REPORT
RAPPORT

SOLAR HEATING FAMILIARIZATION SEMINAR FOR TECHNICAL PERSONNEL OF THE ENGINEERING AND ARCHITECTURE BRANCH

December 1977

Indian and Northern Affairs Canada
Affaires indiennes et du Nord Canada

Technical Services and Contracts
Services techniques et marchés

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For Discussion Only

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997-9166

Contents

I would like to examine with you some aspects of solar heating of buildings. Some of you may already be fairly conversive on the subject, for others it will be a whole new field of study.

The slides I have arranged show a variety of types of solar heated buildings, some of which include domestic hot water systems. The presentation will be semi-technical, indicate schematically how solar heating systems work, show and describe some of the system components and give you information on how solar heating has performed to date.

There are two basic methods of solar heating for buildings in use today. The first is the passive type where the building structure is used for collecting and storing the solar energy. The second is called the active type, where solar collectors are used in conjunction with mechanical systems and fixed capacity storage areas. Today's presentation deals mainly with the active type however we will touch on the passive systems if time permits.

Most solar heated buildings are designed with the solar collectors on the roofs or built-in to the building in some other fashion. Therefore, unless the collectors are remotely located, there are certain architectural design parameters which must be observed in order to obtain optimum performance from the solar energy collection system. These requirements will be discussed shortly during the technical presentation, but first I would like to show you some solar heated houses.

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PHOTOS

Having seen how solar heating can be associated with buildings let us find out what we can expect from old sol, that is, what amount of energy can we collect, what is the most efficient way to collect it and what are the limitations imposed upon us in its use and storage.

First of all, how much useful energy can we obtain from the sun when we need the most heat, during November, December, January, February and March.

The electromagnetic radiation received from the sun is what is commonly referred to as solar radiation. The quantity received varies inversely with the distance from the sun. The amount reaching the upper limits of the earth's atmosphere is essentially constant (as the earth's distance from the sun only varies 3 per cent during the course of a year). This is referred to as the solar constant. Recent measurement define the solar constant value as follows:

1353 Watts per square meter per hour

428 BTU'S per hour per square foot

4871 KJ per square meter per hour

Plate No.1 shows that much of the energy received from the sun outside the atmosphere $\bar{H}_o$ does not reach the earth as direct radiation but is absorbed, reflected and/or diffused by the earth's atmosphere. The term $\bar{K}_T$ is the fraction of solar energy which penetrates the earth's atmosphere on a daily average.

The table gives average daily values for $\bar{H}_o$ and $\bar{H}$ for Ottawa. $\bar{H}$ has been determined from actual measurements and is normally given on charts in Langleys. One langley is = 11.63 wh/m^2 = 41.84 KJ/m^2 = 3.69 BTU's per square foot. $\bar{K}_T$ can be calculated from the formula $\bar{K}_T = \bar{H}/\bar{H}_o$, similarly $\bar{H}_o = \bar{H}/\bar{K}_T$.

As can be seen in this table, the quantity of solar energy falling on the earth at a given point varies considerably from month to month, day to day and even hour to hour. Plate No.2 illustrates the reason for this and why accurate solar energy calculations are fairly complex. The constant change in the solar declination changes the value of $\bar{K}_T$, thus increasing or decreasing the amount of energy reaching the earth at any given time.

Plate No. 3 shows the angle of declination for the 16th of each month, for one full year and gives solar position on the 45^o north latitude for winter and summer.

Plate No. 4. If we tilt the surface of the collector or object receiving the solar radiation as shown, we can increase the amount of energy collected during the winter months by up to 80%, depending on the angle of slope used. The energy collected on a tilted surface is called $\bar{H}_T$. The table gives results for various selected slopes. It has been found that a tilt angle equal to latitude or latitude + 15° provides the best efficiency.

Now that we are able to set the best conditions for solar energy collection, how is it converted into useful heat? There are a number of ways this can be done. In an active system employing water or air as the heat recovery media, the most common collector presently in use is the flat plate collector, shown here (Plate 5). You will see that it is made up of two layers of cover glass and has a black metal absorber plate, to collect the heat. In some instances, the manufacturer has applied a selective surface coating over the absorber plate to reduce the radiation effect of the plate and improve its overall efficiency. The most successful and stable selective surface developed to date is made by electroplating a layer of nickle on the absorber plate and then electrodepositing a thin layer of chromium oxide on top.

Under steady state conditions, the useful heat delivered by the solar collector is equal to the energy absorbed in the metal surface minus the direct and indirect heat losses to the surroundings. The formula shown on <u>Plate No. 6</u> demonstrates this principal.

Solar energy is free, but the hardware to convert radiation to heat is not free, therefore solar generated heat is expensive. Of every five units of radiation incident on the collector, perhaps one of these five units might be converted to useful solar heating. This is due to optical and thermal losses from the collector and through the collector and in transport and from storage resulting in an overall efficiency of something like 20%. Manufactured collectors and systems now in use are doing a little better than this at 30% to 35% overall annual efficiency.

Let us now take a look at a schematic of a typical liquid base system, Plate No. 7. It consists of a solar collector in which anti-freeze is circulated through a heat exchanger to a thermo storage tank containing water or some other cheap liquid, then a heat delivery system to the house. Very simple indeed. A collector, a storage and a heat delivery system.

Now when we have a space heating system, it is wise to install an integrated domestic hot water system where the cold water supply is heated in a preheat tank separate from your normal hot water tank in the building, (which is shown on top as a service hot water tank) and we draw heat from the main storage tank to the preheat tank. Any heat that you can supply through a preheat tank to heat the water will be useful heat. So it is a liquid base system. Now you see in between we have such things as heat exchangers, schematically a counter-flow or single pass water to water heat exchanger, and likewise, over to the preheat tank some form of heat exchanger as required by the health code, in most cases perhaps a double wall heat exchanger.

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The collector loop to the heat exchanger requires from 25 to 30 gallons of anti-freeze. If we did not use a heat exchanger, but circulated directly to the main storage tank, we would greatly increase the cost of the system with the extra anti-freeze required.

The present trend in solar energy storage is to limit the storage capacity from 30 to 36 hours to permit only overnight use of heat. These solar systems are designed to convert solar radiation to heat during the daytime, utilize the heat directly as required during the day, store the excess (if any) for nightime use.

Now you might well ask, why not use a larger storage capacity, because we know that there may be several successive days without sunshine. Surely we ought to be designing for those situations. Well, the question is always one of costs. Can we afford to install enough collectors on the roofs to collect heat to store in a large storage area to last a longer period - three, four, five days? Taken to extremes, can we collect heat during the summer and store it for winter use. Yes, we can design systems to do this. Some have already been built, but experience has shown that the cost in money, and natural resources is too high to provide 100% of our heating requirements from solar energy here in Canada.

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With the 30 to 36 hour storage capacity we can provide from 35 to 65% of our annual total energy requirements, depending on whether or not we include our domestic hot water supply.

The auxiliary heating unit is exactly that. It is not a back-up or standby system in case the solar system fails. It must be designed for 100% of the load as it is required to provide 100% heating capacity a good portion of the time.

Plate No. 8 shows an air system using air through the collectors. The system can also heat domestic hot water through an air to liquid exchanger. The motorized dampers MD1 to MD5 provide flexibility in operation. The heat storage media is a rock bed, in an insulated box located inside the house. Approximately 100 pounds of ¾" to 1½" dia. stone is used per square foot of collector area. A 2000 square foot home in the Ottawa area could operate from the stored heat for about 20 hours at an average outside temperature of $+20^{o}$ F.

Plate No. 8A shows a typical rock storage box, with air inlet and outlet. The box is fully insulated using R19 insulation. The chart shows the temperature build up in the box at various times as heat is being stored during the day, and why it is important to reverse the air flow through the storage bed when using stored heat to heat the house.

Plate No. 9 shows collector temperature patterns for liquid and air flat plate collectors. Liquid leaves the collector at about 150°F. The collector plate temperature is about 10°F more. The average plate temperature is 150°F.

A temperature pattern in a typical air-heating collector operating with an air supply from the space being heated or from the cold end of a pebble-bed storage unit at 70°F is shown. Full sun and a practical air circulation rate of about 2 cfm per square foot of collector are assumed in the example. An air temperature rise of about 60 to 80 degrees F would occur under these conditions, which is much higher than in the liquid case because of the lower specific heat for air. The mass flow rate is about the same as that of the liquid (measured as pounds per hour, for example) for suitable pressure loss conditions. Minor flow rate changes do not greatly affect the efficiency of a liquid collector, but air flow rate changes have a significant influence on air collector performance. Although even greater efficiencies can be achieved with higher air flow rates, the larger pressure drop and power requirements to circulate air at rates above 2 cfm/ft^2 force a compromise between collector efficiency and power consumption. At the same time inlet temperature, ambient temperature, and solar radiation level, the liquid collector is more efficient. It is important to recognize, however, that liquid and air collectors normally operate at very different inlet temperatures, so that air collectors usually operate at conditions substantially nearer the left side of the graph than do the liquid type. The net result is comparable operating efficiency with the two types.

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Now that we have a solar energy heating system with collectors, exchangers, pumps, blowers, valves, etc. how are we going to control all these parts so that they perform the correct function at the right time. Centralized control units have been designed to co-ordinate all the functions required.

Plate 10 shows what the control system must do and in what sequence it should be done.

Most controllers at present are on/off controllers, that is, they command a pump to be either on or off, depending upon certain conditions. The typical control strategy with respect to controlling the flow of a transport medium in the collector loop is to start the collector pump whenever the collector fluid exit temperature is greater, by some set difference, than the tank temperature and to turn off the collector pump whenever the collector outlet temperature approaches the tank temperature. The temperature difference to start the flow is nominally set at 20^{o} F and to stop the flow, at 3 or 4^{o} F.

As a specific example, suppose that the storage temperature is 120^{o} F and the collector temperature is 50^{o} F when the sun rises. The collector temperature will gradually increase and when it reaches 140^{o}F the controller will start the collector pump (assuming that the storage temperature is 120^{o} F.) Then in the afternoon as the sun begins to set the collector temperature will begin to decrease. Suppose that the storage temperature has reached 150^{o} F by 3:30 p.m. When the collector temperature decreases to 153^{o} F the controller will stop the collector pump.

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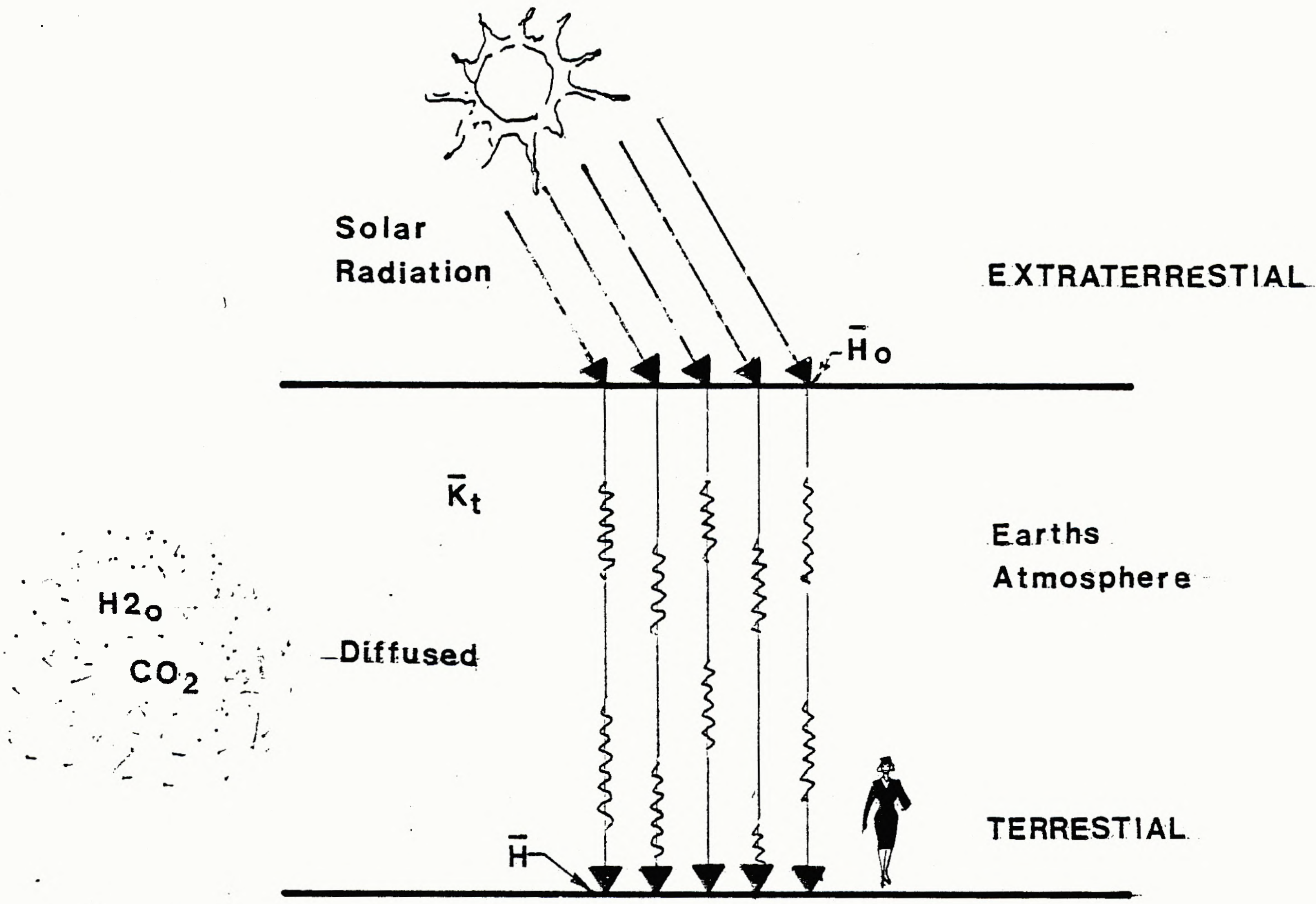
Plate 11 shows a manufacturer's typical control circuit for a solar system control panel.

Summary

From the sample calculations of the useful solar energy available at Ottawa in January as shown in Plate No.12, we can see that proper design and orientation of the solar collector systems is of prime importance if maximum efficiency and lowest capital and operating costs are to be achieved.

Although solar systems are expensive, they can be competitive with other fuels providing the pay-back period is extended and that the design parameters remain within the economic capability of the solar energy system.

Solar Radiation Received at Ottawa



WHERE:

$\bar{H}_o$ = Monthly Average Daily Solar Radiation Falling On A Horizontal Surface Outside The Earths Atmosphere.

$\bar{H}$ = Monthly Average Daily Solar Radiation Falling On A Horizontal Surface At Ground Level.

$\bar{K}_t$ = Monthly Average Cloudiness Index.

VALUES OF $\bar{H}_o$ and $\bar{H}$ ON A MONTHLY BASIS IN BTU'S per SQUARE FOOT per DAY

month	$\bar{H}_o$	$\bar{H}$	month	$\bar{H}_o$	$\bar{H}$
Jan.	1080·4	539·1	July	3652·5	2045·4
Feb.	1578·5	852·4	Aug.	3209·5	1752·4
Mar.	2257·2	1250·5	Sept.	2546·2	1326·6
April	3001·1	1506·6	Oct.	1837·5	826·9
May	3510·7	1857·2	Nov.	1277·7	458·7
June	3762·6	2084·5	Dec.	936·9	408·5

PLATE: I

Solar Radiation Received at Ottawa

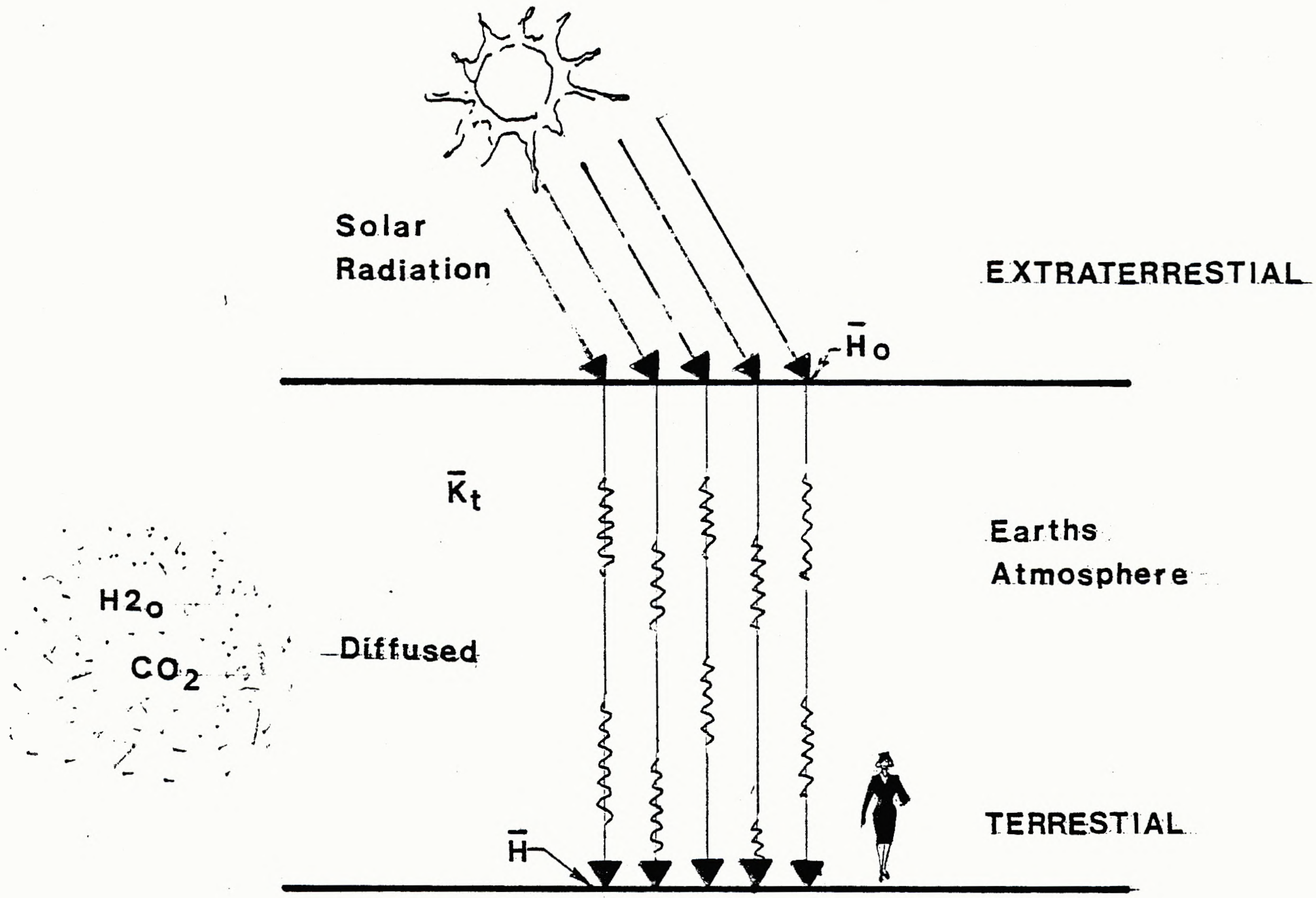


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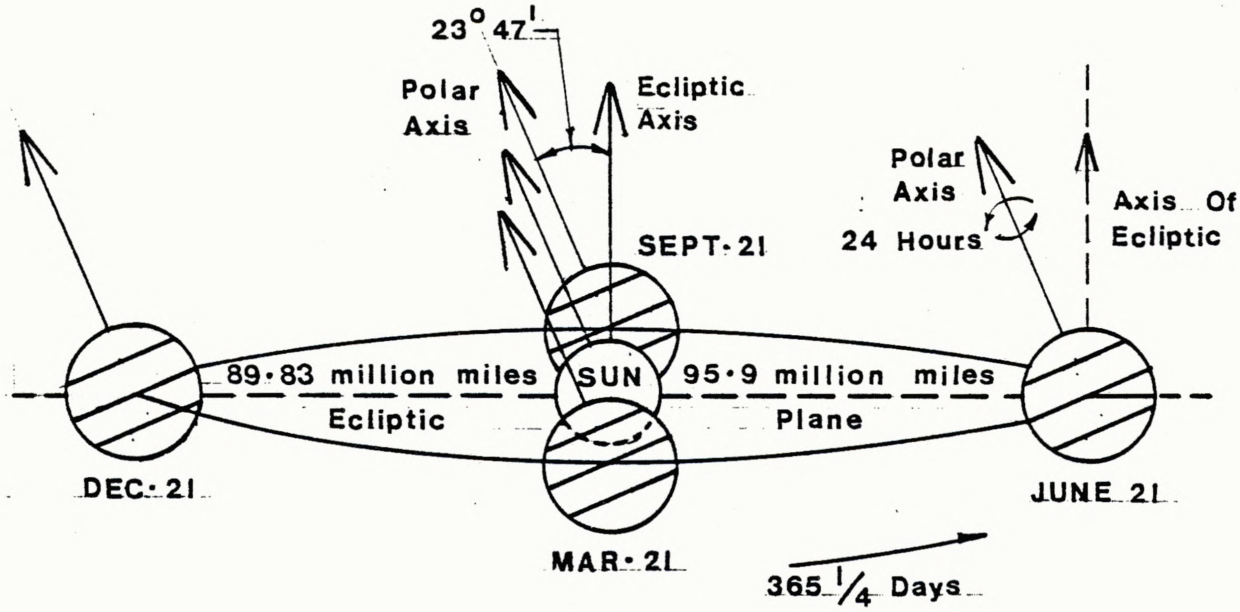
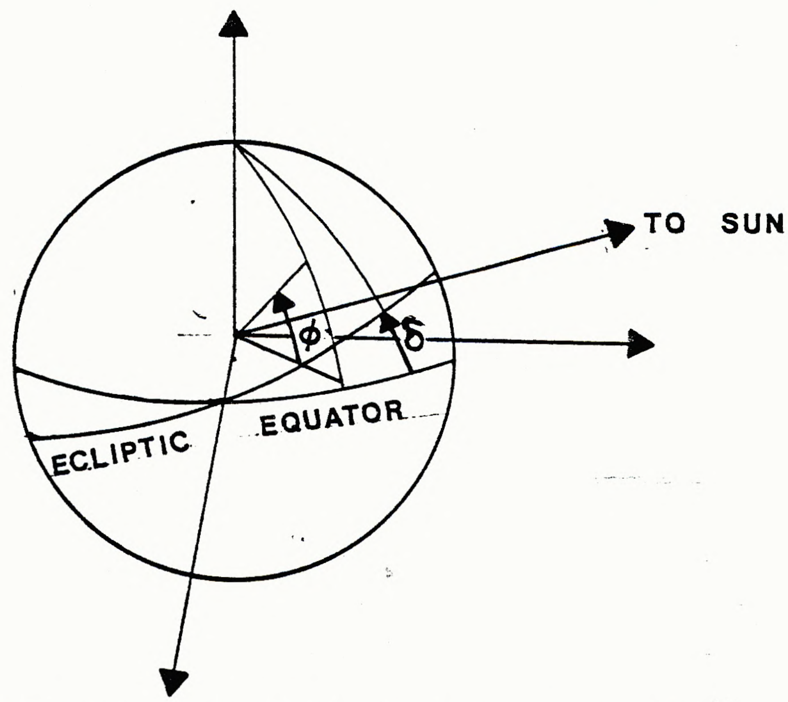
PLATE: I

Motion of The Earth About The Sun



Since the spin axis of the earth is tilted relative to the ecliptic plane, as shown on the sketch, the amount of SOLAR RADIATION falling on a horizontal surface of given area will vary with respect to the time of year.



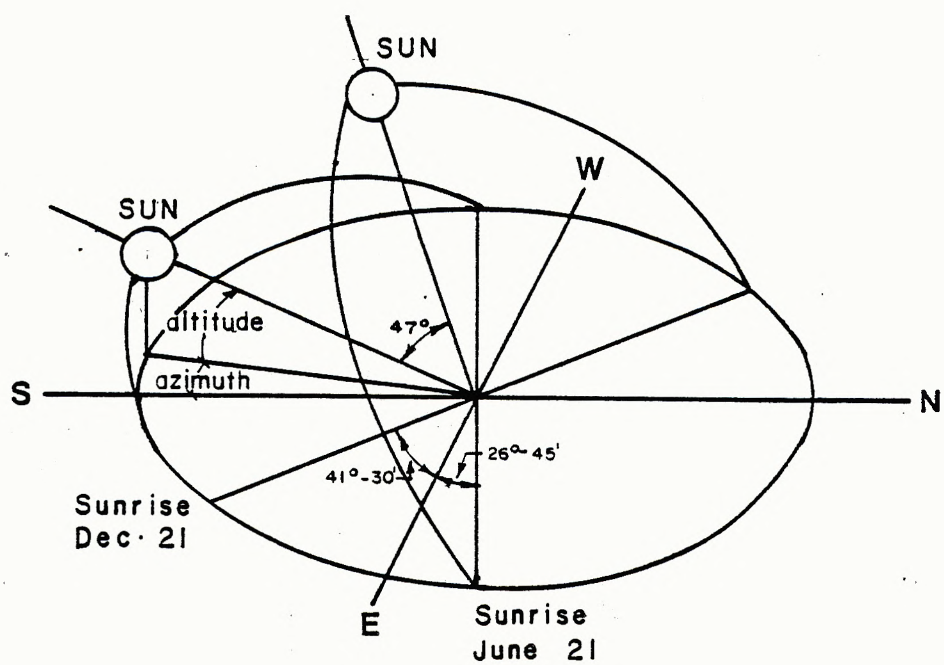
ϕ = LATITUDE ANGLE, DEGREES (NORTH PLUS)

PLATE:2 δ = SOLAR DECLINATION · (POSITION of THE SUN RELATIVE TO THE EQUATORIAL PLANE at SOLAR NOON DEGREES)

Solar Positions And Declinations

TABLE OF DECLINATIONS

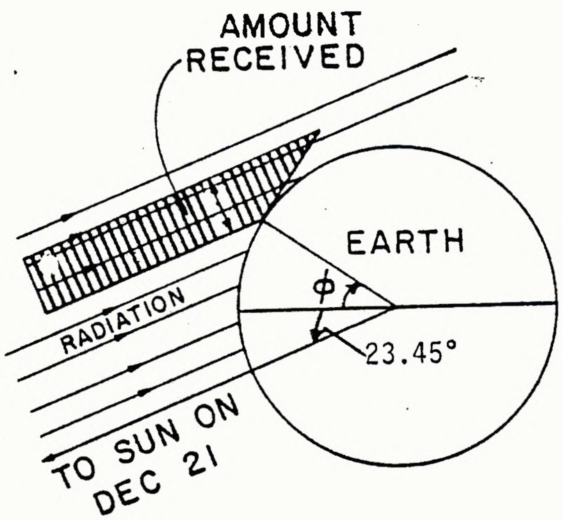
DATE	DAY OF YEAR	DECLINATION, δ (DEGREES)
JAN. 16	16	-21·10
FEB. 16	47	-12·95
MAR. 16	75	-2·42
APRIL 16	106	9·78
MAY 16	136	19·03
JUNE 16	167	23·35
JULY 16	197	21·35
AUG. 16	228	13·45
SEPT. 16.	259	1·81
OCT. 16	289	-9·97
NOV. 16	320	-19·38
DEC. 16	350	-23·37



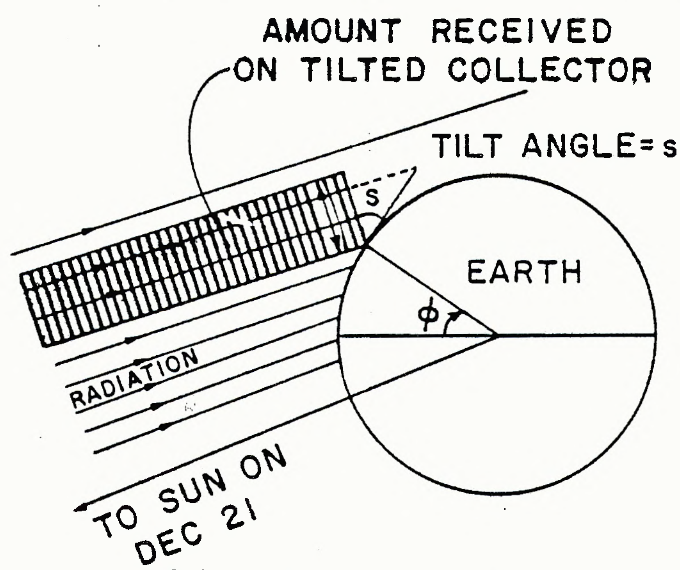
Winter And Summer Solar Positions In Relation To A Location On The 45 Degrees North Latitude·

PLATE: 3

Solar Radiation On A Tilted Surface



(a) Radiation on a Horizontal Collector



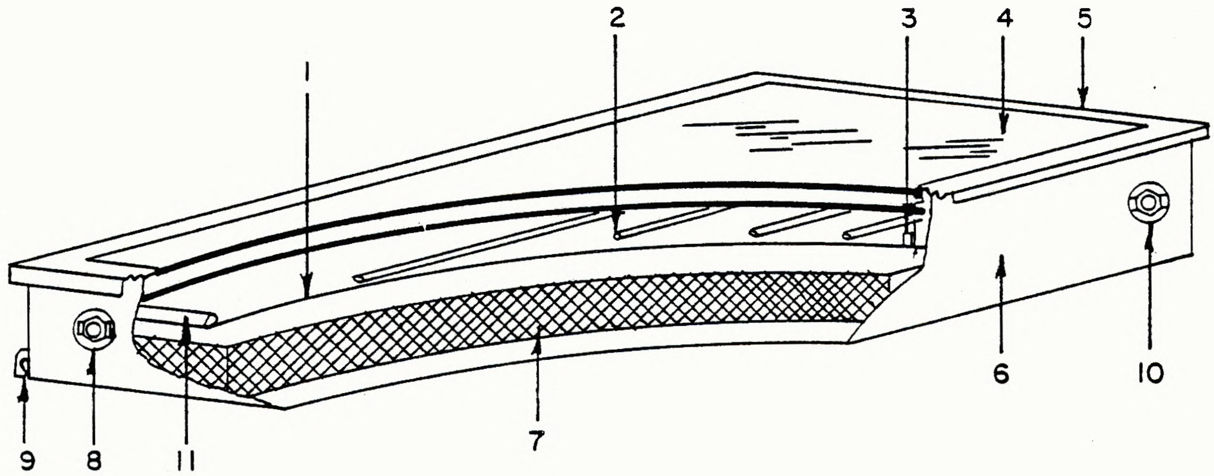
(b) Radiation on a Collector Perpendicular to the Radiation

$\bar{H}_t$ = Monthly Average Daily Solar Radiation Falling On A Tilted Surface

COLLECTOR SLOPE	JAN.	FEB.	MAR.	APRIL	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.
VERTICAL	960	1092	1099	985	888	819	847	929	1043	1163	660	705
LATITUDE +15°	982	1246	1392	1470	1417	1384	1395	1409	1395	1115	680	760
LATITUDE	926	1221	1434	1548	1586	1601	1587	1562	1434	1180	620	670
LATITUDE −15°	850	1129	1391	1606	1722	1784	1728	1639	1454	1098	583	620

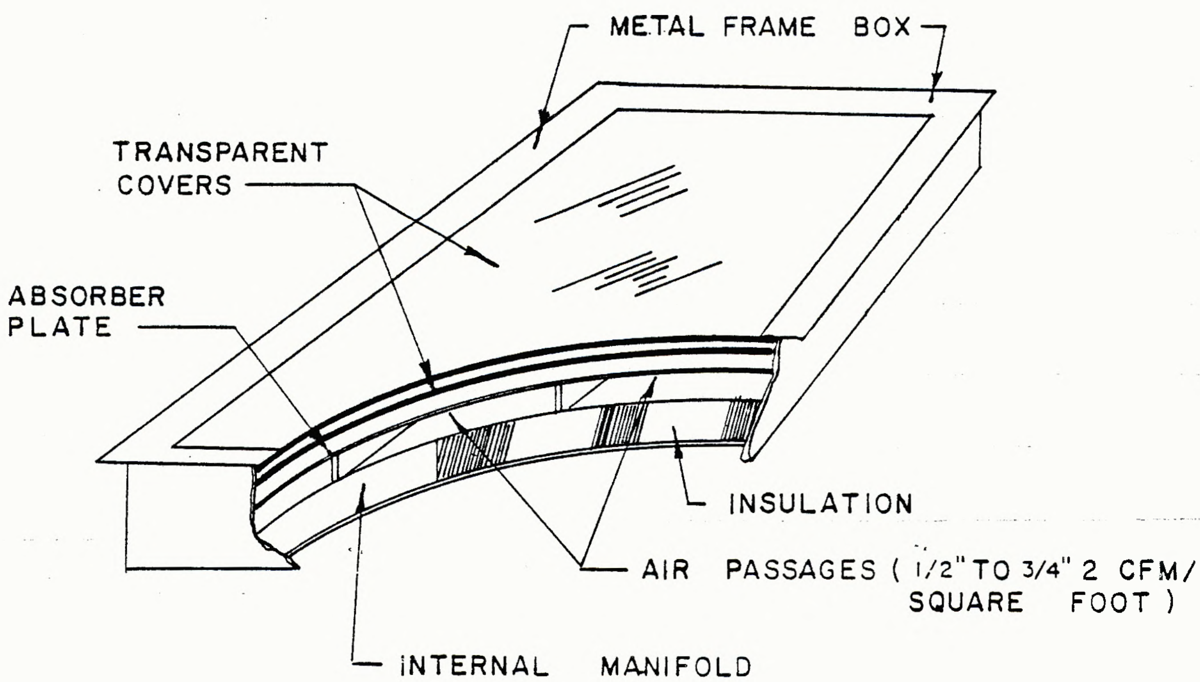
The Above Chart Shows The Values Of $\bar{H}_t$ At Ottawa (LATITUDE 45° 27′) On A Monthly Basis In BTU's Per Square Foot Per Day

PLATE: 4



1. Selective Surface
2. Copper Tubes
3. Silicone Rubber Pads To Isolate Absorber Plate From Frame
4. Two Cover Glasses
5. Glass Seal To Frame
6. Steel Froming
7. Semi-rigid Insulation
8. Plumbing Fitting
9. Mounting Bracket
10. Plumbing Fitting
11. Inlet Water Header

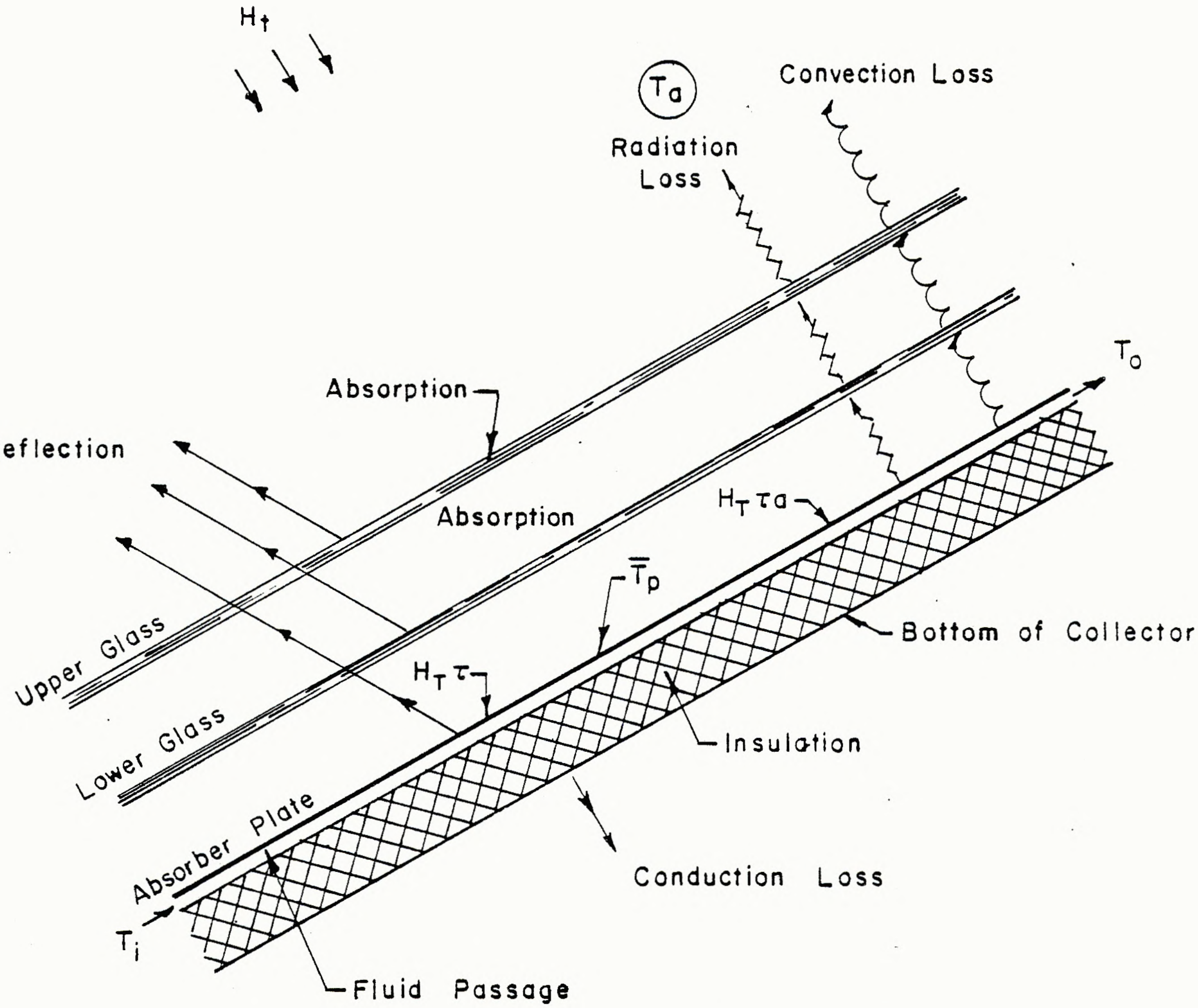
TYPICAL LIQUID-HEATING COLLECTOR



TYPICAL AIR-HEATING COLLECTOR

PLATE: 5

Collector Heat Gains vs Heat Losses



Absorbed Energy = $A_c H_T \tau a$

Effective Heat Loss = $A_c U_L (\bar{T}_p - \bar{T}_a)$

$$Q_u = A_c \left[H_T \tau a - U_L (\bar{T}p - Ta) \right]$$

WHERE:

Q_u = Usefull Energy Delivered By Collector · BTU / HR

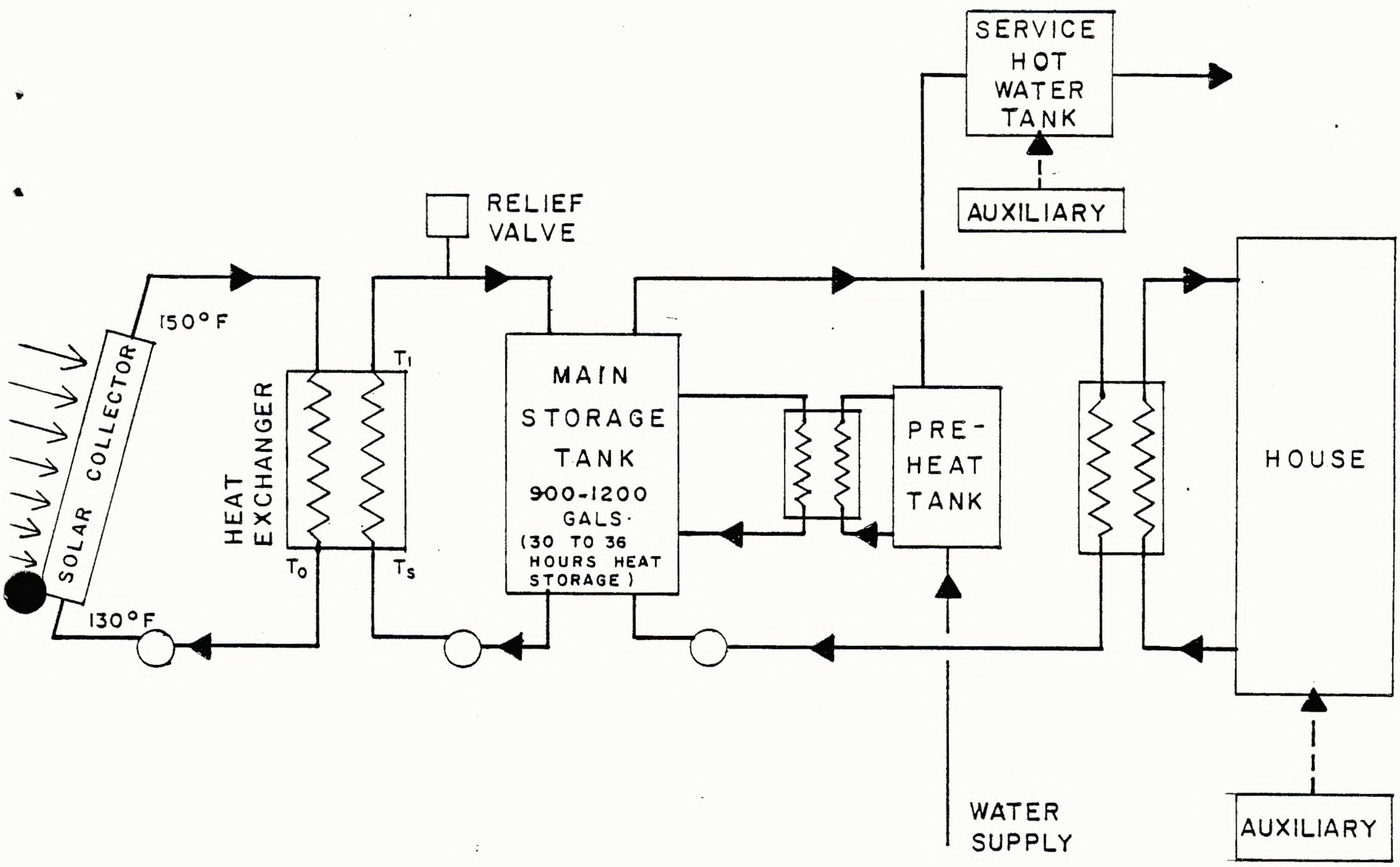
A_c = Total Collect Area Ft^2

τ Fraction Of Incoming Solar Energy Reaching The Absorber Plate

a Fraction Of Solar Energy Reaching The Surface Which Is Absorbed

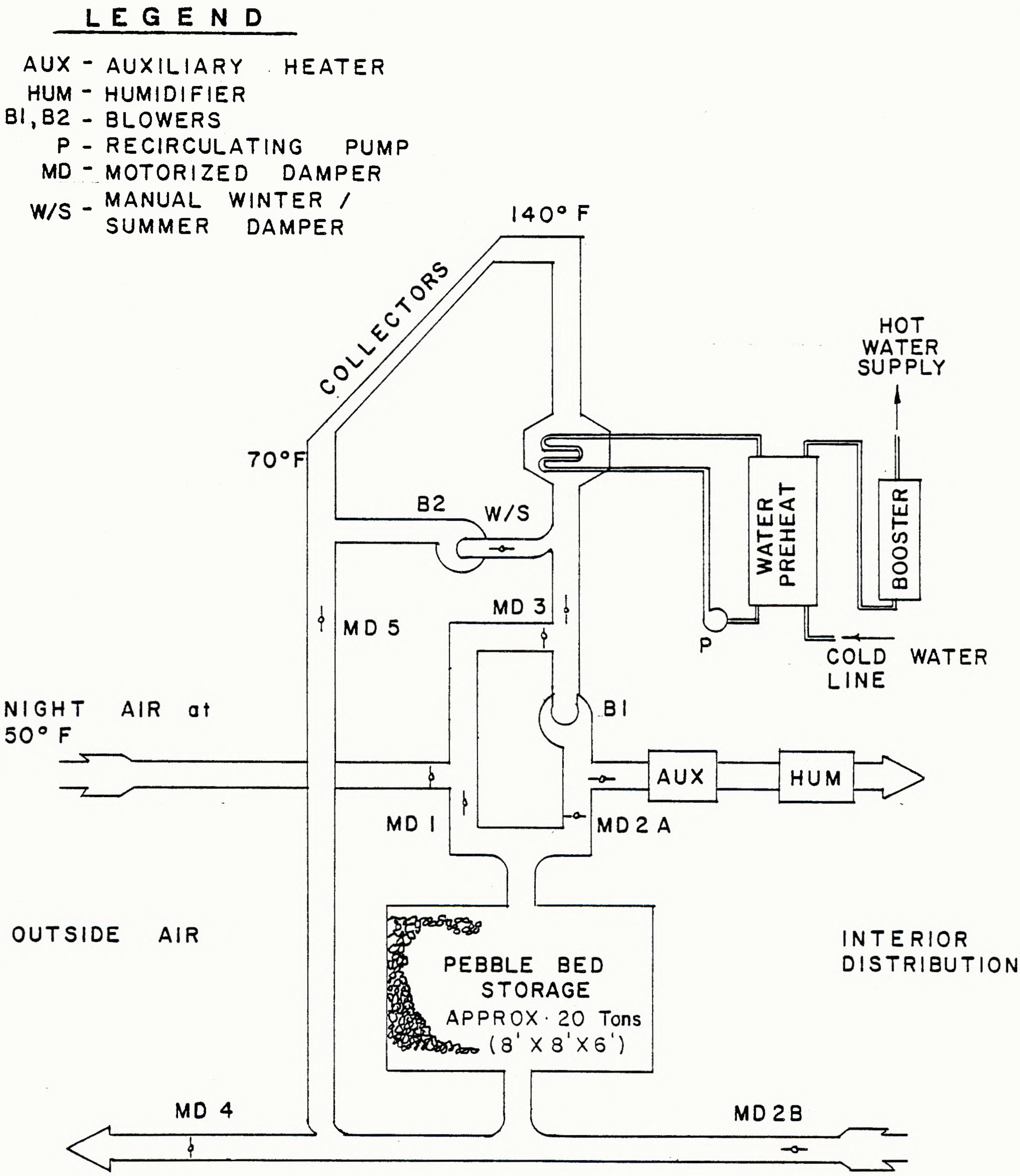
PLATE 6

U_L Collector Loss Coefficient



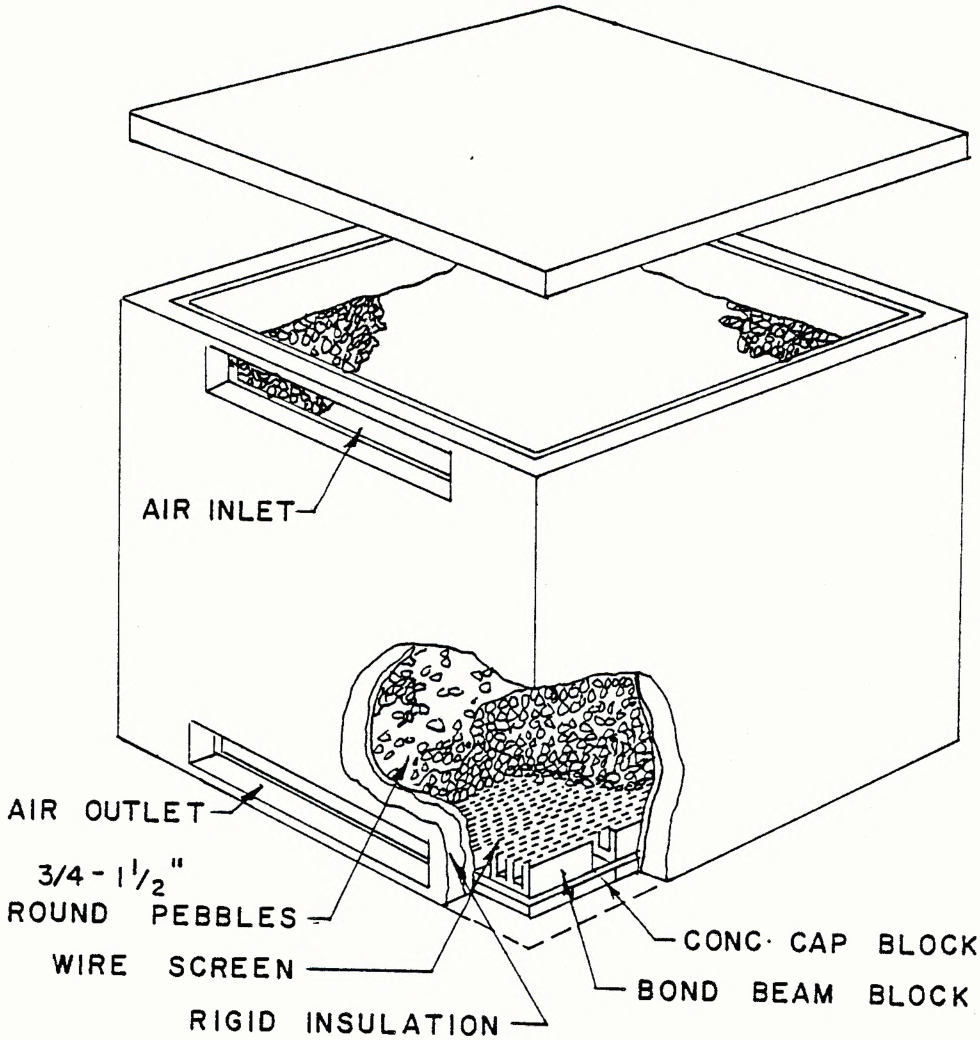
SCHEMATIC DIAGRAM of a LIQUID-BASED SOLAR SPACE and WATER HEATING SYSTEM

PLATE: 7

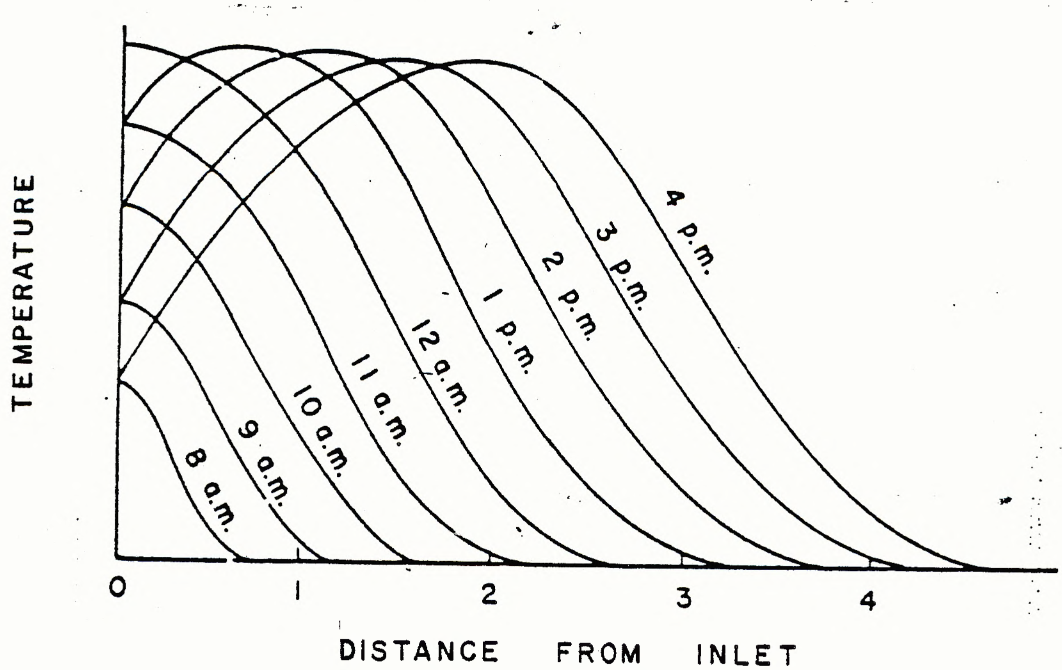


SCHEMATIC OF AN AIR SYSTEM

PLATE: 8

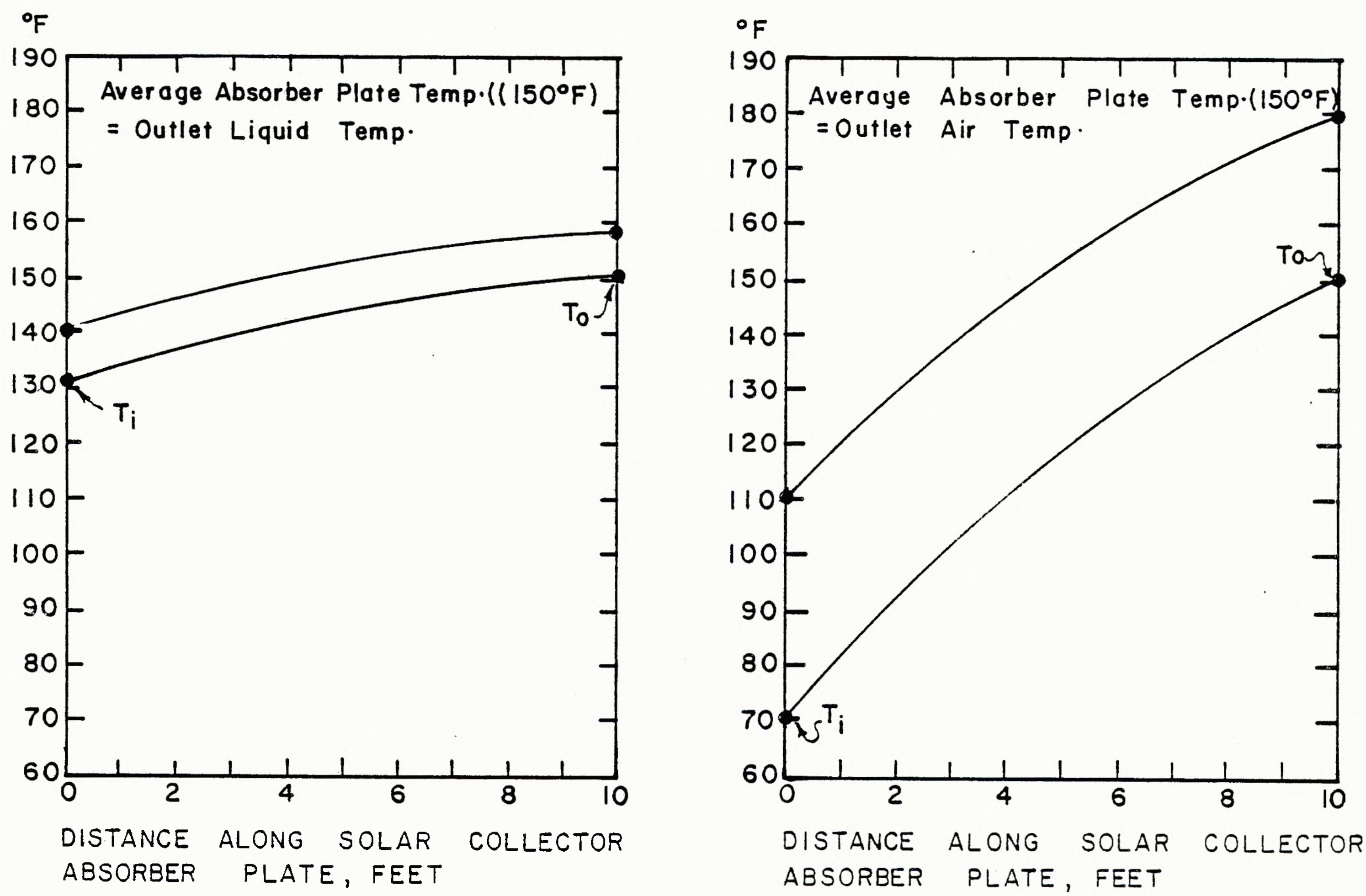


ROCK BED HEAT STORAGE UNIT



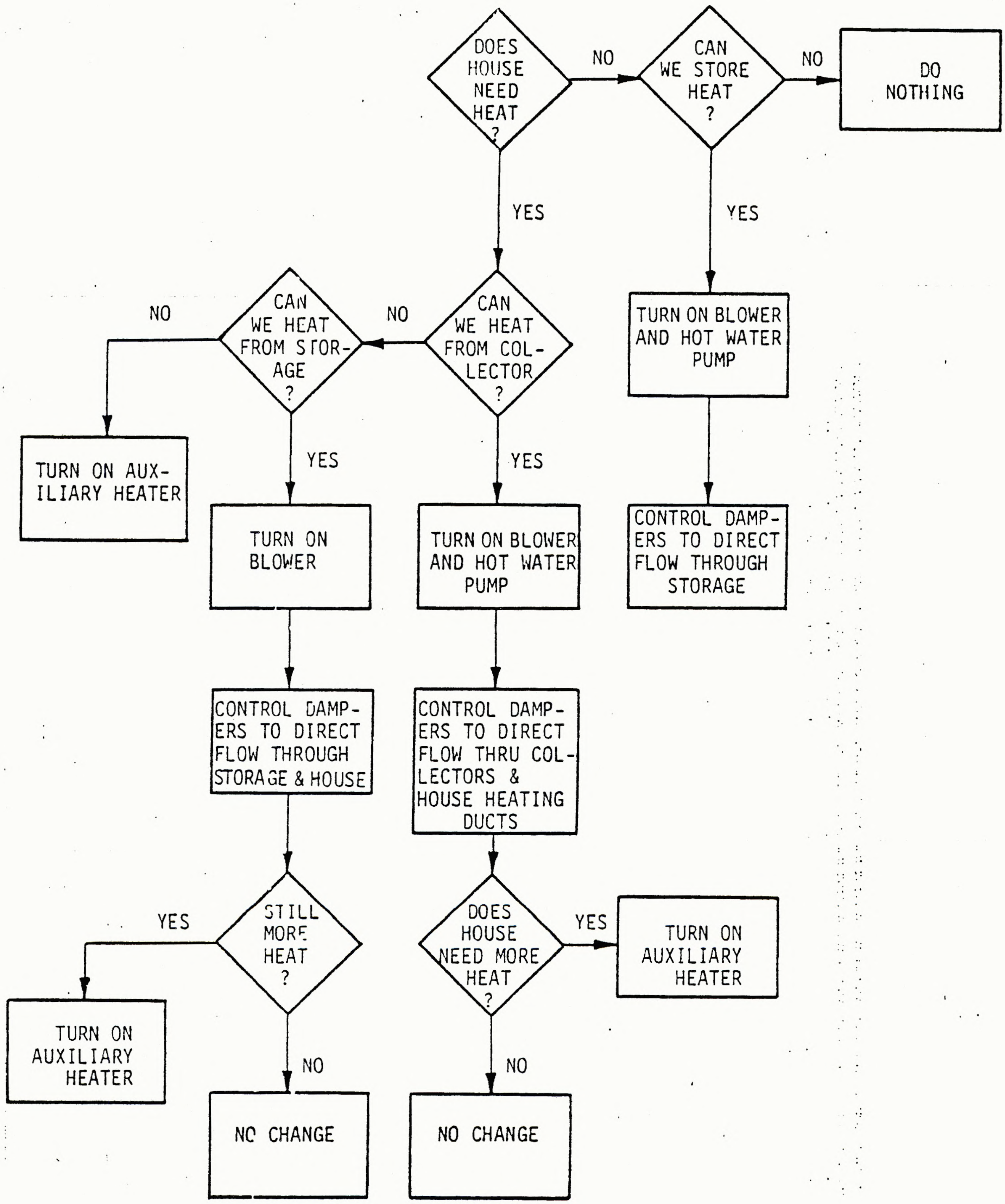
TYPICAL TEMPERATURE PROFILES IN A ROCK BIN STORAGE

PLATE: 8A



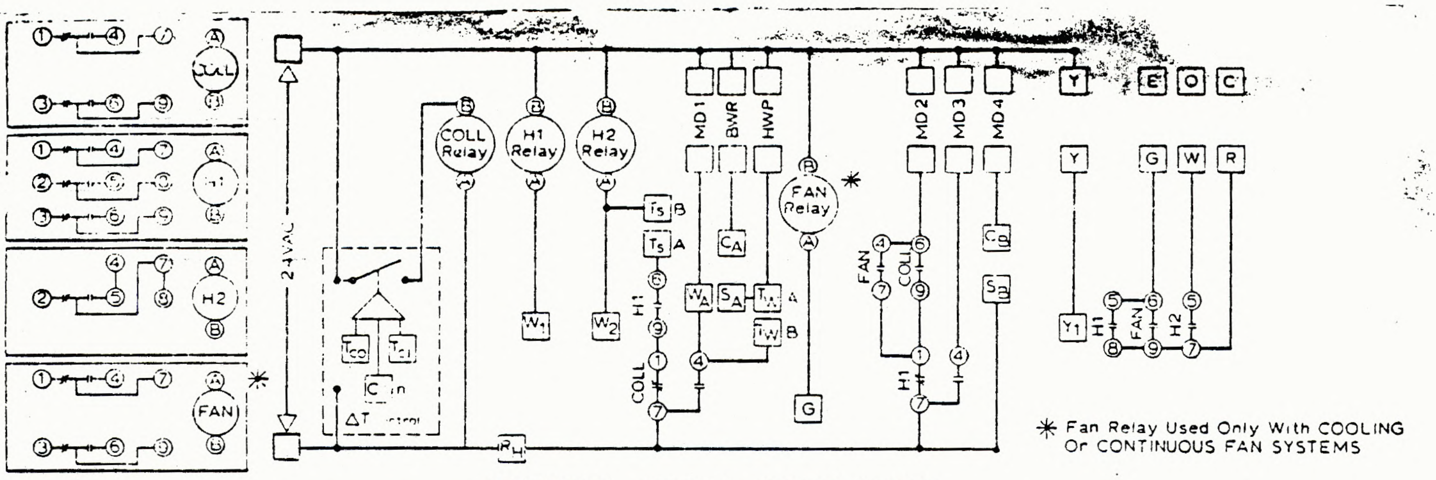
COMPARISON of TYPICAL TEMPS. IN LIQUID & AIR HEATING SOLAR COLLECTORS

PLATE: # 9

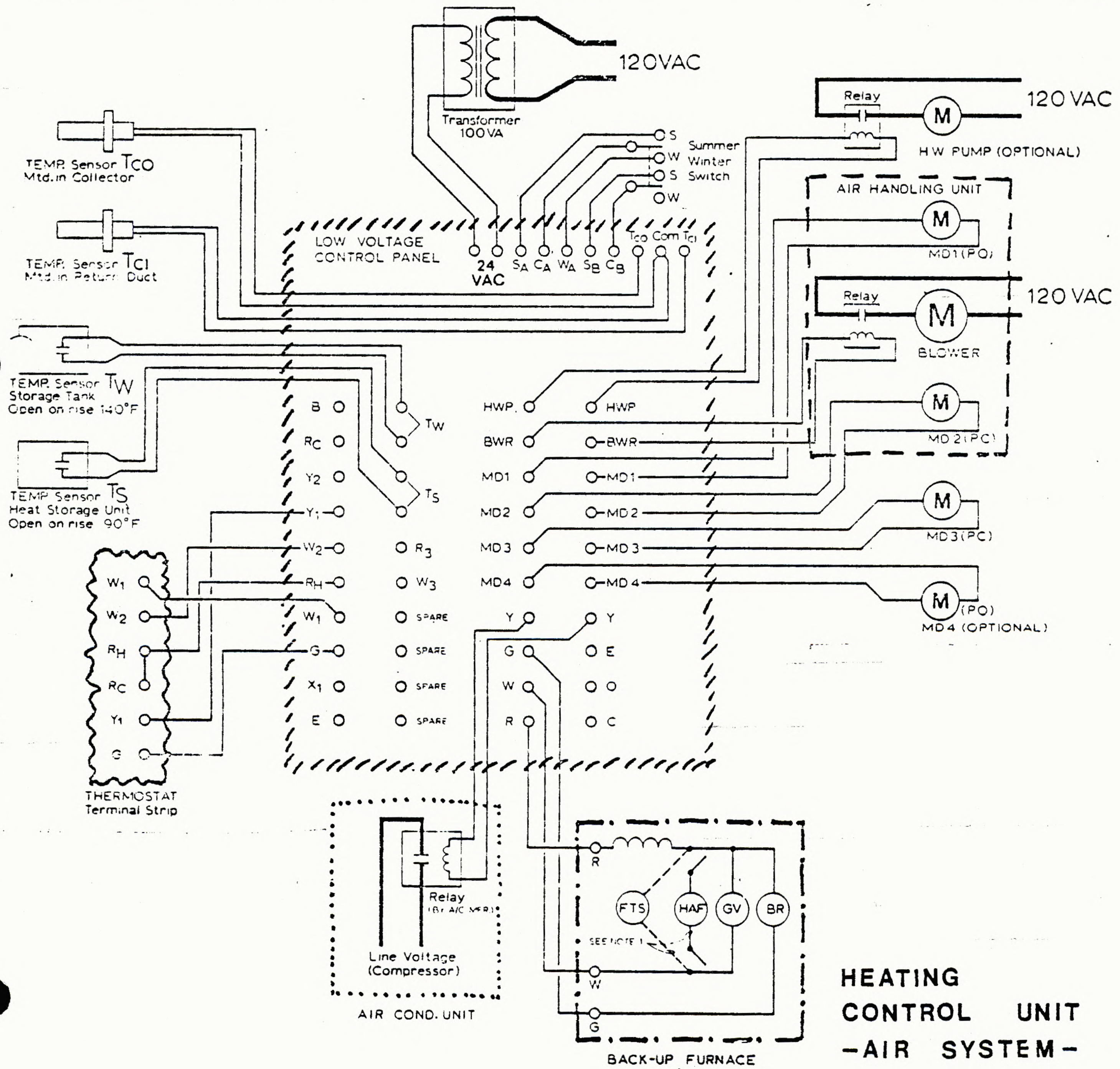


FLOW CHART OF CONTROL STRATEGY

PLATE: 10



CONTROL PANEL SCHEMATIC



HEATING CONTROL UNIT -AIR SYSTEM-

PLATE II

Sample Calculation of Percentage of Solar Energy Obtained for January at Ottawa

1. Average daily solar radiation per square foot.

(a)	outside earth's atmospher $\overline{H}_o$	=	1080 BTU/DAY
(b)	falling on a horizontal collector $\overline{H}$	=	539 BTU/DAY
(c)	falling on a tilted collector set at latitude + 15° $\overline{H}_T$	=	982 BTU/DAY

2. Percentage of monthly total sunshine on a collector which is converted to heat = 68%

3. Percentage of the above which is converted to useful heat = 30% (MAX.)

4. Amount of useful heat obtained per square foot of collector area = 294.6 BTU/DAY

5. Assume that we have a home of 1500 square feet of usable floor area which is insulated using the new energy conservation standards for insulation upper walls R = 17.0
   basement walls R = 9
   roof R = 32.3

   (a) The TD using - 10° F outside DT and + 70°F inside = 80°F TD

   (b) Building hourly heat loss at design temperatures = 32,000 BTU/HOUR

   (c) Average hourly heat loss during January, based on mean average monthly temp. of + 15°F. = 22,000 BTU/HOUR

   (d) Average daily heat loss = 528,000 BTU/HOUR

6. Total average amount of useful heat obtained daily from the collectors, using 550 sq.ft. of collector area. = 169,315 BTU/DAY

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7. Percentage of daily average building heat loss handled by the solar heating system = 32%

Note:

Collector area was selected to handle 63.5% of total annual energy requirements for heating and domestic hot water.