loop.

In comparing the developed systems it is essential to know that they have the following storage capacity to collector area ratios in liters per square meter 37.5, 75, 53.5, 49, and 49 respectively as reported.

Stratified discharge in the first two systems, which is desirable, is noticed when compared with the other systems by comparing the average discharge water temperature of storage capacity and the average storage water temperature before discharge . This may be due to the large capacity of the storage tank of the first two systems (150 liter) compared to the storage capacity of the other systems (less than 60 liters).

Comparing the efficiency of the different developed systems indicates that the storage turn-over time for the system RSS-Turbo is the shortest, which makes the initial collection efficiency higher than the other systems with longer storage turn-over time.

In comparing the energy out put per J.D. cost for the different developed systems it is important to understand that such figures are not standardized to parameters such as storage capacity to collector area ratios.

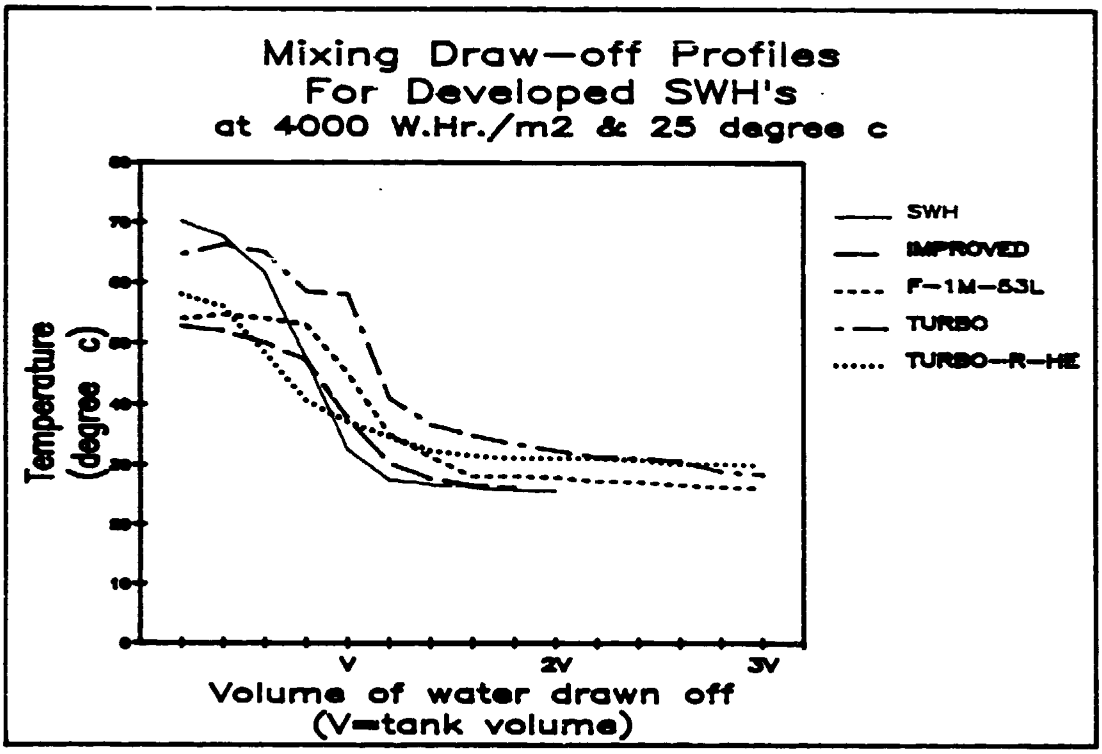


Fig.11 Summer simulation (4000 W.Hr/m2)

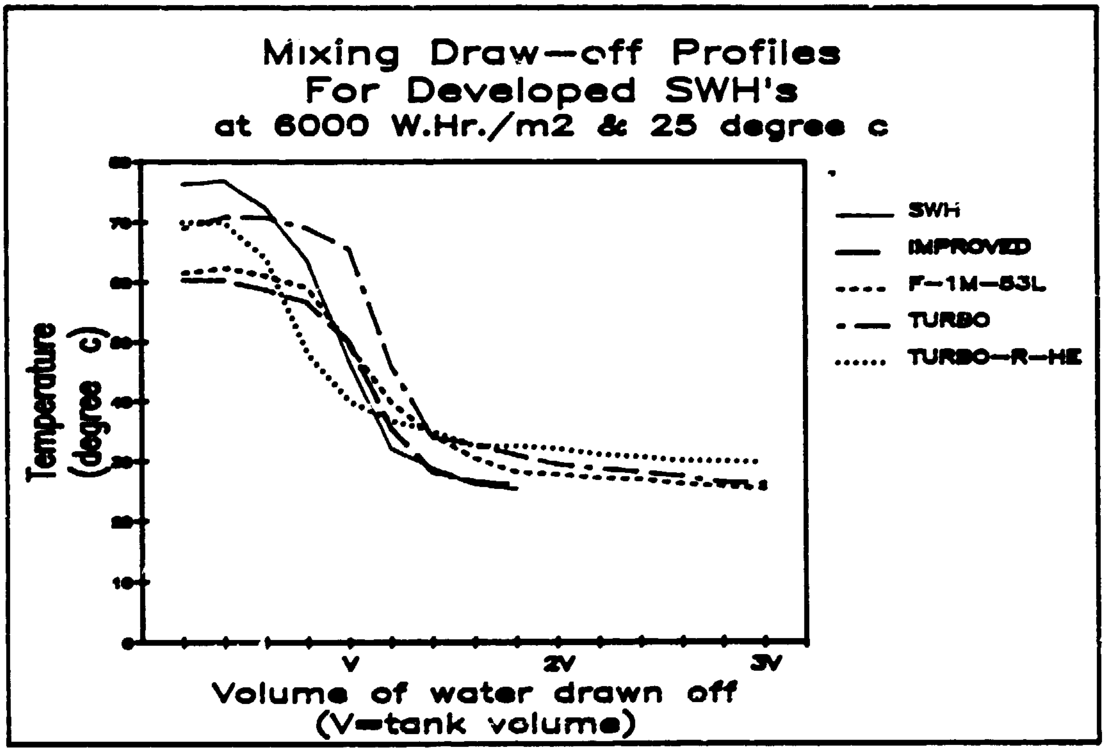


Fig. Summer simulation (6000 W.Hr./m2)

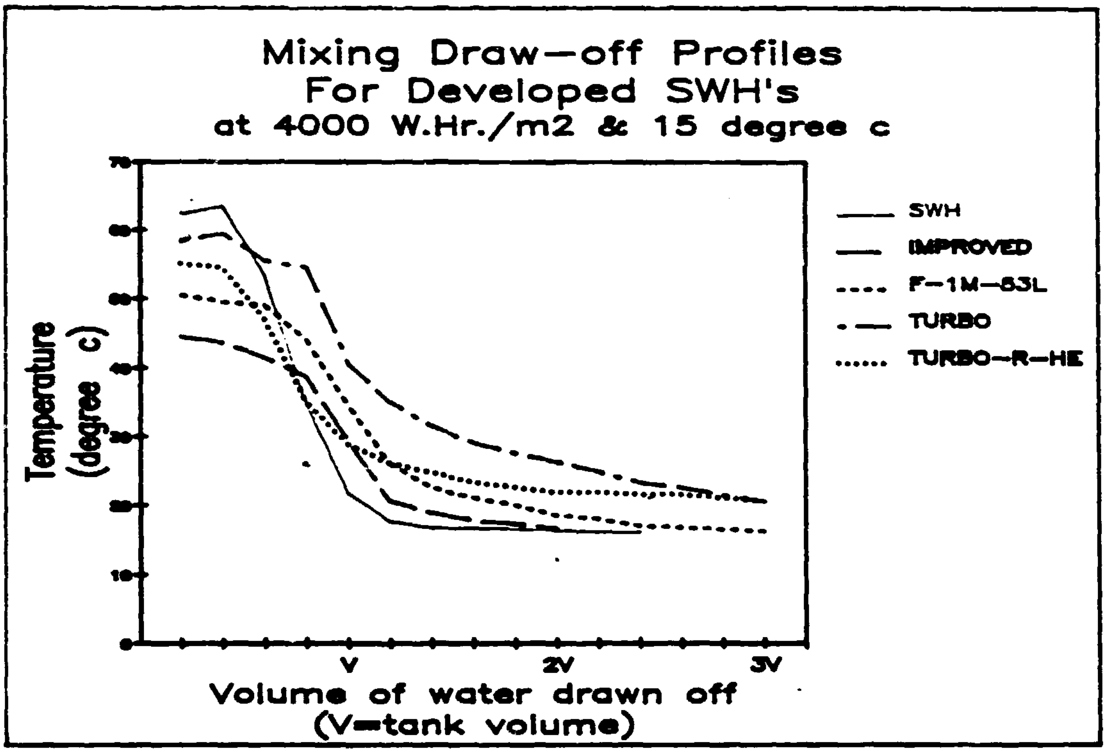


Fig.13 Winter simulation (4000 W.Hr./m2)

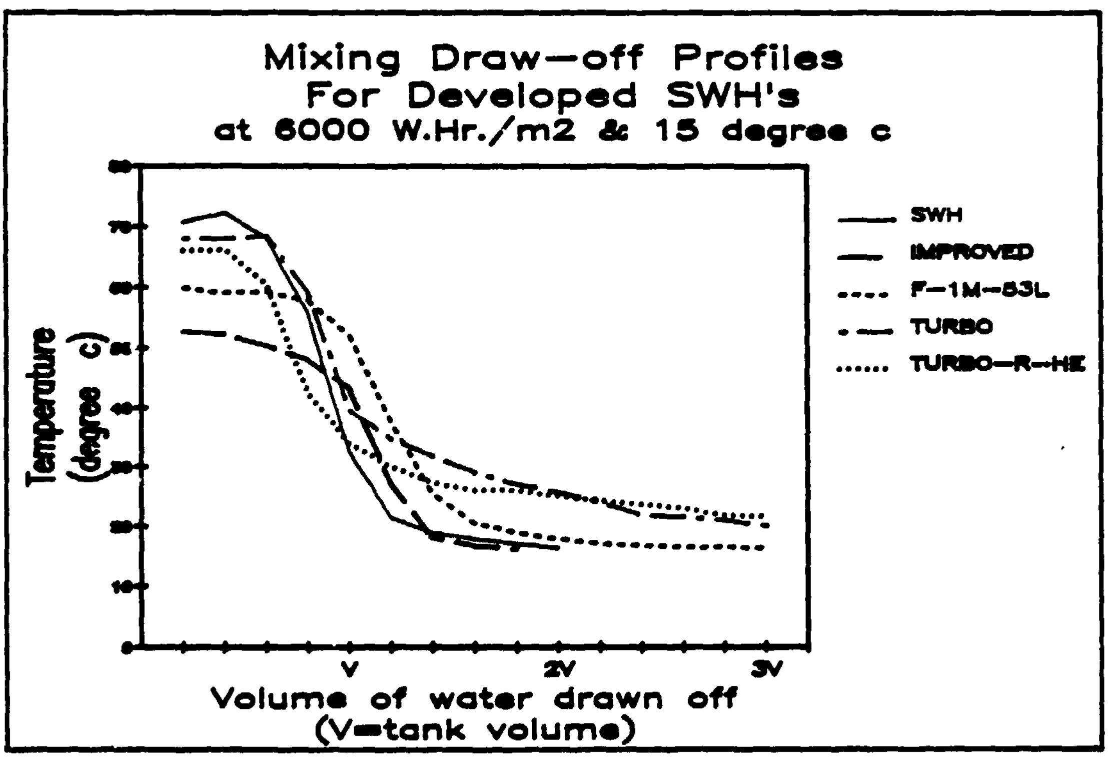


Fig.14 Winter simulation (6000 W.Hr./m2

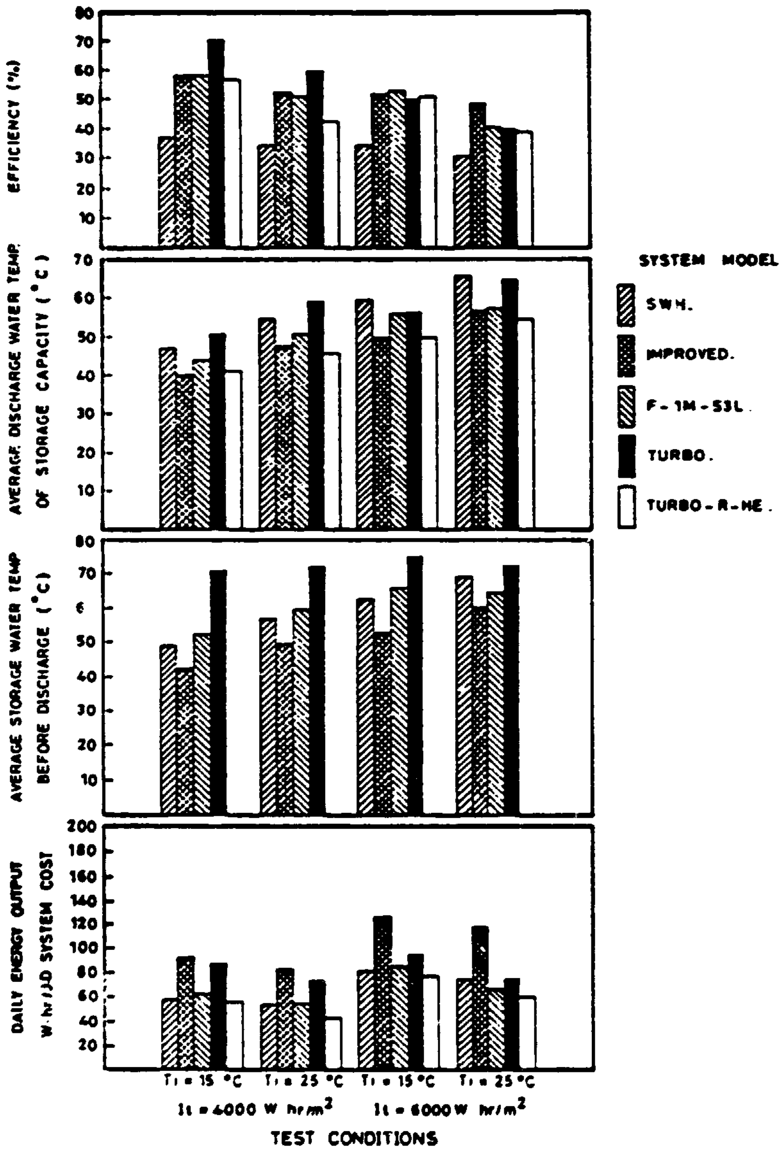


Fig.15 Results of developed solar water heaters at RSS

CONCLUSIONS

The solar collector testing facility at the RSS had proven to be a useful tool in developing and improving FPC in Jordan.

Steel was used for all the developed flat plate collectors due to its moderate cost, availability in the local market, and its minimal corrosion problems when compared with the other alternatives.

The developed absorbers were optimized analytically regarding plate thickness and riser spacing. Also the galvanized steel sheet casing, which was used for all the developed absorbers, was optimized analytically according to material cost in the local market.

Experimental development of the absorber was carried out towards minimizing welding, thus extending the life of the absorber, and increasing the contact between the risers and the plate.

A spray type selective absorber coating was examined and show^d good results. Further work is being carried out towards validating such finding and to check aging effects on this selective absorber coating.

Steel was used for all developed solar water heaters due to its availability in the local market and its moderate cost when compared with the other alternatives.

Development was carried out towards minimizing piping heat loss, collector edge heat loss, and increasing the thermosyphon flow rate,while trying to utilize the cheap available material.

All th: development carried out for flat plate collectors in the direction of absorber design, casing, and collector size as reported earlier is also applicable to the development of solar water heaters, since the improved collectors could be used in a solar water heater.

TESTING OF FLAT PLATE COLLECTORS AND SOLAR WATER HEATERS

ENG. SULAIMAN BATARSEH

1. ABSTRACT

A testing method for determining the thermal performance of flat plate solar collectors was determined and was considered as an Arab standard with the no.(660), and a Jordanian standard with the no.(435). These standards were approved by the Arab Organization for Standardization and Metrology (ASMO), and by the Ministry of Industry and Trade in Jordan.

This paper describes the Indoor/Outdoor Solar Collector Testing Facility, which was erected at the Royal Scientific Society in 1986.

The facility is capable of testing according to most international standards including the Jordanian standard no. 435 and ASHRAE.

A solar simulator is also available to be used during cloudy days to test solar collectors.

An indoor testing method for solar water heater for short time testing was developed at the Royal Scientific Society to compare the thermal performance of different solar water heaters.

2. INTRODUCTION

The objective of testing solar collectors and solar water heaters is the determination of its efficiency, performance and quality. These require a suitable testing equipment providing reliable data and easy handling.

The Royal Scientific Society placed great emphasis to have a high quality testing facility. Since 1986 The Royal Scientific Society has an indoor, outdoor testing facility, which fulfill the requirements specified by national and international standard.

The Royal Scientific Society use this test facility to test solar collectors and solar water heaters for every manufacturer in Jordan, for any institution in any country, and for the developed solar collectors and solar water heaters at the Royal Scientific Society.

3. STANDARDS

Standards have existed for many years for determining the performance of the major components of heating system, components used in process and service water heating. Prior to 1977, no such standard existed for the principal new component of solar systems, the solar collector, but a need for them was perceived.

The solar flat plate collector is a technological product and device designed to convert radiation energy from the sun to sensible heat which is then transferred to a working fluid. any figure or parameter intended to characterize this process is consistently related to the efficiency of performance of this duty.

At least three areas can be identified to reflect the possible application of the test data:

a. Design and development of collectors.

b. Prediction of energy delivery, and its consequent contribution to the design of systems.

c. Consumer protection, quality reassurance.

There are many test methods presently used, however, reviewing those methods one can find that most of these are derived from the widely known ASHRAE 93-77 testing method with the addition of some modifications and recommendations.

The following is a list of the reviewed testing methods:

1) ASHRAE 93-77 (Methods of testing to determine The Thermal Performance of Solar Collectors).

2) CEC (Recommendations for European Collector Testing Methods).

3) NF 50-501 (Liquid Circulation Solar Collector Determination of Thermal Performance).

4) DIN 4757 part 4 (Solar Collector Determination of Efficiency, Heat Capacity and Pressure Drop).

5) Australian Standard 253-1982 (Glazed Flat Plate Solar Collector with Water as the Heat Transfer Fluid-Method for Testing Thermal Performance).

4. DESCRIPTION OF TESTING FACILITY

In general the test facility consists of the collector testing rack, the solar simulator and the data acquisition system. (see Figure (1) and Figure (2)).

Figure 1 : Solar Collectors Testing Facility

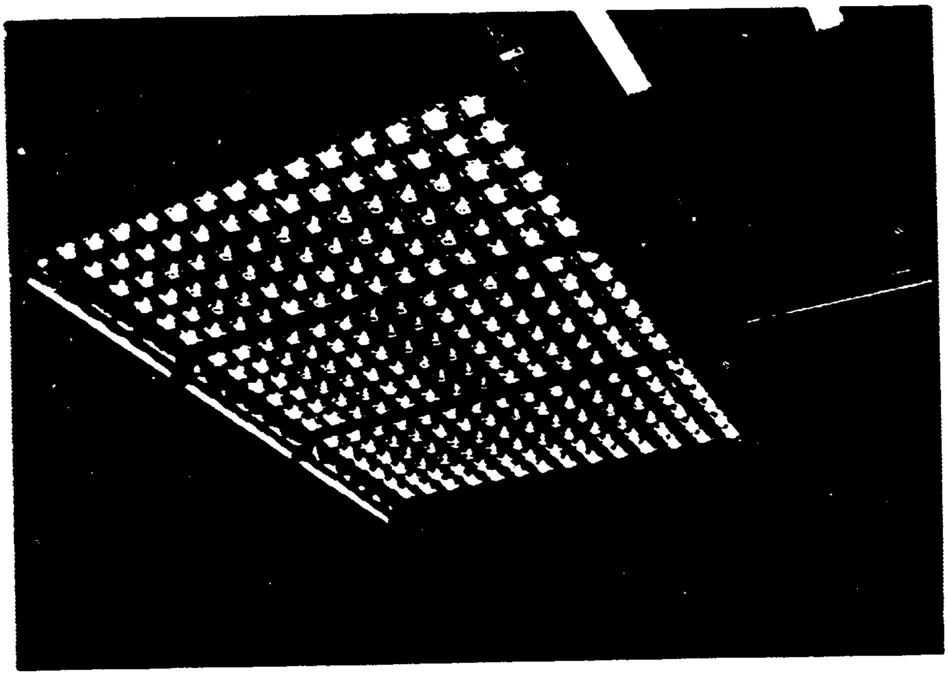


Figure 2 : Solar Simulator for Indoor Testing

4.1 - Collector Testing Rack

4.1.1 Collector Platform

The collector platform is automatically oriented towards the sun by the azimuth and elevation drives which are controlled by electronic sun-tracking system.

The platform is 4.0 m long, 2.0 m wide. The azimuth tracking is from 0 to 180 deg., and the elevation tracking is from 0 - 90 deg. .

Four separate test loops were built for the water-heating collectors. This was done to be able to test more than one collector at a time and still have the flexibility to make adjustments to individual collectors during testing and yet not affect the other collectors being tested. Each two test loops are identical and containing the flow loop within the enclosed base. Two loops are separated by heat exchangers for simultaneous testing of collectors working with water and collectors working with other fluid (see Figure (3)) .

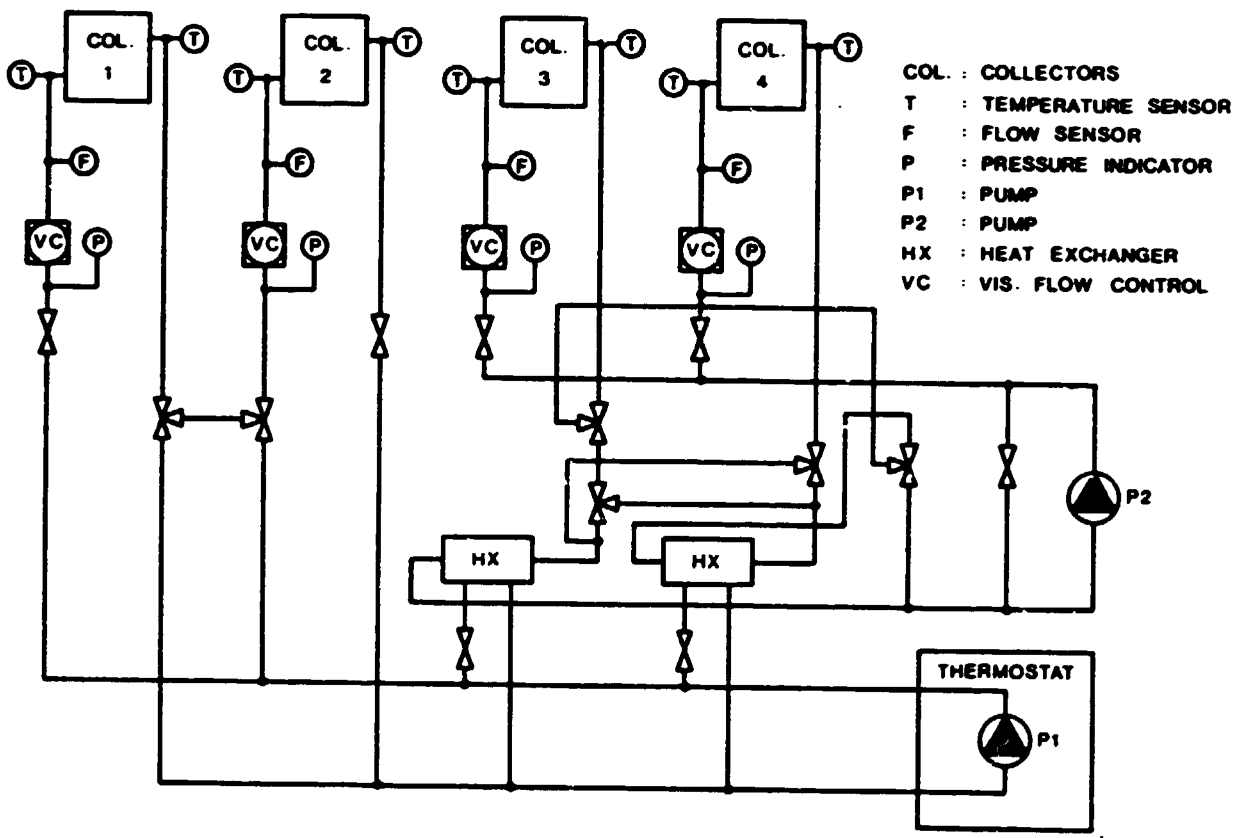


Figure.3. Flow Diagram of Collector Test Facility

The test loops were designed to be able to control and stabilize the collector fluid inlet temperature to within ± 0.5 °C and the fluid flow rate to within ± 1%.

The temperature measurement devices are located immediately upstream and downstream of the collector allowing temperature sensors to be inserted for measurement purposes. The temperatures of the collector fluid is registered at collector inlet and outlet using Pt-100 sensors.

The signal modulators are integrated in the switchboard cabinet. According to the short distance between sensor and modulator, high transmission performance is secured. The modulated signal can finally be transmitted without accuracy impacts to the computer, in the laboratory.

The signal modulators are completely sealed and protected against humidity and dust. Further, by temperature compensation of the electronics, according to different ambient conditions, high accuracy can be maintained.

The ambient temperature is measured by a separate Pt-100. The sensor which is combined with a hygrometer for air humidity measurement is preferably installed on a separate mast, together with the wind speed and wind direction measuring sensors.

The fluid flow in the individual collector loops is measured by non-contact gauging using a magnetic inductive sensor. This implies considerable advantages in practical use, since particles in the piping of the collector loops disturb the measurements, thus additional high accuracy can be provided.

The signal modulators are completely sealed with a visual indication of flow rates to allow for immediate information of the operator during flow rate adjustment.

The collector facility can be used also for determining proper interconnection of collectors either in parallel or in series. These tests of collectors field arrangements require normally higher flow rates of the collector fluid so that in the standard unit, the flow sensor is chosen for highest accuracy in the range of 70 to 1000 l/h. Smaller sensors are optional on request.

The pyranometer used for the solar radiation measurement is mounted on the collector platform in the collector plane. The signal modulator is protected against humidity and installed in the switchboard cabinet. A combined wind sensor provides data for wind speed and wind direction.

The humidity measuring sensor is integrated into the ambient temperature measuring sensor, which is a Pt-100. A special protection of the sensors guarantees reliable operation, avoiding impacts of rain, snow and solar radiation.

A thermostat integrated into the switchboard cabinet provides constant collector fluid inlet temperatures and the selection of defined fluid temperature levels. The temperature is controlled by an electronic PID controller with a sampled electromagnetic valve with an accuracy of 0.05°C.

Up to + 80°C the unit operates pressureless with tap water as heat transfer fluid. Above this temperature a solenoid valve closes automatically and the thermostat operates up to + 160°C as compressed water system. The cooling capacity is provided by an air-cooled compressor.

4.1.2 Switchboard cabinet

The switchboard cabinet is fixed on the turn table of the test rack and guided by rollers on the column. It moves with the azimuth movement of the collector platform.

The switchboard cabinet houses the following items:

- Thermostat
- Piping, valves, pumps for separate loops
- Electronic sun-tracking unit
- Signal modulators and indicators
- Flow measuring sensors
- Safety equipment like expansion vessels, safety valves, filters.

4.2 Solar Simulators

Usually,the solar simulator allows for indoor testing, where the room is air-conditioned to keep the inside temperature constant during indoor testing. (see Figure (4)).

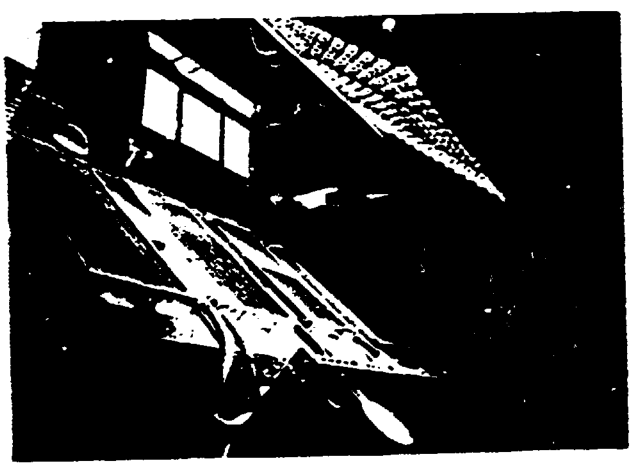


Figure 4 : Indoor Testing with the Solar Simulator

The solar simulator uses special Quartz Halogen Dichroic Mirror Lamps. The lamps are installed in three air-water cooled units with a total of 252 lamps. The entire lamps system is movable in height and angle by electrical motors mounted at the ceiling of the building. The vertical rows of lamps are movable for incident angle modifier measurements. The actual irradiated surface is 2,25 m x 1.75 m and the solar spectrum corresponds to air mass2.

The uniformity of irradiation is ± 10%. The daily radiation profiles of the sun are programmable and computer controlled, with irradiation data adjustable from 0 to 1100 W/m² at 3 m collector distance. Therefore it is possible to test the solar collector at different simulated solar radiation levels.

4.3 Data Acquisition System

A variety of data are monitored and recorded by the data acquisition system and other recorders. Data such as meteorological data, flow-rates, temperatures, are read into one central instrumentation room. Table (1) shows a print out of such data.

SEP. 27, 1988   12:25   ANGLE 0   REPLAY RECORD NR 20

It (W/m^2)	Id (W/m^2)	ta (degC)	wv (m/s)	wd (deg)	h (%)
1049.93	163	27.07	1	113	39.71

TEMP

	COL.1	COL.2	COL.3	COL.4
m/T ... (kg/h)	97.21	95.71	94.79	88.92
ti .... (decC)	58.92	58.96	58.41	58.71
te-ti . (K)	5.61	6.1	6.17	3.84
Ag .... (m^2)	1.32	1.33	1.32	1.23
Qu .... (W)	634	679	680	396
Jt .... (W)	1389	1396	1389	1286
qu .... (W/m^2)	479	511	514	323
eff ... (%)	45.6	48.7	49	30.8
ti-ta . (K)	31.85	31.89	31.34	31.64
(ti-ta)/It*100 .... (K*m^2/W)	3.03	3.04	2.99	3.01

Table 1 : Print Out of Measuring Data

The software for the test evaluation is according to ASHRAE-standard. And DIN 4757 of testing solar collectors.

The Jordanian standard with the no. 435, which is the same as the Arab standard no. 660, is similar to ASHRAE standard, with some changes that were made to be applied in Jordan.

- The used computer specifications are as follows :
- Computer type with two disk drives — Apple II e
- Basic memory — 64 K-byte
- Extended memory with 80 column expansion — 64 K-byte
- A/D transformer — 2 x 12 bit
- Number of channels — 32

5. TESTING PROCEDURE

5.1 Requirements

The solar collectors must be put under a solar radiation of not less than 4722 W/m^2 for 3 days without any connection.

When testing, by using solar test facility, the following conditions must be met :

- The solar collectors must be clean
- All connection must be insulated.
- Total radiation must be more than 630 w/m^2.
- Wind velocity must be less than 4.5 m/sec.
- Ambient temperature must be less than 30°C.
- Mass flow rate of transfer fluid is recommended to be 0,02 Kg/m^2.sec.

- In time constant test, the solar radiation must be equal or more than 900 W/m^2.

5.2 Testing

The testing procedure recommended by the proposal for the determination of the thermal efficiency of solar collectors is performed by passing the heat transfer fluid through it, at steady flow, with the collector mounted outdoors under clear sunny conditions, or indoor using a solar simulator under controlled conditions.

Measurements were required to be made during the day and consisted primarily of determining the fluid flow rate, temperature rise in the fluid as it passed through the collector and the incident solar radiation.

These data could then be used to compute collector efficiency. The test implies that at least 16 steady state efficiency values should be determined over a range of temperature differences between collector inlet fluid and ambient air, in order to draw an efficiency curve for the collector.

The testing procedure specified in the proposal consists of a series of efficiency tests plus additional tests which allow to determine the transient response of the collector as well as how efficiency changes with increasing incident angle. Measurements are made of the fluid flow rate, the temperature of the fluid at the inlet and at the outlet, the incident solar radiation, the ambient temperature, the product of the fluid mass flow rate, its specific heat, and the temperature rise. The heat collected per unit area of the collector divided by the incident solar radiation gives the instantaneous efficiency of the collector.

$$n = \frac{\text{useful energy collected}}{\text{incident solar energy}} = \frac{Q_u / A}{I} \quad (\%)$$

where:

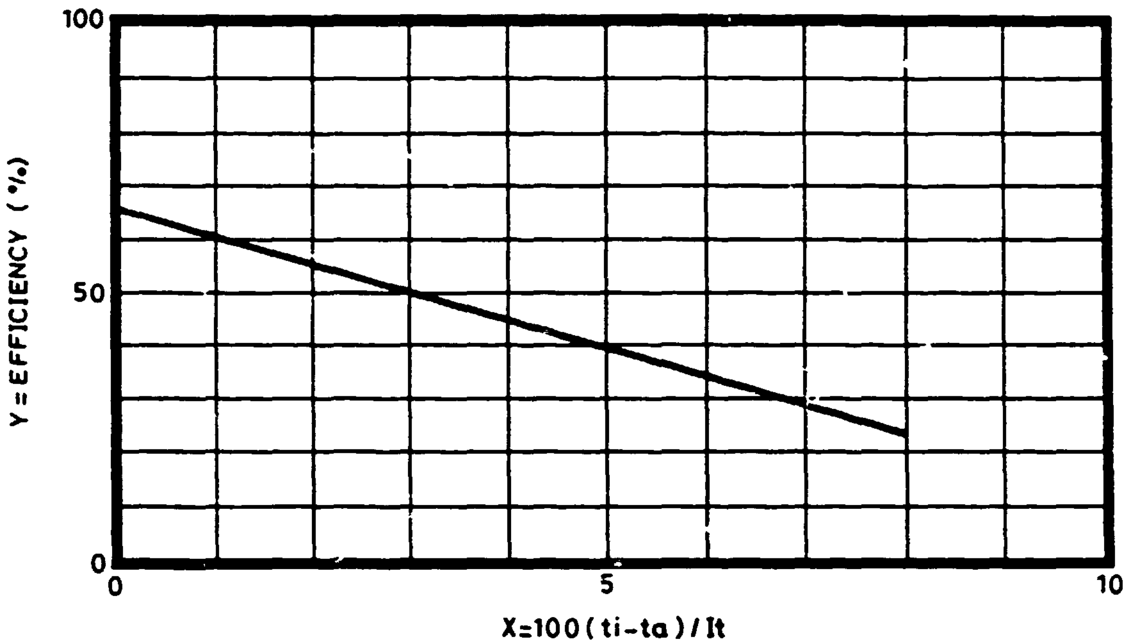
- Q_u = m cp (T_o - T_i) (Watt)
- A = Area of the collector (m^2)
- I = Incident solar energy per unit area (W/m^2)
- m = Mass flow rate (Kg/h)
- cp = Specific heat (J/Kg.°C)
- T_o = Temperature of transfer fluid leaving the collector (°C)
- T_i = Temperature of transfer fluid entering the collector (°C)

The data which are of importance for the collector test evaluation are handled by a computer. The measured data are registered by the computer every 20 seconds and shown on the display. Every 5 minutes, mean values are computed and stored on a disk. On request, the data are given as print-outs. The activation of the plotting programme provides the efficiency curve of the collector.

6. TEST RESULTS

Since the erection of the collector testing facility 43 solar collectors from Jordanian Manufacturers, 14 solar collectors from other countries and 55 solar collector developed at the Royal Scientific Society were tested. A sample of testing results is shown in figure (5), which indicates the first order efficiency curve, while figure (6) indicate the second order efficiency curve for the same collector.

The energy output of the solar collector at different inlet temperatures can be obtained from these curves. Table (2) shows the energy outputs in watt.hour/m^2 for the same tested solar collector at three different inlet temperatures of 30°C, 45°C and 65°C which is required by the Jordanian standard. The energy output was calculated by the computer using the first and second order efficiency equations of the solar collector. The time constant for this solar collector was about 260 sec .



X-AXIS : 100 (ti-ta)/It

Y-AXIS : EFFICIENCY (%) $Y = 65.5 - 5.3 * X$

OUTDOOR TESTING

COLLECTOR TYPE : RSS-SEL-G.

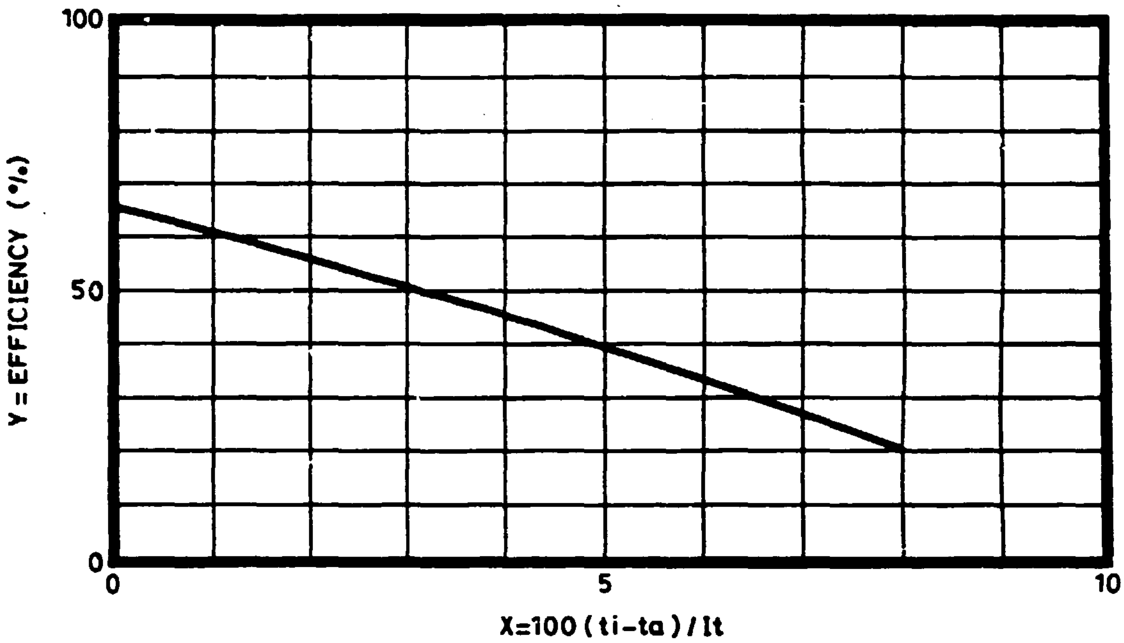
AREA : 1.323 m^2

REMARK : 3

SEP. 27 to SEP 28 in 1988

		AVERAGE
It	= 919.6 - 1050.2 W/m^2	1007.1 W/m^2
Id	= 133 - 178 W/m^2	165 W/m^2
ta	= 21.9-29.3 °C	25.2 °C
wv	= 0 - 2.2 m/sec	1 m/sec.
wd	= 28 - 346°	167°
m/T	= 92-97 kg/h	95 kg/h
ti	= 23.8 - 107.7 °C	

Fig. 5: First Order Efficiency Curve.



X-AXIS : 100 (ti-ta)/It

Y-AXIS : EFFICIENCY (%) $Y=-0.128*X^2-4.63*X+65.5$

OUTDOOR TESTING

COLLECTOR TYPE : RSS-SEL-G.

AREA : 1.323 m^2

REMARK : 3

SEP. 27 to SEP. 28 in 1988

		AVERAGE
It	= 919.5 - 1050.2 W/m^2	1007.1 W/m^2
Id	= 133 - 178 W/m^2	165 W/m^2
ta	= 21.9-29.3 °C	25.2 °C
wv	= 0-2.2 m/sec	1 m/sec.
wd	= 28-346°	167°
m/T	= 92-97 kg/h	95 kg/h
ti	= 23.8-107.7°C	

Fig. 6: Second Order Efficiency Curve.

ROYAL SCIENTIFIC SOCIETY

SOLAR COLLECTOR APPLICATIONS SECTION

COLLECTOR TESTING FACILITY

ENERGY OUTPUT FOR TESTED COLLECTORS AT RSS

Col. Type: RSS-SEL-G. Area(M2)= 1.323

EFF. 1st = -5.300 x + 65.500

EFF. 2nd = -0.128 x2 -4.630 x + 65.500

Amb.Temp. DEG. C	RAD. W/M2	ENER. at ti=30 C	ENER. at ti=45 C	ENER. at ti=65 C
18.000	50.000	0.000	0.000	0.000
19.000	151.000	37.718	0.000	0.000
19.000	252.000	107.984	10.343	0.000
20.000	353.000	181.289	92.802	0.000
21.000	454.000	253.416	170.010	39.067
21.000	555.000	319.987	239.121	115.155
22.000	656.000	391.391	312.868	194.512
23.000	757.000	462.596	385.791	271.548
23.000	858.000	528.849	452.909	341.214
24.000	959.000	599.884	525.029	415.878
ENERGY (W.hr/M2)		2883.115	2188.874	1377.374
ENERGY (W.hr/col.)		3814.362	2895.881	1822.265

Table 2: Energy Output at Different Inlet Temperatures.

7. TESTING OF VARIOUS FLAT PLATE COLLECTOR

In order to assure quality performance and reliability of locally manufactured flat plate collectors and solar water heaters, and to protect both the consumer and manufacturers, the Ministry of Trade and Industry and the Ministry of Energy and Mineral Resources in cooperation with the Royal Scientific Society started testing a sample FPC from each manufacturer once a year at the solar collector testing facility. A total of 32 collectors from different Jordanian manufacturers were tested during 1987 under such cooperation.

A total of seventy six tests were conducted at the solar collector testing facility in 1987. Sixty seven tests were conducted outdoors, while thirteen tests were conducted indoors utilizing the solar simulator. Fig.7 shows the first order efficiency curves for the same collector tested outdoors and indoors.

Fifty five different collectors were tested once, four collectors were tested twice, three collectors were tested three times and one collector was tested four times. The variation of test results due to one year aging for a collector is shown in Fig.8.

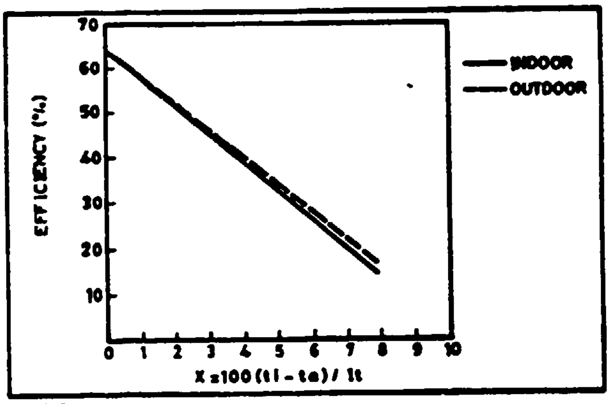


Fig.7: Indoor/Outdoor

A total of sixty three different collectors were tested. Twenty six of them were developed and manufactured at the RSS. The other thirty seven collectors were tested for private sector companies.

All the tested flat plate collectors are glazed water cooled with internal manifolds. For reporting purposes the test results are classified into three different groups. Figure - 9 shows the daily energy output of tested FPC with special absorbers. Figure-10 shows the daily energy output of tested locally manufactured collectors with steel absorbers. Figure - 11 shows the daily energy output of tested collectors with steel absorbers developed at the RSS.

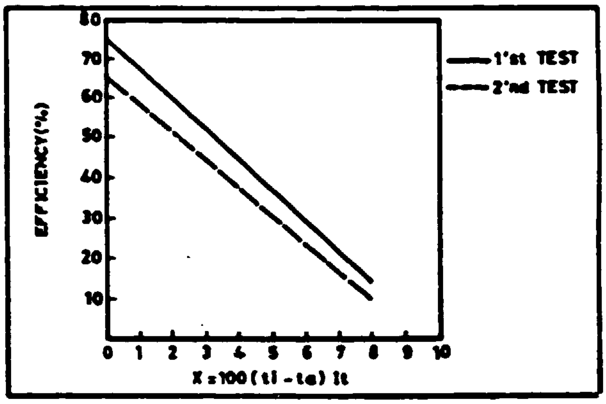


Fig.8: Aging effect

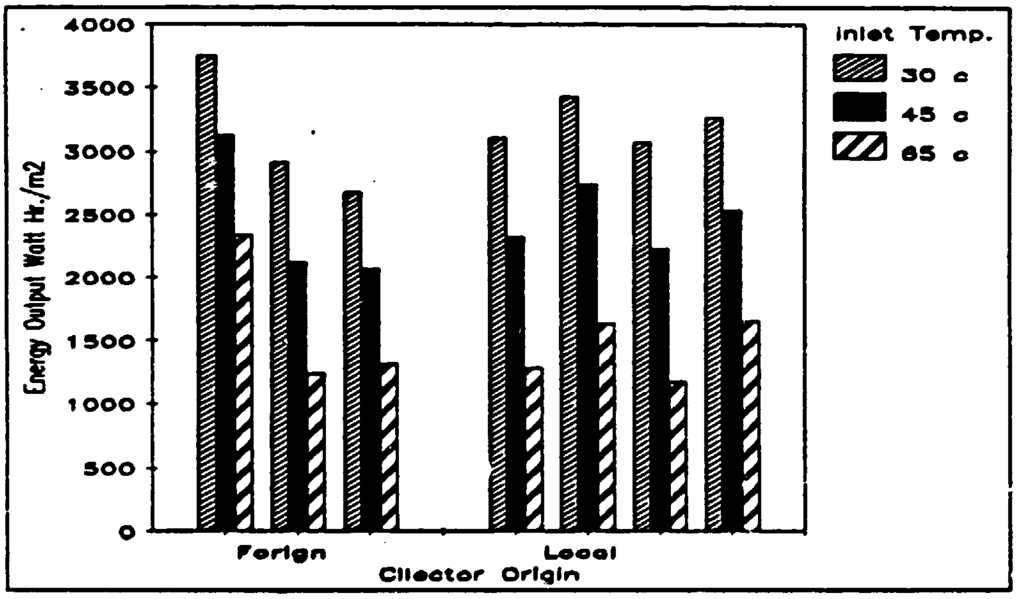


Fig.9 : Energy output for tested collectors at RSS with special absorbers

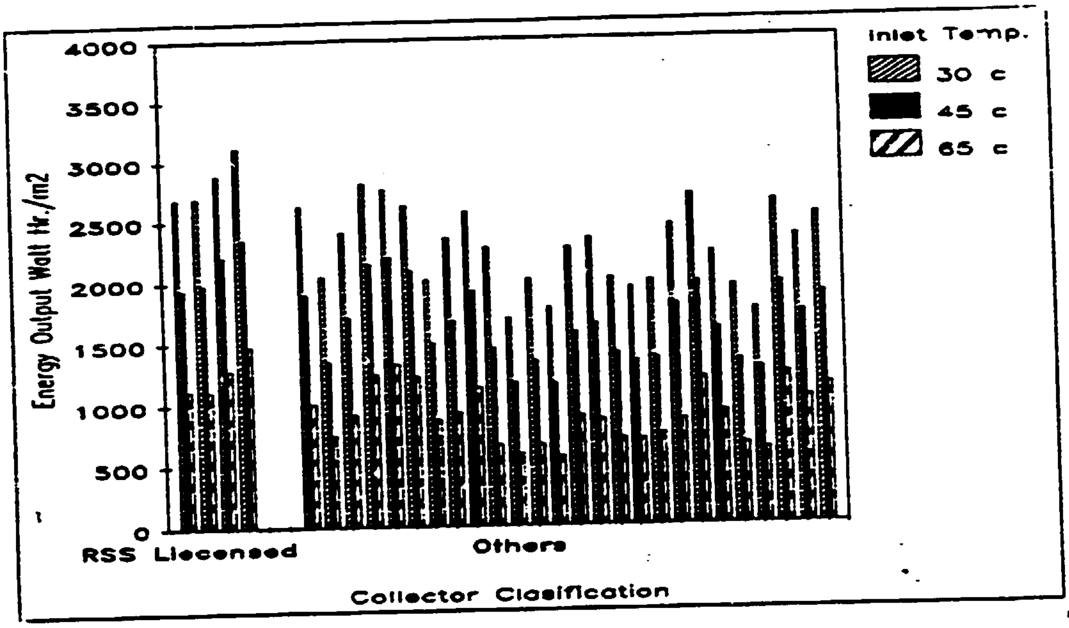


Fig.10 :Energy Output For Tested Collectors At RSS With Steel Absorbers

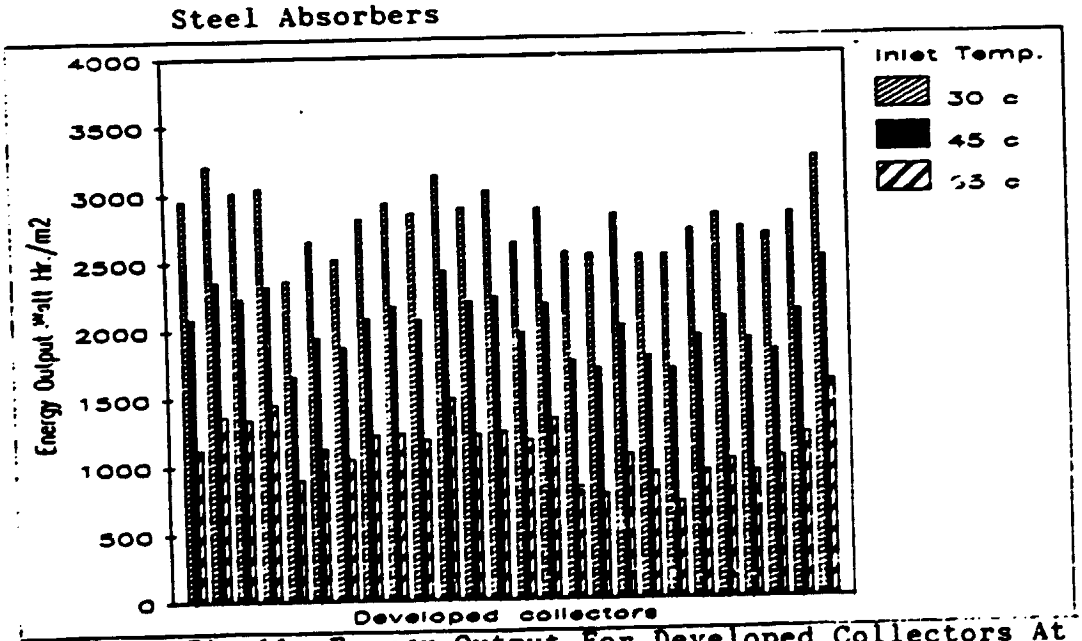


Fig.11: Energy Output For Developed Collectors At RSS With Steel Absorbers

8. SOLAR WATER HEATER TESTING

The solar simulator used for indoor testing, can also be used for testing of Solar Water Heater Systems, with the objective of evaluating their efficiencies and energy gained under specified solar radiation and ambient temperature.

Using test results obtained, one can compare the different Solar Water Heater Systems at certain inlet temperature or solar radiation.

6.1 Testing Method

The testing method of solar water heater systems, which was developed locally using the solar simulator, is as follows :

- The solar water heater is installed, insulated and filled with cold water at, or close to, ambient temperature.

- The solar simulator is fixed at three meter distance from the solar collectors surface, so that the radiation is perpendicular to the collectors surface.

- Controlled by the computer; the solar radiation intensity is given a certain value. The solar radiation is measured using solarimeter at different points on the collectors surface and the average is calculated.

- At the end of the calculated time, to give the total radiation needed, the system is discharged 10 liters quantity at a time, and a measure of the temperature is done to the discharged quantity until the discharged water reaches the inlet water temperature as in the beginning of the test or so close to it.

The following table is an example of the test results obtained, which is for RSS design of a solar water heater system (see table (3)).

TESTING OF SOLAR WATER HEATERS ACCORDING TO WP 1.203

	Model:	RSS-SWH	
Stor. Capacity L	: 150.000	Inlet Water Temperature C:	24.000
RADIATION W/M2	: 743.000	TOTAL RADIATION W.HR/M2 :	4000.000
Date	:Feb,28,87	Collector Area M2 :	4.000

Water Discharge No.	WATER TEMP.C	ENERGY WATT.HR
1	67.600	507.068
2	71.000	546.610
3	68.800	521.024
4	67.800	509.394
5	66.300	491.949
6	65.600	483.808
7	63.200	455.896
8	61.200	432.636
9	57.400	388.442
10	53.100	338.433
11	47.200	269.816
12	39.200	176.776
13	34.500	122.115
14	31.200	83.736
15	28.900	56.987
16	26.500	29.075
17	26.500	29.075
18	26.200	25.586
19	26.000	23.260
20	25.500	17.445
21	25.400	16.282
22	25.200	13.956
23	24.900	10.467
24	24.900	10.467
25	24.700	8.141
26	24.600	6.978
27	24.500	5.815
28	24.500	5.815
29	24.500	5.815

TOTAL ENERGY COLLECTED = 5592.867 WATT HR.

SYSTEM EFF. % = 34.955

Table 3: Sample Results of Testing a Solar Water Heating System.

The data recorded as temperature of each 10 liters of hot water discharged is tabulated from which the energy gained and system efficiency is calculated.

9. CONCLUSION

This paper present a brief idea about the solar collector testing facility available at the Royal Scientific Society. A description was given on the testing procedure followed for solar collectors and solar water heaters testing, showing some sample results.

The test facility helps so much in speeding up the testing operation, and leads to more development work on flat plate collectors, due to fast identification of any improvement in collectors efficiency and energy output. It also help in quality control of the locally manufactured collectors protecting both the consumer and the manufacturer.

INTRODUCTION TO PASSIVE SOLAR DESIGN

Eng. AMMAR TAHER

ABSTRACT

This paper addresses solar passive design ideas for buildings and houses. Passive solar heating techniques are classified according to how they gain heat. A breakdown of a passive solar heating system into five elements is provided and briefly examined. Finally a brief discription of the passive cooling techniques are outlined.

INTRODUCTION

What is called "Passive Solar Design" was used long time ago. Throughout history, civilizations have learned how to adapt their architecture to their climatic conditions and in almost all cases primary importance was given to the relationship with the sun.

ACTIVE AND PASSIVE SYSTEMS

There are two categories of solar applications: active and passive. Passive solar applications, which this paper will address, rely on natural gravity or convection currents to transfer heat from a solar collection device to the living space. Examples of passive solar devices are solar greenhouse, Trombe wall, and thermosyphon water heaters. Active systems, on the other hand, generally require pumps, fans, and controllers to transfer heat from the solar collection device to the place where it will be used.

Passive space heating occurs when the structural elements of a building are used to collect and store solar energy. Unlike active solar heating systems, passive solar heating systems require no significant mechanical equipment involved. Passive solar heating requires that south-facing side of the building remain unshaded during the heating season. Sunlight can then pass through large areas of glass or plastic glazing on that side. Once the solar heat is collected, it is absorbed and stored by thick masonry walls and floors or water-filled containers.

INSULATION AND ENERGY CONSERVATION

Too many solar projects have failed simply because good sense was not used in constructing a building that would be energy efficient and easy to cool or heat. Insulation is a cheap and reliable way to save energy; accordingly, proper insulation and other energy-efficient techniques should be given first priority in any new building or remodeling scheme, especially if solar features are being considered.

Practicing energy-efficient techniques will not only save money in heating and cooling the building, it will also limit the size of whatever auxiliary heating or cooling system is installed to back up the solar system, so that unnecessary expenditures for mechanical equipment can be avoided.

Before any significant energy savings can be realized through solar features, it is essential to properly seal the building. Vapor barriers are also important to energy conservation. A vapor barrier on the inside surface is important to prevent moisture build-up in the wall. This moisture condensation will greatly reduce the effectiveness of the insulation and eventually cause it and the wall to rot.

HEAT LOSS AND GAIN

Heat always moves from one location to a cooler location until there is no longer a temperature difference between the two. There are three types of heat movement: convection, conduction, and radiation.

Convection refers to the movement of heat in currents of air or water. Convection heat loss or gain, or infiltration, is usually the result of poorly weather-stripped doors and windows and their frames.

Conduction refers to movement of heat through a solid. Some materials are good conductors of heat, hence poor insulators. Such materials include metal, stone, concrete, wood, plaster, and glass. Conductive heat loss and heat gain can be minimized by using insulation.

Radiative heat loss occurs when windows are left uncovered at night. Even triple-glazed windows are subject to radiative heat loss into the night sky. In addition, any type of storage mass, like an uninsulated masonry wall, will radiate stored heat out into the night sky. Typical means of preventing radiative heat loss or gain are insulating shutters or shades backed with a reflective sheet.

SITING AND ORIENTATION

The first step in designing a solar efficient structure is the understanding of the geometrical relationship between earth and sun. All solar designs must respond to the universal determinations of these angels. below are the general sun angels for north hemisphere during the course of the year. the sun angel for the 22nd day of the month are given. The diagrams on the left side represent a plan view of the sun's locations when it rises and sets on the 22nd day of the month. The illustration on the right shows the relationship of the sun with the ground plane at noon on the 22nd day of the month. For latitudes not listed, angels may be obtained through interpolation.

In planning the building, it is just as important to design for protection from the summer sun as for access to the winter sun. Overhangs and shading devices are important to keep direct sunlight out of the building during warm weather and care should be taken when designing windows on the east and west exposures of the building, since the sun will shine directly into these windows while it is low in the sky on summer mornings and late afternoons. In addition, the direction of the prevailing breezes at the building site should be taken into account so that adequate natural ventilation can be incorporated in the building to cut the expense of the air-conditioning.

There are many passive design ideas, not all of them may apply to a specific situation.

- some make more sense in cold climates, and others in warm climates.

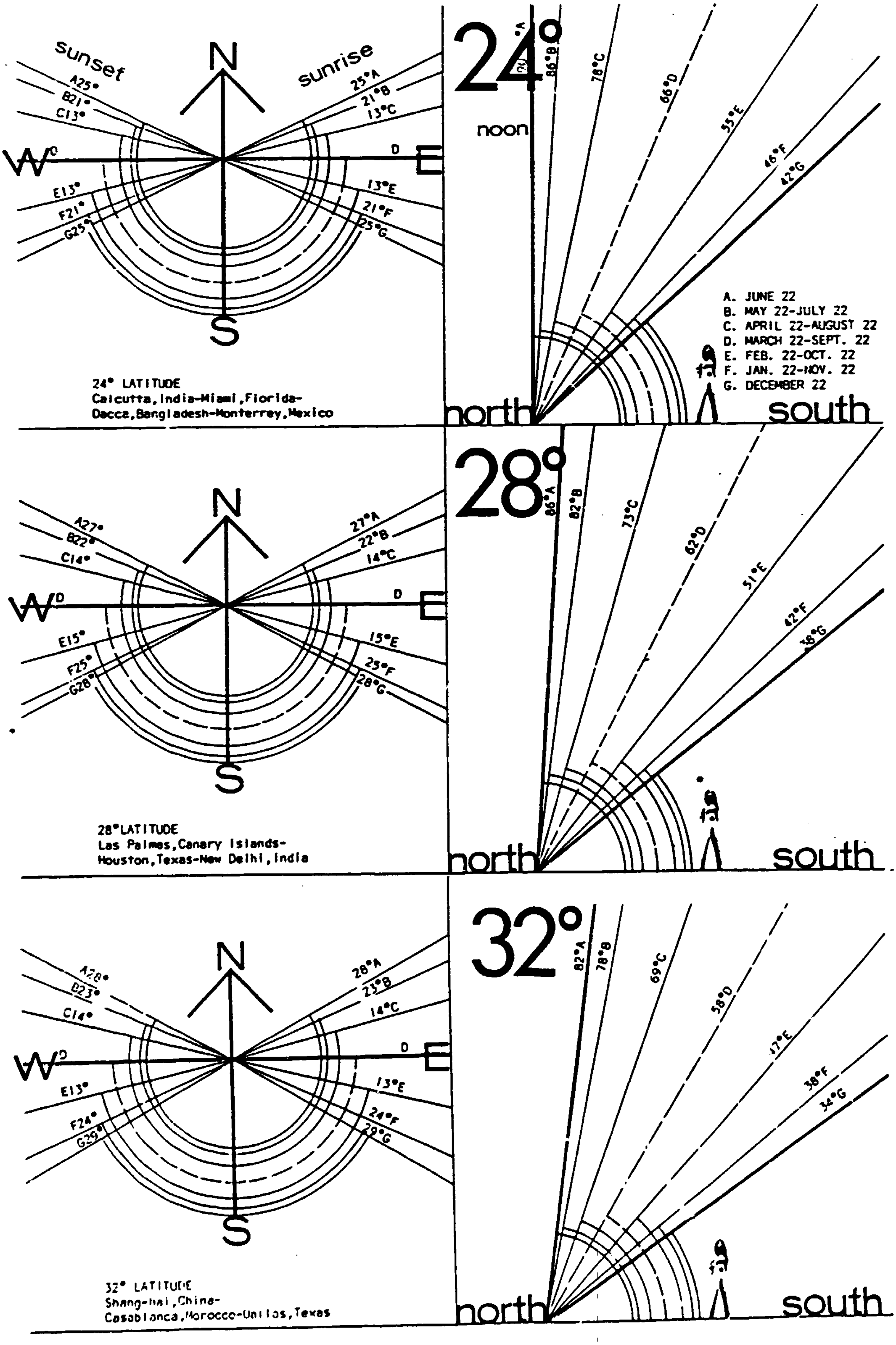
- some can be incorporated into existing homes and others are applicable only in new construction.

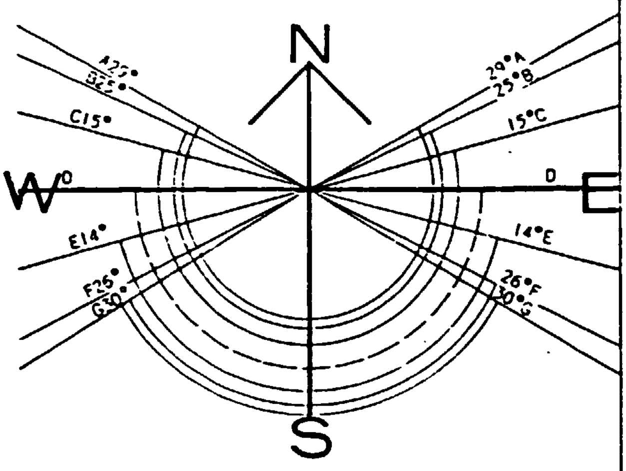
- some may appeal to you, and others may not.

Passive solar concepts are applied most easily in a new building, where they can be incorporated into the original design. Existing buildings can be retrofitted to passively collect and store solar heat.

PASSIVE SOLAR HEATING TECHNIQUES

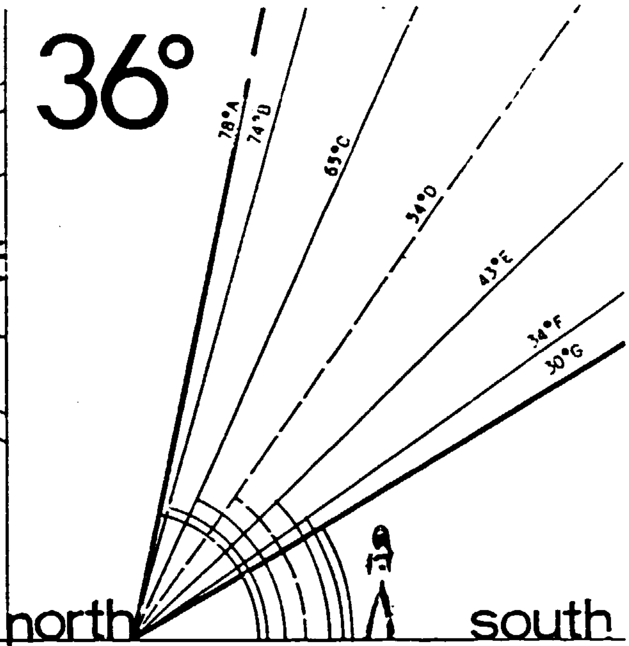
The basic approaches that serve to classify passive systems are distinguished according to how they gain solar heat. The use of one approach to passive solar heating dose not prevent the use of another in the same building . It is not unusual for different approaches to overlap. Ar attached greenhouse, for instance, can be combined with direct gain windows in the wall connecting the greenhouse and the main living space. The same applies to a

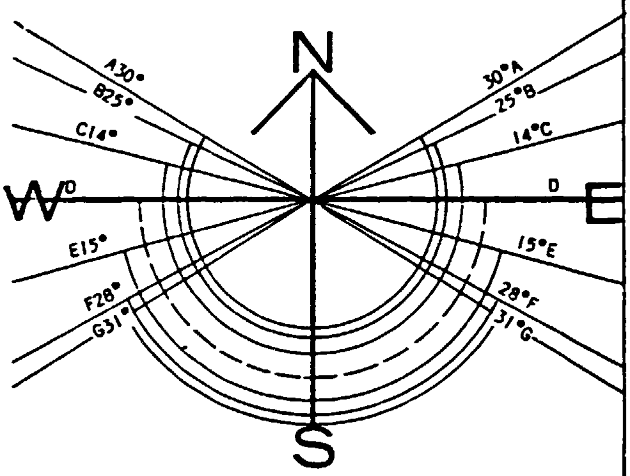

sunset
sunrise
N
S
W
E
D
A25°
B21°
C13°
25°A
21°B
13°C
E13°
F21°
G25°
13°E
21°F
25°G
24°
noon
86°A
86°B
78°C
66°D
55°E
46°F
42°G
A. JUNE 22
B. MAY 22-JULY 22
C. APRIL 22-AUGUST 22
D. MARCH 22-SEPT. 22
E. FEB. 22-OCT. 22
F. JAN. 22-NOV. 22
G. DECEMBER 22
north
south
24° LATITUDE
Calcutta, India-Miami, Florida-
Dacca, Bangladesh-Monterrey, Mexico
A27°
B22°
C14°
27°A
22°B
14°C
E15°
F25°
G28°
15°E
25°F
28°G
28°
86°A
82°B
73°C
62°D
51°E
42°F
38°G
28° LATITUDE
Las Palmas, Canary Islands-
Houston, Texas-New Delhi, India
A28°
B23°
C14°
28°A
23°B
14°C
E13°
F24°
G29°
13°E
24°F
29°G
32°
82°A
78°B
69°C
58°D
47°E
38°F
34°G
32° LATITUDE
Shang-hai, China-
Casablanca, Morocco-Unilas, Texas



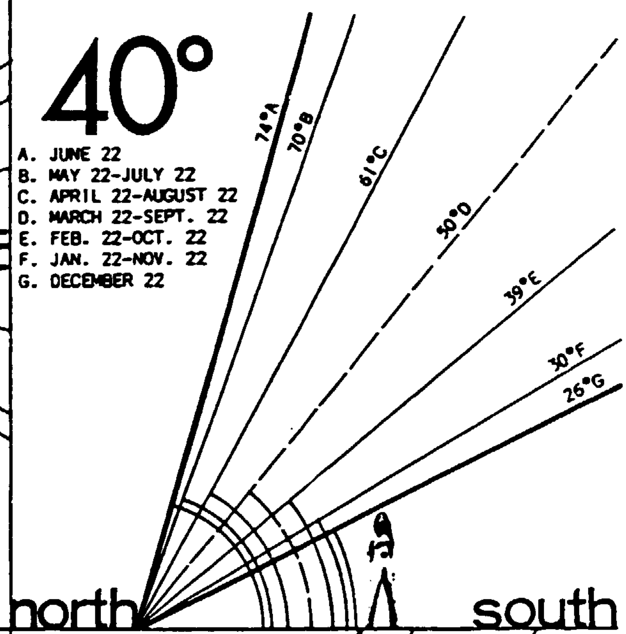
36° LATITUDE
Tokyo, Japan-Tehran, Iran-Kwang-Ju, Korea
Fayetteville, Arkansas-Monterrey, Calif.

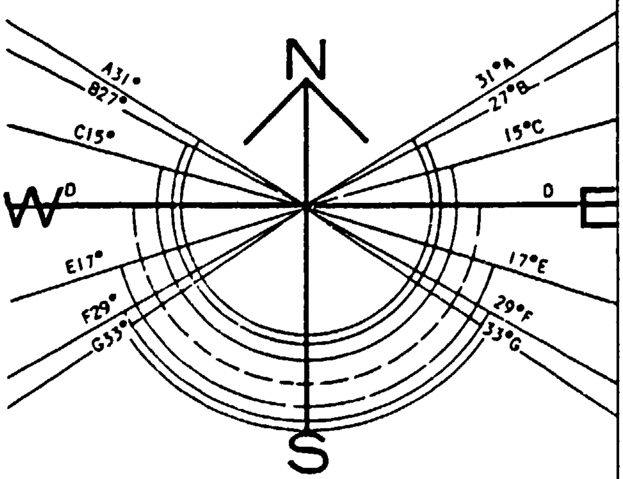
18



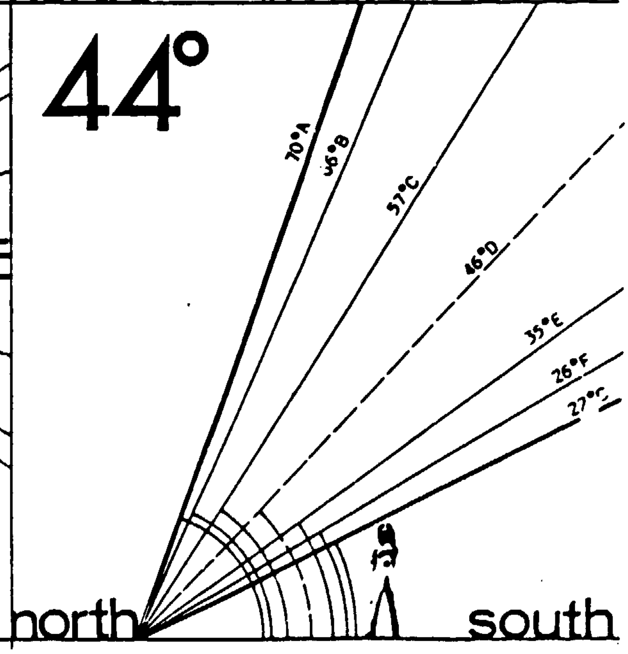


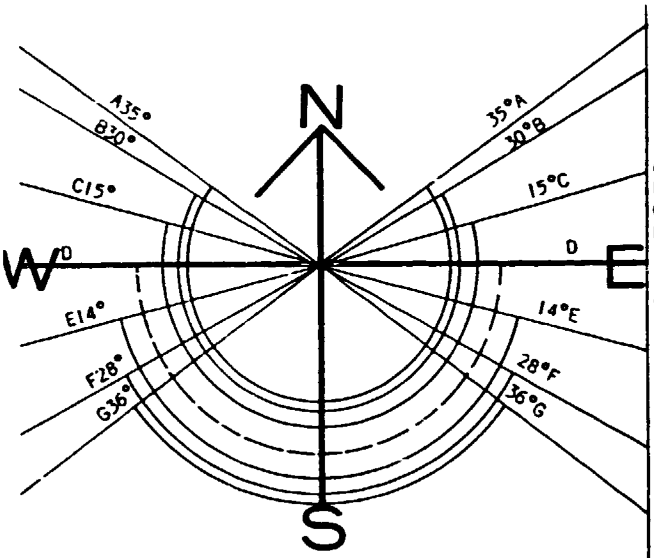
40° LATITUDE
Madrid, Spain-Peking, China-Denver, Colo-
Olympus, Greece-Philadelphia, Penn.

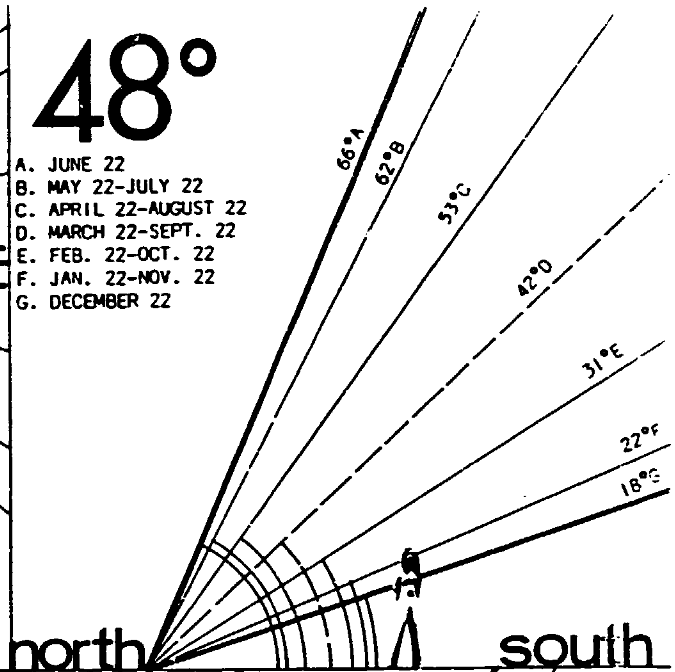




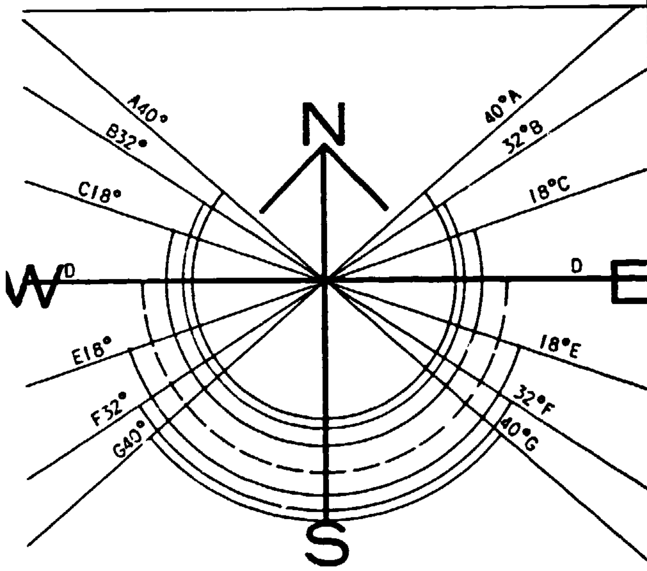
44° LATITUDE
Florence, Italy-Auburn, Maine-
Alma Ata, Russia

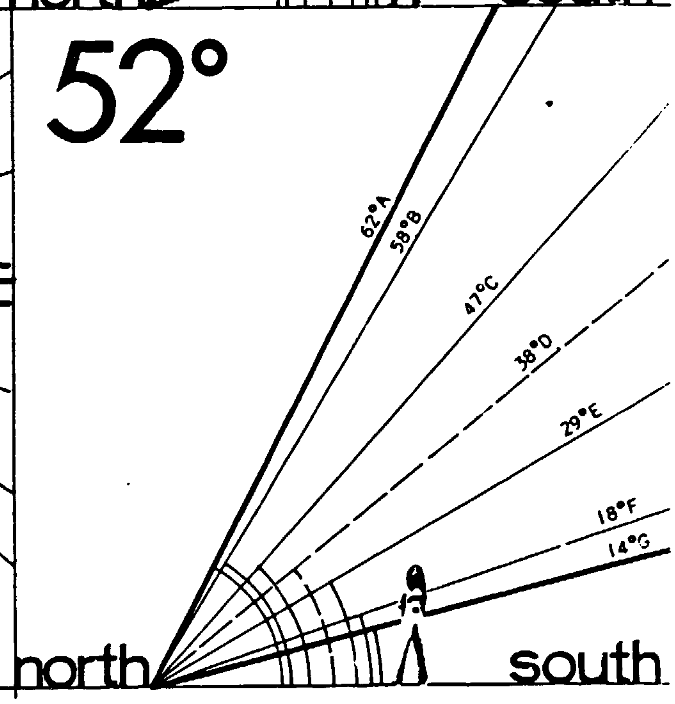






48° LATITUDE
Munich, Germany-Budapest, Hungary-
Seattle, Washington-Montreal, Canada



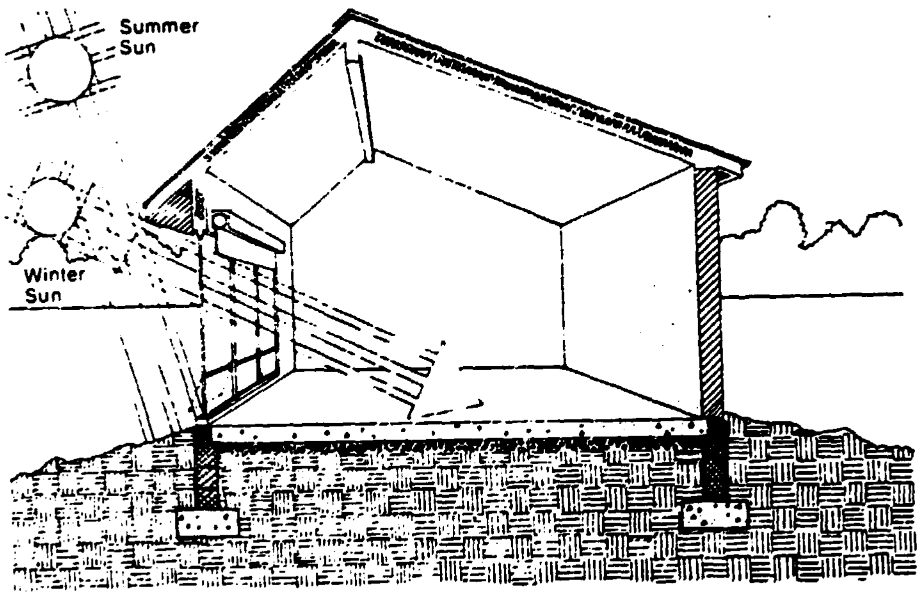


52° LATITUDE
London, Great Britain-Warsaw, Poland-
Rotterdam, Holland-Berlin, Germany

Trombe wall,which can have large window opening in it for direct gain and natural lighting. The variety of passive options leaves a great deal of room for the individual tastes of homeowners and for the market considerations.

1) Direct Gain

The simplest passive heating technique is called direct gain. As shown in Figure(1) sun light enters the house through larger than normal windows facing south and strikes the wall and/or floors, The surface of the walls and floors are a dark color that will absorb the sun's heat, which will then be stored in the masonry. At night, as the room cools, the heat stored in the masonry will radiate into the room. In addition to / or in place of masonry walls and floors, water filled containers can be positioned strategically to absorb and store solar heat.



Figure(1) Direct Gain

To control heat loss, the direct gain house should be equipped with movable night insulation. This insulation covers collector area at night to prevent massive heat loss from the building. In the summer, to prevent overheating, direct sunlight must not be allowed to reach the inside of the house. The movable insulation,in this case,can be closed during the day. A roof overhang will also shade the south-facing window from the summer sun.

2) Indirect Gain

The solar radiation is intercepted by an absorber and storage element - wall - that separates the south facing glass from the room.

a. Trombe wall:

The Trombe wall is the primary example of an indirect gain approach. As shown in Figure(2) it consists of a thick masonry wall on the south side of a house. A single or double layer of glass or plastic glazing is mounted in front of the wall's south surface. Solar heat is collected in the space between the wall and the glazing. The outside surface of the wall is a dark color that will absorb heat, which will then be stored in the wall's mass.Heat is distributed from the Trombe wall to the house in two ways. Over a period of several hours, the heat, will migrate through the wall, reaching its rear surface in the late afternoon or early evening. When the indoor temperature falls below that of the wall's surface, heat will begin to radiate into the room. Most Trombe walls are also designed to distribute heat immediately, while the sun shines. This requires that the wall have two sets of vents , one at floor level and one at ceiling level. As the air between the surface of the wall and the glazing heats up, it begins to rise and flow through the vents. This continuous pattern of natural air movement is called a convective loop (thermosyphon).

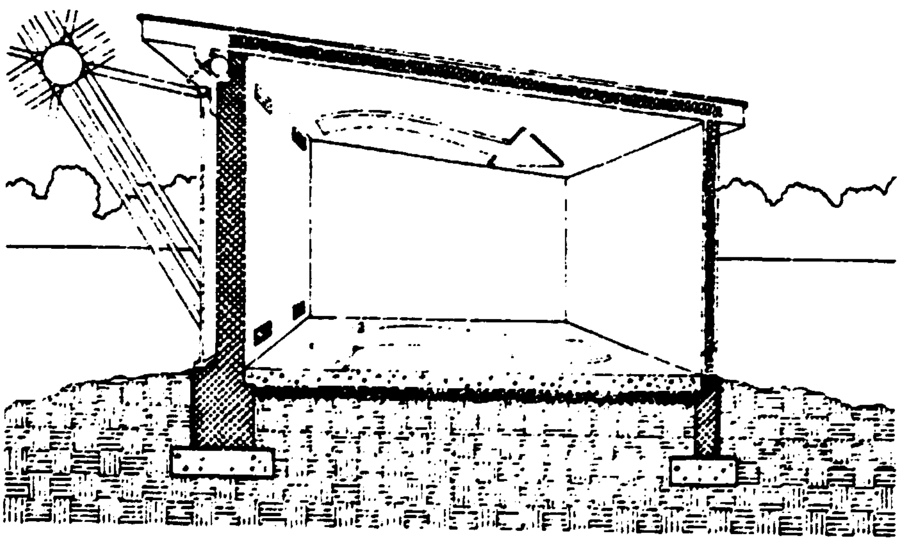


Figure (2) Trombe Wall (Indirect Gain)

Heat from the Trombe wall can be controlled by an insulating curtain that is drawn at night in the space between the glazing and the wall. The Trombe vents are also equipped with "backdraft dampers" to prevent a reverse convective flow at night that would cool the room air.

b. Water wall:

The water wall is a variation on the Trombe wall. In place of a masonry wall, water containers are positioned between the living space and the glazing as shown in Figure (3). Water walls can be built in a number of ways. Any fairly durable container will work, including drums, paint cans, and glass jars. A water wall absorbs and stores solar heat in much the same way as a Trombe wall, with the exception that water holds more heat than an equal volume of masonry.

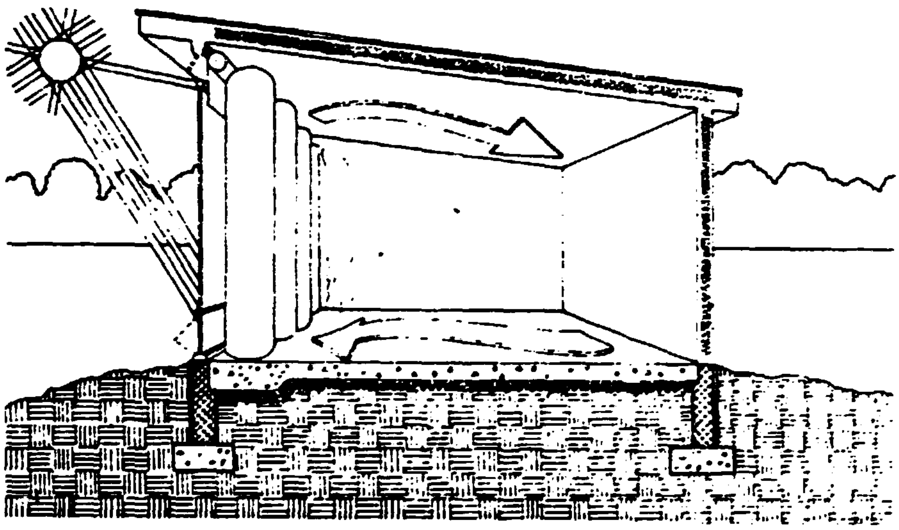


Figure (3) Water Wall (Indirect Gain)

Once again, insulating curtains are used at night to control heat loss from the water containers through the glass.

c. Roof pond:

A variation on the water wall is the roof pond shown in Figure (4). Roof ponds are essentially water beds of sturdy plastic. They rest on special ceiling structure and are covered and insulated on winter nights by movable roof. During the day the mechanically operated roof is opened. Exposing the roof pond to the sun so it can absorb heat to radiate to living area later.

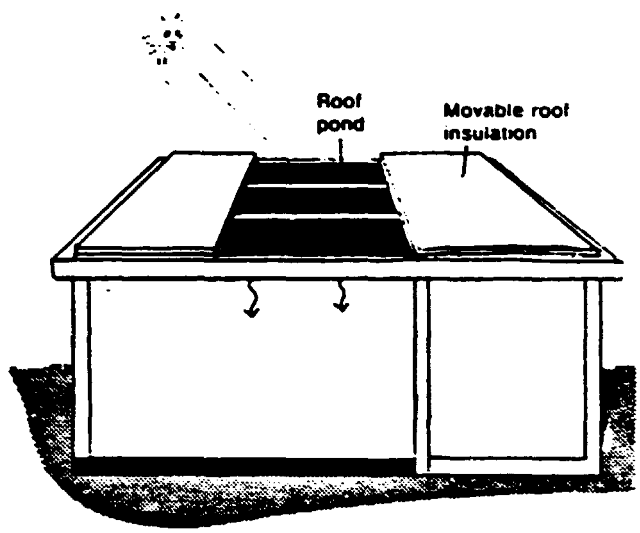


Figure (4) Roof Pond (Indirect Gain)

3) Isolated Gain

The solar radiation is captured by a separate space such as a greenhouse.

a. Solar greenhouse:

Known by many names - solar room, sun space, solarium - the solar greenhouse shown in Figure (5) is a versatile approach to passive solar heating. A solar greenhouse can be built as part of a new building or as an addition to an older building. Solar heat is collected through the greenhouse glazing. It is then absorbed and stored by masonry or water filled containers that can be positioned and sized in a variety of ways. A range of storage options can be used with a greenhouse. These include a masonry wall separating the greenhouse from the main building, water drums inside the greenhouse, and potting beds. Also, a water wall can take the place of masonry wall.

The distribution of heat from a greenhouse can be accomplished in variety of ways. A masonry wall between the greenhouse and the living space can provide "time-lag" heating, as in the Trombe wall, and it can also have ceiling and floor level vents that allow a natural convective loop. Or heat can be circulated by simply opening the connecting doors between the greenhouse and the house. Movable insulation is used to cover the inside of the greenhouse glazing at night. A greenhouse provides a buffer zone

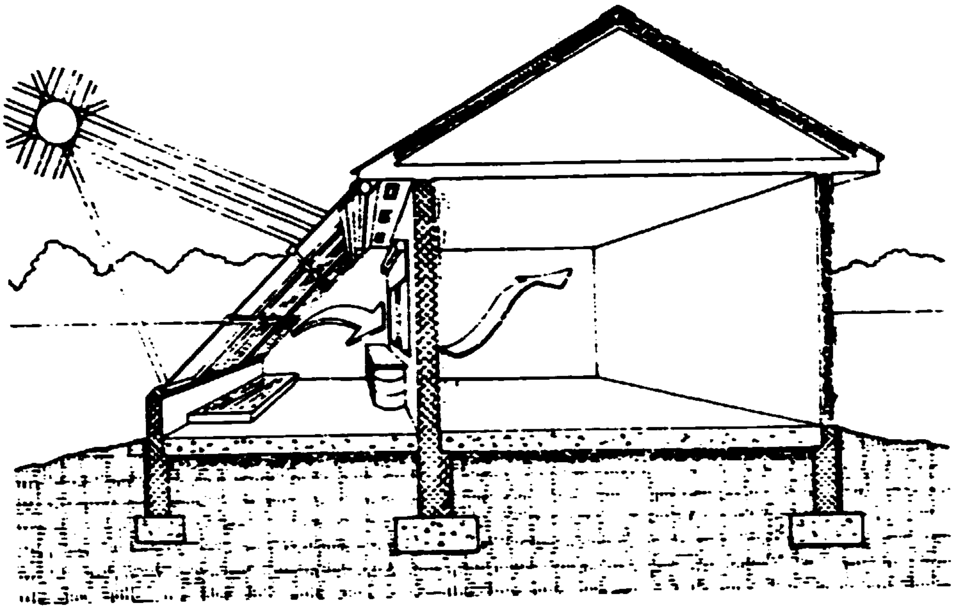


Figure (5) Solar Greenhouse (Isolated Gain)

for the house that will help cut heat loss, and it adds another space to the home, a space that can be used for many purposes, including the growing of food.

b. Thermosyphon collector:

Thermosyphon air collectors use a black painted absorber with glass or plastic glazing. A thermosyphon collector can be built into the south wall of a house at a level lower than the house. As shown in Figure (6) it can be hooked up with a rock storage bin. The heat circulates naturally, but much of it is absorbed and stored as it passes through the bin.

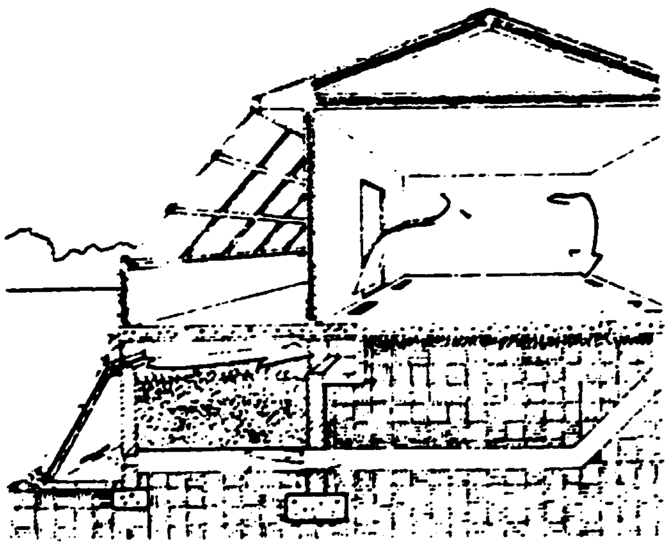


Figure (6) Thermosyphon with Rock-bin under Greenhouse (Isolated Gain)

4) Sun Tempering

Sun-tempering occurs when a house or other building collects solar radiation through large south-facing windows (or thermo-syphon collector as in Figure (7) but does not have a storage element. This is not a complete passive system, and its use is limited to daylight hours. The window collection area must be sized carefully, because without storage mass there is the possibility that the living space will become overheated quickly during the day.

Sun-tempering is used when the goal is to keep the conventional heating system off while the sun shines. Sun-tempering may be specially suited to buildings that are used primarily during the day: classrooms, shops, offices, warehouses.

Passive solar design needs not be limited to single family houses. In most large commercial buildings, the biggest demand for energy comes from lighting, followed closely by cooling. Many techniques have been developed to diffuse, reflect and transmit natural light (day lighting) throughout the building to reduce dependency on costly artificial lighting. Day lighting indirectly reduces cooling costs, since artificial lighting adds substantially to a commercial building's internal heat gain.

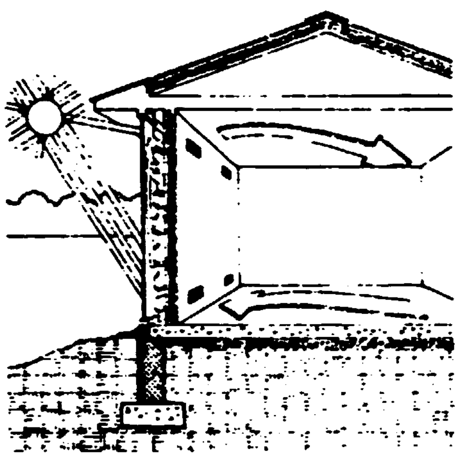


Figure (7) Sun Tempering

THE PASSIVE ELEMENTS

There are five elements that constitute a complete passive solar heating systems. Each performs a separate function, but all five must work together for the system to be successful.

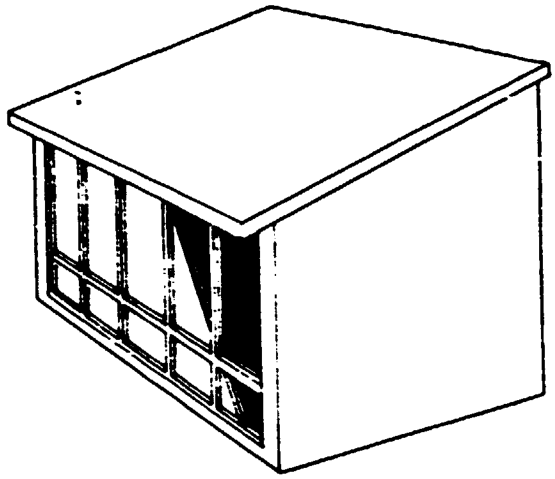
1) Collector

The large glass (or plastic) area through which sunlight enters the building. The collector (s) should face within 30 degree of true south and should not be shaded by other buildings or trees especially from 9 a.m. to 3 p.m. each day during the heating season.

Any material exposed to the sun will collect solar energy. Glazing products have a unique property of trapping long-wave radiation creating the greenhouse effect. Windows, skylights and greenhouses are all collectors.

There are several factors to consider in selecting a collector:

- Transmittance.
- Weatherability.
- Thermal conductivity and infiltration.
- Cost.



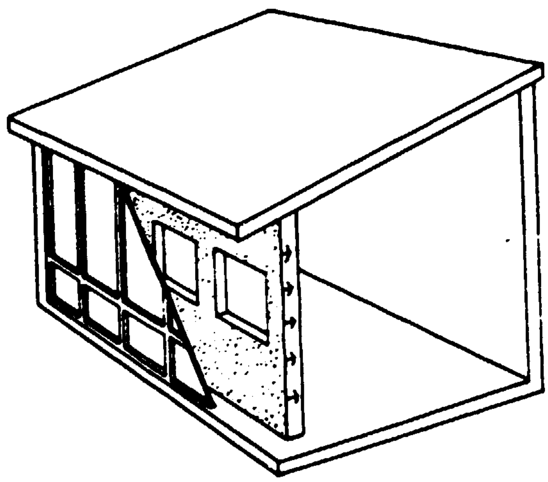
Collector

To capture the necessary solar radiation, it is essential to provide a minimum amount of south-facing glass. The minimal is 1/4 to 1/5 of the floor area (in temperate climates); 1/3 to 1/4 of the floor area (in colder climates).

2) Absorber

It is the hard, darkened surface of the storage element. This surface- which could be that of a masonry wall, floor, or room divider, or that of a water container - sits in the direct path of sunlight. Sunlight hits the surface and is absorbed as heat.

An advantage of both Trombe walls and water walls is the benefit that can be gained from the performance of a selective-surface material that can be glued or sprayed on the outside surface of the wall. A selective-surface material has a high absorbance for sunlight, and a low emission in the thermal range. Since about half of the heat loss through the glass to the outside is transmitted by thermal re-radiation, the performance of the wall can be improved by approximately a third.



Absorber/Storage

3) Storage

The materials that retains the heat produced by the sun are often referred to as "thermal mass", they are usually either masonry (concrete, concrete block, or brick) or water. The difference between the absorber and storage, although they are the same wall or floor, is that the absorber is an exposed surface whereas storage is the material behind that surface.

Once heat is collected, it needs to be stored for later use. Any material will absorb and hold heat for a time, but only certain materials will do it efficiently and cheaply enough to be practical. Basically, there are three mediums used for thermal storage-water, solids (concrete, masonry, and rocks), and phase change materials.

Water is the cheapest material and stores large amounts of heat in a relatively small area. Leakproof storage can be difficult to construct and sometimes expensive, although very inexpensive options are available.

Rocks, concrete and masonry can also be relatively inexpensive. They are very heavy and space consuming. It takes almost four times more brick or rock than water by weight to store the same amount of energy. This can possibly create some structural problem, but masonry or concrete storage can also serve as a floor slab or wall.

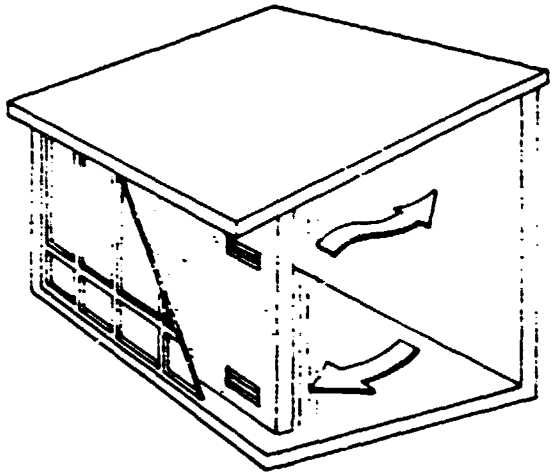
Phase change materials store a great deal of heat in a small area and are very costly. These chemical combinations are formulated to change state at about 30 c and absorb heat as they melt or release it as they solidify. Compared to other types of storage, they can hold tremendous amounts of heat, but their cost may make them prohibitive unless space is at a premium.

The storage capacity required depends on the amount of radiation captured and the building's use characteristics.In temperate climates, for example, it is necessary to provide 45 kg of water or 200 kg of rock storage for each square meter of south-facing glass. if the storage medium cannot be directly exposed to the sun, this number have to be increased by as much as four times. The ratios of floor area and heat storage area should be a minimum of 1:1 to gain the maximum benefit of passive heating system.

4) Distribution

Is the method by which solar heat circulates from the collection and storage points to different areas of the house. A strictly passive design will use the three natural heat transfer modes-conduction, convection, and radiation. In less strict application fans, ducts, and blowers will help with the distribution of heat through the house.

In many passive designs, some sort of distribution device is needed. These devices include fans, blowers, ducts, and dampers. If a passive system must use a fan or a blower, the amount of energy it consumes should not exceed the amount of heating energy that the passive system is supposed to be saving.



Distribution

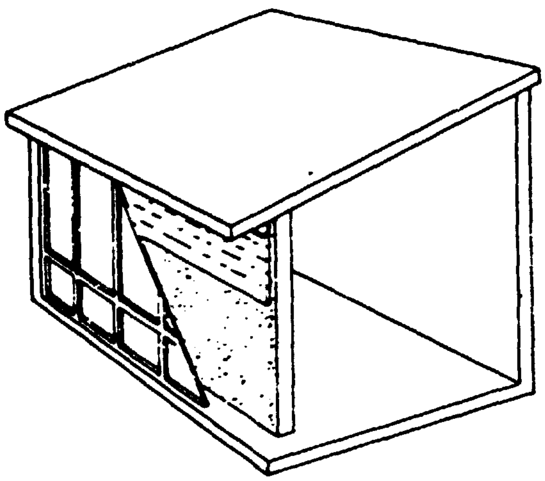
Adequate levels of ventilation are very important to human comfort even during the heating season. Fans and blowers keep air from stagnating and smelling stale in the winter when the house is sealed from fresh outside air. They also can reduce the mechanical cooling load of a home in the summer by creating air movement.

Buying and installing a ceiling or other type of fan is relatively simple compared with designing a duct and blower system and integrating it with an existing system.

5) Control (Heat Regulation Devices)

This is principally movable insulation, on which the performance of the entire system depends. Movable insulation prevents heat loss back through the collector area at night. Other elements that control both under and over heating include:

- electronic senses devices, such as a deferential thermostat that signals a fan to turn on.
- vents and dampers that allow or restrict heat flow.
- roof over hangs or awnings that shade the collector area during summer months.



Control

Care should be taken in selecting such devices. For example,a single device which will insulate in the winter and shade in the summer will often be less expensive than two separate devices for insulating and shading.

Shading devices perform best on the exterior of a window because they intercept the sun's heat before it enters the room. Insulation also has advantages being on the outside of a window where it will not cause condensation on the glazing which can occur with interior window insulation. Exterior devices, however, must built to withstand the effects of weather. They also can be very difficult to design so they operate from the inside.

PASSIVE SOLAR COOLING TECHNIQUES

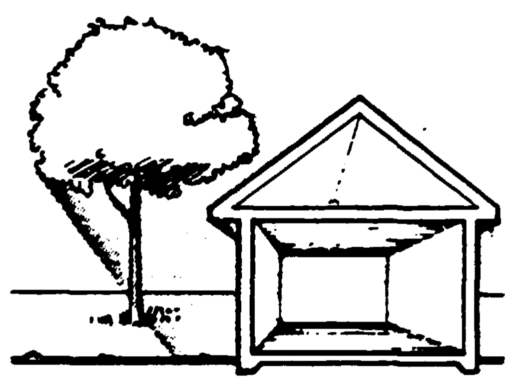
In this section the strategies that can contribute to living comfortably during the summer months will be briefly discussed. Knowledge of these techniques may influence your choice as to a heating strategy; and it is certainly a good idea to consider both heating and cooling before designing the total system.

The best examples of passive cooling are provided by the architecture of the era prior to air-conditioning. The ceilings are high, the rooms light colored and designed for natural ventilation.

Active solar cooling is still in the experimental stages. In active solar cooling, heat is used to run some kind of an absorption refrigeration machine. High temperatures are required in this application and so far have not proven to be cost effective. The passive technology has produced few techniques where by the sun's rays have directly or indirectly resulted in cooling. There are five types of passive cooling techniques : Load avoidance and reduction, Natural ventilation, Earth contact cooling, evaporative cooling, night sky radiation cooling.

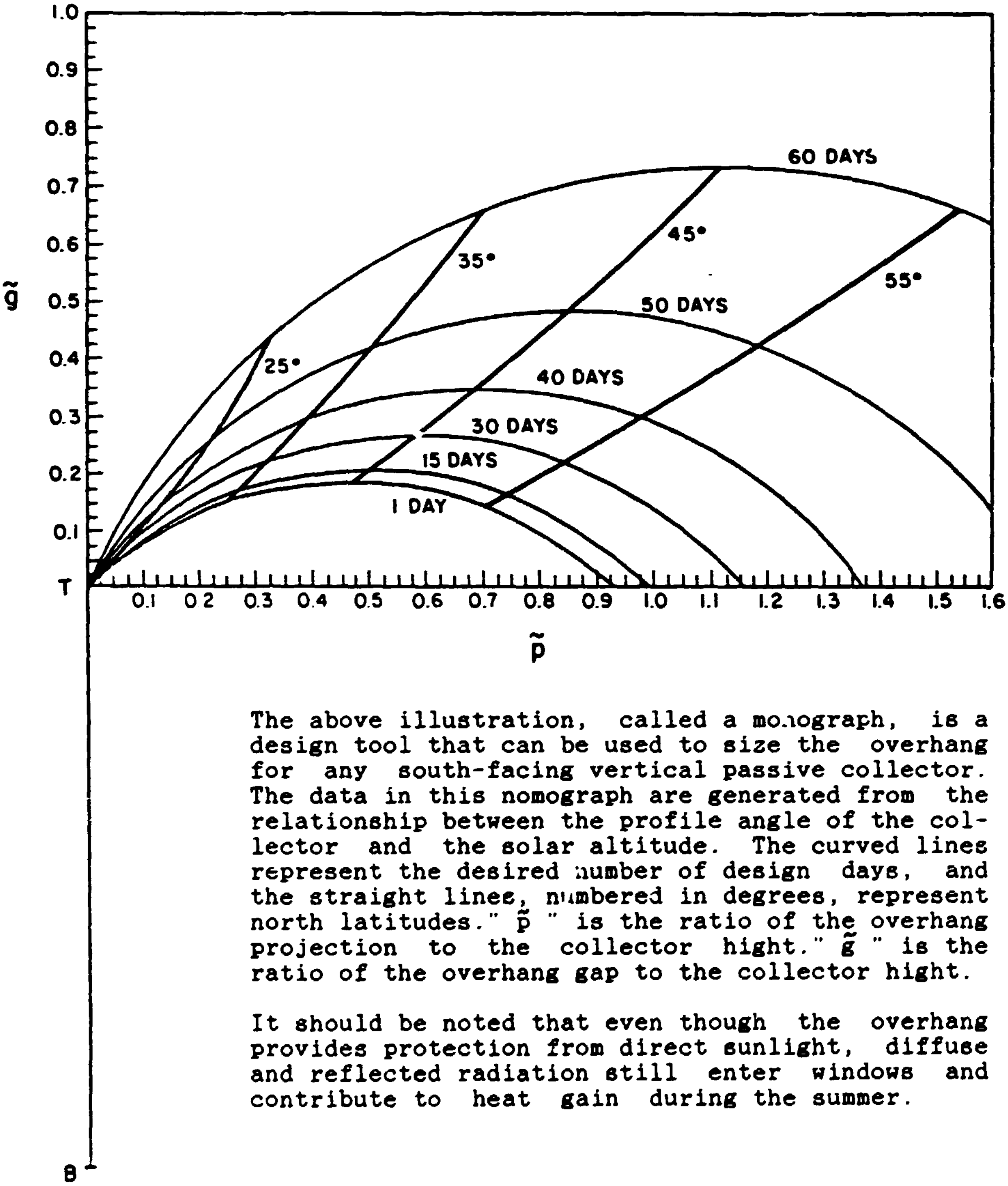
1) Load avoidance and reduction

The basic goal is to prevent passive-solar heating in the summer. This goal is achieved largely by appropriate placement of windows. It is important to shade windows from the summer sun by correctly designed overhangs on the south windows and by placement of vertical louvers, shading walls, or appropriately placed trees on the east and west sides of the building, and light color on outside walls and roof to reflect sun light from the building.



Load Reduction

By means of a chart called a "monograph", the size of a building's overhang can be precisely calculated to let in the sun light during a specified period of time before and after the winter solstice and to shade the glass for any desired period of time before and after the summer solstice.

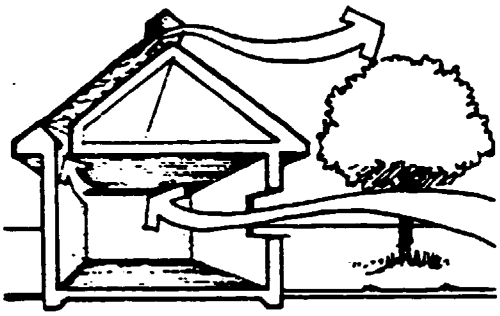


The above illustration, called a monograph, is a design tool that can be used to size the overhang for any south-facing vertical passive collector. The data in this nomograph are generated from the relationship between the profile angle of the collector and the solar altitude. The curved lines represent the desired number of design days, and the straight lines, numbered in degrees, represent north latitudes." $\tilde{p}$ " is the ratio of the overhang projection to the collector hight." $\tilde{g}$ " is the ratio of the overhang gap to the collector hight.

It should be noted that even though the overhang provides protection from direct sunlight, diffuse and reflected radiation still enter windows and contribute to heat gain during the summer.

2) Natural ventilation

Natural ventilation cooling is probably the most important type in most climates. Design for natural ventilation consists of careful siting of the house so that it has good access to the prevailing summer breezes, location of windows so that breezes can blow through the house, and adequate heat-storing mass within the house so that daytime heat can be absorbed by the walls for release to cool night breezes.

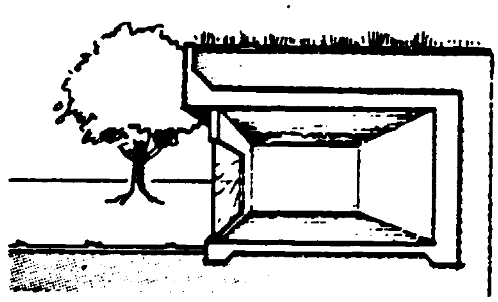


Solar Chimney

Thermal chimney also show promise in aiding hot-weather ventilation. Air within the Chimney is heated causing it to rise, thereby effecting air movement for ventilation or to provide air exchanges. The updraft induced by this device can be coupled with earth tubes or some kind of earth contact or night-cooled storage mass.

3) Earth contact cooling

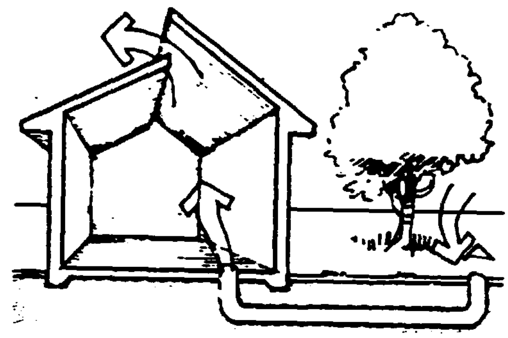
Another techniques for modifying both summer time and winter time temperatures is earth contact or earth sheltering. By digging a building into the ground, or pilling earth up around it, the constant temperature of earth and the associated heat sink can be used to make the building cooler in the summer and warmer during the winter.



Earth Sheltered

At one extreme, earth contact cooling takes the form of underground construction. At the opposite extreme is slab-on-grade construction. In between lies pilling earth against certain outside walls. This requires special attention to structural design for protection from the increased loads and pressure from the ground and also special care in waterproofing of the walls. Because of structural and waterproofing problems, underground construction is a very specialized topic requiring considerable research and engineering.

Another earth contact cooling technique is the earth tubes which are buried underground, and they bring in fresh air that has been cooled as a result of its journey underground.



Earth Tubes

4) Evaporative cooling

A promising passive cooling techniques being devised for hot humid climates relies on "dessicant cooling". A dessicant is a substance through which fresh air may be drawn and dehumidified. When the air is moved around the living area at sufficient speed, a comfort effect based on moisture evaporation from the skin surface results. The dessicant itself must be dried out periodically, and this can be accomplished by solar heat.

In hot dry climates, evaporative cooling may be very effective. There are several types of apparatus that cool by evaporating water directly in the living space (direct evaporative cooling). Interest has increased in equipment that combine the evaporative cooling effect in a secondary airstream with heat exchange to produce cooling without adding moisture to the living space air (indirect evaporative cooling).

5) Night sky radiation cooling

The use of roof ponds also shows promise as a cooling technique. During hot weather, the shutter (cover) is kept closed during the day. At night it is opened, and the pond radiates heat out into the night sky, becoming substantially cooler than ambient temperature. The pond then becomes an effective heat sink during the day.

In cold weather, the process is reversed. The shutter is opened during the day and closed at night.

SOLAR HOUSE PROJECT

ENG. SULAIMAN BATARSEH

1. ABSTRACT

This paper presents the main results of the first and second testing years which was published in [1,2]. Based on theses results, the researchers identified the weak points in the design of the solar house, and the solar hot water heating system and took suitable measures to remedy such weakness. These measures included :

i) replacing the existing single glass, tinted, aluminium frame windows with double regular glass tight plastic frame windows and the addition of a false entrance extension with a tight door.

ii) reinsulating the storage tank with a 250 mm thick-local made-rock wool insulation.

The use of regular glass to replace tinted glass and caused the transparancy for solar radiation to be increased.

The house with the above-mentioned measures was subjected to testing. In the second testing period other type of heating load devices, namely the fan coil units were used, instead the under floor system that was used in the first testing year.

2. INTRODUCTION

In the field of solar space heating, the Royal Scientific Society in cooperation with the Kuwait Institute for Scientific Research, implemented a pilot project to study the technical and economic feasibility of using solar energy for space heating in Jordan and for space cooling in Kuwait.

A solar house was built in Amman where passive and active design creterias were considered. The house was a 65 m^2 heated living space and a 43 m^2 unheated mechanical room.

Two heating systems were choosed for this project, the underfloor heating system, which was tested in winter 1982-1983 and the fan coil unit system, which was tested in winter 1983-1984.

3. OBJECTIVES

The main objectives of the solar house project were to determine the technical and economical possibilities of using solar energy for space heating, utilizing both active and passive solar systems. These main objectives were fulfilled through the following :

- Designing a passive solar house for the purpose of studying the passive heating contribution of solar energy;
- Designing an active solar system utilizing local Jordanian-made flat plate collecters for house heating ;
- Designing an underfloor heating system for the winter 1982- 1983 and a fan coil unit system for the winter 1983-1984;

- Testing the constructed systems (active and passive) for the purpose of determining the technical performance of all systems and subsystems in both years;

- Determining the economic and technical feasibility for the utilization of solar energy in space heating.

4. HOUSE DESIGN

To meet the objectives of this project, a house was designed and built at the RSS location (latitude 32° 01', longitude 35° 53', elevation 980 m).

Both passive and active design criteria were considered when designing this house. The house faces south and has large windows. The ratio of the area of the windows to the total area of the south side is approximately 1/3. The windows are of single glass 6 mm thick. These windows were replaced by double glazed ones for the second testing period.

The house is well insulated. The outer walls were built using 150 mm solid concrete bricks, 100 mm hollow bricks, 50 mm polystyrene sheets and 20 mm plaster. The ceiling consists of different layers, 10 mm roof guard, 120 mm concrete, 50 mm polystyrene sheets, 50 mm concrete layer, 250 mm ribs and 20 mm plaster. The floor consists of 100 mm concrete layer, 40 mm polystyrene insulation sheets, PVC mate of 0.2 mm, underfloor heating tubes with a concrete layer of 70 mm, sand layer of 25 mm, another concrete layer of 25 mm and concrete tiles with a thickness of 25 mm.

The house has two sections, the living space(64.84 m^2) and the mechanical room (43.3 m^2, unheated). The house is currently used as a laboratory for the Solar Energy Research Center. The hot water requiremnet of such a house in Jordan is estimated as 120 L/day-1 at 55°C. This hot water consumption was simulated by a magnetic valve and timer, which is programmed to open at set intervals to give the required quantity of hot water. Another timer controls the lighting of the house, which consists of three bulbs, 100 W each, switched on for the period from 17.00 to 22.00 h. Figure 1 shows the general layout of the house.

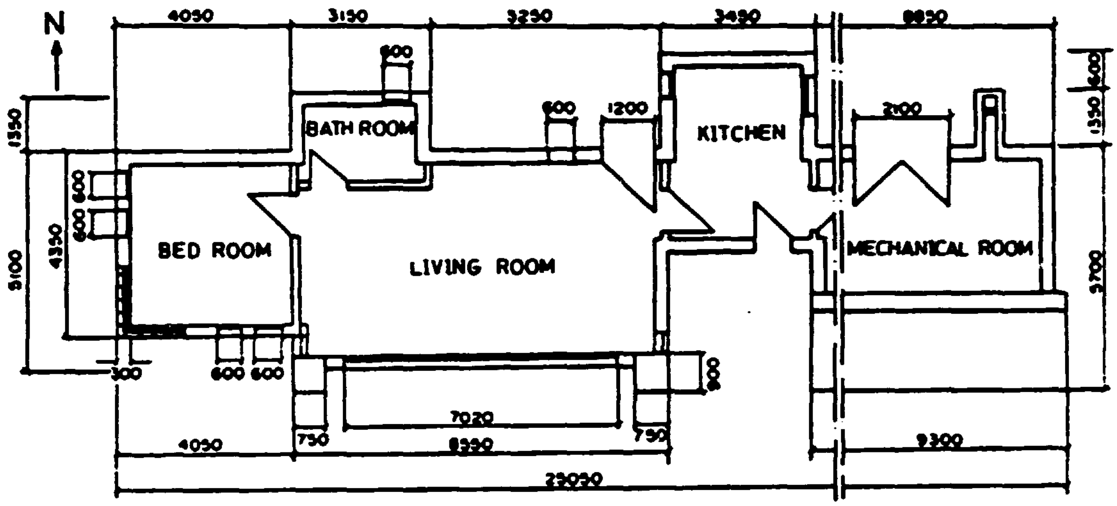


Fig. 1 : General layout of the solar house, Amman.

5. HEATING SYSTEMS

The present system consists of three loops; namely, the collector loop, the space heating load loop, and the domestic hot water water loop (see Fig.2).

The collector loop consists of collectors (3), storage tank (7), circulating pump (1), and other subsidiary components; the space heating loop includes the storage tank (7), the expansion tank (10), underfloor heating system (18) and fan coil units (13) for the second testing phase) and the back up system (11). The system is equipped with a flow control valve (4) (mode selector) and other supplementary components. Finally, the hot water loop includes a storage tank and circulating pump (1).

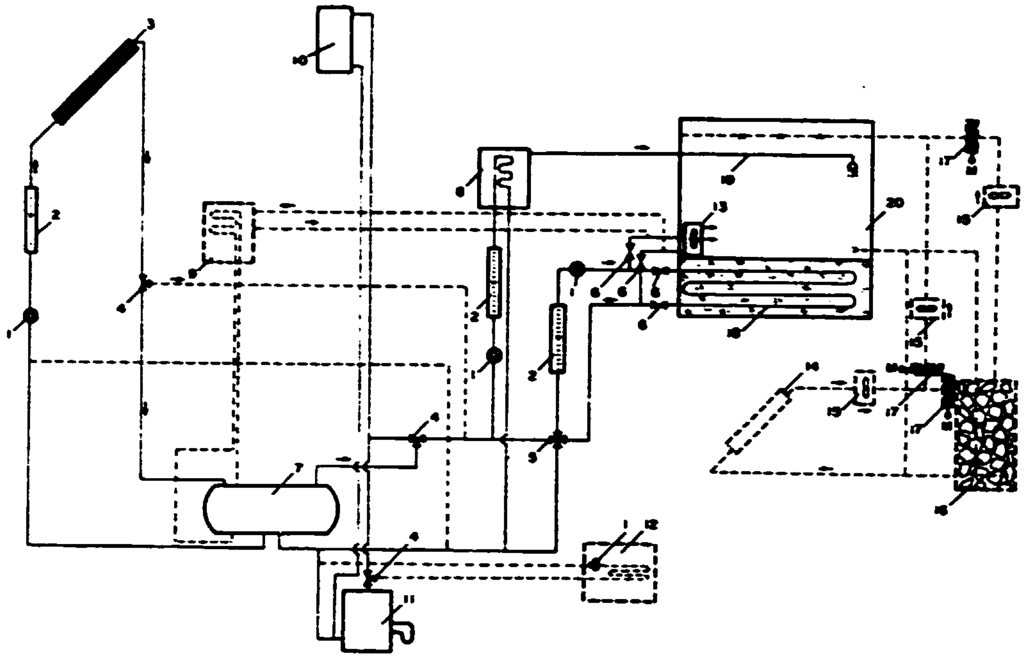


Fig. 2. Block diagram showing Jordan solar house systems. —— Current activities, ---- planned (possible) activities. 1, pump; 2, flowmeter; 3, solar water collector array; 4, three-way valve; 5, four-way valve; 6, two-way valve; 7, hot water storage tank; 8, domestic hot water storage tank; 9, absorption chiller unit; 10, expansion tank; 11, boiler; 12, heat pump; 13, fan coil units; 14, air collector array; 15, ventilator; 16, rock storage bed; 17, damper; 18, underfloor heating system; 19, hot water; 20, house.

a) <u>Collector Loop (Solar collector array)</u>

The array consists of six groups of solar collector subarrays, which are connected in parallel. Each subarray contains six solar collector connected in series. The total area of the solar collector array is 40 m^2 of tube-in plate type with a single glass cover.

These collectors are of the type being designed and manufactured by the RSS. Figure 3 shows the solar collector efficiency curve. Based on the recommendation mentioned in reference [1], a flowrate of 56.25 L h-1 m^{-2} of collector area was chosen for the solar house collectors. This flowrate optimizes the relevant parameters such as heat transfer coefficient, fluid pressure drop and delivered energy.

The collectors are oriented to the south with a winter operation tilt angle of approximately 45° (13° greater than the local latitude).

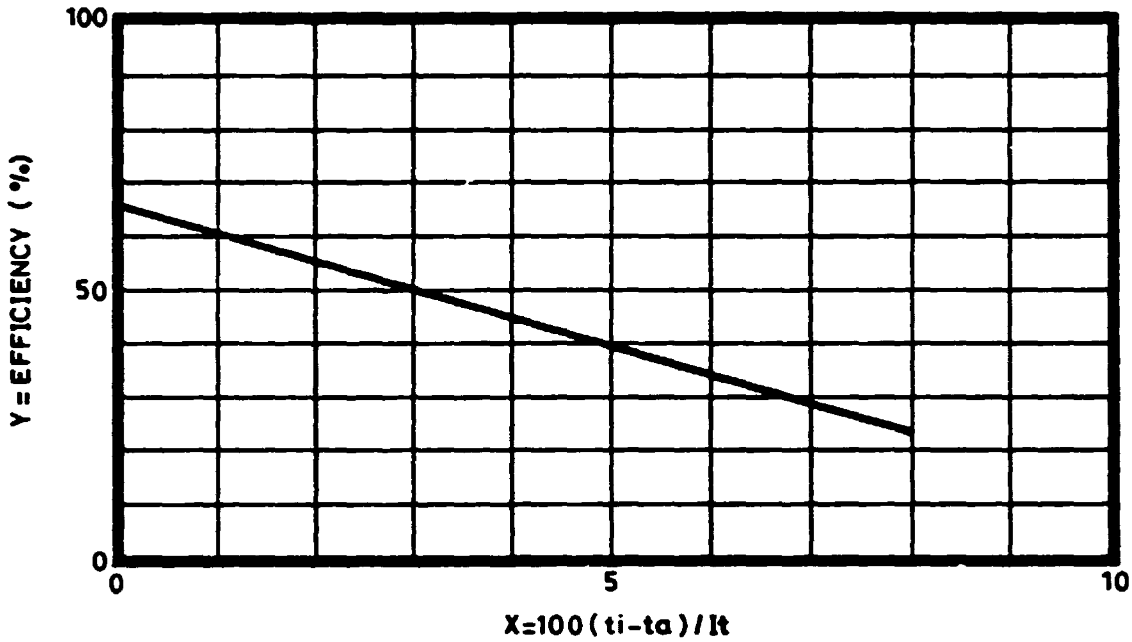


Fig. 3. RSS flat plate collector efficiency curve.

(b) Storage tanks :

The size of the thermal storage tank used in the solar heating system in limited by the law of diminishing returns. Experience [1] has shown that liquid storage amounts of 50-75 kg m^{-2} of the collector are optimal considering the storage tank cost and useful delivered energy. The actual size of the storage tank selected for the project was 62.5 kg m^{-2} of the collector area.

The storage tank is cylindrical type, 1,27 m diameter, 2500 liter capacity 2.5 mm thick galvanized sheet steel. The storage tank was in the first testing year insulated with 100 mm thick fiber glass. This insulation was in the second testing year replaced with 250 mm thick rock-wool insulation.

(c) Space heating load loop:

- Two types of heat transfer elements (load devices) are to be tested in the framework of this project; namely, the underfloor tube heater and the fan coil units. Both systems are designed to operate at 55°C. The underfloor tube heating system was tested in the year 1982-1983, while the fan coil system was tested in the year 1983-1984.

- In order to maintain the required temperature for the heated water entering the load devices at a reasonable temperature level on cloudy days and nights,an oil-fired boiler (power 23-29 kW thermal) was integrated with the heating system.

(d) Domestic hot water loop

To make our study as complete as possible from the thermal behaviour of the solar house point of view, a domestic hot water storage tank of 150 liters capacity was installed. The storage tank is equipped with a heat exchanger, which operates with hot water delivered either from the thermal storage tank or from the back up systems.

6. TEST PROCEDURE

The aim of the measurement taken was to determine the performance of the different systems and subsystems of the solar house and their components. The systems subjected to measurement procedures were :

- Solar collector system;
- Storage tank;
- Space heating and hot water systems.

In order to acheive this aim, different parameters were monitored and registered. These parameters are discused in the following subsections.

Temperature measurement

Temperature measuring probes were placed at different locations of the house and systems. T-type (Cu-constantan) thermocouples with a diameter of 0.5 mm were used to measure the ambient temperature and the temperature in different layers of the floor.

Coated thermocouples of the same type, 3 mm in diameter, were used in the measurement of the storage tank temperature. All temperature probes were connected to a data acquisition system.

Flow rate measurement

The water flow rates for the collectors-storage tank loop, load loop and service hot water loop were determined. The flow rate in each case was chosen to be constant. Rotameter-type flowmeters were chosen to control these flows.

Solar radiation measurement

Pyronometers classified by the world meteorological organization as first class ones to measure the global radiation on a horizontal surface and on a plane parallel to the solar collector array as well as the diffused radiation were used. These pyranometers were connected to calibrated high impedance recording intergrators. These recorders register the solar radiation on an hourly total basis.

Measurement of other weather parameters

An automatic weather station, which records the mean values of wind speed, wind direction, relative humidity and ambient temperature on a 10 min basis in the direct neighbourhood of the solar house, exists. Furthermore, this station records the atmospheric pressure, direct normal radiation and global radiation on a horizontal surface and the sunshine duration on an hourly basis. Thus, the data collected by this weather station was used for the evaluation of the different systems of this project.

7. EXPERIMENTAL RESULTS

The house was continuously monitored for the input and output parameters during the testing periods and provided the information that was later analysed and evaluated.

7.1 House temperature

The house was designed to be kept at the 20°C level during the heating periods. However, the temperature was allowed to be at little higher level as that of the designed temperature to allow the solar radiation to heat the house during the day time (passive feature).

Different temperature sensors were installed at different locations in the solar house to monitor the house temperature.

Table 1 shows the monthly average temperature in (°C) of different spaces in the solar house and their deviation from reference room (living room) for both testing periods.

Table 1 shows that the average house temperature through both testing periods was close to 20°C, which means that the desired temperature was maintained.

The deviation of the values of 1.71°C or less indicate that both heating systems (underfloor and fan coil units) were properly designed.

However, it is to be noted that the underfloor heating device performed better than that of the fan coil unit heating device in many aspects; namely, (i) the fan coil unit required for its operation an amount of 256 kWh electrical energy which is equivalent to 4% of the total heating load, which was not the case in underfloor heating; (ii) the temperature distribution in the house was less uniform compared to the underfloor heating devices, as shown from the temperature readings at different parts of the house. Nevertheless, one might be forced to use fan coil units when retrofitting a conventional house to utilize solar energy.

Month	Mechanical room		Kitchen		Living room	Bed room		Bath room		Average
	unheated		Temp.	Dev.	reference	Temp.	Dev.	Temp.	Dev.	
Nov. 82	17.75	3.25	20.45	0.55	21.0	19.90	1.10	18.30	1.70	20.4
Dec. 82	15.98	5.5	20.8	0.68	21.48	21.0	0.48	20.30	1.18	21.1
Jan. 83	14.4	5.78	19.50	0.68	20.18	19.6	0.58	19.10	1.08	19.8
Feb. 83	14.8	5.90	20.10	0.60	20.70	20.10	0.60	19.70	1.00	20.3
Mar. 83	16.6	4.30	20.40	0.50	20.90	20.30	0.60	19.80	1.10	20.6
Apr. 83	18.48	1.80	20.0	0.28	20.28	19.7	0.98	19.00	1.28	20.0
Average 82-83	16.34	4.42	20.21	0.55	20.76	20.1	0.66	19.37	1.39	20.37
Nov. 83	19.08	2.05	20.29	0.84	21.13	20.30	0.83	19.62	1.51	20.67
Dec. 83	15.57	4.9	19.81	0.66	20.47	19.80	0.67	18.86	1.61	20.05
Jan. 84	13.45	6.91	19.8	0.56	20.36	19.41	0.95	19.08	1.28	19.96
Feb. 84	14.55	7.04	20.9	0.69	21.59	20.52	1.07	19.50	2.09	21.01
Mar. 84	14.87	6.48	20.83	0.52	21.35	20.31	0.40	19.40	1.95	20.85
Apr. 84	17.66	3.77	21.22	0.21	21.43	20.75	0.68	19.62	1.81	21.05
Average 83-84	15.86	5.19	20.48	0.58	21.06	20.18	0.87	19.35	1.71	20.6

Table 1 : Monthly average of different space temperature (°C) for the periods November 1982 through April 1983 and November 1983 through April 1984 and their deviation from reference room (living room).

7.2 Solar collector array

The configuration of the solar collector array during the first and second testing periods was kept unchanged. The efficiency of solar collector array depends mainly on the falling solar radiation, ambient temperature, wind speed.

These parameters were measured during the testing periods and presented in Table 2.

Parameter	Year	Month						Period Average
		Nov.	Dec.	Jan.	Feb.	March	April	
Global radiation on 45° tilted Surface(Wh/m^2.d)	1982-1983	5015	4230	3990	4016	5754	5778	4797
	1983-1984	5376	5017	4464	6576	4864	6072	5395
Ambient temperature (°C)	1982-1983	8.5	5.3	2.2	3.6	7.7	11.7	6.5
	1983-1984	12.2	8.0	5.6	8.4	9.7	11.8	9.3
Relative humidity (%)	1982-1983	66	77	82	79	70	74	74
	1983-1984	71	71	77	58	67	59	67
Wind speed (m s)$^{-1}$	1982-1983	6.1	6.4	6.7	6.6	5.9	6.0	6.3
	1983-1984	5.4	4.7	3.5	3.9	4.4	4.5	4.4

Table 2 : Monthly daily means of global radiation on 45° tilted surface, ambient temperature, relative humidity and wind speed

The monthly efficiencies for the first and second periods are shown in Table 3.

	Year	Nov.	Dec.	Jan.	Feb.	March	April	Average
Efficiency(%) (measured)	1982-1983	29.88	22.32	17.54	21.09	23.66	19.29	22.3
St.deviation (%)		13.38	14.06	11.29	14.06	12.49	8.18	4.3
Efficiency(%) (measured)	1983-1984	26.43	20.83	19.96	26.65	15.38	14.1	21.99
St.deviation (%)		14.73	10.18	11.88	8.9	9.6	9.13	5.53

Table 3 · Monthly means efficiencies of the solar collector array in (%) and their standard deviation in (%) for both testing periods.

7.2.1 Operating time of the solar collectors

The collectors-storage control subsystem followed the logic that "if and only if the temperature of collector array outlet exceeds that of the bottom storage tank layer by 5 °C the collector pump will be activated and will continue to do so until the collector and storage tank bottom temperature are within 1-2 °C of each other". The collector pump was connected to a X-t recorder, which recorded its operating time.

The total operating time for the whole first testing period was determined to be 716 hours and the consumed electrical energy for this period of operation was 28.6 kWh. The total operating time for the whole second tesing period was 701 hours and the consumed electrical energy for this period of operation 28.1 kWh.

7.3 Storage tank

Analysis of heat losses showed that the storage tank and its arrangement was inefficient in the first testing year (the tank was insulated with 100 mm thick fiber glass). To increase the efficiency of the storage tank, it was reinsulated with 250 mm thick rockwool insulation.

Since the temperature in the storage tank is a function of the availability of solar radiation and the heating load, the storage tank temperature is expected to differ from one year to another. Table 4 demonstrates this fact.

Parameter	Year	Month						Period Average
		Nov.	Dec.	Jan.	Feb.	March	April	
Efficiency (%)	1982-1983	54.22	72.76	63.21	57.00	61.44	47.20	58.57
	1983-1984	14.83	36.31	46.96	46.88	74.22	59.52	43.45
Temperature (°C)	1982-1983	46.76	42.34	35.04	38.76	46.24	51.97	43.52
	1983-1984	57.28	52.87	43.96	46.93	46.93	58.49	51.58

Table 4 : Storage tank monthly mean efficiency (%) and its associated monthly daily mean temperature (°C)

For comparison purposes the monthly and the period average storage tank efficiencies for both testing years were calculated and presented in Table 4. The calculation showed that the storage tank period average efficiency decreased from 58.57% in the first testing year to 43.45% in the second testing year. The decrease in storage tank efficiency led to the conclusion that the lower quality of insulation may have been the major contributor.

7. AUXILIARY BOILER

The auxiliary boiler had delivered the necessary heat required for the solar house, when the storage tank temperature is under the specified temperature, (this occurs in extrem weather conditions, cloudy days and at night) to keep the house temperature at the 20 °C-level.

The efficiency of the boiler was determined for both testing years. The efficiency, and the operation time for the auxiliary boiler are represented in Table 5.

Parameter	Year	Month						Period Average
		Nov.	Dec.	Jan.	Feb.	March	April	
Efficiecy (%)	1982-1983	86.48	78.14	78.62	83.45	81.8	77.84	80.4
	1983-1984	83.67	74.47	67.59	61.09	54.62	64.44	64.17
Operation time (h)	1982-1983	263.9	423.9	594.4	451.4	276.7	79.7	2062.4
	1983-1984	12.2	75.6	143.3	35.1	93.7	24.5	384.4

Table 5 : Efficiency and operation time of auxiliary boiler

7.5 Space heating requirement

As noted earlier, the space heating load was maintained by both solar and conventional oil-fired burner system. The total energy supplied by both systems and for testing periods is presented in Table 6.

The solar system supplied 4271 kWh, and the auxiliary boiler supplied 15841 kWh, in the first testing year. The total solar system supplied 3091 kWh, while the auxiliary boiler supplied 3097 kWh in the second testing year.

This means that the average of solar energy contribution amounted to 21.23% in the first testing period, while it amounted 49.95% in the second testing period.

7.6 Hot water load requirement

As mentioned earlier, the domestic hot water load was maintained by both solar and conventional oil fired burner system, the total energy supplied by both systems for both heating periods is presented in Table 6, 343 kWh was supplied by the solar system while 490 kWh was supplied by the auxiliary boiler, in the first testeing year. The total solar energy supplied was 680 kWh, while the auxiliary boiler supplied was 168 kWh in the second testing year.

This means that the average of solar energy contribution amounted to 41.11% in the first testing period, while it amounted 80.23% in the second testing period.

7.7 Heating load

It was found in the first testing year, that the thermal load for the solar house was considerably high. This was due to the fact that single glass, large, tinted and aluminum frame windows and doors were available. Consequently, windows were replaced by double glazed tight plastic frame windows. In addition and to avoid heat infiltration by the frequent entry to the house, a false entrance extension with a tight door was retrofitted.

The heating load of the solar house was reduced about 25% as a result of the improvements made.

8. ENERGY SITUATION IN THE SOLAR HOUSE

The two testing years, under which the solar house was investigated, presents two extreme years. The 1982-1983 testing winter could be considered as the coldest for many decades, while the 1983-1984 could be considered as a mild winter. A typical Jordanian winter for this site could be considered as the average of these two years.

Table 6 shows the energy situation in the solar house for both testing years. The contribution of solar energy to the space heating, water heating and to total load is presented.

Since the solar energy share is defined as the ratio between the energy delivery to the total load; it is concluded that this ratio will be increased as the energy delivery increased and/or the load decreased. Thus, this ratio can't be taken as a qualification for the solar energy system. More accurate evaluation parameter will be the cost of (kWh) delivered energy by the solar system.

9. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from the work performed in the first and second years.

- The underfloor heating devices had performed better than that the fan coil units especially when used in conjunction with solar energy systems. Nevertheless one might be forced to use fan coil units when retrofitting a conventional house for the utilization of solar energy.

- The solar collector manufactured by Royal Scientific Society have shown no degradation and that the collector efficiency was kept as expected fairly constant during the two testing years with measured efficiency of 22%.

- Storage tank efficiency is still low; additional work should be done to eleminate this wead point from the system in particular and in most of the solar energy and conventional storage systems in general.

- Passive designs that include orientation, and wall insulation is of great benefit from both the energy point of view as well as from its favourable economic impact.

	Solar Energy (KWh)			Aux. Boiler (KWh)			Total (KWh)			Solar Energy Contirbution [%]		
Month	Hot Water	Space Heating	Total	Hot Water	Space Heating	Total	Hot Water	Space Heating	Total	Hot Water	Space Heating	Total
Nov. 82	42.16	987.73	1029.89	86.5	1594.86	1681.39	128.66	2582.59	2711.28	32.76	38.24	37.98%
Dec. 82	51.09	816.46	867.55	101.5	3186.24	3287.77	152.59	4002.7	4155.32	33.49	20.39	20.87
Jan. 83	44.07	463.82	507.89	105.9	4463.65	4569.65	149.97	4927.07	5077.4	28.98	09.41	10.0
Feb. 83	38.61	549.26	587.87	106.6	3808.7	3915.30	145.21	4357.96	4503.19	26.58	12.6	13.05
Mar. 83	80.22	865.01	945.23	61.56	2175.63	2237.19	141.78	3040.64	3182.42	56.58	28.44	29.7
Apr. 83	87.8	589.21	677.01	28.38	6111.43	639.81	116.18	1200.64	1316.82	75.57	49.07	51.41
Total	343.95	4271.49	4615.44	490.44	15840.51	16330.9	834.39	20112	20946.4	41.11	21.23	22.03
Nov. 83	111.3	76.4	187.7	1.5	64	65.5	112.8	140.4	253.1	98.67	54.41	74.16
Dec. 83	145.2	458.0	603.2	22.5	531.6	553.8	167.4	989.7	157.1	86.73	46.27	52.13
Jan. 84	90.3	494.1	584.4	55.1	1181.9	1236.9	145.4	1676.0	812.3	62.10	29.48	32.08
Feb. 84	143.4	843.5	986.9	9.5	369.6	379.1	152.9	1213.1	366.0	93.78	69.53	72.22
Mar. 84	136.5	598.8	735.3	20.4	757.2	777.6	156.9	1356.0	512.9	87.22	44.16	48.60
Apr. 84	53.7	620.3	673.9	59.1	193.1	252.2	112.7	8134.0	926.1	47.64	76.26	72.77
Total	680.4	3091.4	3771.5	167.6	3097.4	3265.0	848.0	6188.5	7036.5	80.23	49.95	53.60

Table 6 : Energy situation in the Jordanian Solar House for the both tesing years

- The addition of active solar features to the house heating design does not (given the current fuel prices) provide a favourable economic impact on the user.

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Amman, Jordan, 28 February - 12 March 1989

WORKSHOP PROCEEDINGS*

VOLUME II

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* This document has not been edited.

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Table of Contents:

BASIC HEAT TRANSFER THEORY

DR. RIZEQ TA'ANI

PRINCIPLES OF HEAT TRANSFER

The purpose of this lecture is to give a brief survey with some numerical examples about heat transfer phenomena. Heat transfer theory is given in some details in many reference books [1-5]. Therefore it will be concentrated on applying the heat transfer phenomena, without going in the details of theory.

HEAT TRANSFER

The sun is a heat source and therefore in order to deal with this heat, all heat transfer formula can be applied associated with conduction; convection; radiation and thermal storage, whether heat gain or heat loss.

1. CONDUCTION HEAT TRANSFER

Conduction is the only heat transfer mode in opaque solid media. Heat will be transferred from the higher to the lower temperature region. The rate of which heat is transferred by conduction q_k; is proportional to temperature gradient dT/dx times the area A through which heat is transferred.

$$q_k = - K.A\ (dT/dx) \quad .... (1)$$

Where:

q_k = rate of heat transfer
A = cross sectional area
K = thermal conductivity
T = temperature
X = thickness

If the Area is in square meters (m^2), the temperature in Kelven (K), X in m, and the rate of heat flow in Watt (W), K has the units of Watt per meter per Kelvin (W/m.K), in the English system Btu/h.ft.F.

The thermal conductivity is a material property. Except for gases at low temperatures, it is not possible to predict this property analytically. Available information about thermal conductivity of materials is therefore largely based on experimental measurements. In general, the thermal conductivity of materials varies with temperature, but in many practical situations a constant value based on the average temperature of the system will give satisfactory results. Table (1) lists typical values of thermal conductivities for some metals, nonmetallic solids, liquids, and gases to illustrate the order of magnitude to be expected in practice.

Table (1):Thermal conductivities of some metals, nonmetallic solids, liquids, and gases; adapted from [1].

materials	Thermal conductivity at 300 K (W/m.K)
Copper	386
Aluminum	204
Carbon steel	54
Glass	0.75
Plastics	0.2 - 0.3
Water	0.6
Ethylene glycol	0.25
Engine oil	0.15
Freon (liquid)	0.07
Hydrogen	0.18
Air	0.026

1.1 The plane wall

First consider the plane wall where a direct application of Fourier's Law (Eq.1) may be made. Integration Yield.

$$q = -\frac{K \cdot A}{\Delta X} (T_2 - T_1) \quad \text{.........................(2)}$$

When the thermal conductivity varies with temperature according to some linear relation $K = K_o (1 + \beta T)$, the resultant equation for heat flow is :

$$q = -\frac{K_o \cdot A}{\Delta T} \left[(T_2 - T_1) + \frac{\beta}{2} \cdot (T_2^2 - T_1^2) \right] \quad \text{.......(3)}$$

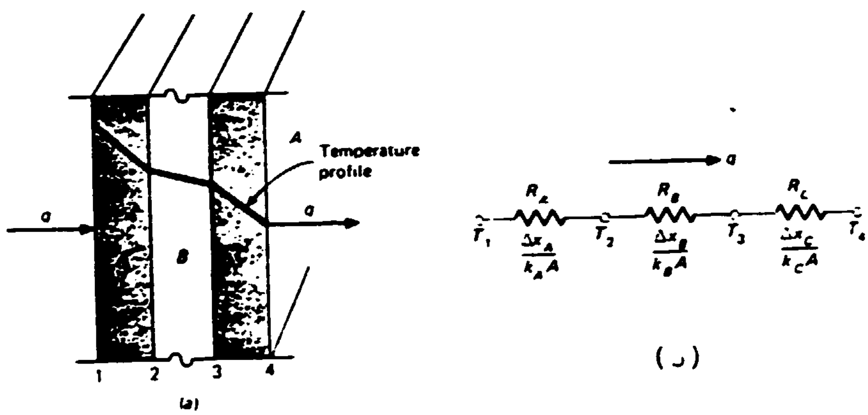

Fig. 1 : One-dimentional heat transfer through a composite wall and electric analog.

If more than one material is present, as might be used in multilayer wall shown in Fig. (1), the analysis would proceed as follows : The temperature gradient in the three materials are shown, and the heat flow may be written

$$q = -K_A \cdot A \frac{T_2 - T_1}{\Delta X_A} = -K_B \cdot A \frac{T_3 - T_2}{\Delta X_B} = -K_C \cdot A \frac{T_4 - T_3}{\Delta X_C}$$

Note that the heat flow must be the same through all sections.

Solving these equation simultaneously, the heat flow is written

$$q = \frac{T_1 - T_4}{\Delta x_A / K_A . A + \Delta X_B / K_B . B + \Delta X_C / K_C . A} \quad ....(4)$$

At this point we retrace our development slightly to introduce a different conceptual viewpoint for Fourier's Law. The heat transfer may be considered as a flow, and the combination of thermal conductivity, thickness of material, and area asaresistance to this flow.

The temperature is the potential, or driving, function for the heat flow, and the Fourier equation may be written :

$$\text{Heat flow} = \frac{\text{Thermal potential difference}}{\text{Thermal resistance}}$$

a relation quite like Ohm's Law in electric-circuit theory. In eq (2); the thermal resistance is (X / K.A) and in eq. (4) it is the sum of the three terms in the denominator. We would expect this situation in eq. (4) because the three walls side by side act as three thermal resistance in series. The equivalent electric circuit is shown in Fig (1 b).

The electrical analogy may be used to solve more complex problems involving both series and parallel thermal resistances. A typical problem and its analogous electric circuit are shown in Fig. 2. The one dimensional heat flow equation for this type of problem may be written :

$$q = \frac{\Delta T_{overall}}{\Sigma R_{th}} \quad ....(6)$$

where the R_{th} are the thermal resistance of the various materials.

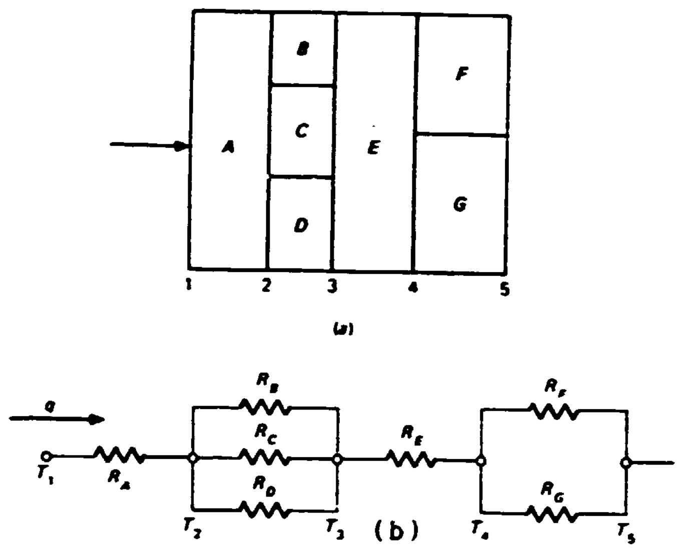

Fig. 2 : Series and parallel one-dimentional heat transfer through a composite wall and electric alnalog

It is well to mention that in some systems like that in Fig. (2) two dimensional heat flow may result if the thermal conductivities of materials B, C, and D differ by an appreciable amount. In these cases other techniques must be employed to effect a solution.

1.2 Radial systems - Cylinders and spheres

Heat conduction through tubes, pipes and spherical containers is of importance in many engineering systems. Consider first a long hollow cylinder of inside radius ri, outside ro and length L, such as the one shown in Fig. (3).

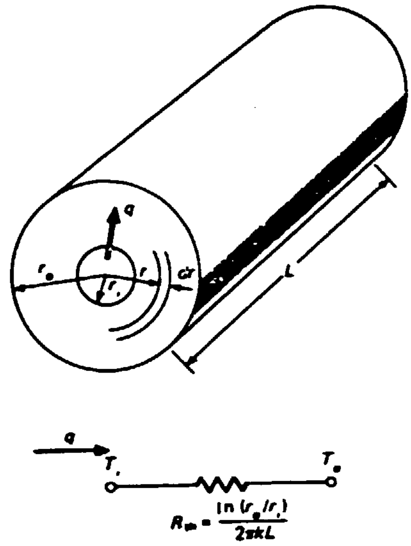

Fig. 3 : One-dimensional heat flow through a hollow cylinder and electric analog.

We expose this cylinder to a temperature differential $T_i - T_o$ and ask what the heat flow will be. It may be assumed that the heat flows in radial direction so that the only space coordinate needed to specify the system is r. Again, Fourier's Law is used by inserting the proper area relation. The area for heat flow in the cylindrical system is:

$$A_r = 2 \pi r . L$$

So that Fourier's law can be written in the form

$$q_r = - K . A_r \frac{dT}{dr} = - 2 \pi K r L \frac{dT}{dr} \quad \ldots\ldots (7)$$

separating the variables in eq. (7) gives

$$q_r . \frac{dr}{r} = 2 \pi K L \, dt \quad \ldots\ldots (8)$$

Eq (8) can be integrated subject to the boundary conditions:

$$T (r_i) = T1 \; ; \; T (r_o) = T_o$$

This yield the following relation for the rate of heat conduction through the cylinder:

$$q = \frac{2 \pi KL (T_i - T_o)}{Ln (r_o/r_i)} \quad ..... (9)$$

and the thermal resistance in this case is

$$R_{th} = \frac{Ln (ro/ri)}{2 \pi KL} \quad ..... (10)$$

The thermal - resistance concept may be used for multiple-layer cylindrical walls just as is used for plane walls.

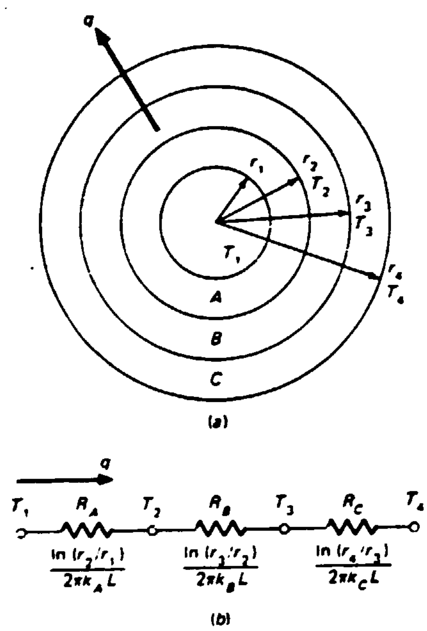

fig. 4 : One dimentional heat flow through multiple cylindrical sections and electrical analog.

For the three layer system shown in Fig. (4) the solution is:

$$q = \frac{2\pi L\ (T_1 - T_4)}{Ln(r2/r1)/KA + Ln(r3/r2)/KB + Ln(r4/r3)KC} \quad \ldots.(11)$$

Spherical systems may also be treated as one dimensional when the temperature is a function only of radius. The heat flow is then

$$q = \frac{4\pi K\ (T_i - T_o)}{1/ri - 1/ro} \quad \ldots..\ (12)$$

Example (1)

A thick walled tube of stainless steel (18% Cr, 8% Ni, K = 1 g W/m.°C) with 2 - cm ID and 4 - cm OD is covered with a 3 - cm layer of asbestos insulation (K = 0.2 W/m °C). If inside wall temperature of the pipes is maintained at 600 °C and the outside of the insulation at 100 °C, calculate the heat loss per m of length solution.

Fig (4) shows the thermal network for this problem. The heat flow is given:

$$q = \frac{2\pi (T_1 - T_2)}{Ln\ (r2/r1)/Ks + Ln\ (r3/r2)Ka}$$

$$= \frac{2\pi\ (600 - 100)}{Ln\ (2)/19 + Ln\ (5/2)/0.2} = 680\ W/m^2 \quad \ldots(13)$$

2. CONVECTION HEAT TRANSFER

When a fluid comes in contact with a solid surface at a different temperature, the resulting thermal energy exchange process is called "convection heat transfer". This process is a common experience, but a detailed description and analysis of the mechanism is complicated.

Convection is subdivided into two different kinds, natural and forced. Natural convection occurs between a solid and a fluid undisturbed by other effects when there is a temperature difference between the two, as in a kettle of water. It is not often that a fluid can be regarded as entirely at rest, so frequently there is a small amount of forced convection as well as of the fluid in relation to the source or sink of heat, so that natural convection is negligible. Within both modes, there are sub-divisions of laminar and turbulent flow convection.

Many factors are involved in forced heat convection such as flow separation from solid surfaces, as in flow cross outside of a pipe or convection with phase change occurring in the fluid as in steam raising and condensing plant. Newton in 1701 proposed a general equation describing convection heat transfer. It is

$$q = h.A\,(T_1 - T_2) \quad \ldots\ldots (14)$$

His equation for transfer from a surface at a temperature T_1 to fluid flowing above it at a temperature T_2, where A is the cross - section and h is the coefficient of heat convection.

Table (2): Shows some values for h for various systems of convections.

Table (2): Approximate ranges of convection coefficient.

	Range of h ($W/m^2.K$)
Air, free convection	6 - 30
super heated steam or air, forced convection	30 - 300
Oil, forced convection	60 - 1800
Water, forced convection	300 - 6000
Water, boiling	300 - 60000
Steam condensing	6000 - 120000

Experimental data for convection heat transfer are usually correlated in term of dimensionless quantities. The heat transfer coefficient, non-dimensionalized in term of nasselt number Nu, is defined as:

$$Nu = \frac{h \cdot L}{kf} \qquad \text{.................................... (15)}$$

where L is a length dimension characteristic of a system (e.g, the diameter for flow in a tube or the distance between the collector surface and the cover in free conversion these surfaces) and K_f is the thermal conductivity of the fluid in W/m.K, usually evaluated at the arithmetic mean between the surface and bulk fluid temperature.

A second dimensionless parameter of importance is the Prandtl number Pr, defined as :

$$Pr = \frac{Cp\,\mu f}{K_f} \qquad \text{...(16)}$$

where Cp is the specific heat of fluid at constant pressure in J/kg.K and μf is the viscosity in $N.s/m^2$. The Prandtl number represents the ratio of momentum diffusivity to thermal diffusivity in a substance.

A third dimensionless parameter of importance is the Reynolds number Re, defined as :

$$Re = \frac{U_\infty . X}{\nu} \qquad \text{...(17)}$$

where U_∞ is the free stream Velocity, X distance from leading edge and ν = the kinematic viscosity.

Eq.18 gives the relation between dynamic and kinematic viscosity :

$$\nu = \frac{\mu_f}{\rho_f} \qquad \text{...(18)}$$

where ρ_f the density of fluid. In general the Nusselt number for forced convection can be related to the Reynolds number Rel and Prandtl number Pr by a relation of the form.

$$Nu_L = C. Re^n_L Pr^m \qquad \text{.........................(19)}$$

where c, n and m are empirically determined constants and subscript L indicates a value based on a characteristic length dimension. Sometimes a functional relation to account for variation in geometry and physical properties is also incorporated into this correlation.

For free convection, in general the Nusselt number can be related to the Grashof number and the Prandtl number by a relation of the form.

$$Nu_L = C (Gr_L . Pr)^n \qquad \text{................................ (20)}$$

where C and n are constants determined empirically for given system geometries.

The Grashof number in Eq.(20) is defined as

$$Gr_L = \frac{\rho^2 g \beta_t (T_1 - T_2) . L^3}{\mu^2} \qquad \text{................... (21)}$$

where:

- ρ = fluid density in kg/m^3
- g = gravitational constant, equal to 9.81 m/sec^2
- L = characteristic length dimension in m
- βt = coefficient of expansion of the fluid in 1/K; for ideal gases Bt equals the reciprocal of the absolute temperature, i.e., $\beta t = 1/T$. In solar energy systems, convection heat transfer plays an important role in the transfer of heat from the absorber plate of a flat plate collector to the working fluid, the heat loss from the outer cover of a collector, the transfer of heat between the collector surface and the transparent cover.

Example 2

Water at 60° enter a tube of 1 - In (2.54 cm) diameter at a mean flow velocity of 2 cm/s. Calculate the exit water temperature if the tube is 3.0 m long and the wall temperature is constant at 80 ° C.

Solution

We first evaluate the Reynolds number at the inlet bulk temperature to determine the flow regime.

The properties of water at 60° are [5]:

ρ = 985 kg/m³ ; cp = 4.18 kJ/kg.°C
μ = $4.71 * 10^{-4}$ kg/m.sec
K = 0.651 W/m.°C

The Reynolds number

$$Re_d = \frac{\rho Um.d}{\mu} = \frac{(985)\ (0.02)\ (0.0254)}{4.71 * 10^{-4}} = 1062$$

So the flow is laminar

The Prandtl number

$$Pr = \frac{cp.\ \mu f}{K_f} = \frac{4.18\ \frac{KJ}{Kg.°C}\ .\ 4.71 * 10^{-4}\ \frac{Kg}{m.sec}}{0.651\ \ W/m.C}$$

$$Pr = \frac{4.81 * 4.71 * 10^{-4}}{0.65}\ \ KJ/sec.W$$

1 J = 1 W.sec

$$Pr = \frac{4.18 * 4.71 * 10^{-4} * 10^{3}}{C.65} = 3.02$$

For determination the laminar heat transfer in tubes, a simpler empirical equation was proposed by Siedler and Tate [7].

$$Nu_d = 1.86\ (Re_d.\ Pr)^{1/3}\ .(d/L)^{1/3}.\ (\mu / \mu_W)^{0.14} \quad \ldots (21)$$

In this formula the average heat transfer coefficient is based on the arithmetic average of the inlet and outlet temperature deferences, and all fluid properties are evaluated at the mean bulk temperature of the fluid, except μ_w, which is evaluated at the wall temperature. Eq. (21) obviously cannot be used for extremely long tubes since it would yield zero heat transfer coefficient. Investigations show that Eq.(21) is valid for Red.Pr d/L>10. By conducting $Re_d\ .\ Pr\ \frac{d}{L} = \frac{(1062)(3.02)(0.0254)}{3} = 27.15 > 10$

One can conclude that Eq.(21) is applicable.

We do not know the mean bulk temperature to evaluate properties, so we first make the calculation on the basis of 60°C, determine an exit bulk temperature, and then make a second iteration to obtain a more precise value. When inlet and outlet conditions are designated with subscripts 1 and 2, respectively, the energy balance becomes :

$$q = h\pi d_L\ (T_w - \frac{T_{b1} + T_{b2}}{2}) = m^{\bullet}.c_p\ (T_{b1} - T_{b2}) \quad \ldots.(a)$$

At the wall temperature of 80°C we have

$$\mu_W = 3.55 * 10^{-4}\ \frac{Kg}{m.sec}$$

From Eq. (21)

$$Nu_d = 1.86\ [\frac{(1062)\ (3.02)\ (0.254)}{3}]^{1/3}\ (\frac{4.17}{3.55})^{0.14} = 5.816$$

$$h = \frac{K_f \cdot Nu_d}{d} = \frac{(0.651)\ (5.816)}{0.0254} = 149.1\ \frac{W}{m^2.°C}$$

The mass flow rate is :

$$m^{\bullet} = \frac{\pi \rho d^2}{4}\ U_m = \frac{(985).\ \pi (0.0254)^2\ (0.02)}{4} = 9.982 * 10^{-3} Kg/sec$$

Inserting the value for h into Eq.(a) along with in the $T_{b1} = 60°C$ and $T_w = 80°C$ gives

$$(149.1)\pi(0.0254)(3.0)\left(80 - \frac{T_{b2}+60}{2}\right) = [9.982*10^{-3}](4180)(T_{b2}-60)$$

This equation can be solved to give
$T_{b2} = 71.98°C$

Thus, we should go back and evaluate properties at T_b, mean $= \frac{71.98 + 60}{2} = 66°C$

We obtain :

$$\rho = 984 \frac{Kg}{m^3}; \; Cp = 4.185 * 10^3 \frac{KJ}{Kg°C}; \; \mu = 4.36*10^{-4} \frac{Kg}{m.sec}$$

$K_f = 0.656 \; W/m^2.°C \quad Pr = 2.78$
and $Re = 1147$
$Nu = 5.743$
$h = 148.3 \; W/m^2.°C$
We insert this value of h into Eq.(a) to obtain
$T_{b2} = 71.88°C$
==============

This example illustrates the necessity of going back to reference book, when calculating the convection heat transfer.

3. Radiation Heat Transfer

In contrast to the mechanisms of conduction and convection, where energy transfer through a material medium is involved, heat may also transferred into region where a perfect vacum exist. The mechanism in this case is the electromagnetic radiation.

In 1879, Stefan proved experimentally and then in 1884 Boltzmann proved theoretically the radiation equation between two bodies at same temperature in vacuum.

$$Qb = \sigma . A . T^4 \quad \text{..........(22)}$$

where :
A = surface area
T = absolute temperature
σ = a constant equal $5.663 * 10^{-8} \frac{J}{m^2 . sec \ K^4}$

or $q_b = \sigma . T^4$ per unit area ....(23)

Blackbody radiation consists of emission over the entire range of wavelength. Therefore if $q_{b\lambda}$, is the energy emitted per unit area at wavelength λ then

$$q_b = \int_0^\infty q_{b\lambda} \cdot d\lambda = \sigma T^4 \quad \text{..........(24)}$$

Real materials that are not black will have monochromatic emittance that are different from $q_{b\lambda}$,therefore emissivity can be defined as:

$$q_\lambda = \varepsilon_\lambda \cdot q_{b\lambda} \quad \text{..........(25)}$$

Therefore for a grey body $q = \varepsilon q_b = \varepsilon \sigma T^4$
Kirchoff's Law says that for grey body, the absorptivity is equal to the emissivity at any given temperature
$\varepsilon = \alpha$

3.1 Grey Body Radiation Exchange

Hotel introduced a new factor which take into consideration the emissivity of the surface concerned, J, this is :

$$Q_{1-2} = A_1 \ J_{1-2} \cdot \sigma (T_1^4 - T_2^4) \quad \text{..........(26)}$$

where

$$J_{1-2} = \frac{1}{\frac{1}{\varepsilon 1} + \frac{1}{\varepsilon 2} - 1} \quad \text{..........(27)}$$

Radiation coefficient :

$$Q_{1-2} = \sigma \cdot A_1 \cdot J_{1-2} (T_1^4 - T_2^4) = A_1 \cdot h_r (T_1 - T_2)$$

The radiation heat transfer coefficient hr can be calculated to :

$$hr = \frac{\sigma J_{1-2} (T_1^4 - T_2^4)}{T_1 - T_2} = \sigma J_{1-2} (T_1 + T_2)(T_1^2 + T_2^2) \quad \ldots.(28)$$

Example 3

Two very large parallel planes with emissivities 0.3 and 0.8 exchange heat. Find the percentage reduction in heat transfer when a polished-aluminum radiation shield (ε = 0.04) is placed between them.

Solution

The heat transfer without the shield is given by :

$$\frac{q}{A} = \frac{\sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon 1} + \frac{1}{\varepsilon 2} - 1} = \underline{0.279 \quad (T_1^4 - T_2^4)}$$

Since the shield does not deliver or remove heat from the system, the heat transfer between plane 1 and the shield must be precisely the same as that between the shield and plane 2, and this is the overall heat transfer. Thus

$$\frac{q}{A} = \frac{\sigma (T_1^4 - T_3^4)}{\frac{1}{\varepsilon 1} + \frac{1}{\varepsilon 3} - 1} = \frac{\sigma (T_3^4 - T_2^4)}{\frac{1}{\varepsilon 3} + \frac{1}{\varepsilon 2} - 1} \quad \ldots..(29)$$

The only unknown in Eq. (29) is the temperature of the shield.

Rearranging form Eq. (29) we obtain

$$\frac{q}{A} = \frac{C_1^2}{C_1 + C_2} \cdot \sigma(T_1^4 - T_2^4)$$

where :

$$C_1 = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1} = \frac{1}{\frac{1}{0.3} + \frac{1}{0.04} - 1} = 0.036$$

and

$$C_2 = \frac{1}{\frac{1}{\varepsilon_3} + \frac{1}{\varepsilon_2} - 1} = \frac{1}{\frac{1}{0.04} + \frac{1}{0.3} - 1} = 0.0396$$

Thus

$$\frac{q}{A} = \frac{0.036}{0.036 + .0396} \cdot \sigma(T_1^4 - T_2^4) = 0.01902 \cdot \sigma(T_1^4 - T_2^4)$$

So that the heat transfer is reduced by 93.2 percent.

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FLAT PLATE COLLECTORS THEORY

Eng. Malek Kabariti

1. INTRODUCTION

One of the main requirements when one designs a flat plate collector is to predict the basic energy balance for that collector. Equations in this regard, have been analytically developed by Hottel and Whillier [1] Duffie and Beckman [2,3]. These equations are utilized in determining the energy balance and the useful energy gain of the collector by an interative procedure starting by assuming a plate temperature equal to the inlet collector temperature.

In this paper we will present and discuss the theory of the flat plate collectors and the development of the analytical model for predicting the thermal performance of solar collectors and the procedure that will solve this model and the flow chart associated with the model.

As for the computer program listing and samples of the output we present them in the appendix.

2. ANALYTICAL MODEL AND METHOD OF SOLUTION

The analytical model outlined below is developed from equations obtained through the literature review concerning the thermal performance of solar collectors. A typical solar collector is illustrated by Fig.1.

A value for the useful energy gain per unit area of collector (Qu) is derived based on the collector geometry and mass flow rate of the fluid. The algorithm is divided into the following eight steps:

1. Assume the plate temperature, Tpm equal to fluid inlet temperature, Tfi.

2. Determine collector heat loss coefficient, U_L.
   The major component of U_L is the top loss coefficient

   Ut. An empirical equation for predicting Ut is:

$$Ut = \left[\frac{N}{\frac{C}{Tpm}\left(\frac{(Tpm - Ta)}{(N + F)}\right)^{e}} + \frac{1}{hw} \right]^{-1}$$

$$+ \frac{\sigma \; (Tpm + Ta)\,(Tpm^2 + Ta^2)}{(\epsilon_p + 0.00591 N hw)^{-1} + \frac{2N + f - 1 + 0.133\epsilon_p}{\epsilon_g} - N} \quad \ldots\ldots (1)$$

where N= number of glass covers;

$f = (1 + 0.089hw - 0.1166hw\,\epsilon_p)(1 + 0.07866N)$

$C = 520(1 - 0.000051B^2)$ for $0 < B < 70$
for $70 < B < 90$, use $B = 70$

$e = 0.43(1 - 100/Tpm)$

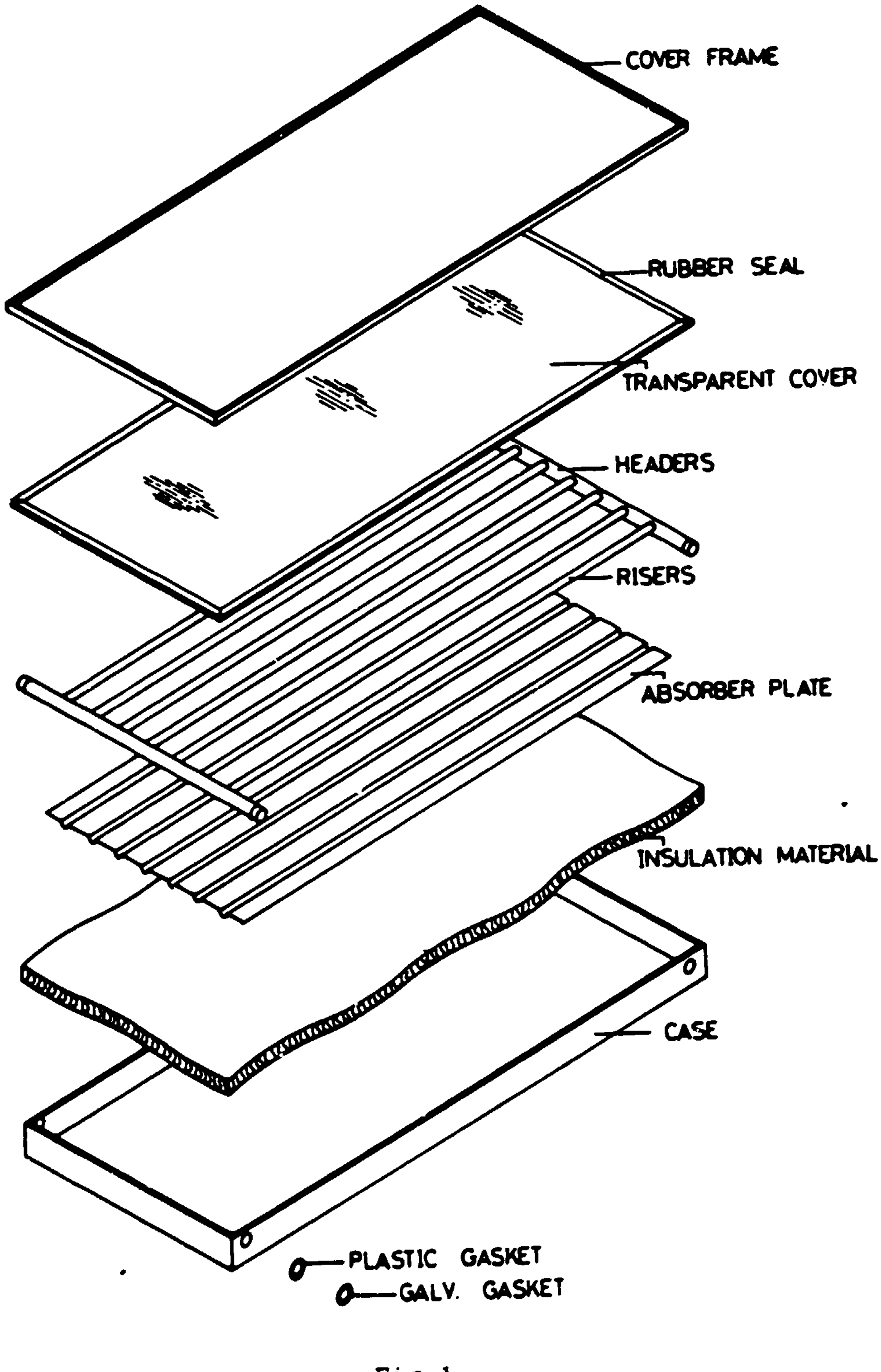

COVER FRAME
RUBBER SEAL
TRANSPARENT COVER
HEADERS
RISERS
ABSORBER PLATE
INSULATION MATERIAL
CASE
PLASTIC GASKET
GALV. GASKET

Fig.1

B = collector tilt (degrees)

ϵ_g = emittance of glass (0.88)

ϵ_p = emittance of plate

Ta = ambient temperature (°K)

Tpm = mean plate temperature (°K)

hw = wind heat transfer coefficient (W/m^2 °C)
= 5.7 +3.8 V

V = wind speed (m/s)

σ = Stephan-Boltzman constant
= 5.6697×10^{-8} (W/m^2 °K^4)

The collector heat loss coefficient U_L is the summation of the top, bottom and edge coefficients, where:

U_L = Ut + Ub + Ue ....(2)

Ub = Bottom loss coefficient = K/L

K = Thermal conductivity of insulation (W/m^2 °C)

L = Thickness of insulation

Ue = Edge loss coefficient = K/L

3. Determine the Fin Efficiency, F, which may be considered as a standard fin efficiency for straight fins with rectangular profile and is defined as:

$$F = \frac{(\tanh m(W - D)/2)}{m(W - D)/2} \quad \text{....................(3)}$$

where D = Outer tube diameter (m)

W = Mean distance between tubes (m)

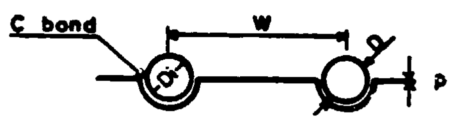
$m = (U_L / K_p \delta_p)^{1/2}$

K_p = Plate thermal conductivity (W/m °C)

δ_p = Plate thickness (m)

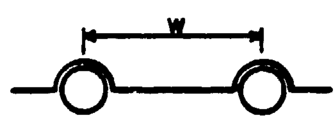
4. Determine the collector Efficiency Factor, F', for different designs of flat plate collectors as follow:

a) Tubes above plate



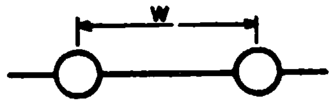
$$F' = \frac{1}{\dfrac{W U_L}{\pi D_i h} + \dfrac{1}{\dfrac{D}{W} + \dfrac{1}{\dfrac{W U_L}{C_{bond}} + \dfrac{W}{(W-D)F}}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

b) Tubes below plate



$$F' = \frac{1}{\dfrac{W U_L}{\pi D_i h} + \dfrac{W U_L}{C_{bond}} + \dfrac{W}{D + (W - D)F}} \quad \ldots\ldots\ldots(5)$$

c) Tubes integral with plate



$$F' = \frac{1}{\dfrac{W\ U_L}{\pi\ Di\ h} + \dfrac{W}{D + (W - D)F}} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

where h = Fluid heat transfer coefficient ($W/m^2\ ^\circ C$)

$$h = \frac{K}{Di}(4.36) + \frac{0.067\ ((Di/L)\ Re\ Pr)}{1 + 0.04\ ((Di/L)\ Re\ Pr)^{2/3}} \quad .(7)$$

K = Fluid thermal conductivity ($W/m\ ^\circ C$)

$$K = 0.552 + 0.00256T_F - 0.0000187T_F^2 + 59x10^{-9}T_F^3 \quad ..(8)$$

T_F = Mean fluid temperature ($^\circ C$)

L = Tube length (m)

Re = Reynold number = $4M/\nu\ \rho\ \pi\ Di$

M = Mass flow rate (Kg/s)

ν = Fluid viscosity (m^2/s)

$$=1.779x10^{-6} - 48.1x10^{-9}T_F + 0.6x10^{-9}T_F^2 - 2.61x10^{-12}T_F^3 \quad .(9)$$

ρ = Fluid density (Kg/m^3)

$$= 1002.31 + 0.0191T_F - 5.9x10^{-3}T_F^2 + 0.15.5x10^{-6}T_F^3 \quad (10)$$

Pr = Prandtl number = $Cp\ \nu\ \rho\ /K$

Cp = Specific heat ($W\ s/Kg\ ^\circ K$)

$$Cp = 4216.85 - 2.31T_F + 0.03485T_F^2 - 0.1554\times10^{-3}\ T_F^3 \quad .(11)$$

5. Determine the collector Heat Removal Factor 'F_R' using the following equation:

$$F_R = \frac{G\ Cp}{Ac\ U_L}\left\{1 - e^{-(Ac\ U_L\ F'/G\ Cp)}\right\} \quad ....(12)$$

where G = Flow rate for unit of collector area ($Kg/s\ m^2$)

Ac = Collector area (m^2)

6. Determine the total useful energy gain of the collector 'Qu'using the following equation:

$$Qu = Ac\ F_R\ (I\ \tau\ \alpha - U_L\ (Tfi - Ta)) \quad ....(13)$$

where I = Solar radiation (W/m^2)

τ = Cover transmittance

α = Absorber plate absorptivity

Tfi = Fluid inlet temperature (°C)

7. Calculate the absorber plate temperature, Tpm. The temperature difference between the absorber plate and the fluid will not be constant along the flow direction due to change in collector heat loss. However, as an approximation, the temperatures are related by the following equation:

$$Tpm = Tfm + Qu/h\ \ Di\ \pi\ n\ L \quad ....(14)$$

where $T_{fm} = T_{fi} + \frac{Q_u/A_c}{U_L F_R} \left(1 - \frac{F_R}{F'} \right)$ ....(15)

Tfm = Fluid mean temperature

n = Number of tubes in the collector

L = Length of each tube (m)

8. If Tpm doesnot equal Tp then let Tp = Tpm and reiterate steps 1 through 7 until Tpm = Tp.

3. COMPUTER PROGRAM

A computer program was developed to analyze and solve for the plate mean temperature and then to calculate the thermal performance of liquid solar collectors. A condensed flow chart is shown in Fig.2.

4. CONCLUSION

An analytical model was developed to predict the thermal performance of any liquid flat plate collector. This model will help in studying the behaviour of different collectors with different geometrical dimensions and different collector materials.

This will aid in forseeing the best geometrical design and the best use of materials taking into account the economic feasability.

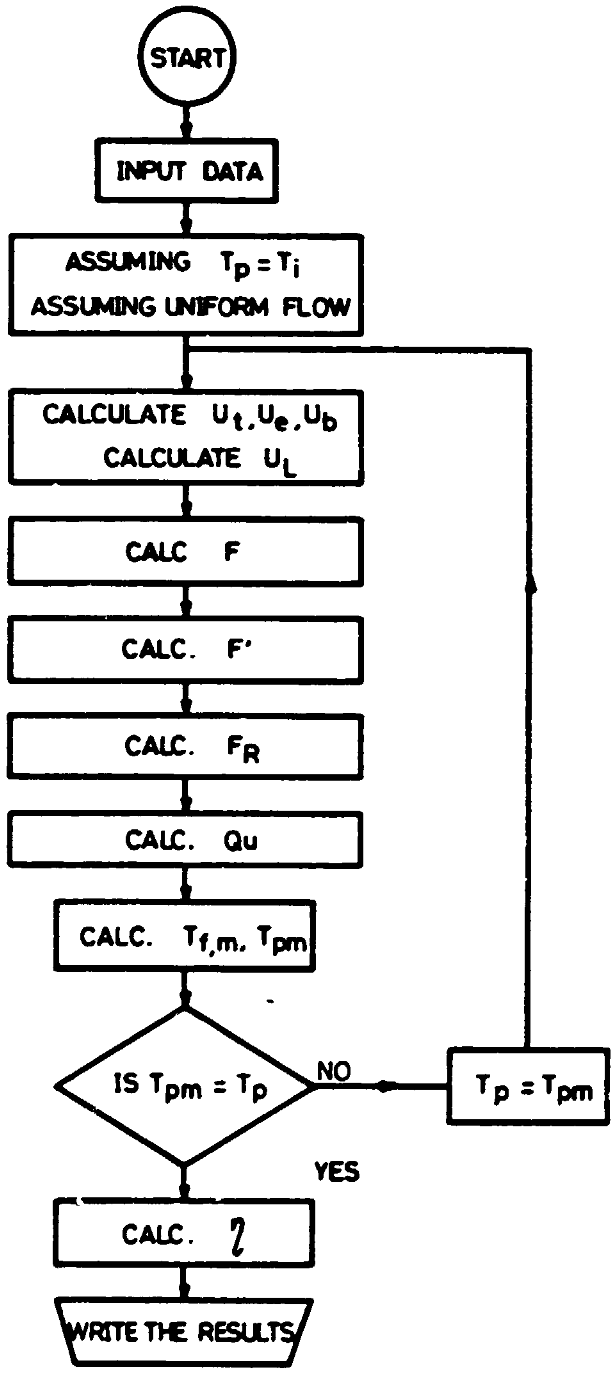

START
INPUT DATA
ASSUMING $T_p = T_i$
ASSUMING UNIFORM FLOW
CALCULATE U_t, U_e, U_b
CALCULATE U_L
CALC F
CALC. F'
CALC. F_R
CALC. Qu
CALC. $T_{f,m}$, T_{pm}
IS $T_{pm} = T_p$
NO
$T_p = T_{pm}$
YES
CALC. η
WRITE THE RESULTS

Fig.2

5. REFERENCES

(1) Hottel H.C.Y Whillier A. evaluation of Flat-Plate Solar Collector Performance.

(2) Duffie J.A. Beckman W.A. Solar Energy Thermal Processes, 1974, Wiley-nterscience.

(3) DUFFIE, J. and BECKMAN, W., "SOLAR ENGINEERING OF THERMAL PROCESSES", A Wiley - Interscience Publication, 1980.

INPUT/OUTPUT DATA

COLLECTOR WITH TUBES ABOVE ABSORBER PLATE

ABSORPER PLATE

Width	1 M.
Length	1 M.
Thickness	.001 M.
Conductivity	45 W/M.C
Emissivity	.95
Absorpivity	.96
Dist.Between Tubes	.1 M.
No.Of Tubes	10
Outer Tube Dia.	.021 M.
Inner Tube Dia.	.0145 M.
Bond Conductance	45 W/SQ.M.C

COLLECTOR

Thickness	.1 M.
Tilt	45 DEGREES
Mass Flow Rate	.02 KG/S SQ.M
Inlet Temp.	80 C

COVER

No.Of Covers	1
Emissivity	.88
Tranmittance	.85

INSULATION

Back Thickness	.05 M.
Side Thickness	.02 M.
Conductivity	.036 W/M C

METEOROLOGICAL

Solar Radaiation	800 W/SQ.M
Ambient Temp.	10 C
Wind Vilocity	3 M/S

OUTPUT

Fin Efficiency F	0.912
Coll Eff Factor F'	0.856
Heat Removel Fac FR	0.820
Heat Loss Cof. UL	8.507 W/SQ.M.C
Mean Plate Temp.	80.74 C
Mean Fluid Temp.	80.28 C
Eixt Fluid Temp.	80.56 C
Useful Power	47.03 W
Coll. Efficiency	5.88 %
(TI-TA)/I	0.088 C SQ.M./W

INPUT/OUTPUT DATA

COLLECTOR WITH TUBES ABOVE ABSORBER PLATE

ABSORPER PLATE

Width	1 M.
Length	1 M.
Thickness	.001 M.
Conductivity	45 W/M.C
Emissivity	.95
Absorpivity	.96
Dist.Between Tubes	.1 M.
No.Of Tubes	10
Outer Tube Dia.	.021 M.
Inner Tube Dia.	.0145 M.
Bond Conductance	45 W/SQ.M.C

COLLECTOR

Thickness	.1 M.
Tilt	45 DEGREES
Mass Flow Rate	.02 KG/S SQ.M
Inlet Temp.	11 C

COVER

No.Of Covers	1
Emissivity	.88
Tranmittance	.85

INSULATION

Back Thickness	.05 M.
Side Thickness	.02 M.
Conductivity	.036 W/M C

METEOROLOGICAL

Solar Radaiation	800 W/SQ.M
Ambient Temp.	10 C
Wind Vilocity	3 M/S

OUTPUT

Fin Efficiency F	0.931
Coll Eff Factor F'	0.872
Heat Removel Fac FR	0.844
Heat Loss Cof. UL	6.500 W/SQ.M.C
Mean Plate Temp.	20.99 C
Mean Fluid Temp.	14.29 C
Eixt Fluid Temp.	17.50 C
Useful Power	545.22 W
Coll. Efficiency	68.15 %
(TI-TA)/I	0.001 C SQ.M./W

WEATHER PARAMETERS MEASUREMENT

DR. RIZEQ TA'ANI

INTRODUCTION

The weather parameter knowledge is very essential for the determination of the behavior of solar systems.

In order to optimize the design of any solar application, the daily and solar variation in each radiation constituent must be well understood along with their relationships with other meteorological elements.

Daily and hourly records of the amount of sunshine are necessary to optimize the design of a particular solar collector. For example, if a location consistently reports and increased frequency for afternoon cloud cover thereby providing less hours of sunshine than in the morning, non-tracking collectors can compensate for this phenomenon by facing south east to collect more of the early morning radiation.

The knowledge of ambient temperature, relation humidity, and wind speed and direction is required for the determination of the collector efficiency and the calculation of heat load and heat loss.

1. SOLAR RADIATION INSTRUMENTS

There are dozens of different types of instruments in use for measuring either solar radiation intensity or integrated solar energy over a given time interval.

Most solar radiation sensors measure the intensity of some component of solar radiation, such as the intensity of the direct component or the diffuse component. Other sensor measure are the global radiation - the sum of direct and diffused component . Records of integrated amounts of solar energy are obtained by summing these intensity readings.

1.1 Measurements of Direct Radiation

Normal incidence pyrheliometer (NIP) are used for measuring the intensity of the direct component of solar radiation on a surface normal to the direction of the rays. Such measurements are directly applicable for focusing collectors which can only utilize the direct component of solar radiation. Normal incidence pyrheliometer typically consist of (1) a radiation sensor element monthed inside (2) a collimating tube; this apparatus is mounted on (3) a sun tracking mechanism. A simplified schematic drawing is shown in Fig. (1).

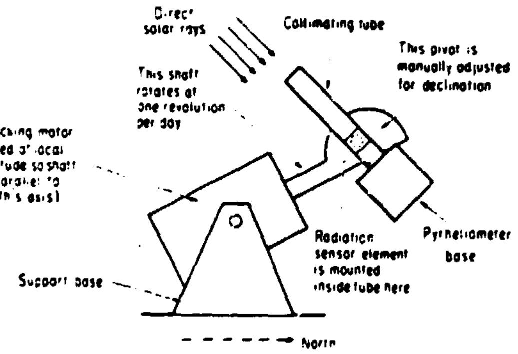


Fig. 1 : A schematic drawing of a normal incidence pyreliometer and its sun-tracking mount

The collimating tube serve to limit the energy reaching the radiation sensor to the direct component. In practice, most normal incidence pyrheliometer admit radiation to the sensor from about a 5.7° field of view. Thus, measurement of "direct-normal" radiation usually include some diffuse radiation. Under clear sky condition, this portion generally represents no more than 5 % of instrument reading.

The sensitive element is either a thermopile (by Eppley Normal Incidence pyrheliometer is the sensitive element 15-junction bismuth-silver thermopile) or a photodector such as silicon solar cell.

The photovoltaic silicon pyrheliometers advantages are relatively lower cost and faster response time for instantaneous measurements. The major disadvantages is the highly specular dependence of the cell output.

1.2 Total or Global Radiation Measurements

A pyranometer is an instrument for the measurement of the solar radiation received from the whole hemisphere. It is suitable for the measurement of the global or sky radiation. Sometime the term solarimeter is used instead at pyranometer. In a horizontal position, a pyranometer measure the intensity of total (direct plus diffuse) solar radiation on a horizontal surface, in a tilted position it measures the total radiation intensity on a tilted surface; in this case, the diffuse portion includes reflected radiation from that part of the earth which the pyranometers sees.

Pyranometers are similar to pyrheliometers. They consist at a radiation sensor element under a transparent cover, usually a quartz dome (see Fig. 2). Just as for a pyrheliometer, the sensor element is usually a thermopile or a photodector.

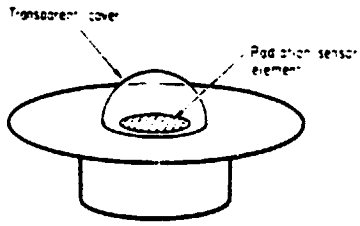


Fig. 2 : Pyranometer used for measuring global solar radiation

1.3 Diffuse Radiation Measurement

There are two commonly used methods for measuring the intensity of diffuse solar radiation. The first of these simply shadows the radiation sensor element of a pyranometer from the direct solar rays with an opaque "shading disk"

These are typically hand-held at the end of a slender rod while a measurement is recorded.

A "Shadow band" or "Shade ring" is a device which can be used to automatically record measurements of diffuse radiation in a routine fashion. The shadow band is mounted over a pyranometer in such a way as to block the direct rays of the sun from the sensor element through the entire day. The shadow band must be reset as necessary to adjust for the changing solar declination.

1.4 Sources of Measurement Error

Solar radiation measuring devices are not generally considered to be very accurate by the usual standards of physical science. At best, values to within several percent are probably more unusual than most would want to acknowledge or believe. And, as a point of reference, the solar constant is known only a little more precisely, to around general, pyranometers left to perform in fluctuating temperatures, wind, moisture, and radiation environments places considerable stresses on materials, and hence the performance of the system or instrument.

Accurate solar radiation measurements strongly depend on several major variables, all of which are in some way a function of the limiting characteristics of the instrument. These limits are then classified as to the additive errors they introduce and thereby provide a picture of what one can expect from a given type of instrument. The accuracy of the respective types of instruments is summarized in Table 1 by the World Meteorological Organization. In this case, the Eppley module PSP and Spectrolab model 75 are considered first-class instruments. The Eppley models 10, 50 and 8-48 as well as similar instruments (e.g., Kahl, Kipp, and Zonen) are second-class pyranometers, with third-class instruments being those such as some based on photovoltaic cells and bimetallic sensors. Since much of the data used for classification purposes is based on manufacturers' specifications, they should be viewed as generally optimistic and appropriately adjusted. It is interesting to note that there is a twofold difference in the additive error from one classification to the next.

A field survey of the approximately 75 solar stations in California was conducted in the fall of 1976. These data are summarized in Table 1 and indicate that about 67 percent of the stations are second class, 21 percent are third class, and the remaining 12 percent are first class. The summary of site visits as shown in Table 1 also gives a rough cross-sectional slice of other instrument characteristics in California's solar data network at that time. For example, when examined, only 67 percent of the instruments had sensors that did not show signs of discoloration and change, 58 percent of the pyranometers were not level, and roughly half were in need of a desiccant change. There were other influences as well, the combination of which casts doubts on the data quality of any station that is not known to be very conscientious in its practices.

Table 1: Classification of Solar Radiometers *

	Pyranometers			Pyrheliometers	
	1st Class	2nd Class	3rd Class	1st Class	2nd Class
Sensitivity (mW/cm^2)	± 0.1	± 0.5	± 1.0	± 0.4	± 0.5
Stability (% change per year)	± 1	± 2	± 5	± 1	± 2
Temperature (maximum error due to changes of ambient termperature, in %)	± 1	± 2	± 5	± 1	± 2
Selectivity (maximum error due to departure from assumed spectral response in %)	± 1	± 2	± 5	± 1	± 2
Linearity (max. error due to nonlinearity not accounted for, in %)	± 1	± 2	± 3	± 1	± 2
Time constant (maximum, in s)	25	60	240	25	60
Cosine response (deviation from that assumed, taken at Sun elevation 10° on clear day, in %)	± 3	± 5-7	± 10		

Azimuth response(dev. from that assumed, taken on clear day, in %)	± 3	± 5-7	± 10		
Errors in associated recording apparatus, in%)	± 0.3	± 1	± 3	0.2	± 1
Example	Eppley model PSP; Spectrolab SR-75	Eppley Black & While (model 8-48) ; light bulb type	Bimetallic-Strip pyranograph	Eppley model NIP (temperature comsated)	Eppley model NIP (uncompensated)

Source: From World Meteorological Organization.

* Based on commercially available instruments.

1.5 Sunshine Duration

The term "sunshine" is associated with the brightness of the solar disk relative to the background diffused sky light. As such it is more related to visual radiation than to energy radiated at other wavelenghts, although both aspects are inseparable.

Based on the analysis of many data from station where direct solar radiation, and duration of sunshine were recorded, mean threshold values between 100 and 200 Wm^2 were found.

Several specialists have suggested that the value of 200 W/m^2 be adopted, while more recently 105 W/m^2 has been proposed.

1.5.1 Instruments

1.5.1 The Campbell-stocks sunshine recorder

The Campbell-stockes sunshine recorder consists essentially of glass sphere mounted concentrically in a section of spherical bowl, the diameter of which is such that the sun's rays are focused sharply on a card held in grooves in the bowl.

It should be noted that the aforementioned problems of the burn obtained under variably cloudy conditions indicates that this instrument, and indeed any instrument using this method, does not provide a measurement of true sunshine duration.

1.5.2 Automatic sunshine recorder

For recording the duration of sunshine at automatic stations, electronic instruments have been developed. They mainly use photoelectric detectors and are based on the principle of the threshold definition. In order to avoid continuous tracking of the sun, they sense the difference between the radiance of the sky and the sun with an array of detectors.

The associated electronics normally provide the sunshine duration in digital form say as the output of a clock counter which only counts if the solar radiation is higher than a preset threshold.

1.6 Estimation radiation from sunshine records

The most frequently used relationship between solar radiation and duration of sunshine is the equation :

$$H = Ho\ (a + b\ pp) \qquad \text{.............................}(1)$$

In this equation (pp) represents the percent of possible sunshine, that is, the recorded sunshine duration divided by the maximum possible sunshine duration for the day (calculated day length). The variable H and Ho are the estimated total-horizontal radiation and the extraterrestial radiation on a horizontal surface, respectively. Ho can be obtained from the following equation :

$$\bar{H}o = 2\,I_{ex} \left[\frac{hsr}{15} \sin L \cdot \sin \delta + \frac{12}{\pi} \cos L \cdot \cos \delta \cdot \sin hsr \right] \ldots\ldots 2$$

where hsr is the sunrise hour angle, δ the declination for that day, L is the local latitude and I_{ex} is the solar constant.

The value of the parameters a and b are derived empirically at locations where both types of data are available.

2. TEMPERATURE MEASUREMENT

Temperature is the condition which determine the direction of net flow of heat between two bodies. In such a system, that body which, overall, loses heat to the other is said to be at the higher temperature. In order to measure the temperature of an object a thermometer can be brought to the same temperature as the object (i.e. into thermodynamic equilibrium with it) and then the temperature of the thermometers itself can be measured. Alternatively, the temperature can be determined by a radiometer without need for thermal equibrium.

2.1 Thermometers

Any physical properties of a substance which is a function of temperature, can be used as the basis of thermometer. The properties most widely used in meteorological thermometers are thermal expansion and the chang^ in electrical resistance with temperature.

Thermometers which indicate the prevailing temperature are often known as "ordinary" thermometers while those which indicates extreme temperature over a period of time are called "maximum" or "minimum" thermometers.

2.2 Response time of thermometers

For routine meteorological observations there is no advantage in using thermometers with a very small time constant, since the temperature of the air continuously fluctuate up to a degree or two within a few seconds. Thus to obtain a representative reading with such a thermometer would require taking the mean of a number of readings, whereas a thermometer with a larger time constant tend to smooth out the rapid fluctuations. Too long a time constant, however, may result in error when long-period changes of temperature occur. It is recommended that the time constant, defined as the time required by the thermometer to register 63.2 percent of a step change in air temperature, should be between 30 and 60 seconds, in a wind speed of 5 m/sec. The time constant is roughly inversely proportional to the square roof of the wind speed.

2.3 Types of thermometers

2.3.1 Liquid-in-glass thermometers

For routine observation of air temperature, including maximum, minimum and wet-bulb temperatures, liquid-in-glass thermometers are still commonly used. Such thermometers make use of the differential expansion of a pure liquid with respect to its glass container to indicate the temperature.

2.3.2 Mechanical thermographs

The types still commonly used are supplied within bimetallic or Bourdon-tube (The temperature sensitive element is in the form of a curved metal tube of flat elliptical section, filled with alcohol) sensors since these are relatively inexpensive, reliable and portable. However, they are not readily adapted for remote or electronic recording. Such thermographs incorporate a rotating chart mechanism common to the family of classical recording instruments.

2.3.3 Electrical thermometers

Electrical instruments are becoming increasingly popular for measuring temperature. Their main virtue lies in their ability to provide and output signal suitable for use in remote indication, recording, storage or transmission of temperature data. The most frequently used sensors are electrical resistance elements, thermistors and thermocouples.

2.3.3.1 Electrical resistance thermometers

A measurement of electrical resistance of a material whose resistance varies in a known manner with the temperature of the material can be used to represent the temperature.

For large temperature changes and for certain metallic alloy the following equation give the relation between resistance and temperature :

$$R_T = R_o \ (1 + a.t + \beta t^2)$$

Where :

R_T : is the resistance of a fixed amount of the metal at temperature T.

R_o : is its resistance at a reference temperature.

The value for the coefficient (a) and (β) can be found by the caiibration of the thermometer concerned.

2.3.3.2 Thermistors

Another type of resistance element in common use is the thermistor. This is a semiconductor with a relatively large temperature coefficient of resistance, which may be either positive or negative depending upon the actual material. Mixtures of in-sintered metallic oxides are suitable for making practical thermistors, which usually take the form of small discs, rods or spheres are often glass coated. The general expression for temperature dependence of the resistance, R, of the thermistor is given in the following equation :

$$R = a\exp(b/T)$$

where a and b constants and T is the temperature of the thermistor in Kelvins.

2.3.3.3 Thermocouples

Thermocouples are mostly used when a thermometer of very small time constant and capable of remote reading and recording is required. A disadvantage, if absolute temperature is required, is the need of a constant-temperature enclosure for the cold junction and the ancillary apparatus for the measurement of the electromotive force set up; thermocouples are best suited to measurement of differential temperatures, since this complication does not then arise.

Copper-constantan or iron-constantan combination are suitable for meteorological work, as the electromotive force produced per degree celius is higher than with the rare, and more expensive metals which are normally used at high temperature.

2.4 Measurement technique

Digital measuring procedures are increasingly applied because of their high accuracy and the possibilities of transmission, indication, storage and processing. In addition when a digital computer is used for the acquisition and processing of data from a large number of observing site, then digital measuring techniques are essential.

With electric measurement of temperature the output signals of the sensors are direct current, direct voltage or else resistance (i.e. continuously varying magnitudes). Signal conditioning units are used for quantization and conversion the output signals into a coded digital form. Rapid progress in the field of electronics had led to the use of a great number of conversion principles. Due to their greater immunity from electrical noise, integrating analogue-to-digital converters are normally used.

3. RELATIVE HUMIDITY

The relative humidity is defined as the ratio of the actual vapor pressure to the pressure of saturated vapor at the prevailing dry bulb temperature. It is to be noted that relative humidity is a property of the vapor is mixed with air. It is a method of expressing the departure of the vapor from saturation.

3.1 Humidity measurement

3.1.1 Dew point method

This method is based on the definition of the dew point. A metal plate is cooled electrically or other mean to the point where moisture condensate on the plate. The time when this occurs can be detected by an electric eye that notes the reflection or nonreflection of beam of light .

This point is partically valuable when the dew point increase rapidly with a small change in moisture.

3.1.2 Hygrometers

Hygrometers measure relative humidity, often by using the change in dimensions of hygroscopic material such as human hair, wood or paper; these instruments are simple and inexpensive but require frequent calibration. The electrical resistance of an electrolytic film can also be used as indication of relative humidity.

3.1.3 Wet-and dry-bulb psychrometer

This method is widely used. Humidity measurement of air flowing in ducts can be made with psychrometers that use mercury-in-glass thermometers, thermocouples, or resistance thermometers. Humidity measurements of still air can be made with sling psychrometer of aspiration psychrometers. Psychrometic wet-bulb temperatures must be corrected to obtain thermodynamic wet-bulb temperature, or there must be adequate air motion past the wet bulb thermometer to ensure a proper balance between radiation and convection.

4. WIND

Wind velocity is a vector quantity specified by the direction and by the speed. The extent to which wind is characterized by rapid fluctuation in velocity is referred as "gustiness'. Wind direction, speed and gustiness are generally best determined instrumentally, but when such determination is not practicable wind direction and speed are estimated.

4.1 Wind-speed measurement

Cup and propeller anemometers are commonly used for the determination of wind speed and consists of two sub-assemblies : the rotor and signal generator.

In well-designed system the angular velocity of the cup or propeller rotor is substantially directly propotional to the wind speed, or more precisely in the case of the propeller rotor, to the component of wind speed parallel to the axis of rotation. Near the starting threshold speed, however, substantial deviation from linearity occur.

Also, in such well designed anemometers, the linearity of response is independent of air density, has good zero and range stability and is easily reproduced in a manufacturing process.

Since both cup and propeller rotor turn with angular velocity directly propotional to speed or to the axial component, they are particularly convenient for driving a wide variety of signal generator. Alternating and direct current generators, optical and magnetic pulse generators, and turn-counting dials and registers have been used to advantage. The choice of signal generator or transducer depends largely on the type of data processor and readout instrument to be used.

Care should be taken to ensure that bearing and signal generator have low starting and running fractional torques and that the moment of interia of the signal generator does not enlarge the distance unreasonable.

4.2 Wind-direction measurement

The wind-direction vane consists of two sub-assemblies, the vane and the signal generator or transducer.

For the purpose of obtaining a satisfactory measurement, a wind vane will be suitable if it is well balanced so as not to have a preferred position in case the axis in not vertical and if it is sufficiently well designed to have a single equilibrium position with respect to each wind direction. The aerodynamic torque on a vane is propotional to atmospheric density and wind speed squared.

The signal generator is essentially a shaft-angle transducers, and many varieties have been employed. Potentiometer, alternating and direct current synchros, variable capacitors and inductors, direct reading dials and rotary switches have been used to advantage. The choice of signal generator is largely a matter of the type of data processor and readout instrument used. Care should be taken to ensure that bearings and signal generators have low starting and running frictional torques and that the moment of interia of the signal generator does not diminish the damping ratio unreasonably.

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DESIGN OF LARGE SOLAR WATER HEATER SYSTEM

ENG. MALEK KABARITI

1. ABSTRACT

The purpose of this paper is to describe a practical method for sizing and designing of solar water heating systems, i.e., systems which collect solar energy, store the energy, and distribute it as needed to heat water for domestic use.

The major parts of the solar heating systems considered here are the solar collector which heats liquid, the energy storage unit which is a water tank, and an auxiliary heater. The auxiliary energy source supplies heat as needed when the collected solar energy is insufficient to meet the entire heating needs, which we refer to as the hot water load.

It is technically possible to build a solar heating system which would supply 100 % of the annual water heating load, and which would then not require an auxiliary heater. A solar heating system designed to supply all of the energy required during the coldest months would then be greatly oversized (capable of supplying far more energy than needed) during other months of the year. We know that there is a large economic penalty resulting from oversizing a solar heating system.

In almost all cases, it is more economical to design a solar heating system to supply part of the annual water heating load, and provide an auxiliary energy source (conventional furnace) to supply additional energy as needed.

2. INTRODUCTION

Solar heating of water for comercial purposes is one of the oldest and most cost-effective uses of solar energy. The temperature levels required (40 - 70°C) can be produced efficiently by simple, relatively inexpensive collection devices. In addition, the demand for hot water tends to be uniform throughout the year. The combination of moderate temperature requirements and uniform annual demand makes the production of hot water for domestic, commercial, and industrial uses a particularly attractive application for solar energy.

3. SYSTEM DESIGN

The following steps are to be considered for the design of solar water heaters:

- Obtain climatic and insolation data for the location of the solar water heater, and select outdoor design temperature conditions.

- Calculate the average monthly hot-water load required.
- Determine the collectors array orientation and tilt angle.
- Select collector area to provide about 50 to 70 percent of the annual load.
- Using the effiency curve provided by the manufacturer for his collector, determine the amount of heat that can be delivered to load.
- Determine the thermal storage-tank(s) size in liters.
- Calculate the flowrates for each discrete piping circuit.
- Prepare an outline description of the proposed system including the control logic and various modes of operation, i.e., (a) solar collector heat to storage, (b) storage to load, (c) auxiliary or backup heat.
- Select differential controller, sensors, and other automatic control equipment needed.
- Prepare a schematic design chart showing the solar collectors and its supports, storage tanks, piping, pumps, and controls. Calculate piping lengths and sizes, and valve sizes and calculate the pumping head required under peak conditions. Select the proper size of pumps from manufacturer's performance curves.

- The collector area and storage volume should now be changed in increments of 10 percent to determine the performance and cost sensitivity to these changes. The percent solar contribution to the heating load can be examined for values of 40 to 90 percent. Select the most optimal system with respect to cost.
- Prepare design development and mechanical drawings for the system selected showing all points of interface with the building structure and the mechanical and electrical systems.
- Prepare working drawings, detailed specifications, and final cost estimates for the system.

3.1. Water Heating Load

The actual water heating load (the amount of energy required to heat water for domestic purposes) is highly dependent upon the lifestyle of the building occupants.

Assuming a daily hot water consumption of 100 liter/person the monthly water heating load l_w can be estimated as:

$$L_w = N \times (\# \text{ of persons}) \times 100 \times (T_w - T_m) \times p \times C_p \qquad (1)$$

where

N is the number of days in the month

T_w is the minimum acceptable temperature for hot water; approximately 60 C

T_m is the mains supply water temperature

P is the density of water (1 kg/liter)

C_p is the specific heat of water (4190 J/kg-C)

Note that the energy needs given by Equation 1 can be adjusted upward or downward if higher or lower hot water needs per person are anticipated.

For buildings other than residences, the same basic methods of estimating water heating loads can be used, i.e., the amount of energy needed is the product of the volume of hot water required, the density of water, the specific heat of water, and the difference between the desired hot water temperature and the mains supply water temperature. On a monthly basis, the water heating load is:

$$L_w = V \times p \times C_p \times (T_w - T_m) \qquad (2)$$

where V is the volume of hot water required for a month and other terms are as defined under Equation 1.

The amount of collector area required for a particular application depends strongly on monthly water heating loads. The calculation of the water heating loads is often the most difficult of the calculations needed to design solar heating systems.

3.2 Design and Sizing Methods

We will discuss in this section the methods that have been developed for the analysis and design of water solar heating. There are several objectives to be served by active solar system analysis and design methods.

First, the design methods are needed to determine the size of the collector array. The decision should be made on an economic basis where the life-cycle cost of the solar system is compared with that of the fuel saved in its lifetime.

Second, after selecting the collector size, the components and the system configuration and control strategy must be selected. These decisions are made through performance or cost optimization studies. Such studies are done by analyzing the dynamic performance of systems using tools or computer programmes that predict system behavior. Integrated energy quanitities over long periods (usually a year) can be computed, such as useful solar energy supplied to the load, the amount of auxiliary energy needed, and the times when these energy flows occur. Such a process has been accomplished in developing the F-CHART design methodology. Detailed simulation studies for new configurations should be accomplished during the design process. The generalized results of the design analysis could be used in graphical or tabular form to decide on component sizing.

Third, Economic feasibility of a proposed solar design can be studied using a life-cycle cost analysis. Results of such studies depend on parameters related to local weather, system design, and fuel costs.

3.2.1 Solar system sizing characterisics

Design of solar energy systems differ from that of conventional systems in respect to three aspects that relate to system performance and collector-sizing requirements.

First, incident solar energy is variable during time and may not be available at all during peak demand periods. Auxiliary energy supply systems must be provided when solar energy may not be able to meet all demands. The auxiliary system is sized for peak loads while solar system component are sized based on overall system performance.

Second, load matching affects the overall system performance and total energy collected.

Third, solar energy is typically collected and delivered over a large temperature range. This influences the performance of heating system. For these reasons, conventional "peak load" design methods are not acceptable.

3.2.2 Solar system simulation

All design methods in use today (manual, calculators, computer programmes) were developed using simulation models. The application of simulation in the development of design tools is discussed.

The performance of a solar heating system depends on:

- Solar radiation available
- Ambient temperature
- Wind condition
- Collector design
- Inlet fluid temperature
- Thermal load

A detailed system simulations is required to predict system performance with respect to the above factors.

Predicting system performance is difficult because solar systems always operate in transient modes. They are driven by constantly varying weather, the relationship among system components is complex, and the systems are nonlinear in their response to solar radiation. Thus, a computer programme is needed to calculate the long term performance of the system using hour-by-hour data, while the short term performance information could be used in selecting some of the components. Figure 1 describes a typical simulation model.

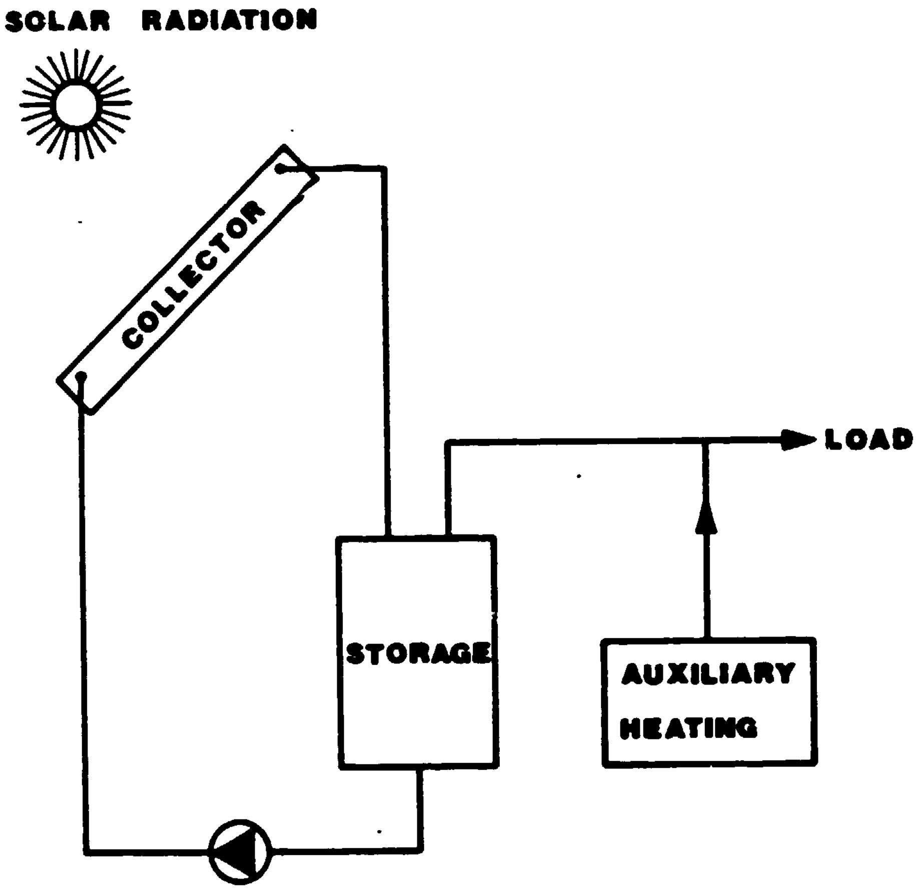

Figure 1 . Typical Simulation Model

3.2.3 Classification of design methods

The manual and computer design methods will be discussed. Manual methods are those which are executed on hand-held calculators or graphs, tables, and manually solved equations. While those executed on computers are classified as computer methods.

a) Manual methods

Many manual design methods have been developed for solar heating systems. Two factors should be considered in selecting the design method. The first is the required water temperature and the second is the load profile.

b) The F-Chart method

The F-Chart method [3] is the most widely used. It was developed by the University of Wisconsin using the TRNSYS computer programme. F-CHART was developed by using the TRNSYS programme to simulate representative types of solar heating at several different geographical locations, using either air or water as a heat transfer fluid.Correlations were determined between the monthly solar fraction and two dimensionless quantities that are particular to a given system being analyzed. One is a measure of the monthly solar radiation absorbed by the collector, and the other is a measure of the collector thermal energy losses. The result of this is a graph (or chart) showing the solar fraction, f, as a function of these two dimensionless quantities. The F-CHART for a liquid system is shown on Figure 2. The curves shown in Figure 2 may be represented analytically as follows. The equation that gives the solar fraction for water f_w as a function of the dimensionless quantities, X and Y, for a liquid system is:

$$f_w = 1.029\ Y - 0.065\ X - 0.245\ Y^2 + 0.0018\ X^2 + 0.025\ Y^3 \quad (3)$$

One may determine the solar fraction for each month of the year for a given solar system by calculating the X and Y values and then either using one of the above equations or referring to the appropriate F-CHART and reading the solar fraction directly from the F-CHART.

3.3 Shading

3.3.1 Solar access

Solar radiation must not be obstructed from collecting surfaces during the winter months and collectors sites should be chosen to avoid winter time shading of collecting surfaces by nearby structures. Partial shading of the collectors may significantly affect the system performance. If solar access is at all in question, a study of winter time shadow patterns should be made.

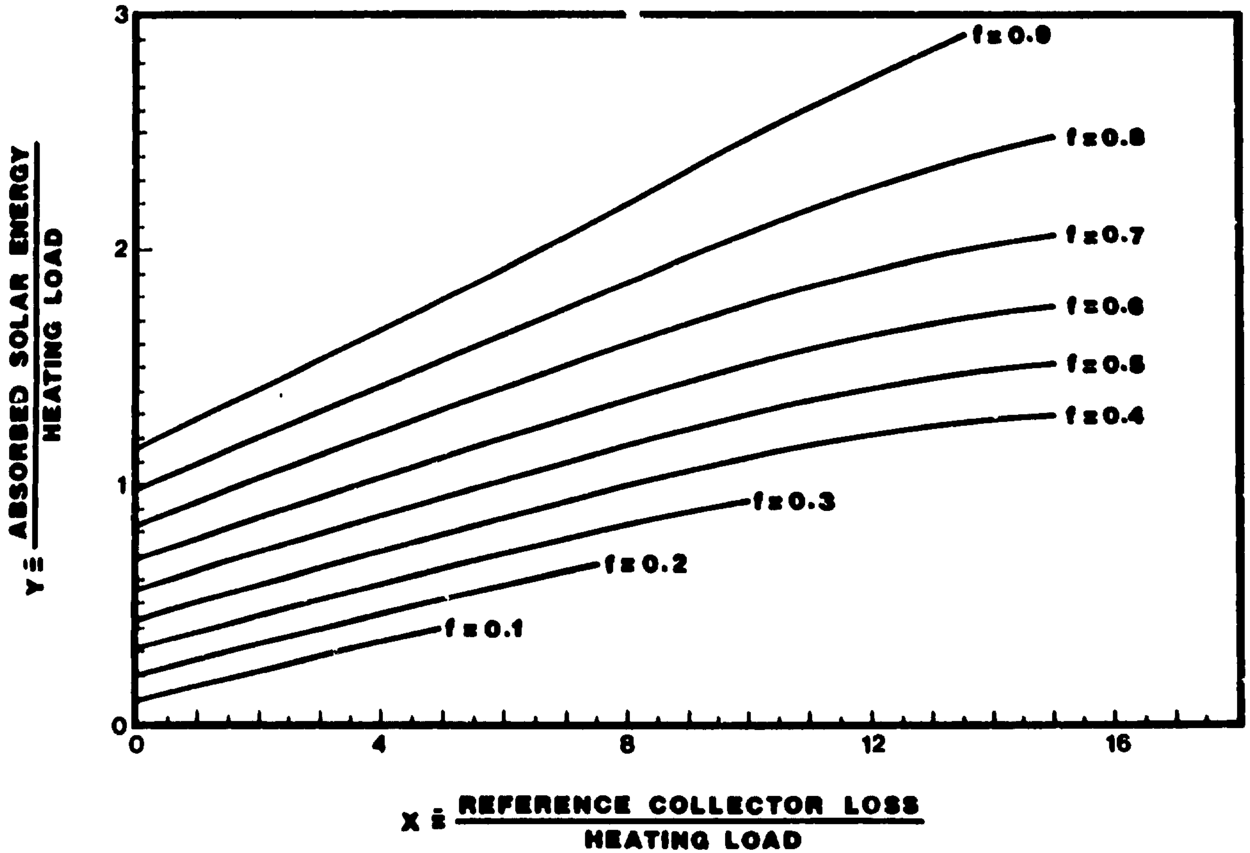

Figure 2 . F- Chart for Liquid Systems

3.3.2 Shadow mapping

As a rule of thumb, collecting surfaces should be exposed to direct sunlight between the hours of 9 a.m. and 3 p.m. During this period, the designer should trace the shadow patterns cast on-site and determine where the optimal location for solar collection might be [1]. Figures 3 and 4 illustrate the effect of altitude and azimuth angles on shading.

3.4 Collector Tilt

Collector tilt (the angle the surface of the collector makes with the horizonal) is an important factor in system performance. The incident solar radiation must be as normal to collector surfaces as possible. For a solar water heating system, a tilt equal to the local latitude usually is considered as the optimum angle throughout the year. Variation of 10 degrees either way will not seriously affect the total annual performance of the system. For winter usage of the system a tilt equal to latitude plus 10 degrees is favorable.

3.5 Thermal Energy Storage

The following variables should be considered when selecting a particular type of storage tank:

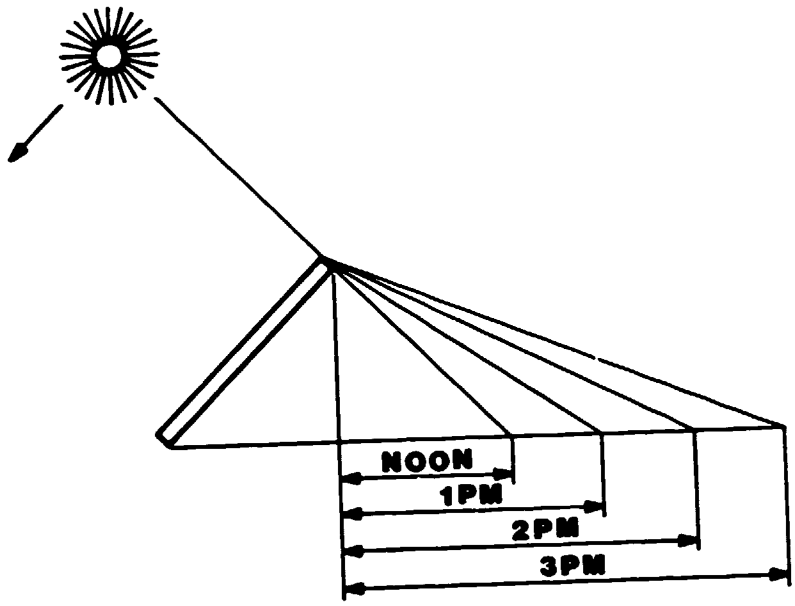

Figure 3 . Shading With Respect to Altitude Angle

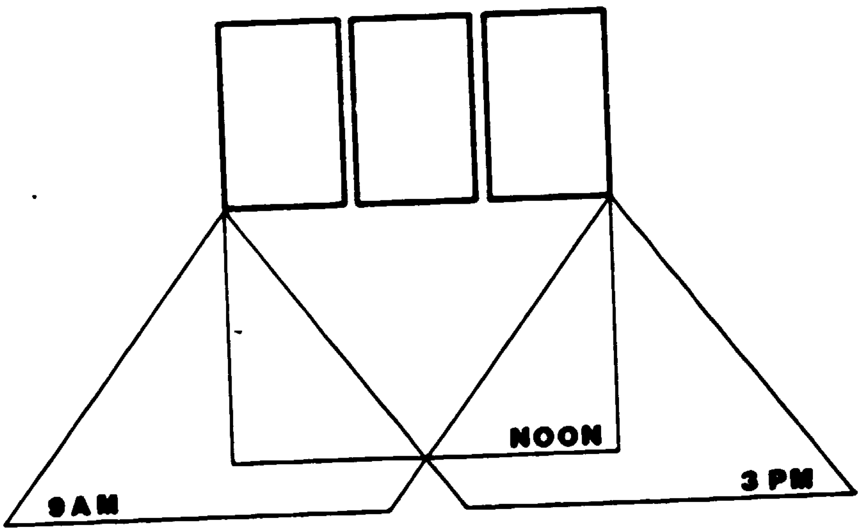

Figure 4. Shading With Respect to Azimuth Angle

- Size and shape
- Material
- Location
- Insulation
- Cost
- Leak protection
- Protective coating
- Installation
- Pressure and temperature limits

Water heating systems require storage temperatures no higher than 90°C. Most direct water heating systems use unpressurized tanks.

The best tank materials to be used must meet the temperature and the pressure requirements are steel, fiberglass, concrete, or wood with plastic lining. All types of tanks can be purchased or constructed in any size likely to be used in storage systems. More than one storage tank can be used depending on available space. However, two small tanks cost more than a large one, and a multiple tank system requires more insulation.

Several studies have been conducted to assess the effect of storage capacity on long-term system performance. It is found that if storage capacity is greater than about 50 liters of water per square meter of collecter, only small improvements in the yearly performance result from added storage capacity.

3.6 Pipe and Pump Sizing

The arrangement and sizing of the piping in a solar system have important effects on its performance. It is critical that piping is sized correctly so that suitable velocities, mass flow rates, and pressure drops are achieved at specific points throughout the system with reasonable pump sizes. In any system, the improper selection of a pipe size can cause noise, inefficiency, insufficient flow rates, air traps, and erosion problems.

The basis for calculating collector loop pipe size is derived from the mass flow rate requirement (as determined by collector flow rate recommendations) .015 - 0.02 l/sec m^2 and the desired flow velocities through the pipe section.

The supply and return manifolding for the collector array should be sized to provide uniform flow through the collectors. It is also recommended that reverse return manifolding, be used. This will aid in achieving uniform flow through the collectors. If uniform flow is not present, then some collectors will not perform as well as expected.

The pump in a solar water heating system is usually a low-horsepower centrifugal circulator. The flow rate of the pump is the number of liters per second of heat transfer fluid that should flow through the collectors. It is usually between

0.015 - .02 l/sec per square meter of collector surface. The head of the pump is the pressure a pump must push against. There are only two types of heads that are of concern to solar water heating systems. These are static and friction, and they must be added together.

Friction between the transfer fluid and piping in the system causes pressure losses. These friction head losses can be determined by consulting standard plumbing tables in a number of sources [4].

Static head is the height the water must be pumped. Unlike pressure loss, it has no relationship to the length of the heat transfer fluid circulation loop. Static head is a factor in an open-loop system, and it is not in closed-loop systems [4]. Consult the catalogs and literature of several manufacturers of appropriate pumps and examine the performance curves. Pump curves shows flow (horizontal axis) versus head (vertical axis). Friction head varies with the square of the flow rate. For example, if the flow doubles, the friction head is quadrupled (see Figure 5).

Pick a pump that most closely matches the design curve of the system being installed. That curve is a product of the total head pressure (which must be determined) and the collectors flow rate specified by the collector manufacturer.

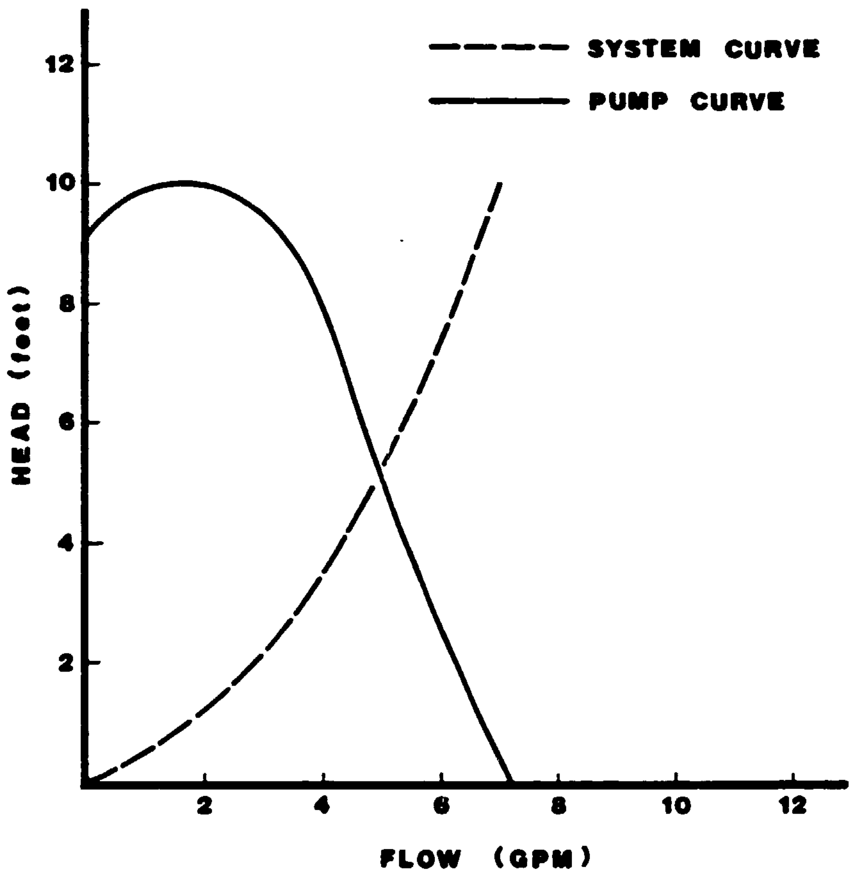

Figure 5 . Pump and System Curves

3.7 Example Problem

A small industrial town, Ruseifa, had been selected as the area for a possible installation, partly because it has a number of industrial plants with low grade heat requirements, and partly because of its proximity to Amman.

The existing boiler produces approximately 1 tonne of steam per hour. This steam is used in several heat exchangers to produce low temperature hot water for various purposes. The boiler is supplied from a cold water feed-tank, into which some of the water is returned. The daily water consumption is about 7 m^3.

3.7.1 Rough sizing

Figure 6 shows the existing standard collector, which has a net absorber area of 1.16 m^2. Figure 7 gives the efficiency curve of this collector.

An interactive computer programme was developed to do the design claculations. The results and the output are shown in the following:

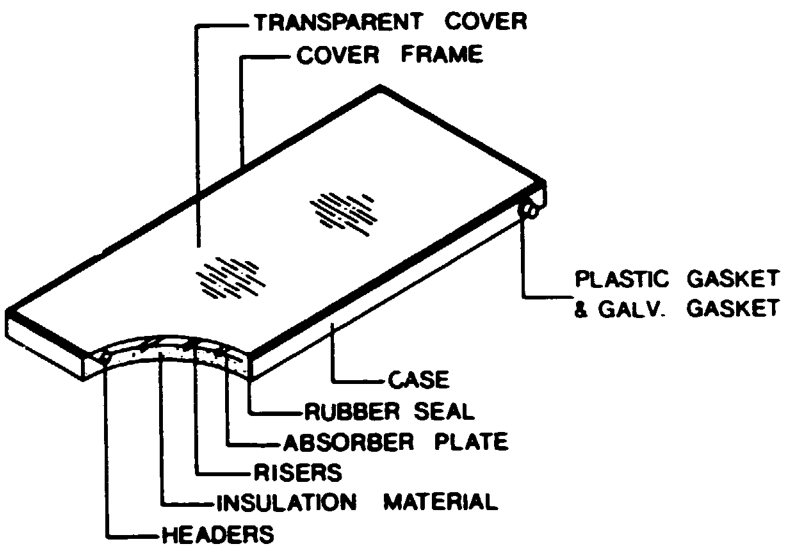

Figure 6 . The RSS Flat Plate Solar Collector Panel

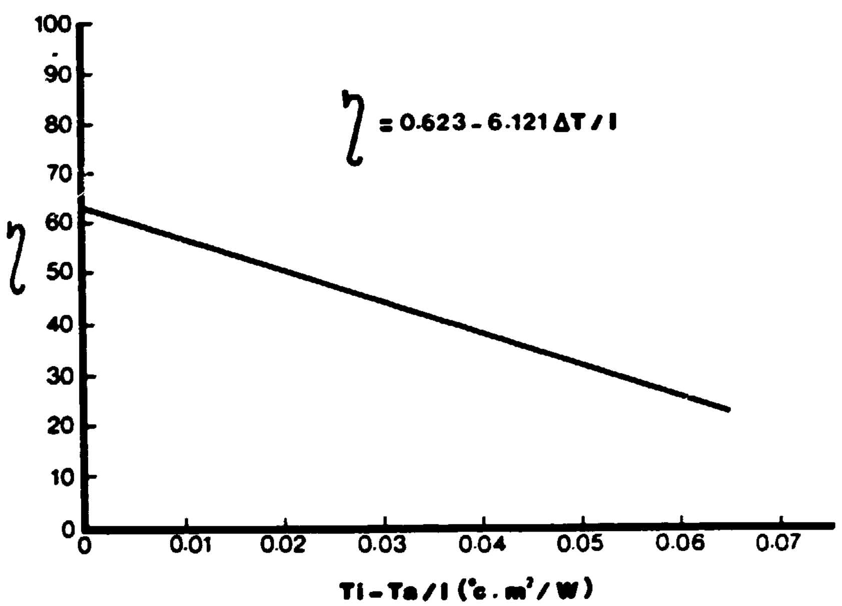

Figure 7 . Collector Performance Curve (Tested by RSS)

PROJECT NAME UNIDO

LOCATION AMMAN DATE FEB.1989 DESIGN BY M. KABARITI

WATER CON LIT./DAY	DT DEG.C	COL. AREA SQ. M.	STORAGE LIT.	FRTA	FRUL
7000.00	45.00	111.00	5000.00	0.62	6.12

THE FRACTION OF YEARLY LOAD SUPPLIED BY SOLAR ENERGY 63.53 %

	I MJ/DAY M2	Ta DEG.C	f %
JAN.	13.09	8.00	33.42
FEB.	16.81	12.00	47.76
MAR.	22.83	17.00	67.62
APR.	27.85	20.00	81.34
MAY	30.95	22.00	88.79
JUN.	29.65	25.00	86.75
JUL.	26.26	27.00	79.28
AUG.	24.67	31.00	76.25
SEP.	24.30	26.00	73.95
OCT.	18.69	20.00	55.96
NOV.	14.85	12.00	40.91
DEC.	12.42	6.00	30.37
YEAR	262.37		63.53

F- Chart Simulation

FOR R.S.S. SOLAR SYSTEM AT RUSEIFA

Jordan Dairy Company

geographical latitude		32 deg N
collector array area		111 m^2
	orientation	south
	tilt angle	42 deg
performance function:		Eff. = 62.3 - 612.1 (dT/I)
tank	volume	5 m^3
	diameter	1.6 m
	height	2.5 m
	U-value	0.47 $W/m^2.K$
load	7000 litres of water drawn off from the tank, at whatever temperature the tank is at.	

3.7.2 <u>Collector array</u>

The installation of 96 collectors in one array demands careful attention and consequently not a simple task. The size of the header pipe in the given collector (25 mm) is such that it allows the close-coupling of three panels, ie. the 3 x 7 = 21 riser tubes operating in parallel. This is normal practice with the domestic hot water systems of the RSS, which proved to be successful. So the basic unit consits of 3 panels in parallel. In order to avoid excessive temperatures, and therefore a reduced heat loss, the maximum of two such units can be connected in series. This gives a sub-module of 6 panels. Two of such sub-modules in a mirrored arrangement can share the inlet and outlet connections. Figure 8 shows the proposed module of 12 panels, with the two symmetrical sub-modules connected in parallel. This module should, in itself, ensure a balanced flow. The total array will consist of 8 such modules.

As the latitude of Rusiefa is 32 deg.N, for an annual maximum collection 32 deg. would be the optimum tilt angle. The best economies will however be achieved if the solar system output is fairly uniform throughout the year. Consequently the collector tilt has been set as latitude + 10 deg. = 42 deg. The resulting module dimensions are shown

3.7.3 Array position

Figure 10 shows the critical dimensions and orientation of the factory building. The initial advice received from the factory manager was that the long axis of the building runs east-west, therefore the mounting of the 8 modules in one straight line was considered. Thus, the length of the whole array would be 8 x 5.25 + 7 x 0.2 m = 43.4 m (assuming

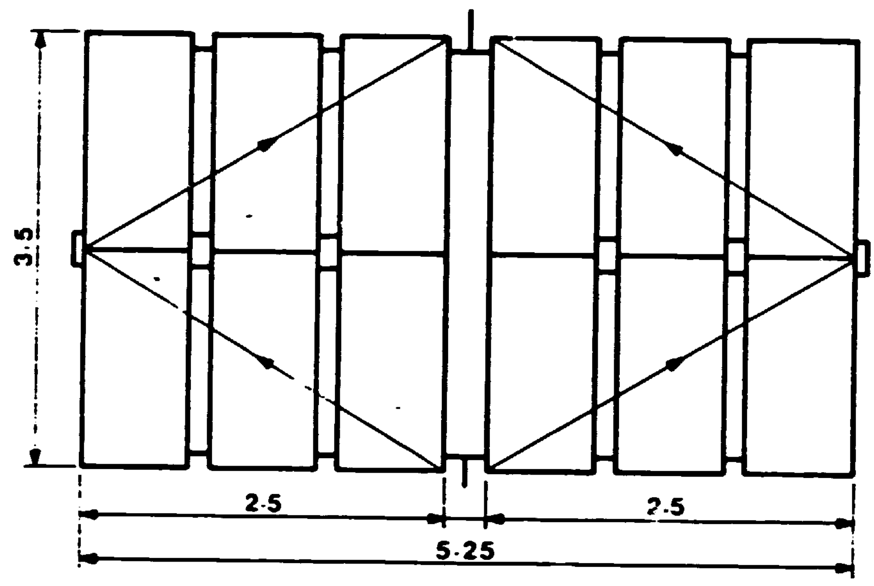

Figure 8 . Twelve Collector Panels Connected to Form a Module

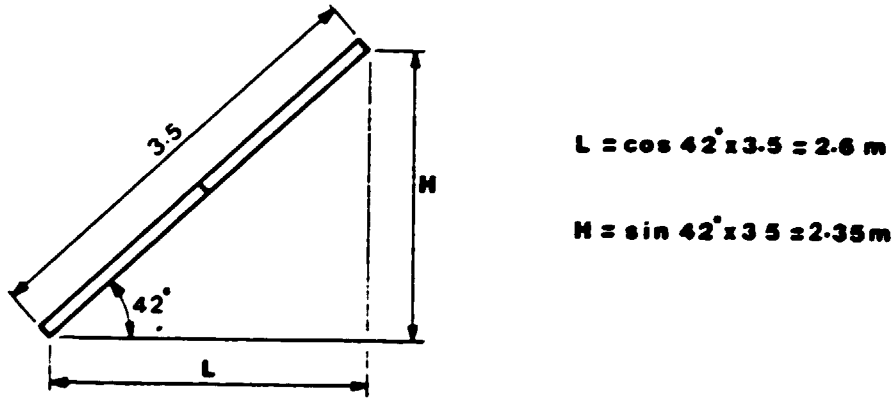

Figure 9 . Tilt and Sectional Dimensions of the Standardized Module

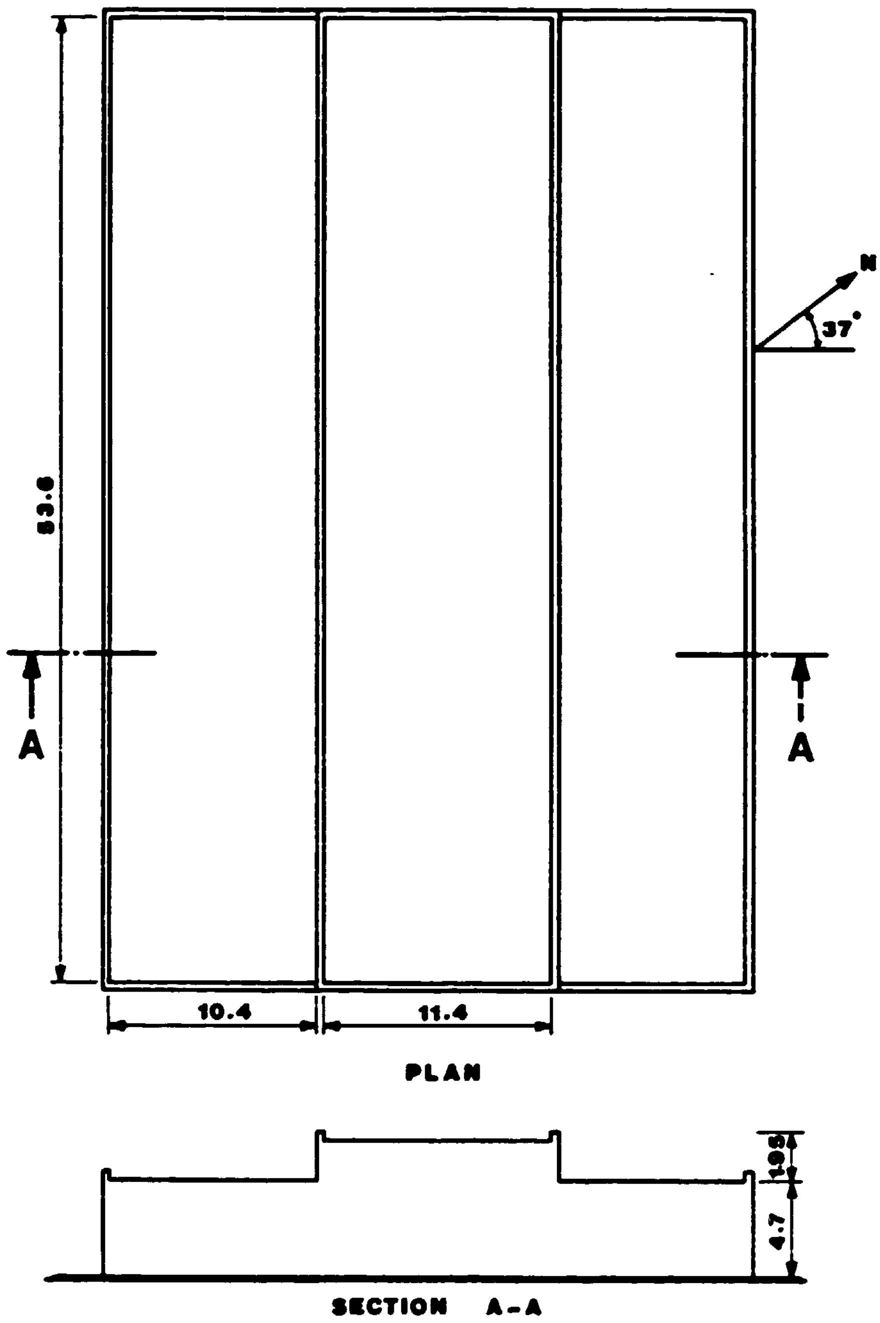

Figure 10. Dimension and Orientation of the Factory Building

0.2 m spacing between modules). As the length of the building is 53.6 m, this could be easily accomodated. A visit to the site however revealed that the long axis of hte building runs near south-east to north-west, i.e. the orientation is 37 deg. west of south. Consequently the collectors must be mounted in a diagonal position.

The three roof-plan sketches in Figure 11 show :

A: The original intentation, with one straight array running parallel with the building (this would actually face 37 deg. west of south).

B: The attempt to locate the straight array in a diagonal position, where the width of the roof would limit the orientation to some 26 deg. west of south.

C: Breaking the array in two sections of 4 modules each, which would allow an orientation of 12.5 deg. west of south.

As the feasibility of such a system is marginal, any such deviation from the optimum would copromise the success, therefore all these solutions were takent as unacceptable.

It is apparent that the array must be broken into at least three sections, eg. 2 + 3 + 3 modules. If this is to be done however, then the slightly narower lower roof could give sufficient width to accomodate tha array. This location

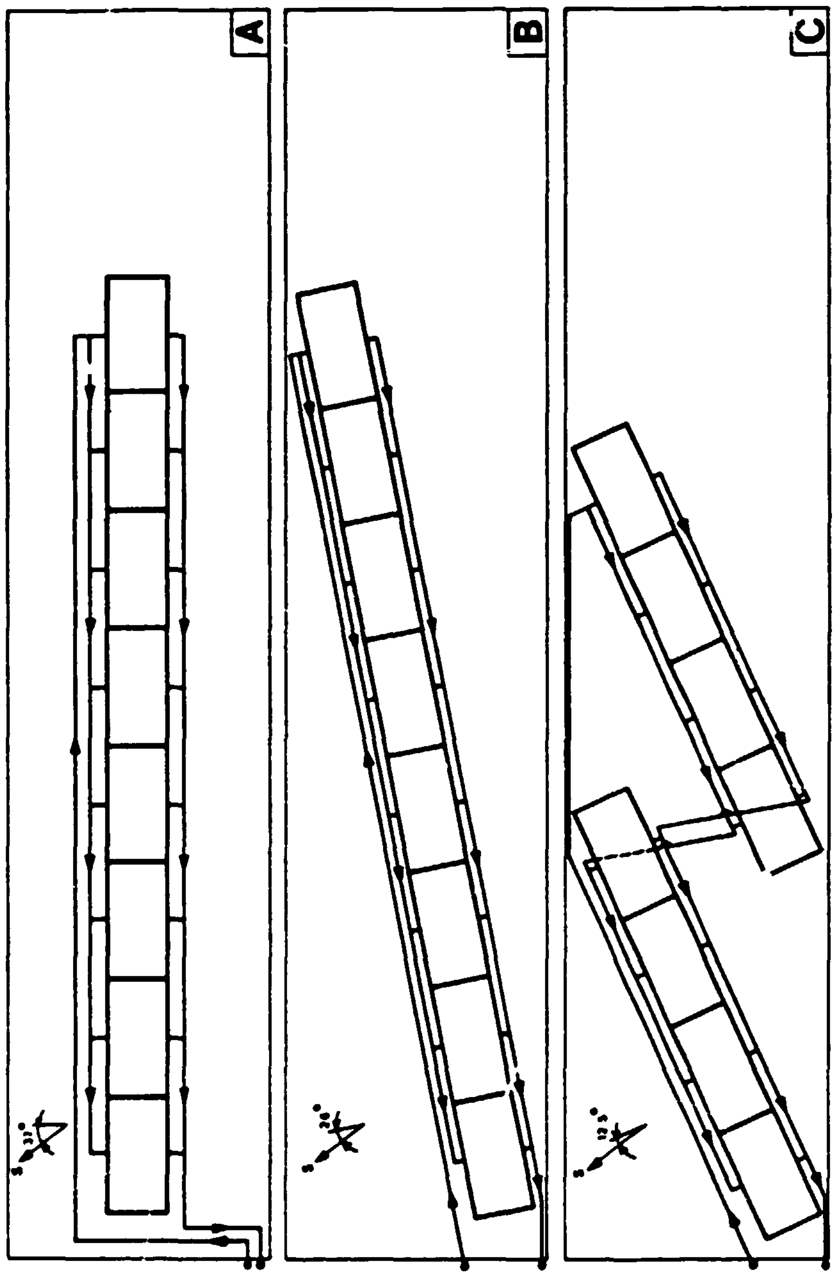

Figure 11. Possible Arrangements of Collector Array on Upper Roof (Unsatisfactory)

would have the benefit that the h' her part of the roof would provide some protection from the c l northerly winds, whilst the parapet of this higher roof would provide support for the high-level pipe.

Two further possible arrangements are shown in Figure 12

D: The 2 + 3 + 3 module arrangement, which would stil enfroce an orientation of 1 deg west of south (barely acceptable)

E: The 4 x 2 module layout, which allows a due south orientation and quite a neat pipe layout.

Scheme E has been agreed upon.

3.7.4 Detailed Sizing

The next task was to determine the water flow rate, pipe and pump sizes, flow rates between .015 and 0.02 $kg/s.m^2$ are normal.

A variable flow rate would be desirable to allow a useful temperature increase under low irradiance conditions, eg. in the early morning hours. A low starting flow rate would also avoid or at least reduce the occurance of repeated ON/OFF switching of the ther-mostat at start-up. Thus the suggestion is to install two pumps in parallel, giving appproximately 2.5 and 3.5 m^3/h flow rates respectively at the system's head loss and somewhat under 6 m^3/h when operating jointly.

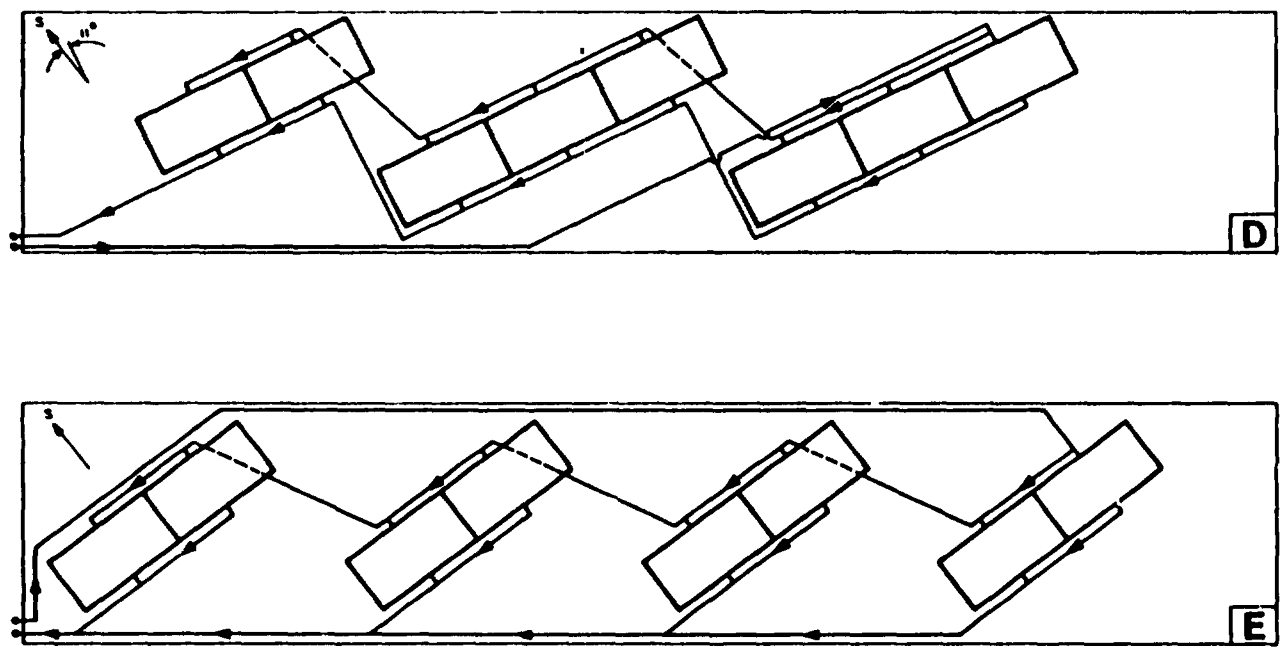

Figure 12. Possible Arrangements of Collector Array on Lower Roof (E- Selected Arrangement)

A subsequent detailed pipe-sizing calculation (using the computer program) showed that the pressure loss is dp = 2.6 m head of water, thus slightly larger pumps are needed namely; two pumps giving 2 m^3/h (0.55 kg/s) and 4 m^3/h (1.11 kg/s) respectively. Figures 13 and 14 shows the finally proposed system diagram.

3.7.5 Storage

As a rule of thumb it is suggested that a storage volume of 40 to 70 litres for every m^2 collector area is recommended. For the proposed 111 m^2 collector array a tank size of between 5.5 and 7.7 m^3 would be required. The daily water consumption is in the order of 10 m^3, used between 5 am and 3 pm. The early morning demand would have to be supplied from the previous day's collection (stored overnight), but later in the day the collection would match the demand.

Therefore it is suggested that only half of the daily water use should be stored. The collection after 3 pm. would give in this smaller tank a sufficient temperature for next morning's use, whilst in a larger tank the temperature would be inadequate and overnight the tank would become destratified. Thus, it has been decided to use a 5 m^3 tank. It should be of a vertical cylindrical shape, which is better from the point-of-view of temperature stratification. A 1.6 m diameter and = 2.5 m high tank would seem satisfactory.

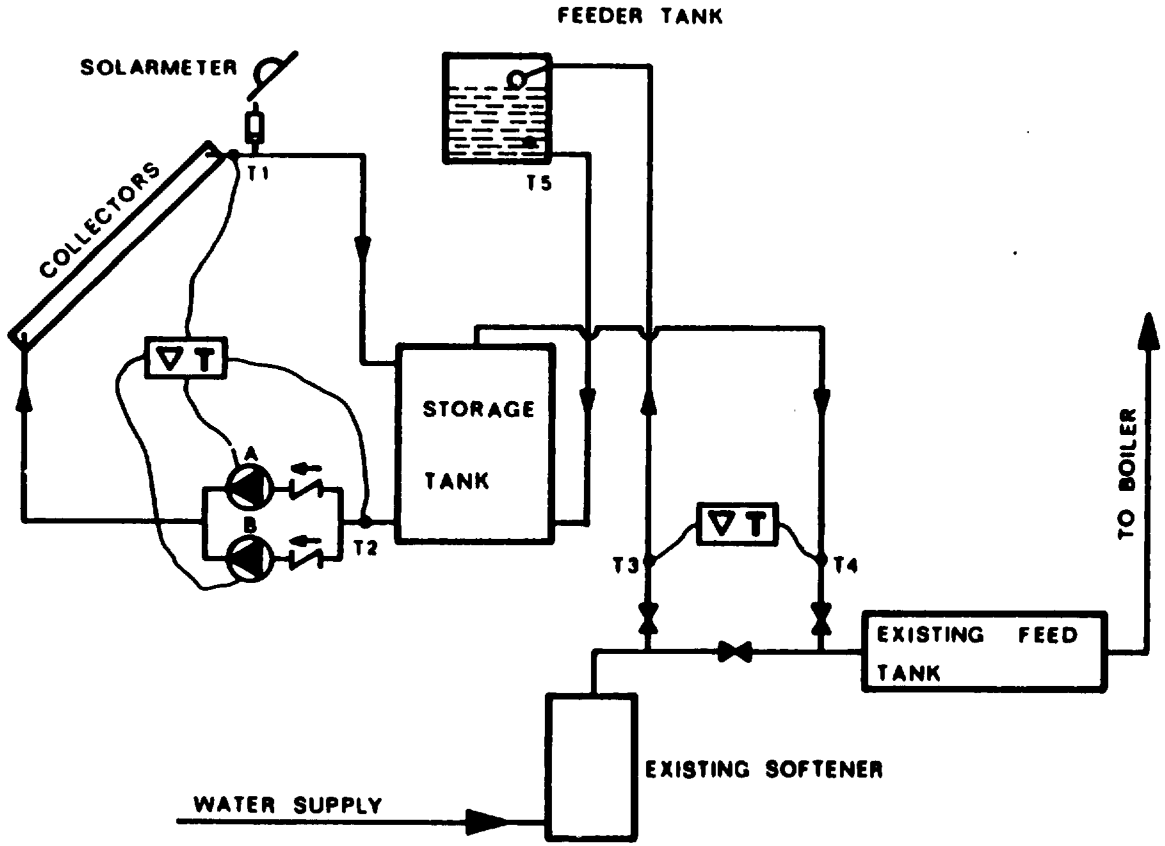

Figure 13. System Diagram

($0.8^2 \times Pi \times 2.5 = 5.02\ m^3$). To prevent overnight cooling down, a good tank insulation is necessary eg. 200 mm polyurethane cover.

3.7.6 System controls

The two pumps would be controlled by two temperature sensors namely; T1 located at the top of the collectors, and T2 located at the outlet (bottom) of the tank. The follwoing initial control settings are suggested:

(a) If T1 > (T2 + 8) - A only (2 m^3/h) if T1 < (T2 + 1) - both off
(b) If T1 > (T2 + 12)- B only (4 m^3/h) if T1 < (T2 + 9) - B off
(c) If T1 > (T2 + 16)- A + B on (=6 m^3/h) if T1 < (T2 + 13)- A off

The above control function would be carried out by a microcomputer used for data logging, through an activator relay, thus the control settings can be readily changed by software. After the final results are obtained a hardware control system will be installed at the optimum setting.

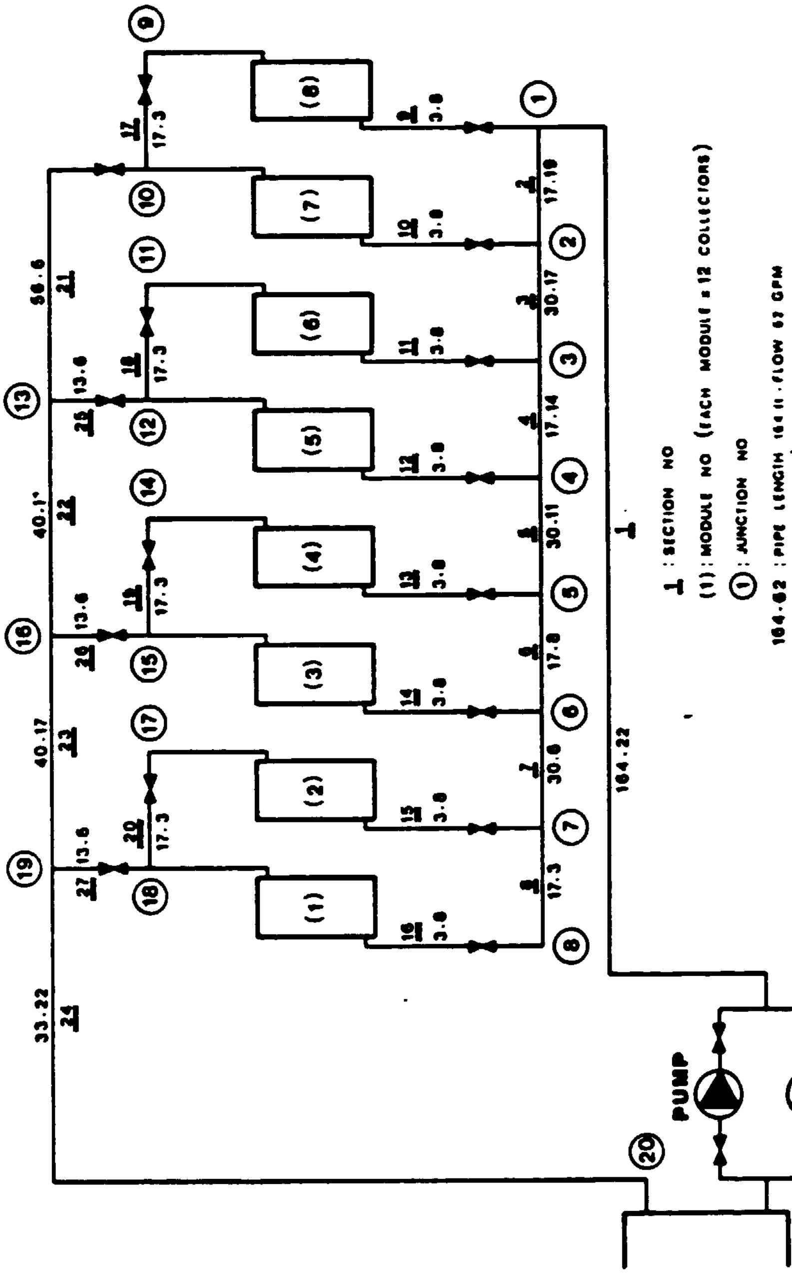

Figure 14. System Piping Design

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MANUFACTURING OF SOLAR WATER HEATERS

AIDMAR BEANO

ABSTRACT

This paper goes through the manufacturing processes of solar water heaters in brief.

The paper also includes the manufacturing consideration and safty guidlines.

The machinary needed to perform the manufacturing processes of solar water heaters are also presented.

INTRODUCTION

There are some specialized manufacturers with production lines, who produce SWHs with nationally and internationally known brand names. However many SWHs do not require special machines. They can be manufactured using common workshop tools and machines. The precession and the neatness of the systems and their efficiencies depend to some extent on the machines used.

The following suggestions may help in choosing the proper designs for manufacturing techniques when manufacturing SWHs :

1- Put down your ideas on paper.

2- Make designs of your ideas.

3- Discuss your designs with colleagues, and never underestimate somebody else's ideas.

4- Make prototypes.

5- Redesign if you are not pleased with your prototype.

6- Upgrade your designs.

7- Do not throw your scratch papers until the work is done. They might contain valuable information.

We at Royal Scientific Society (RSS) are working on SWHs since 1973 and have designed, redesigned, manufactured and tested many SWHs which vary in size, shape and materials used.

MANUFACTURING CONSIDERATION

There are many criteria of importance by any design such as cost, time, material consideration and production capabilities. Therefore it is strongly recommended that the designer understands the available machines and consults with expert in the appropriate field before the part has been progressed so far that it becomes very costly to change.

The achievement of design which incorporate the advantages of maximum economy in manufacture requirements of a part is dependent upon designer's ability to apply certain basic rules.

1- Design all functional and physical characteristics for maximum simplicity.

2- Design for the most economical production method.

3- Design for minimum number of machining operations.

4- Specify finish and accuracy no greater than are actually needed.

PROCESSING CHECKLIST

Once a product has been conceived, the various methods by which the component parts can be made should be thoroughly evaluated by applying the items as listed in the processing checklist which follows. For every manufactured part there usually is an optimum cost manufacturing process. There are many acceptable methods of evaluating the relative processing capabilities. Most designers employ a method that begins by systematically examining the advantages and disadvantages of every possible process. The final step involves elimination the obviously inappropriate processes and in narrowing down the search to a few choice alternatives which can then be researched in greater detail.

The following processing checklist consists of important points that the product designer should consider in evaluating specific process capabilities :

1- Suitability of materials.

2- Properties of materials.

   a - Strength

   b - Load deformation

   c - Resistance to corrosion

   d - Conductivity

   e - Weldability

3- Dimensional accuracy.

4- Typical size and weight ranges (maximum and minimum).

5- Lead time.

6- Minimum and maximum production quantities.

7- Production rate (i.e.. pieces/hour).

8- Surface finish (as-fabricated or as-machined).

9- In-plant production capability.

10- Inventory.

11- Cost factors

a - Influence of special desired features (complexity of part shape, inserts, coring, external surface detail)

b - Materials (availability, scrap)

c - Tooling (jigs and fixtures)

d - Subsequent machining operation

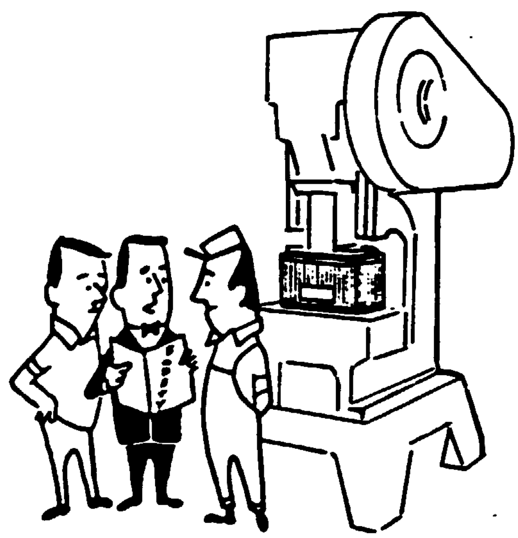
e - Subsequent machining operations

f - Handling equipment

g - Gaging

SAFETY GUIDE

The following steps are intended as guidelines for the workshop management. It is hoped that, by pointing out definite areas of responsibility, the entire safety program at workshops will receive everybody's participation.



Any safety program works best when it has the strong backing of management, and each employee's responsibilities are clearly defined. Safety programs must be constantly reviewed and evaluated and management must exchange ideas with others who have demonstrated interest in safety.

1- Make certain machine operators are properly trained.

2- Set up a program of daily, weekly and monthly machine inspections. Make a check list and follow through to make certain the job is being done correctly.

3- Establish a definite preventive maintenance program with check lists for each machine . Keep a historical record of all work, repairs and adjustments.

4- Make frequent evaluation checks of all machine safety guards and devices - especially during actual production runs. Correct any unsafe practices or situations immediately.

5- Establish safe, convenient material handling systems.

6- Provide a clean, safe, uncluttered work area around each machine.

7- Cooperate with other employees to promote safe operating procedure, and make a sustained personal effort to work safely from your first moment on the job.

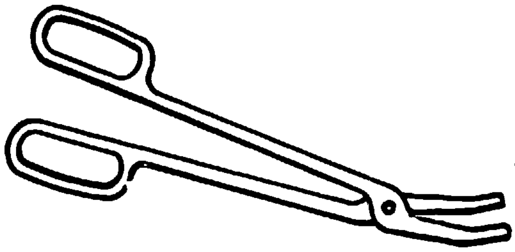
8- Provide adequate fire protection equipment.

9- Provide safety blocks of the correct size, with electrical interlocks, for each press.

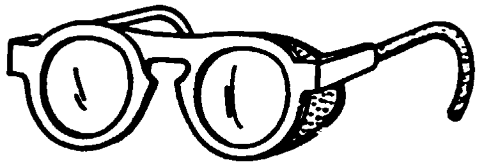
10- If machine malfunction is reported, stop the machines immediately and correct the problem, before resuming production.

11- Organize a company safety committee. Schedule periodic meetings to review and update all safety regulations.

12- Provide personal protective equipment such as safety glasses, safety helmets, tongs, gloves, hand pads, spats and protective sleeves as required to suit the operation.

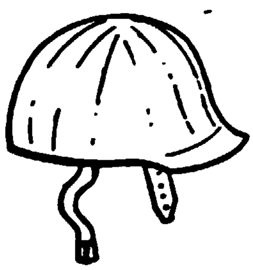


13- Establish a firm policy on machine safety regulations. Pub lish your objectives and spell out each mployee's responsibil-ities. Make certain all employee know, unmistakably, what is expected of them.

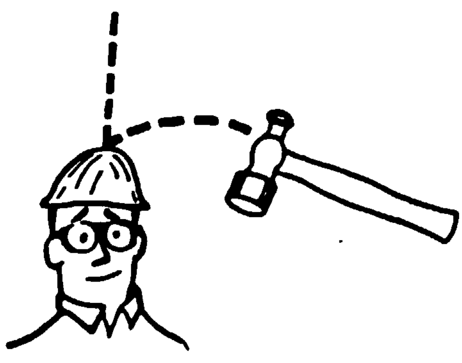


14- Thoroughly investigate all accidents and "close calls". Take immediate action to prevent a recurrence of the incident. Keep records of the investigation and of the corrective measures which were taken.

15- Publish a list of names, addresses, and phone numbers of physicians and members of the organization who are to be called upon in emergencies.

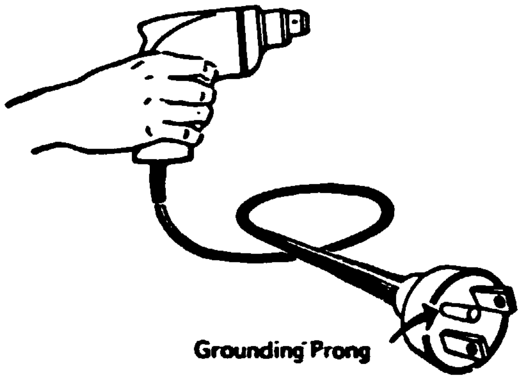


16- Make certain that all machines and associated equipment are properly connected to earth ground. Grounding should be in accordance with the National Electrical Safety Code and consistent with sound local practices.



17- Never overload the machines.

18- All electrical tools should be properly grounded or double insulated.

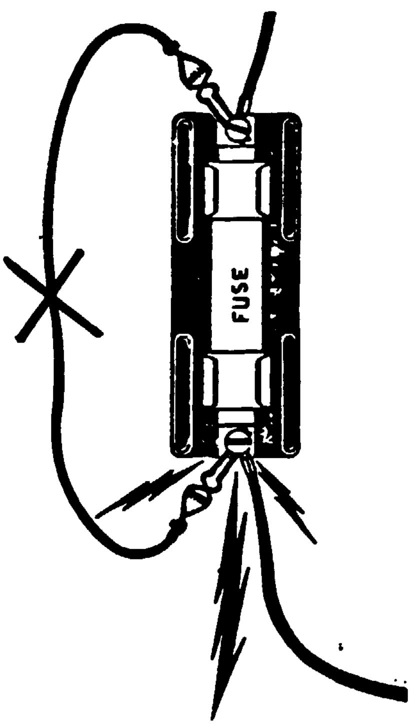


All electrical power tools should be properly grounded or double insulated.

19- Make certain; machine frame is properly connected to earth ground with an electrical conductor sized to comply with recognized codes. Installation should be in accordance with the National Electrical Code and/or local codes.

20- Never touch electrical equipment when hands are wet, nor activate electrical circuits while standing on a wet surface.

21- Replace fuses only with same size as originally furnished - never larger.



NEVER Jumper out fuses or circuit breakers

22- If it should become necessary to work on "live" electrical equipment, technicians should avoid working from any position in which a shock or slip would tend to bring the body toward exposed live parts. In this situation, it is generally better to work from below, rather than from above.

23- Inspect extension cords, before using, for worn insulation and exposed wires. Never use defective cords. Never route cords across aisles or through water and oil.

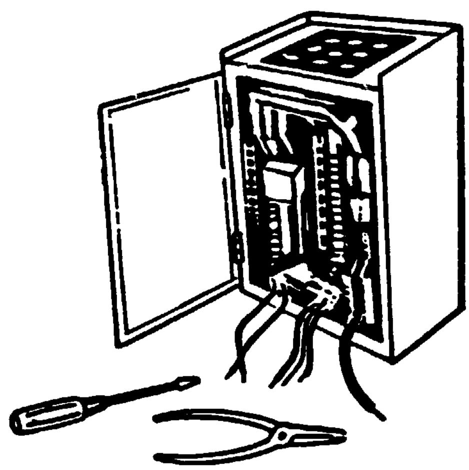
24- Never attempt to modify or rework the machine electrical control system.

25- Wear safety glasses - especially when chipping, grinding or doing work which causes particles to fly about. Put up a screen to protect other workers.

26- Misuse of compressed air can be dangerous - never use it to clean dust and chips from machines or from your clothing.

27- Never use compressed air for practical jokes or point the hose at another person.

28- When using compressed air, keep pressure low as possible to do the job adequately. To prevent hose from whipping about, never turn on pressure unless the hose nozzle is secured. Install shields or barriers to confine the air blast.



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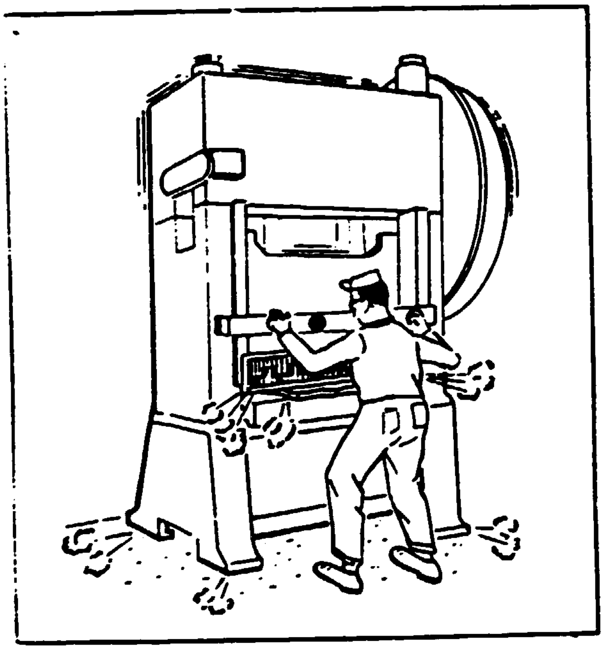


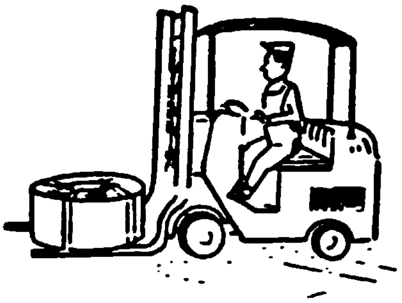
NEVER Overload Machines

29- Handle cylinders of compressed gas with extreme care. Keep protective caps in place whenever cylinders are not in use.

30- Never stand, walk or drive under any suspended load. Caution others to keep away from under the load.

31- Never permit load to be lifted on a point of a hook. A rope or chain sling should be used around the middle of the hook.

32- Use care when manually lifting heavy objects. Stand in the proper position, keep your back straight, bend your knees, and use your leg muscles for lifting. Wear safety shoes in case the object should slip and fall.



Use proper lifting equipment when handling heavy loads.

33- Never lifts objects when your body is off balance or in a twisted position.

34- Never pile or stack parts in a manner which would cause them to become unsteady. Stack parts only to a safe height.

35- Keep rags or waste away from revolving grinding wheels.

36- Never use grinding wheels which are known to have been droped, They must be discarded.

37- Never use low speed grinding wheels in high speed grinders.

38- Never attempt to brake or slow down moving parts of the machine with your hands, or with makeshift devices.

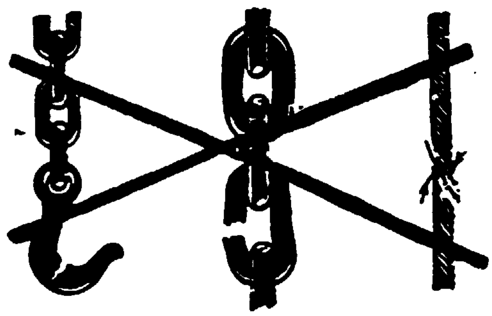
39- Use caution wh n using hydraulic jacks or gear fullers. Never stand directly behind the jack when it is energized for the purpose of pulling off (or pushing on) gears, pinions, flywheels, clutch sleeves or other machine components. Keep other people away from this area. A pulling stud, or other part, could break loose with explosive force, usually without warning.

40- Never place your hands or any part of your body under the ram or within the die are of the press.

41- Never attempt to install, adjust, or remove dies without first shutting off power to the press, waiting for the flywheel to stop and blocking the ram (or positioning it at dead bottom of stroke).

42- Never use the file as a pry bar-it is very brittle and will break. Flying particles from the broken file could cause serious eye injury.

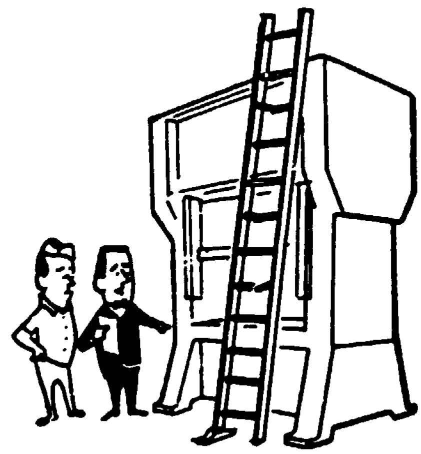
43- Make certain that all tools, jacks,cables, chains, ropes and lifting equipment are in good condition before using.



44- Never leave tools lying around on machines, ladders, scaffolding, or on the floor-they could cause accidents and they could get lost.

45- Do no work which would expose others to dangers from gases, fumes, sparks or flying particles.

46- When necessary to work above floor level, install scaffolding and a good solid work platform - or use a hydraulic elevator platform. Be sure supports and plat



Inspect ladders for defects such as cracked rungs, missing cleats, broken spreaders and general condition.

form are strong enough to carry the load. Install a temporary railing around outside perimeter of platform.

47- Make certain work platform is free of any defects, trash or slippery substances.

48- Use a fixed ladder to climb up (or down) on scaffolding. Never climb on scaffold framework.

49- Never use stools, chairs, barrels, boxes, crates or similar items as substitutes for scaffolding.

Never use barrels, boxes, crates, stools, or similar items as substitutes for scaffolding.

50- Never use ladders as a part of the scaffolding.

51- Never use metal ladders when working on or near electrical circuits.

52- Use caution when placing a ladder near aisles or doorways - install warning signs and barricades and have another worker hold it at the bottom.

53- Straight ladders, used to climb onto a work platform, should extend at least 3-1/2 feet above the platform.

54- Always face the ladder when climbing up or down, and use both hands.

Use caution when placing a ladder near aisles or doorway — install warning signs and barricades.

55- Never use a screwdriver as a punch, wedge, chisel, pinchbar or a pry.

56- Read and understand instructions in the machine service manual before operating, servicing or adjusting it.

57- Never place hands or any part of the body under the ram or within the die area without first shutting off power to the press, waiting for the flywheel to stop, and blocking the ram.

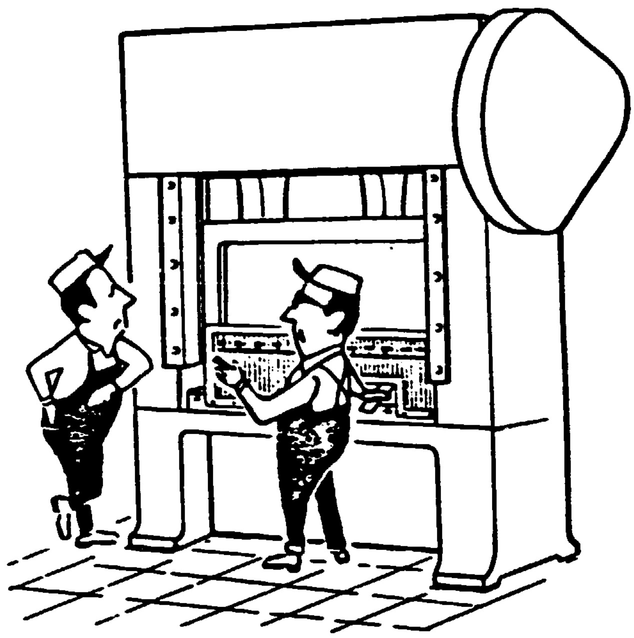
58- If you are not certain about the proper way to do a job, ask your foreman before going ahead.

59- Safety blocks should never be taken from one press and placed in another.

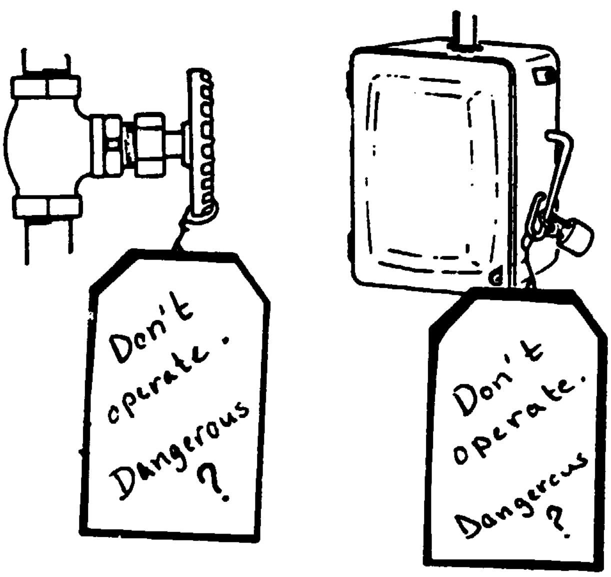
60- Never wear jewelry, neckties or loose clothing when working on or near machinery.

61- Disconnect electrical power from machine before attempting to perform maintenance or repairs - make certain that no one can turn it on again without your knowledge. Warning tag to disconnect switch.

62- Hand tools should be carried only in tool boxes or tool belts, never in pockets or under trouser belt. Be especially careful when car



NEVER talk to anyone who is engaged in the operation of a press.



SAMPLE WARNING TAGS: Attach WARNING sign to machine controls as an added safeguard when maintenance procedures are in progress.

rying, or using, sharp edged and pointed tools.

63- Eliminate protruding sharp edges and angles, especially where people must pass.

64- Make certain that all air and hydraulically actuated components are completely assembled and properly attached to the press before applying charging pressures.

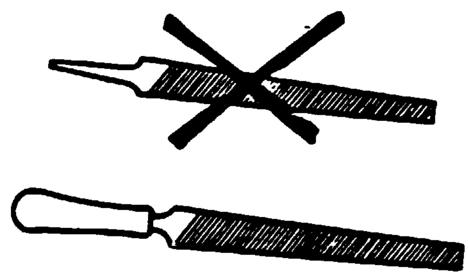
65- Use only the proper size and type of tools for the job.

66- Never use worn, dull or defective hand tools, If heads on striking tools are mushroomed, get them ground down before using.

67- If replacement parts are required, obtain new ones from the original manufacturer.

68- At times it may become necessary to work with outside contractors, riggers technicians and service personnel. Make certain that they understand your company's safety regulations and work accordingly.

69- When drilling, grinding or chipping on or near a press, take precautions to prevent metal chips from being thrown into the machine or its auxiliary equipment.



Never use a file without a handle firmly attached—the tang is pointed enough to injure the mechanic if the file should momentarily "hang up" while filing.

70- If holes are cut in floors, place barriers around the openings immediately.

71- When working with hand tools, the mechanic may sustain cuts, scrapes and abrasions. Injuries should be given first aid treatment immediately.

72- Never use pliers as a substitute for a wrench. Pliers "chew up" nuts and bolt heads and will not grip securely. They may slip when force is exerted causing the workman to lose his balance and possibly sustain injury.

73- Make certain that all tools, scaffolding and other repair equipment have been cleared away from the press before attempting to cycle it.

74- After machine repairs are completed, replace all guards, remove all tools, start the machine and check for proper operation. Never release the machine for production operation until you are certain that it is performing correctly.

75- Never leave machines with the power turned on.

76- Clean up all oil and grease spills. Leave the entire area around the press clean and orderly.

77- Never hang an ignited torch on the hose rack. When torch is not in use, it should be turned off.

78- If cylinders of compressed gas must be moved, use a cylinder dolly, if available. If cylinders must be lifted manually, use two men for the job.

79- Always keep cylinders of gas standing on end, strapped securely to keep them from falling. Make certain they are not placed near oil, grease, salt, acid, heat or flames.

Eliminate, if posible, use of flammable liquids and gases; if used, make certain they are in proper safety containers.

80- Protect oxygen cylinder controls- never permit oil or grease to come in contact with them. Oil and grease in the presence of oxygen may ignite with explosive violence.

81- Make certain there are no combustibles in the area before welding, or before using a flame for heating or cutting.

82- When welding with an electric arc-welder, never attempt to strike an arc on any cylinders of compressed gas; this practice could cause a serious fire or explosion. It is most important to keep welding electrodes, electrode holders and cables away from all cylinders.

83- Hoses from cylinders of compressed gas should never be repaired with tape. Escaping gas, such as acetylene, may start a serious fire and could cause severe burns.

84- Press pits may contain accumulations of oil and other flammable compounds. When cutting metal, or welding, near press pits, make certain that top of the pit is well covered with sheet metal to prevent sparks from falling into the pit and causing a fire. It would also be wise to keep a fire extinguisher handy.

85- Eliminate, if possible, use of flammable liquids and gases; if used, make certain they are in proper safety containers.

86- If solvents -chemicals or gases- must be used, provide positive ventilation. Keep fire fighting equipment nearby and ready for immediate use. Avoid excessive contact with skin.

87- Never use carbon tetrachloride as a solvent or for cleaning purposes.

88- Dispose of all wiping rags, paper, rubbish, empty oil and paint cans.

89- Establish your own safety guidlines according to the different jobs and machines.

MANUFACTURING MACHINERY :

Most of the SWHs require more or less the same manufacturing machinery *, some of the machines used in the mechanical workshop

* Many booklets and catalogues can and will fulfill their purpose only, if they are made available to the operator of the machine. Therefore, they should be handed over to the operating staff. The instructions are misplaced if they are put in the filing cabinet of the foreman or the works manager.

of the MED by the RSS are :

1- Power Plate Shear :

This machine (shown in Fig. 1) is used to cut sheets to produce the collector casings, the cover frames, the absorber plates, the inner hot water storage tanks and their cover casings and finally the cold water storage tanks (Reservoirs).

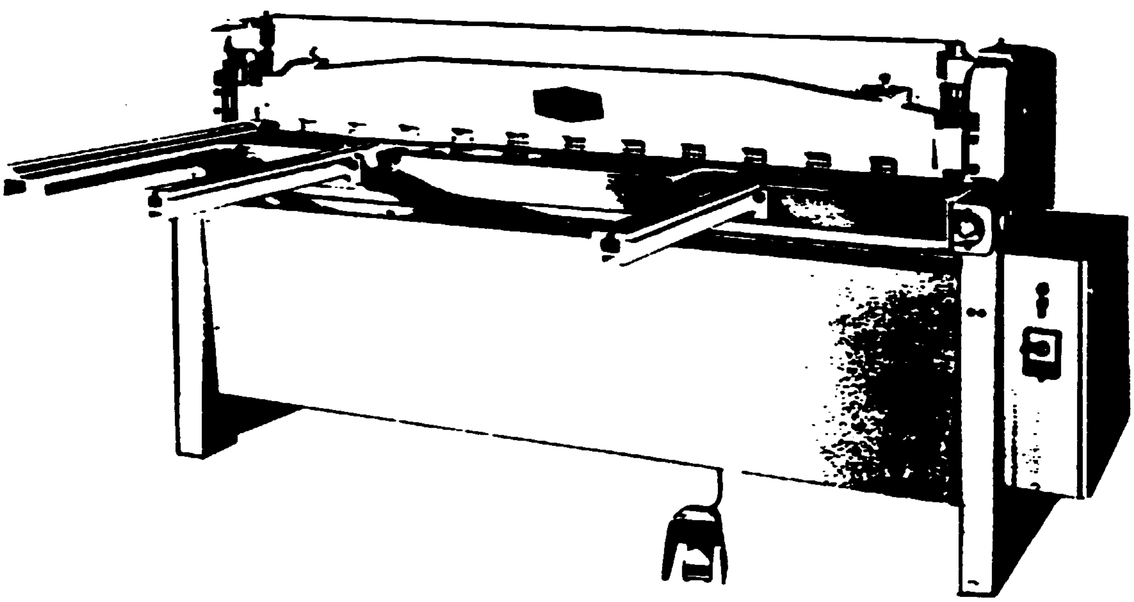


Fig. 1 : Power Plate Shear

Cutting is a press operation that may be accomplished in varity of related, but distinctly different ways . Cutting operations generally consist of blanking (cut off, parting, shearing, lancing nutching nibbling) piercing or punching (slitting, perforating, extruding) and edge-improvement methods (Trimming , shaving , fine-edge blanking).

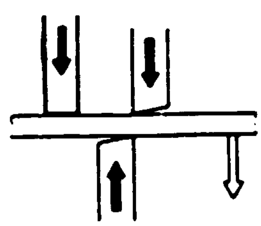


Fig. 2 : Motion of Bench Shears

2- Production Hack Saw :

This saw (shown in Fig. 3) is used to cut the riser and header pipes, the L-profiles, the flat steel bars. and all other similar profiles.

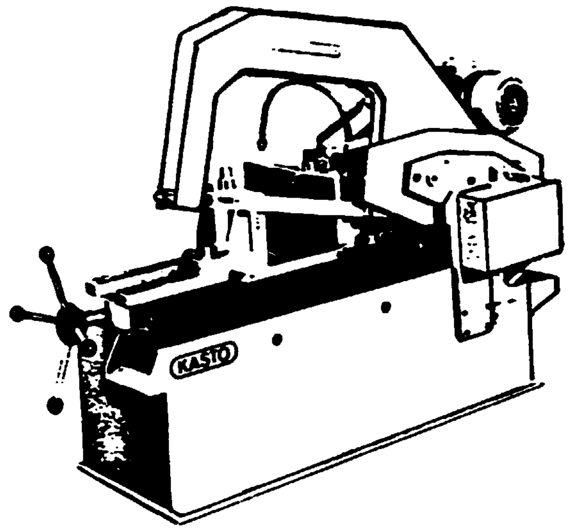


Fig. 3 : Production Hack saw

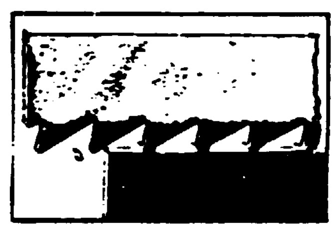


Fig. 4 : The single Point Cutting

The cutting action in power sawing process is accomplished by action of continuous series of Single-Point cutting tools as they pass over the work piece. Power saws are classified according to the kind of motion used in the cutting action. Three general types are in common use in workshops recipr-ocation saw (hack-saws) cir-cular saws and band saws. The most common and simplest is the hack saw. The sawing action takes place in only one direction with the straight saw blade lifted slightly off the stock on the return stroke.

3- Heavy Duty Drilling Machine :

This machine is used to make holes on the header pipes to insert the risers in them.

Drilling may be defined as a machining process by which a cylindrical hole is made on a fixed workpiece. The cutting action is generated by rotating cutting tool. Speed and feed are important cutting factors. Speed is a term that describes the cutting speed of the rotating cutting tool as it moves past the cutting edge of the workpiece. Cutting feed is the rate of advance of the cutting tool per revolution.

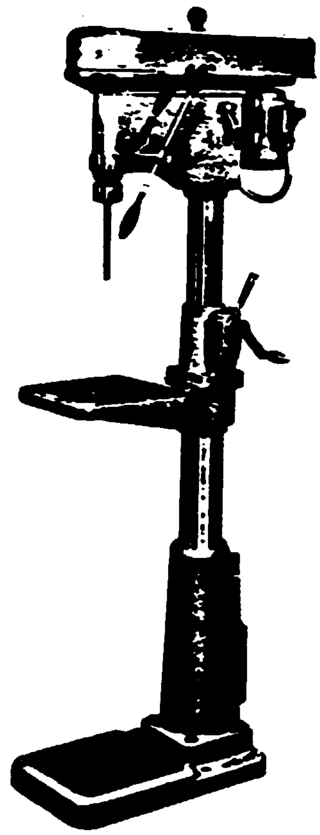


Fig.5:Drilling Machine

Speeds and feeds that are too low consume excessive time, which usually result in increase in working piece costs. However, optimum speeds and feeds are not necessarily the maximum that the workpiece and machine will tolerate. Excessively high speeds and feeds result in shorter tool life and therefore in increase tool cost.

The cutting tools become dull after long time of normal use or after short time of missuse. These cutting tools must be sharpened correctly otherwise the process of cutting is partly or totally converted to pressing which means overload for the machine, longer drilling time and often burning of drills. Fig. 6 shows correctly sharpened drill.

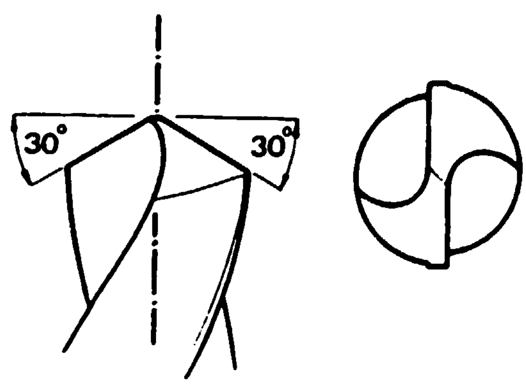


Fig.6:Point angle and cutting edges correctly sharpend

Different cutting tools are used for different materials. See instructions or ask your foreman for correct drills to be used for specific drilling jobs.

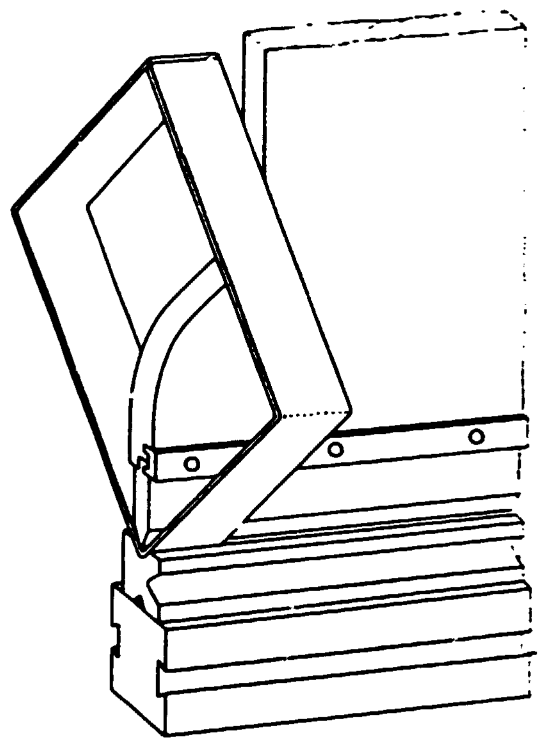
4- <u>Hydraulic Press Break</u>:

This machine is used generally for forming and punching purposes. The forming operation is giving a shape to material without any cutting action. These operations in SWH manufacturing are : Making absorber grooves, bending the collector casings and folding the storage tank sides for seaming and welding.

The punching works such as punching holes on sheets for storage tanks, collector casings and fitted fin absorber plates. As well as punching out casing corners.

The sheets used for SWHs can be black steel, polished steel, stainless steel, galvanized steel, cooper, Aluminum,or brass.

The press break machine has a rigid lower beam and movable upper beam called the ram.



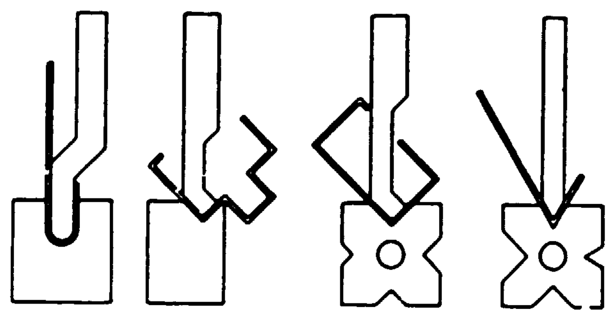


Fig. 7 : Press operation for different dies

A die is fixed on the lower beam. This die may have all kinds of shapes to form material. The punch, the upper part, of the die is mounted on the ram.

5- Universal Steel Workers And Punching Machine :

This machine can do the work of a hacksaw and of a hydraulic press break. It can cut many profiles instead of using hack-saw and can punch different holes according to the dies available as a press break.

6- Manual Folding Machine :

Is manually operated and used often to fold sheets for prototypes. The main parts of it are the upper and lower beam and the bending beam. Fig. 8 shows :

1- The folding machine
2- Upper beam
3- Interchangeable guide beam
4- Workpiece
5- Lower beam
6- Bending beam

It is necessary that the material to be bent is not thicker than it is specified for particular folder.

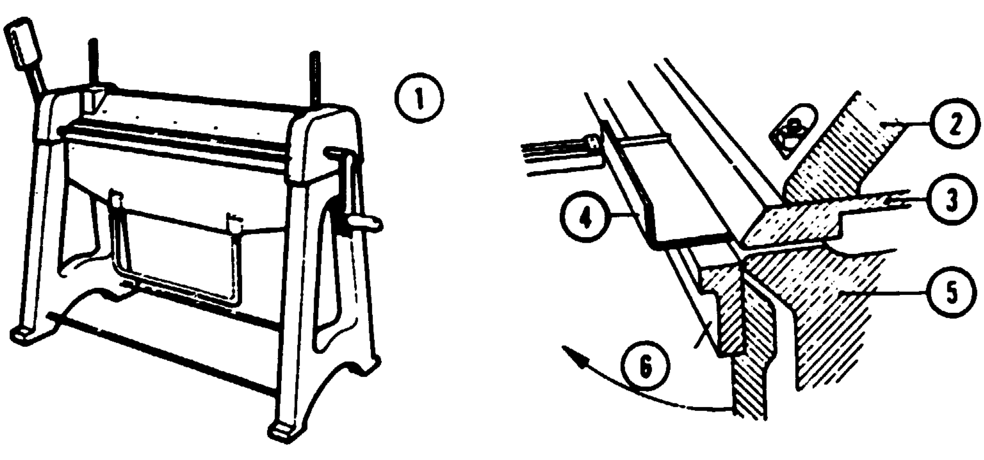


Fig. 8 : The folding Machine

7- <u>Tripoles Rolling Machine :</u>

This machine, shown if Fig. 9, is used to roll sheets for the hot water storage tank and its cover casing as well as for other purposes. Although there are three and four roll machines, the three roll machines are in common. see Fig 10.

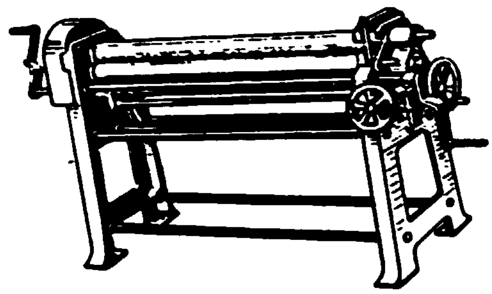


Fig. 9 : Manual rolling machine

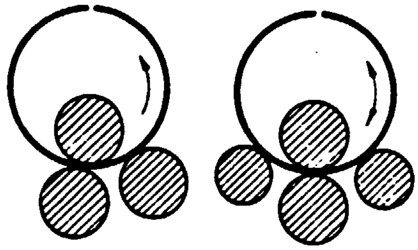


Fig. 10 : Three roll and four roll operation

Before the sheet is placed between the rolls a distance(X) shown in Fig. 11 should be round by hammering the sheet on one of the bottom rolls.

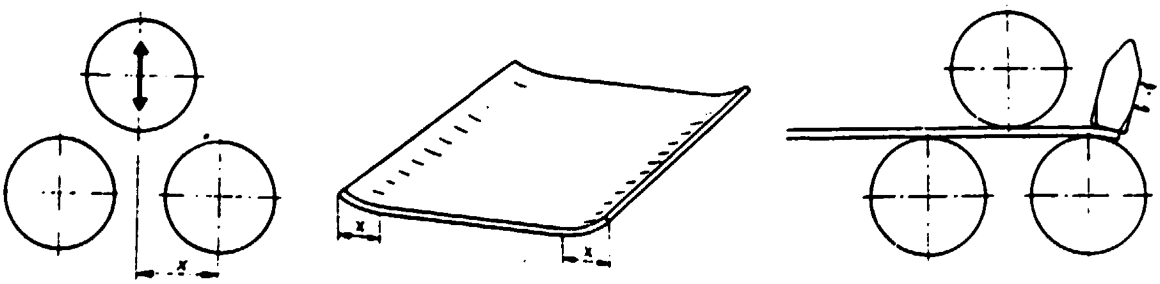


Fig.11 : The distance needs to be hammered and the hammering on the lower roll

The rolling should be done in steps as shown in Fig. 12. For each run through the rollers the top roll is lowered a further distance.

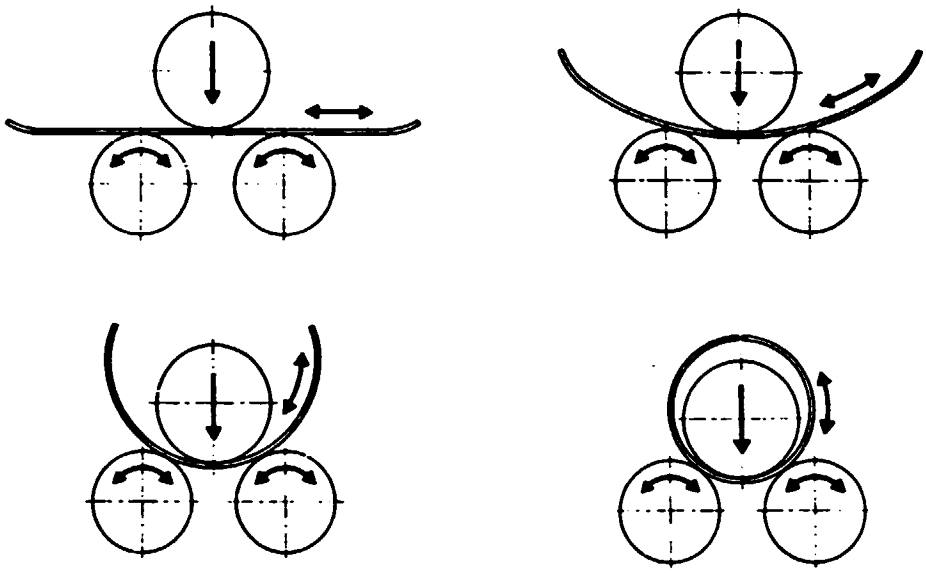


Fig. 12 : The rolling steps and the lowered top roll

8- <u>Ring And Circle Cutting Machine</u> :

The machine is used to cut circular sheets to be used for hot water storage tanks and their cover casings. These machines can be ,as shown in Fig. 13, either manual or power operated as shown in Fig 14.

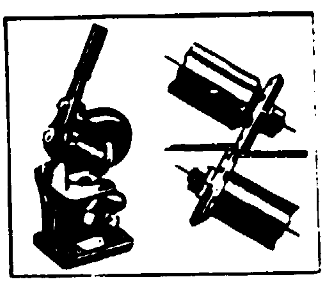
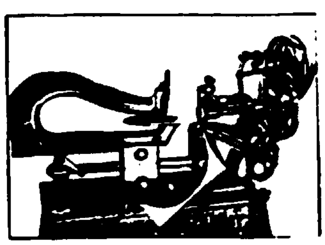
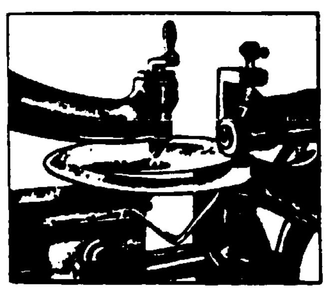




Fig. 13 : manual circular cutter

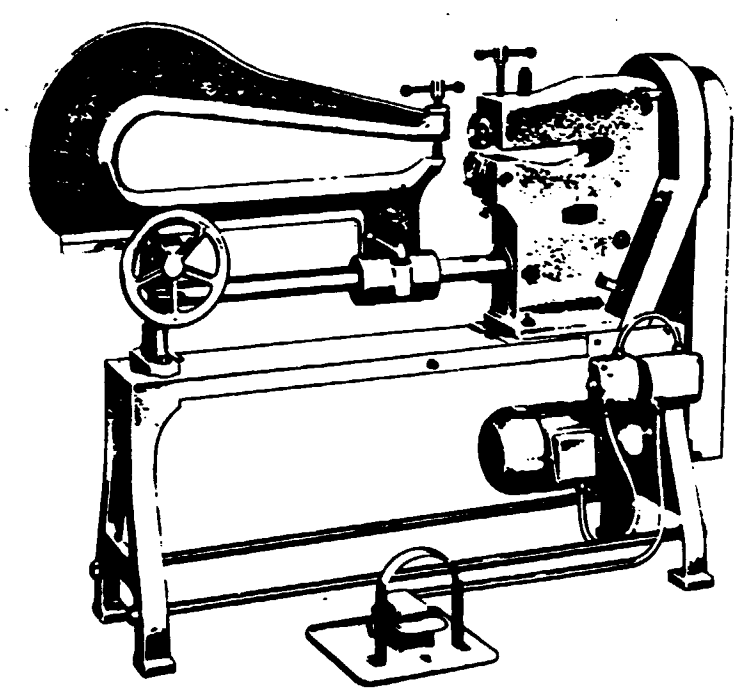


Fig. 14 : Power operated circular cutter

The diameter of circular sheets are adjustable from the minimum to the maximum. The minimum and maximum diameter differ from one machine to another according to the models of the machines. The right machine must be chosen for the specific jobs.

9- Hydraulic Pipe Bending Machine :

This machine is used for SWH installation and manufacturing of some special models only. Pipe bending (hand-operated or hydraulic bender shown in Fig. 14) normally results a radius of about 3D (3X the outer diameter of the pipe). If bending radius is smaller than the pipe it should be filled with sand.

Care must be taken that pipes with seam are only bent with the seam on the neutral axis.

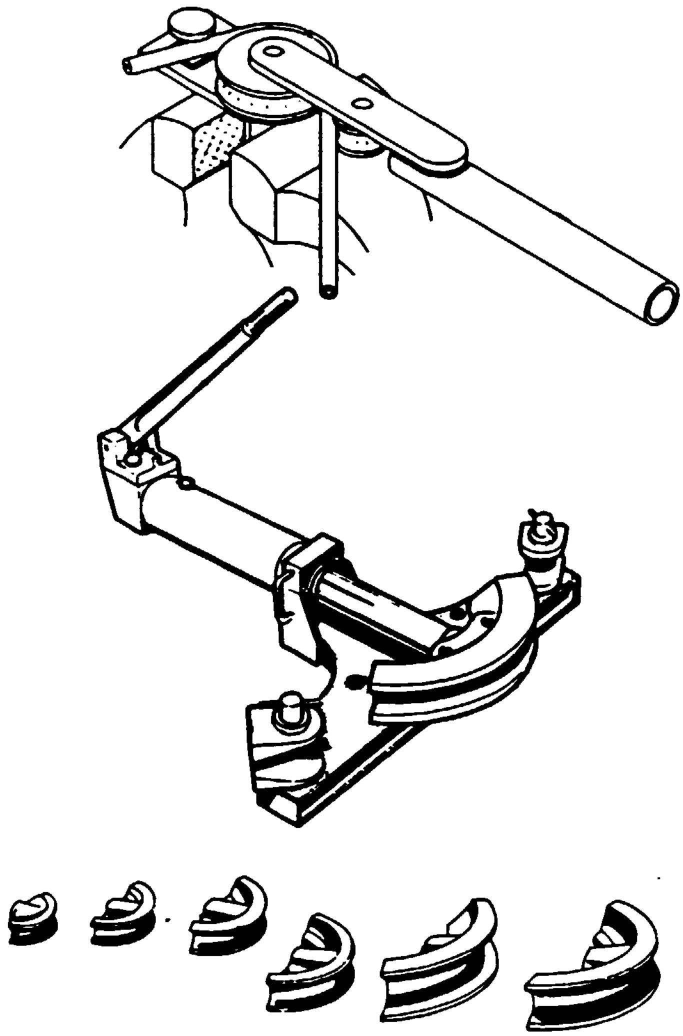


Fig. 14 : Hand-operated and hydraulic pipe benders with some clamping dies

10- Pipe Thread Maker :

Is used to make threads for the pipes used by SWHs and those used for installation. There is a wide range of thread makers in the market.

Workshops use normally power operated once. Those power operated thread makers are equipped with pipe cutting tool, pipe sharp end removing device and lubricating fluid.

11- Mechanical Under Cut Saw :

Is used to cut light metal profiles such as aluminum for collectors with aluminum sides. The profiles can be cut in different angles, since the vice mounted to the machine is turnable.

12- Arc Welding Machine :

Is used generally to do all the welding works, such as welding the headers and the risers, welding of inner storage tanks, welding of some fittings to the storage tanks, welding of the collector stands and welding the absorber plates to the absorber risers.

Welding is a joining process entirely and behavior of metals, where as mechanical joints depend on the engineering properties (strength, ductility ... etc.). On arc welding the heat, necessary to melt the metal is produced by and electric arc.

The electrode is a metal bar with -mostly- a coating. It conducts the current and melts down the joint, the coating melts with the electrode and forms the slag, where thin electrodes are used for thin metals. The data on electrode box give -normally- the use of the electrode, such as amperage, type of weld, polarity. These instructions should be followed carefully.

After the arc welding is finished, the slag must be shipped away with a chip hammer and cleaned with steel wire branch.

13- Spot Welding Machine :

Is used by some SWH manufacturers to spot weld risers to absorber plates, to spot weld collector casings and to spot weld storage covers.

14- Grinding wheels :

They are used to remove the sharp ends of unthreaded riser pipes, of the flat and profiled metal workpieces ... etc.

Grinding is a surface forming operation by the use of rotating abrasive wheel composed of many small and hard bonded abrasive grains. Each individual and irregularly shaped grain acts a cutting tool.

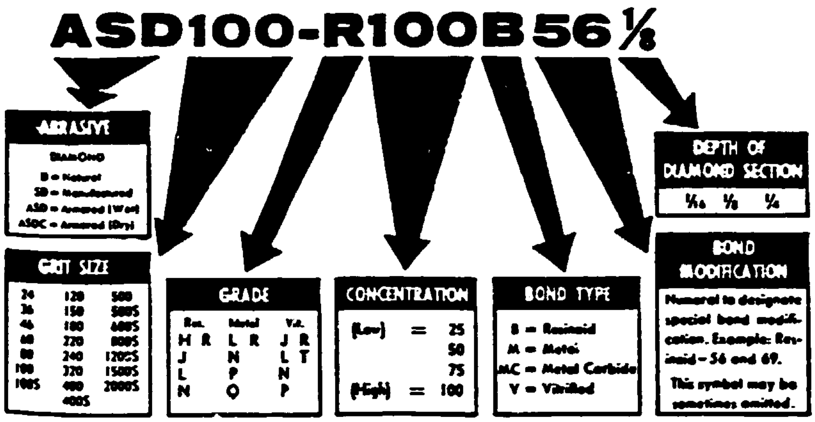


Fig. 15 : Grinding wheel information

Wheel manufacturers have adopted a standard marking system for identifying important grinding wheel information. This data is printed on each grinding wheel as and aid in selecting the best wheel for particular grinding job.

15- Tools:

Hand drills, riveting tools, screwdrivers, silicon tube guns, pipe wrenches, pipe vices ... etc. are used to assemble collectors, storage tanks and others, so as to install the solar water heater systems.

PRODUCTION OF COLLECTOR

Absorber :

Many sheets are used to form the absorber plates such as blacksteel, copper and aluminum. Rubber and plastic absorbers are extruded. The latter absorbers need headers only, since the absorbers have the riser pipings in them.

The absorber sheets are normally formed according to the piping net used. The connection between the absorber plate and water piping can be made in different ways, where better connections is aimed.The absorbers convert solar energy into thermal energy.

The pipes used for the absorber are also different, they could be steel, copper, plastic ... etc. where steel pipes are in common.

The absorbers are sprayed with special black-mat paints or selective surfaced.

Absorber casing :

Galvanized steel, stainless steel and plastic sheets are used to form the casing. Wooden boxes are not recommended since they don't resist weather conditions. Plastic sheets must be UV stabilized. The dimensions of the casings differ from model to another.

The casings act as green houses and should insulate the heat as much as possible. Therefore the absorber is insulated from the rear and from the sides by using any insulation material (fiber glass) and the gap between the absorber and glass cover should be minimum 20 mm.

Glass cover

Normal window glass is used generally to cover the collector. Some manufacturers use double glazing where others use tempered glass or low iron glass.

Assembling the collector

Assemblings are made in different ways. However some caution must be taken :

1- The cover glass should be cleaned.

2- The paint must be dry.

3- The casing must be water proof and air tight.

Production of hot water storage tank

The storage tanks are usually made in cylindrical shape out of galvanized steel sheet with different capacities. However they can be made in other shapes and out of other materials such as concrete or fiber glass.

The storage tank designer must consider :

1- The low heat loss coefficient.

2- The low pressure drop for different fluid flow rates (thermosyphon type).

3- The high heat transfer coefficient (heat exchanger type).

4- The high effective thermal capacity (in J/°C). The effective thermal capacity of the store is the total thermal capacity of the store, reduced by thermal capacity of any dead zones in the tank. For example large volumes of water below the heat exchanger.

The insulation thickness must be financially justified to the amount of energy saved.

Production of the stand

The stand can be manufactured out of L-profiles or steel pipes. The stands vary in design to be mounted on floors, flat roofs, attics or attached to the wall.

For whatever purpose the stand is to be made, make sure that the storage tank is placed higher than the collectors for better thermosyphon effect.

The storage tank can be placed vertically or horizontally according to the design.

The stand must be fixed to the floor in some stormy areas. These areas should be avoided if possible.

The stands should be lifted up in some location to avoid shading.

MANUFACTURING OF A 50L SOLAR WATER HEATING SYSTEM

AIDMAR BEANO

ABSTRACT

This paper describes the manufacturing of a solar water heater with a 50L storage capacity and 1 m^2 collector area. It includes technical drawings which illustrate the manufacturing steps of each part of the system. The manufacturing steps can be followed for later manufacturing of such system.

This system was designed at the Royal Scientific Society (RSS) as an "install it yourself" unit.

INTRODUCTION

This small SWH unit was designed originally to serve singles and small families living in rented apartments, and may move from one apartment to another often.

This 50L-system is also designed to fit in the car trunk and doesn't require much know-how in pluming to install it since the whole system needs only two $^1/_2$" unions to mount it together.

The machinery used to produce this system are discussed in the previous paper entitled "Manufacturing of solar water heaters".

1. PRODUCTION OF THE COLLECTOR

1.1 Production of the absorber

Nine 0.9 mm black steel sheets are cut with the dimensions of 120 mm x 880 mm. Seven 35 mm x 10 mm holes are punched in every sheet. These sheets are then alternatively grooved along their longer axis by using a 22 mm half rounded formers made especially for this purpose. Nine 1/2" galvanized pipes in length of 930 mm are inserted in the grooves of each sheet, after each fin has been cleaned from oil and dirt. The 1/2" pipes are extended about 25 mm from each side of the fin. Fig. 1 shows the process of a fin production.

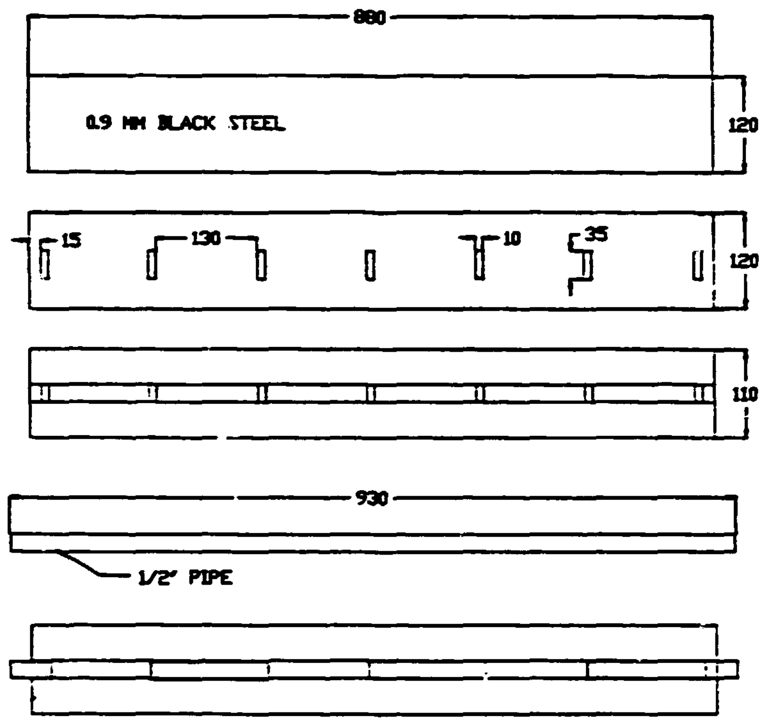


Fig. 1: The process of a fin production

The absorber consists of the above mentioned nine fins, the upper header, the lower header, the outlet pipe and the inlet pipe, as shown in Fig. 3.

The upper header, the 1" galvanized pipe, has the length of 920 mm (see Fig. 2). Nine O 23 mm holes are made in the header with a distance of 100 mm between each two centers to weld the risers to it. In the other side of the nine holes of the header pipe one O 23 mm hole is made in a distance of 22 mm from one end of the header, where the collector outlet pipe will be welded.

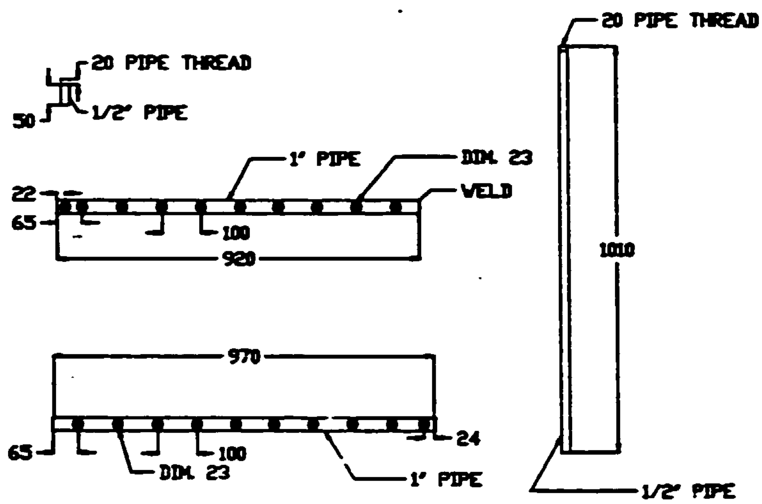


Fig. 2 : The pipes used to produce the absorber

The outlet 1/2" galvanized pipe is cut in length of 70 mm (see Fig. 2) and threaded from one side only where the other side will be welded to the upper header.

The lower header, the 1" galvanized pipe, has the length of 970 mm . Nine 23 mm holes are made on this pipe with a distance of 100 mm between each two centers to weld the risers to it. A tenth O 23 mm hole is also made, where the collector inlet pipe will be welded, in a distance of 24 mm from one end of the header pipe and in the same direction of the nine holes (see Fig. 2).

The $^1/_2$" galvanized collector inlet pipe is cut in length of 1010 mm (see Fig. 2) and threaded from one side only where it will be to be welded from its second side to the above mentioned tenth hole of the lower header.

The header pipes are fixed parallel on a special made table in a distance of 943 mm between their centers. The $^1/_2$" riser pipes with the fins are inserted into the headers, so that the distance between the fins and the headers remains 15 mm from each side. The $^1/_2$" pipes are then welded accordingly to the header.

The complete absorber is sprayed from the rear with silver paint to reduce heat losses, and to protect it from corrosion. The front side of the absorber, imposed to solar radiation, is sprayed with a special black mat paint to increase its absorbtivity.

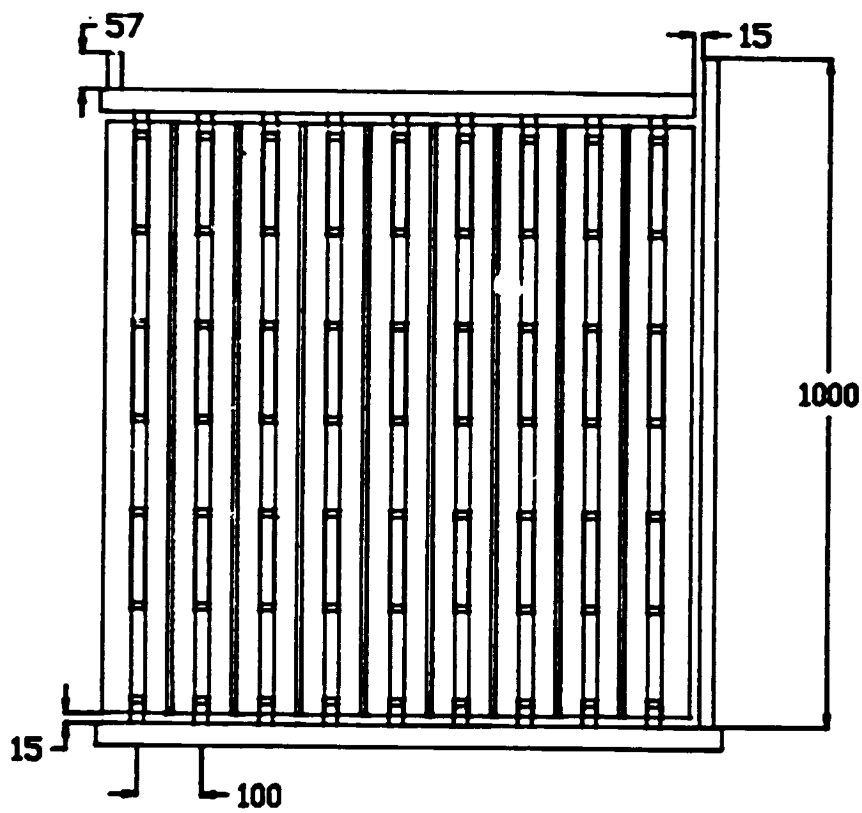


Fig. 3 : The complete absorber

1.2 Production of the collector casing

A 0.7 mm galvanized steel sheet is used to form the casing, at dimensions of 1250 x 1250 mm. The corners of this sheet are punched out, as shown in Fig. 4. Two holes with diameter of 30 mm are made for the inlet and outlet pipes of the absorber . In a distance of 7 mm from the edges, the sheet sides are bent in right angles to give the casing rigidity. The sides are bent again in a distance of 16 mm in right angles. These 16 mm edges are made to hold the collector cover glass.

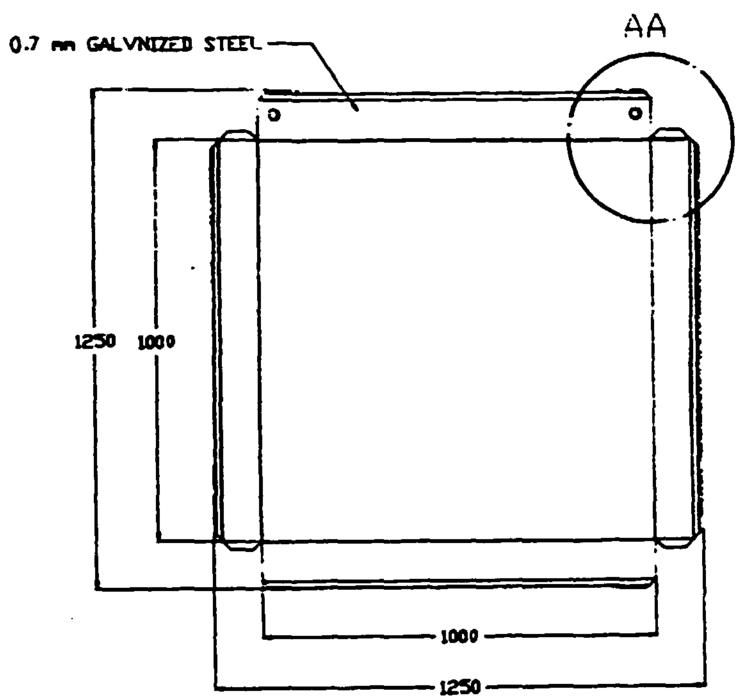


Fig. 4 : A collector casing

The 22 mm corner sides are bent in right angles, these sides are used to assemble the collector casing sides by using screws or rivets.

Finally the 100 mm sides are bent in right angles. These 100 mm sides are actually the collector casing sides and doesn't represent collector height, since the total height of the collector includes of thickness of the rubber seal, the glass cover and the cover frame, in addition to the collector casing sides as shown in Fig. 5.

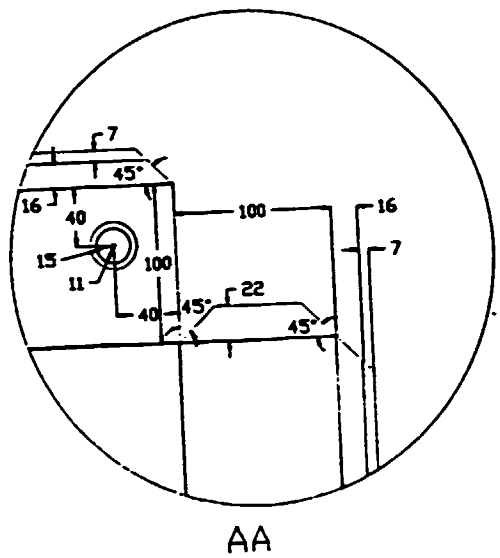


Fig. 5 : Detailed corner of a collector casing

Fig. 6 shows the collector casing after it has been bent and assembled.

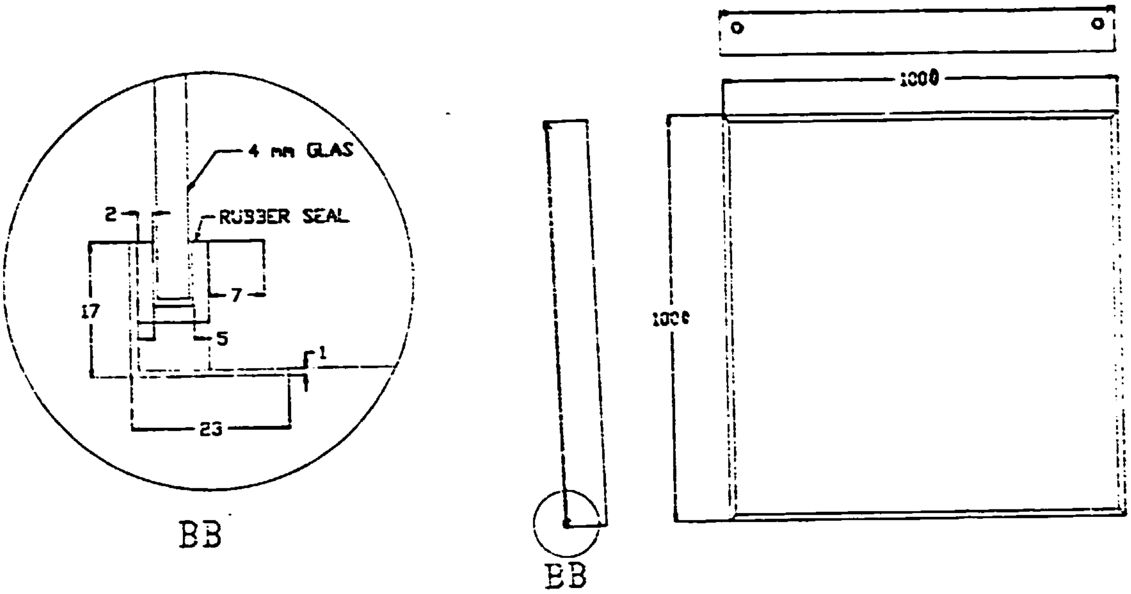


Fig. 6 : The collector casing after it has been bent

1.3 Cover glass

The low iron cover glass (normal window glass will do) is purchased in dimensions of 980 mm x 980 mm x 4 mm from the local market.

1.4 Production of cover frame

A 1.0 mm galvanized steel sheet is used to form the L-profile frame shown in Fig. 5. Each collector needs four sheets 1005 mm x 40 mm. These sheets are bent at right angles using the hydraulic press to form the L 23 x 17 x 1 profiles. Their 17 mm side-ends are cut at 45° to avoid overlapping (see Fig. 6).

1.5 Assembling the collector

The process of assembling can be carried out on a working table. The insulating material (such as fiber glass or rock wool in dimensions of 1000 mm x 1000 mm x 50 mm) is layed into the casing under the absorber to insulate the absorber backside (note that the paint should be dry and no outgassing may occur). The sides of casing are screwed or riveted together. The glass cover is cleaned and framed with a rubber seal, which can be purchased from the local market, and then layed on the collector casing. The cover frame tightens the glass cover to the casing, so that no dust or rain water may drain into the collector. The inlet and outlet 1/2" pipes are separated by rubber material to avoid heat transfer from the absorber to the casing and then to the environment.

2. PRODUCTION OF THE HOT WATER STORAGE TANK

The hot water storage tank consists of the inner hot water tank, the insulating material and the outer casing.

2.1 Production of the inner hot water tank

A 2.0 mm galvanized steel sheet, shown in Fig. 7, is cut in length of 1000 mm and width of 660 mm on the Plate Shear. One 21 mm hole is made at one corner in distance of 150 mm from the longer side and 50 mm from the other side. This sheet is then curved on the Tripoles Rounding Machine, and then its shorter sides are welded together.

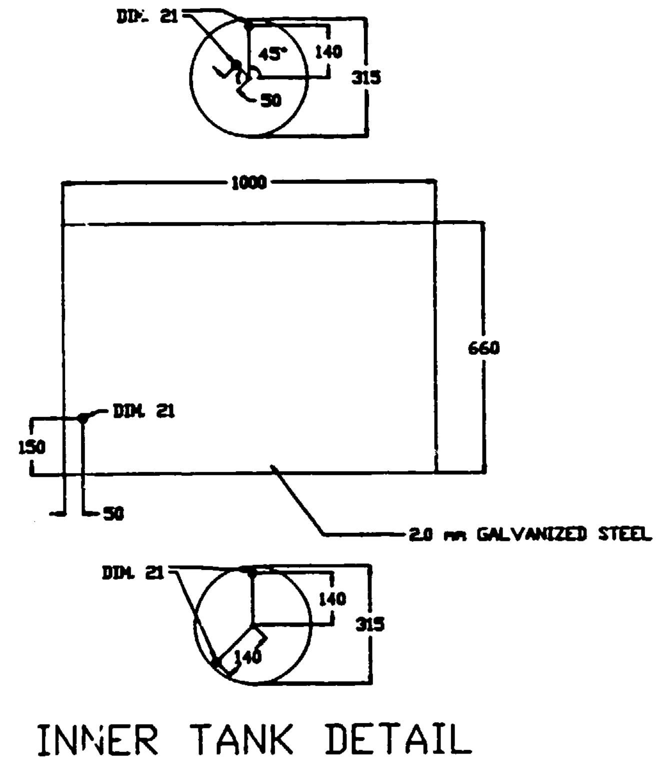


Fig. 7 : The sheets used to produce the inner storage tank

Two circles in diameter of 315 mm are cut out from a 2.0 mm galvanized sheets to be used as storage tank sides. Two O 21 mm holes are made on each side. On the left side one hole is made in a distance of 140 mm from the center in 90° angle from the X-axis assuming the center of circle as the origin of x, y. The other hole is made in a distance of 50 mm in 135° angle from the X-axis. On the right side, one hole is made in a distance of 140 mm in 90° angle. The other hole is made in a distance of 140 mm in 225° angle from the X-axis.

These two sides are welded to the previous curved and welded cylinder to form the inner hot water storage tank. 1/2" sockets are then welded to the holes, and the hot water storage tank is then tested hydrostaticly at a minimum pressure of 3 bars.

2.2 Production of the hot water storage casing

A 0.7 mm galvanized steel sheet is used for the outer storage tank. This sheet is cut in dimensions of 1300 mm x 750 mm as shown in Fig. 8.

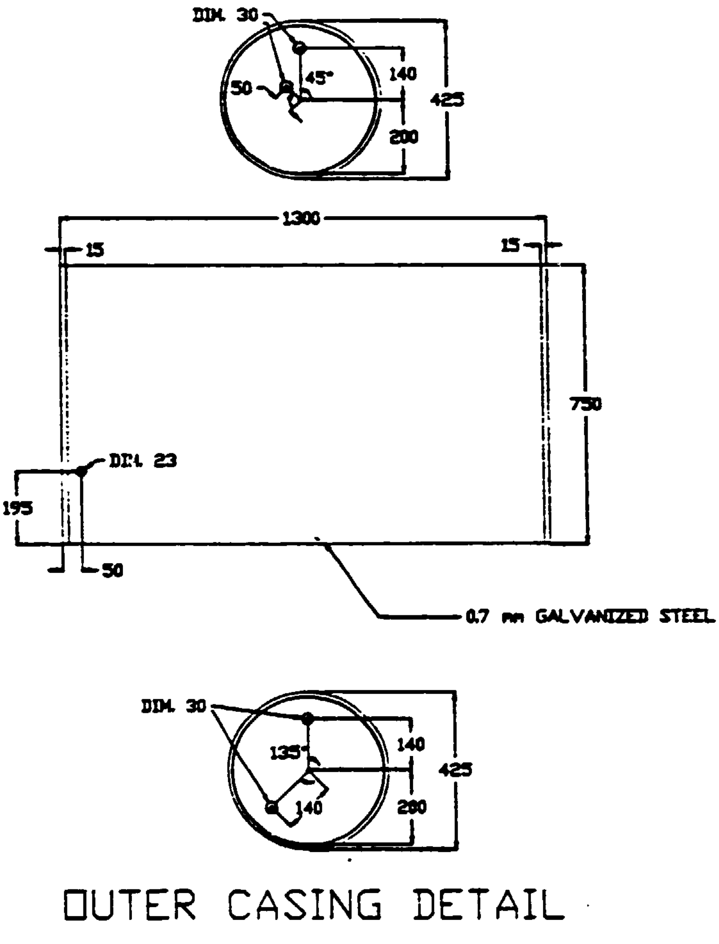


Fig. 8 : The sheets used for cover casing

A O 23 mm hole is made on this sheet in a distance of 50 mm frcm the shorter side and 195 mm from the longer side. This is also curved cn the Tripoles Rounding Machine. The shorter sides are bent in 180° degree in a distance of 15 mm in opposite directions for seaming purpose. After seaming them, they are hooked together, maleted tight and welded in few points or riveted.

Two circles in dianeter of 425 mm are cut out of a 0.7 mm sheets to be used as outer storage cover sides. Each side is bent at right angle on its edge to from a 12.5 mm bent flange, so the cylinder fits in to the both flanges.

Two holes of 30 mm diameter in each side are made according to the holes of the inner tank sides.

2.3 Assembling the hot water storage tank

The inner hot water tank is put inside the outer cover and insulating material (such as fiber glass or rock wool) is used to fill the gap between the two tanks. Finally the cover sides are riveted or screwed to the cover to complete assembling the hot water storage tank.

3. PRODUCTION OF THE STAND

The stand is made out of the following :

1. Two steel L 30 x 3 in length of 1045 mm.
2. Six steel L 30 x 3 in length of 750 mm.
3. Two steel L 30 x 3 in length of 350 mm.
4. Two flat steel 30 x 3 in length of 830 mm.
5. Two flat steel 30 x 3 in length of 430 mm.
6. Four flat steel 30 x 3 in length of 170 mm.

The stand, shown in Fig. 9, holds the hot water storage tank and the collector. The latter is layed on a frame, the front frame, which is made out of L-profiles. Two L 30 x 3 in length of 1045 mm and two L 30 x 3 in length of 750 mm are used to from a rectangle frame. One of the 750 mm L-profiles, the lower one, is welded in a distance of 25 mm from the lower ends of the 1045 mm L-profiles. This profile provides an end stop for the collector and lifts it up from the rain water. The other 750 mm L-profile is welded to the other ends of the 1045 mm L-profiles in such a way to lay this frame on the rest of the stand with 45° angle from the horizont. The way, the profiles are welded together is shown in Fig. 9.

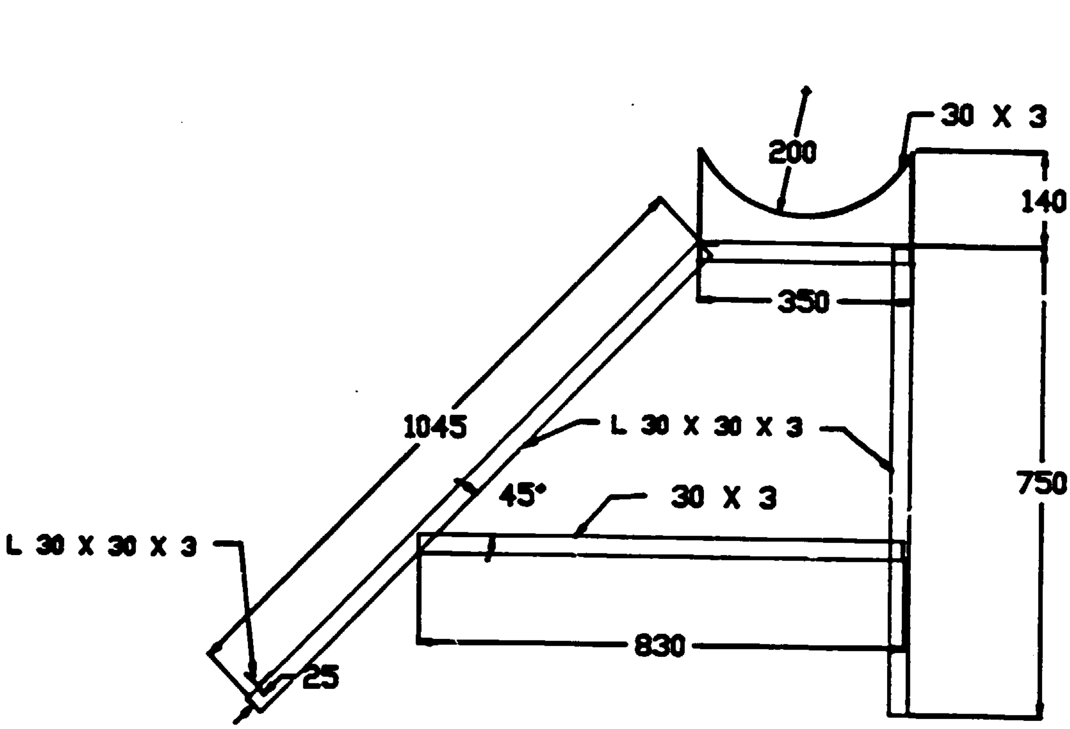


Fig. 9 : The stand of the system

The rear frame is made out of L-profiles in length of 750 mm. The shape, shown in Fig. 10, of this frame is produced by spacing the lower L-profile 250 mm from the bottom. The front and rear frames are welded together using two 350 mm L-profiles to be welded to the upper sides of the frames, and two 830 mm flat steel pieces welded to the lower sides of the two frames with the spacing shown in Fig. 10.

Each of the two hot water storage tank-holders is made out of two 170 mm and one 430 mm flat steel 30 mm x 3 mm pieces. The latter is rounded with radius of 200 mm, where the other two are bent in a distance of 30 mm in right angle. Then welded to the L-profiles as shown in Fig. 9 and Fig. 10.

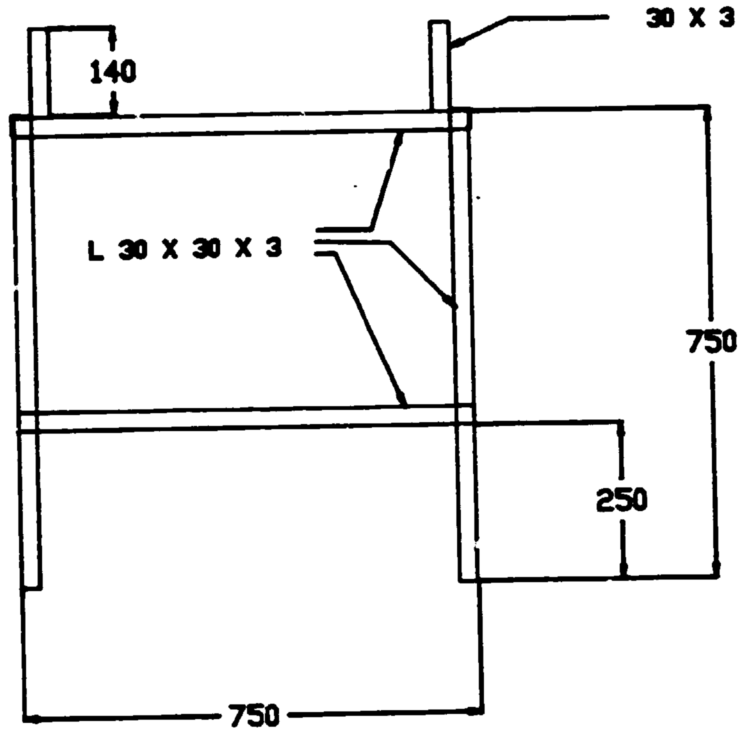


Fig. 10 : The stand from the back side

The stand is then painted first with primer paint then with any other oily paint of favorite colour.

Blue prints are included with the workshop proceeding.

INSTALLATION OF SOLAR WATER HEATING SYSTEMS

ENG. SULAIMAN BATARSEH

1. ABSTRACT

This paper presents in brief the proper installation guidelines for solar water heating systems (thermosiphon systems) to insure that such systems operate properly with good performace during their lifetime, and to increase the durability of these systems.

2. INTRODUCTION

In the last few years, thousands of solar water heating systems have been install all over Jordan. Solar water heaters are produced by many manufactures in the country. Most of the installed system are thermosiphon, while few of them are forced circulation systems. Many systems failed to perform properly due to poor installation practices. The correct installation is as important as the design and manufacturing of such systems. Some ideas concerning system installation will be described in this paper so as to reach good performance of such systems and to increase their lifetime, which leads to the economic feasibility of these systems.

3. INSTALLATION PROCEDURE

Thermosiphon systems are the oldest type of solar water heaters system (See figure 1). The storage tank is recommended to be positioned at least 15 cm above the upper end

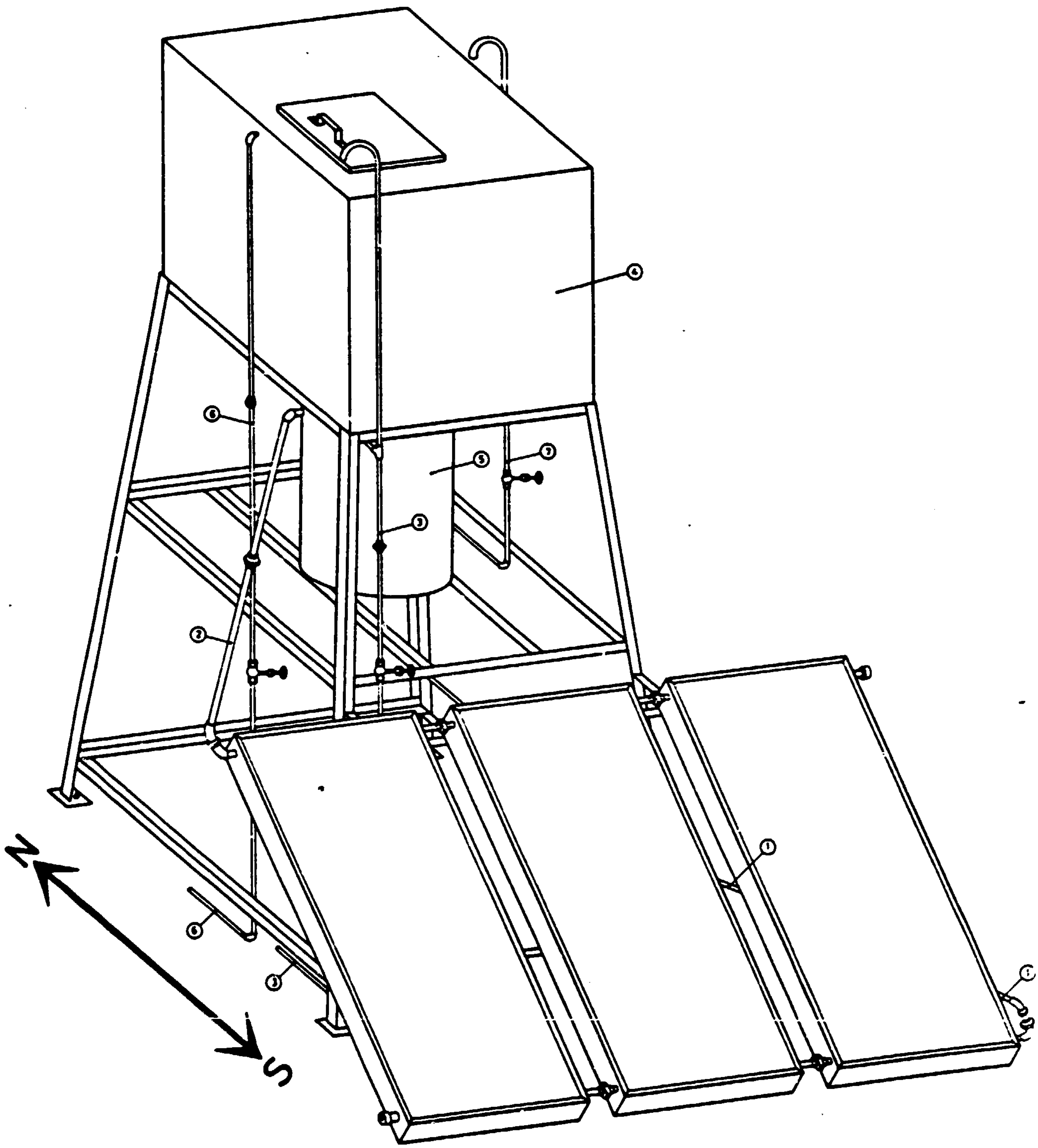


Fig. 1: Thermosiphon System Design.

of the collector array, and the heated water in the collectors flows up to the upper third of the storage tank by natural convection. Hot water is drawn off the top of the tank. Cold water is fed into the bottom of the tank and then descends to the bottom of the collector array to be heated. Thermosiphon systems are often impractical in freezing climates. However, thermosiphon systems are simple and relatively inexpensive and would be ideal in warmer climates or for summer-time use.

3.1 System Siting

The solar water heater should be placed, where it will receive the maximum amount of solar radiation available during the day. Usually a roof mounting is suitalble , when no shading from other buildings or trees accur especially during sunshine hours in middle of the day (between 9.00 a.m. and 3.00 p.m.) and should be as close as possible to the hot water users.

3.2 Collector Orientation

For optimum performance the solar collectors should be installed to face the equatoor (True South in the Nothern Hemisphere, True North in the Southern Hemisphern) to catch as much of the solar daily radiation as possible. However, variations at up to 10° east or west from True Orientation will have little effect on performance, if the system is running properly. It is not worth the added expense to build a special mounting base to face collectors true orientation if the roof is pointed within + 10° limits.

A faster way to determine a local north - south line is as follows:

- Insert a stake vertically in a horizontal surface.
- The shadow of the stake cast by solar noon will be on the true north - south line. Solar noon is exactly haflway between sunrise and sunset on a given day. Most local weatther news gives the exact times of sunrise and sunset each day.

Although performance will not be substantially affected, take local weather conditions into consideration when deciding on collector orientation. Although orienting the collectors toward the east will start the system earlier in the morning, while orientation slightly to the west can increase system performance because ambient temperatures are usually higher in the afternoon. As a result, collectors will lose less heat and operate more efficiently. If early morning fogs are common in your area, angle the collectors slightly toward the west.

3.3 Collector Tilt

The tilt angle of the surface of the collector is an important factor in system performance. Ideally, collectors should be as nearly perpendicular to the solar radiation as possible. For solar water heater system a tilt equal to the local latitude usually is considered the optimum for all over the year. The tilt angle of the surface of the collector should be the latitude + 10° for winter time, and lat titude - 10° for summertime utilization (see fig. 2).

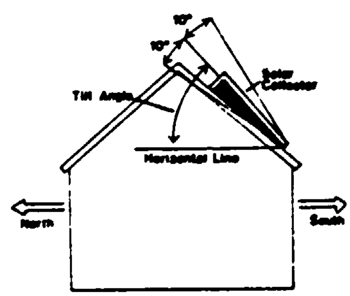


Figure 2: Collector Tilt.

3.4 Collector Shading

No more than 5 % of the collector area should be shaded between 9:00 a.m. and 3:00 p.m. Standard Time when greatest solar potential occurs. One of the major sources of shading is trees, so the home owner should be aware of the effect of future growth. Chimneys, other buildings, new construction, and even fences may shade the collector array, especially in the winter when sun angles are low and shadows are long.

3.5 Other Factors to be Considered

3.5.1 Ability of the roof to resist load

The ability of the roof to resist the solar water heater - load must be taken into consideration before installing the system. The load of normal domestic solar water heater varies from 1 to 2 tons.

3.5.2 Wind power

According to the local weather conditions, the mounting structure should be built to withstand winds. Flat-plate collectors mounted flush with the roof surface should be constructed to withstand the same wind power.

3.5.3 Snow loads

Collectors mounted on a roof should be designed to support the snow loads that occur on the roof area they cover. The collector array may be tilted 5° to 10° greater than the latitude to expedite snow sliding, with only a minimum loss in efficiency.

The roof structure should be free of objects that could impede snow sliding and the collectors should be raised high enough to prevent snow build-up over them.

4. INSTALLATION

There are many ways to install solar water heater in buildings. Some ways are good, while other are less. The experience gained from installing solar water heater systems manufactured at the Royal Scientific Society is briefly described as follows:

- First the roof condition are checked and the suitable place to install the solar water heater at the closest point to user is found.

- The stand and the cold water supply tank are fixed on the right place taking in consideration the orientation and the tilt angle (figure 3).

- The hot water storage tank is placed on the stand and connected with the first collector (figure 4).

- The other collectors are connected together by using unions and the last collector is connected with the bottom of the hot water storage tank, an inclination to hot water flow direction is established, to allow the air to exist from the collectors.

- The water supply line is connected with the cold water supply tank, and the cold water supply tank with the hot water storage, and finally connecting the storage with the hot water using points (figure 5).

- The hot water line going to user must be ventilated to eliminate air blockage.

- The system is filled with water to check if leak points exist.

- After that, all warm lines must be insulated.

- It should be noted here that all the piping must be as short as possible with minimum fittings to insure maximum thermosiphon flow.

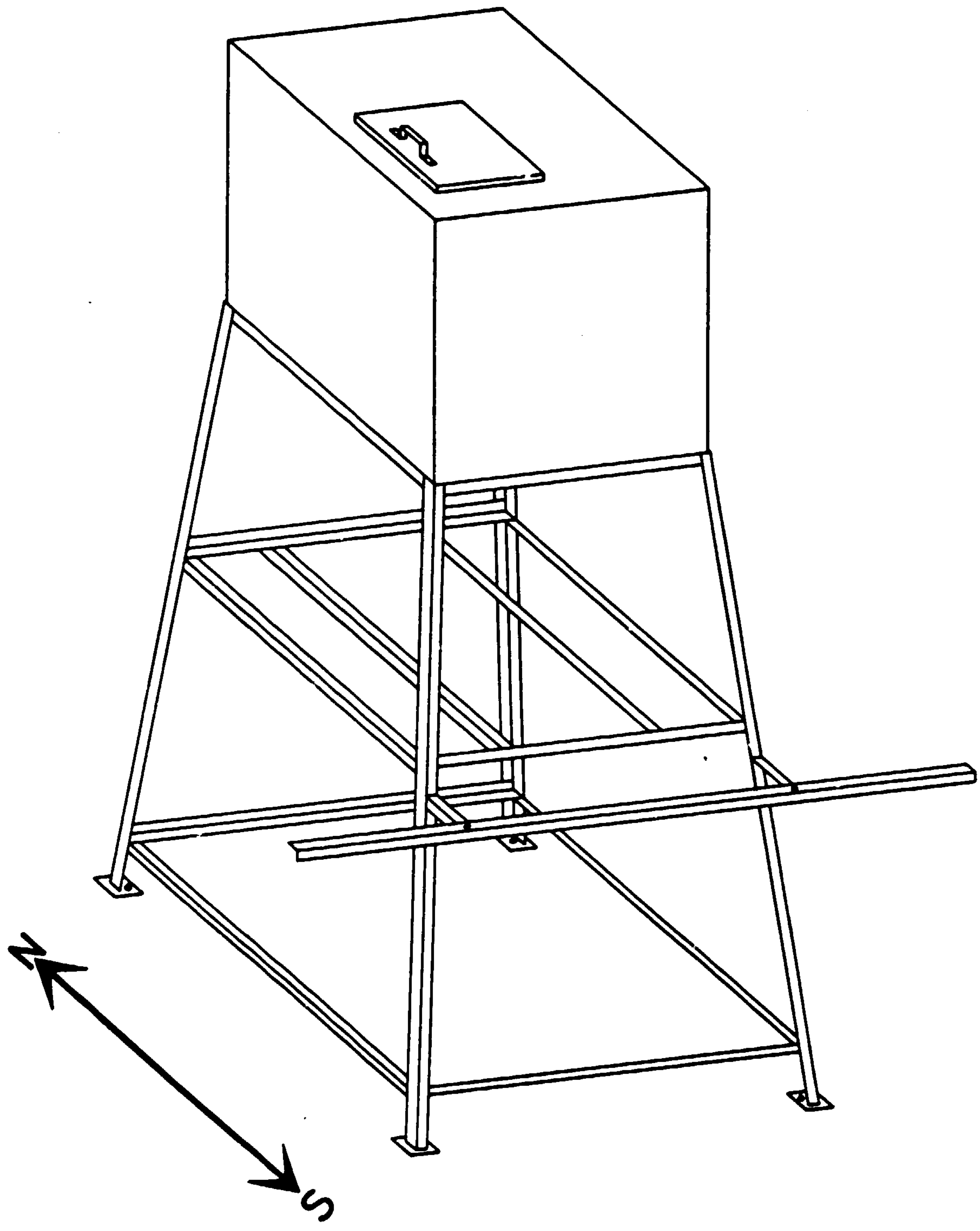


Fig. 3: Stand and cold water supply tank.

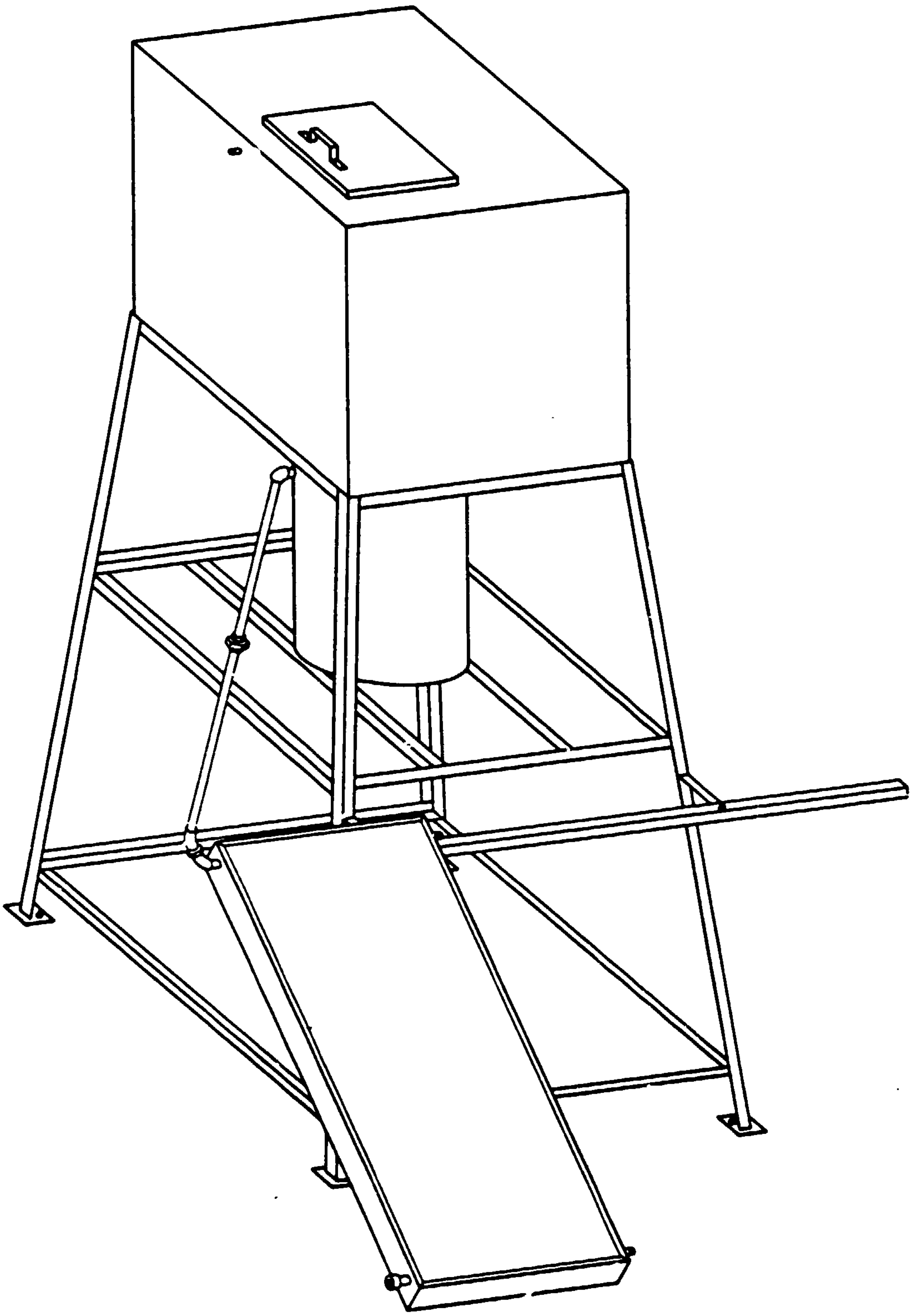
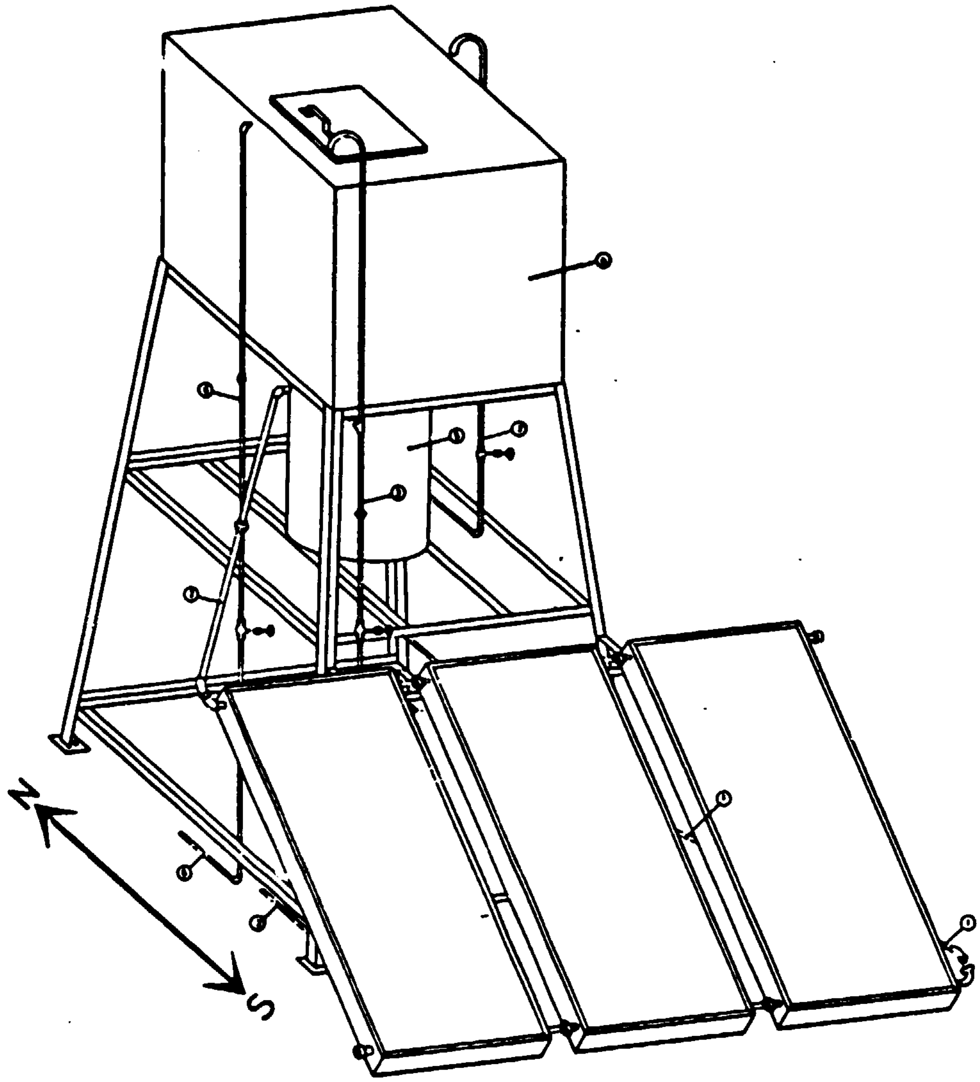


Fig. 4: First collector with hot water storage tank.



① COLLECTOR FEED LINE.
② COLLECTOR RETURN LINE.
③ HOT WATER OUTLET.
④ COLD WATER SUPPLY TANK.
⑤ HOT WATER STORAGE TANK.
⑥ COLD WATER SUPPLY.
⑦ HOT WATER STORAGE TANK FEED LINE FROM COLD WATER SUPPLY TANK.

Fig. 5: Solar water heating system with all connection.

5. INSULATION

The insulation is very important to reduce the heat lose from the system to the atmosphere. All pipes connecting collectors, hot water storage tank, and hot water domestic line must be well insulated, valves and air vents must be also insulated. The insulation should fit the pipes tightly and without gaps.

The insulation material can be fiber glass or armoflex tube. The insulation must be weather proofed or covered with aluminum tape to resist weather conditions.

6. FREEZING PROTECTION

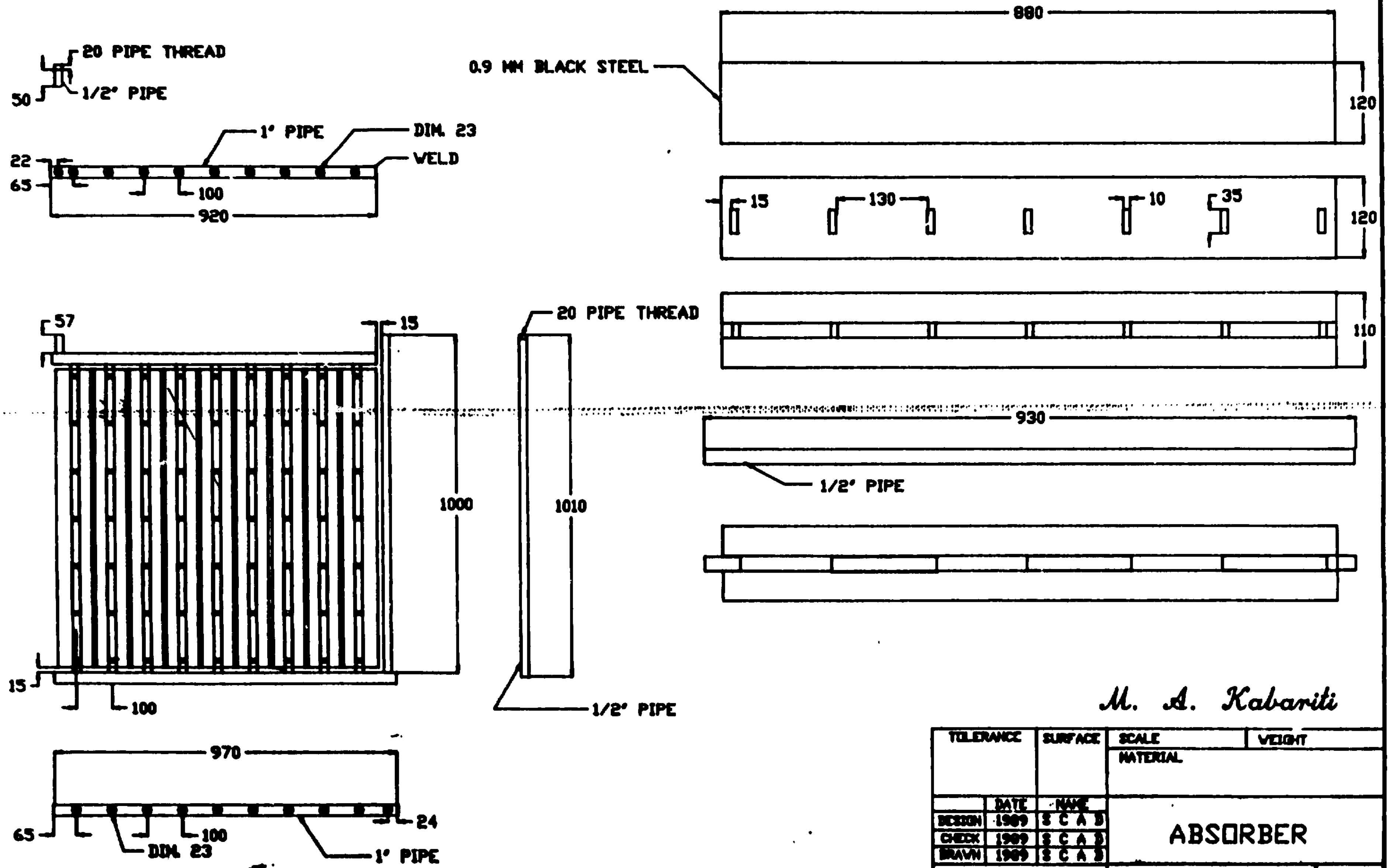
Because the collectors are located outside, freezing could be a major probiem in cold countries. It will lead to pipes damage, therefore some freeze protection measures should be taken in consideration. Some choices are:

- Empty the collector from water when needed, this requires adding some valves.

- Recircultating the water between collectors and storage, which needs a pump and control resulting in an added cost to the system.

- Use heat exchanger system using anti-freeze working fluids, which are non-toxic.

In general, good insulation of outside pipes leads to some kind to freeze protection.



M. A. Kabariti

TOLERANCE	SURFACE	SCALE	WEIGHT
		MATERIAL	

	DATE	NAME
DESIGN	1989	S C A D
CHECK	1989	S C A D
DRAWN	1989	S C A D

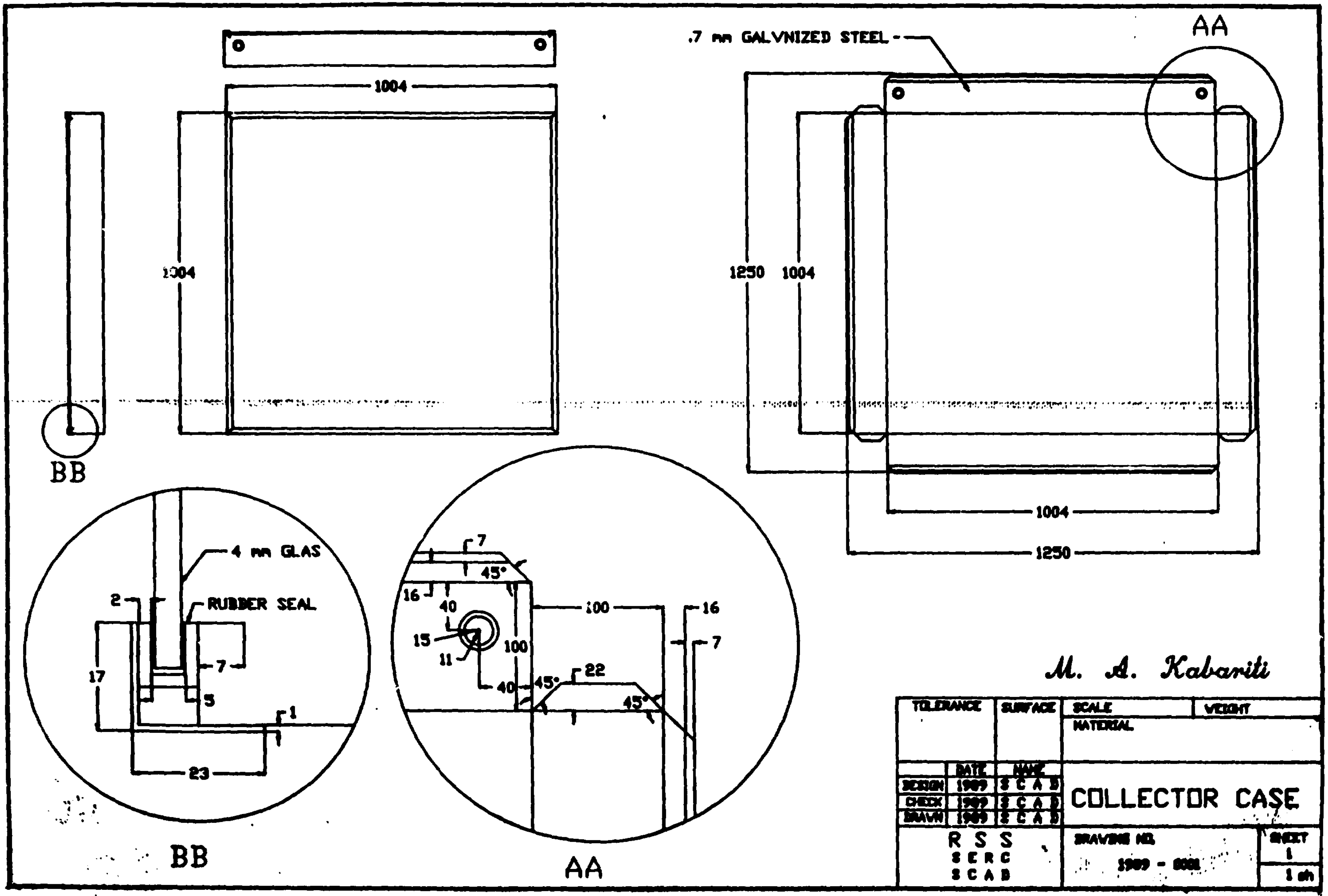
ABSORBER

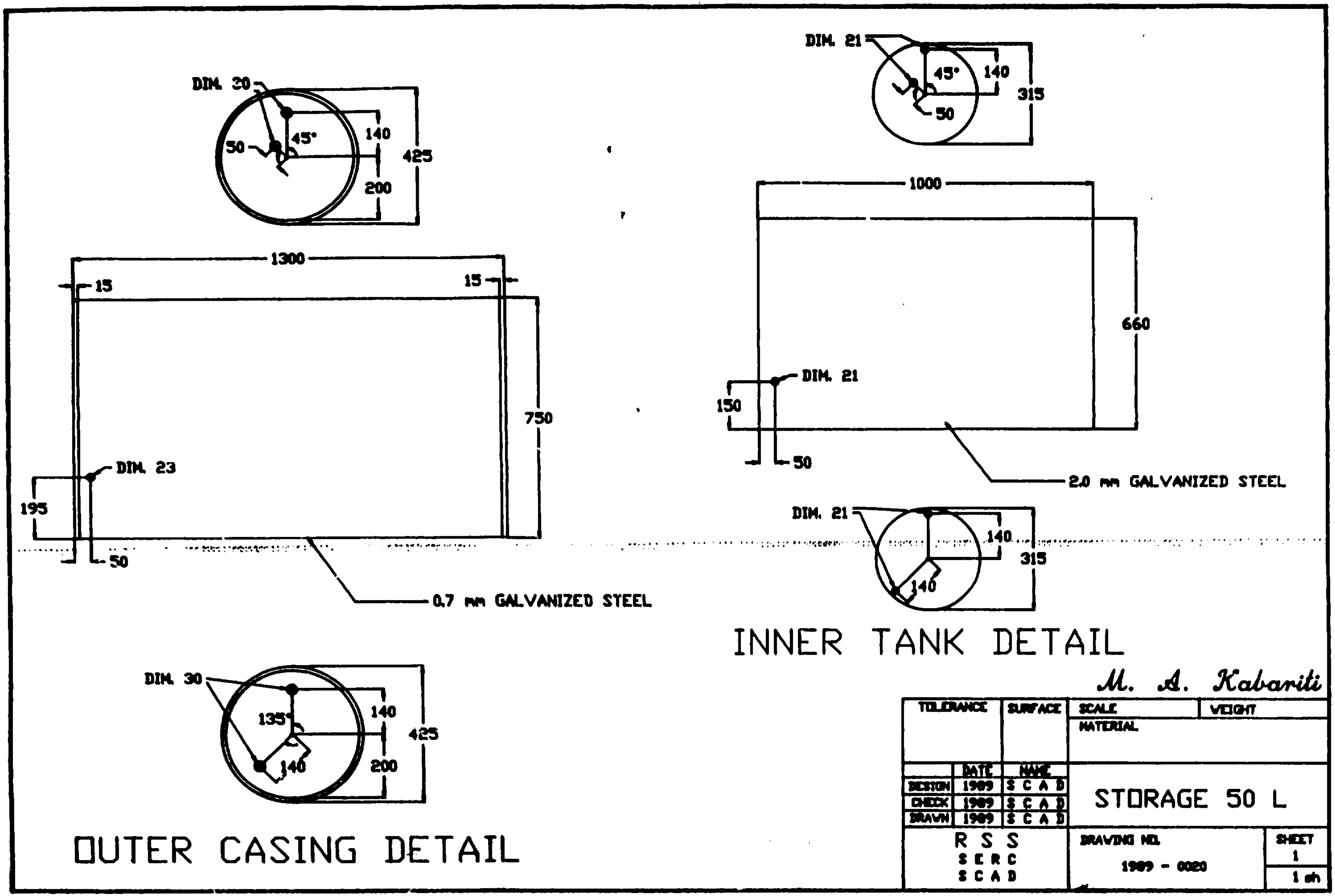
R S S
S E R C
S C A D

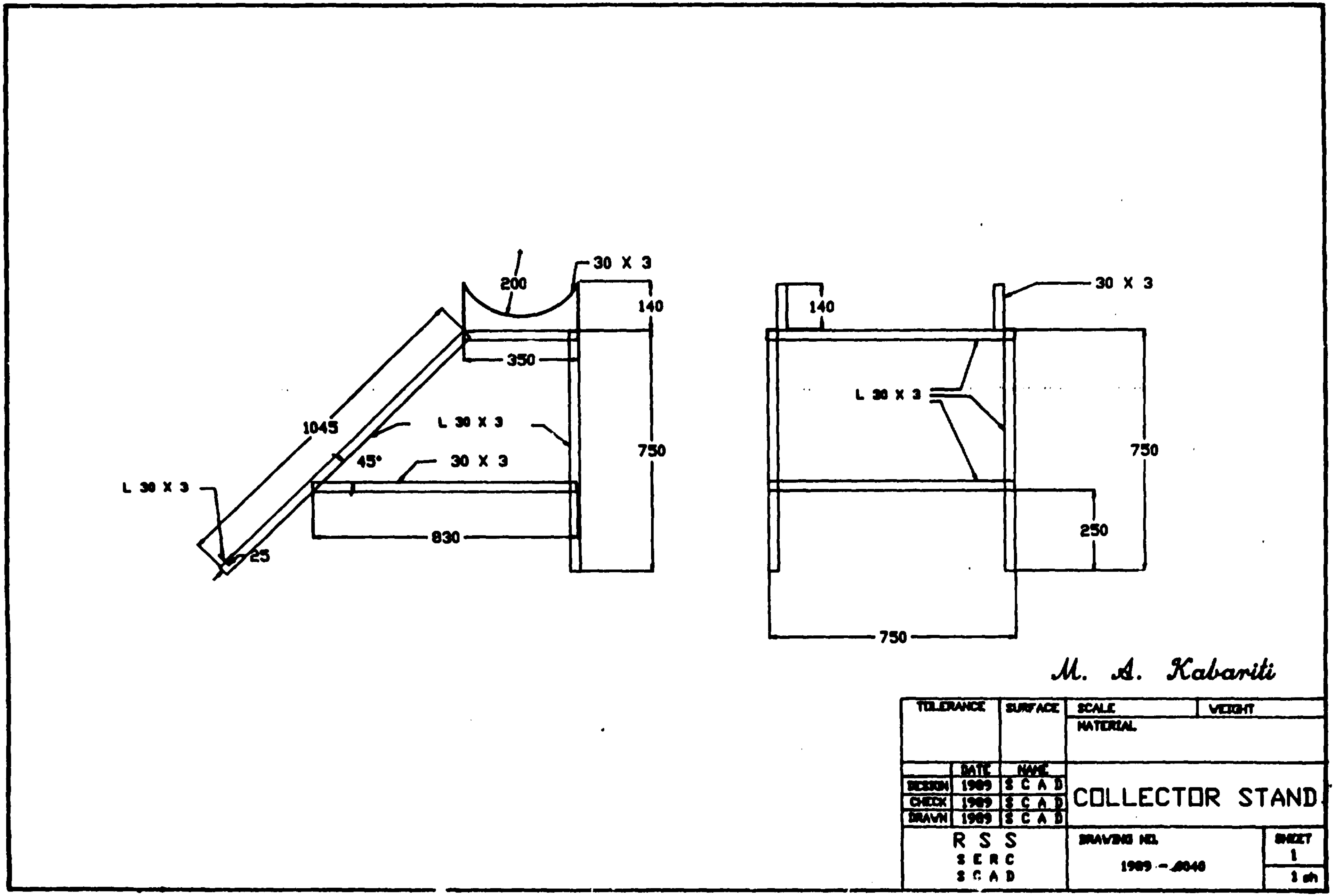
DRAWING NO. 1989 - 8010

SHEET 1

1 sh


.7 mm GALVNIZED STEEL
AA
1004
1004
1250
1004
1004
1250
BB
4 mm GLAS
RUBBER SEAL
2
17
7
5
1
23
BB
7
45°
16
40
15
11
100
100
16
7
40
45°
22
45°
AA
M. A. Kabariti
TOLERANCE
SURFACE
SCALE
WEIGHT
MATERIAL
DATE
NAME
DESIGN 1989 S C A D
CHECK 1989 S C A D
DRAWN 1989 S C A D
COLLECTOR CASE
R S S
S E R C
S C A D
DRAWING NO.
1989 - 0001
SHEET
1
1 sh


DIM. 30
50
45°
140
425
200
1300
15
15
750
DIM. 23
195
50
0.7 mm GALVANIZED STEEL
DIM. 30
135°
140
140
425
200
OUTER CASING DETAIL
DIM. 21
45°
140
315
50
1000
660
DIM. 21
150
50
2.0 mm GALVANIZED STEEL
DIM. 21
140
315
140
INNER TANK DETAIL
M. A. Kabariti
TOLERANCE
SURFACE
SCALE
WEIGHT
MATERIAL
DATE
NAME
DESIGN 1989 S C A D
CHECK 1989 S C A D
DRAWN 1989 S C A D
STORAGE 50 L
R S S
S E R C
S C A D
DRAWING NO.
1989 - 0020
SHEET
1
1 sh



30 X 3
200
140
350
1045
L 30 X 3
45°
30 X 3
L 30 X 3
25
830
750
30 X 3
140
L 30 X 3
750
250
750
M. A. Kabariti
TOLERANCE
SURFACE
SCALE
WEIGHT
MATERIAL
DATE
NAME
DESIGN 1989 S C A D
CHECK 1989 S C A D
DRAWN 1989 S C A D
COLLECTOR STAND
R S S
S E R C
S C A D
DRAWING NO.
SHEET
1
1 sh