SOLAR COOKER

TRAINING IN ALTERNATIVE ENERGY
TECHNOLOGIES
SOLAR ENERGY LAB.
UNIVERSITY OF FLORIDA

Designed and Constructed

by

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I. Introduction

Why Solar Energy

Many people in the world have expressed their concern about the worldwide energy crisis which is affecting, and will continue to affect both the industrialized and the developing countries, although at varying degrees. The energy crisis is characterized by the unpredictable high fuel oil prices, as well as by frequent fossil fuel shortages, because of the limited resources.

The energy demands for the industrialized countries in both the urban and the rural sectors can no longer be satisfied by the present conventional energy resources. Partly due to the high costs of the imported fuel oil and also partly due to the dwindling conventional fuel resources, the industrialized countries have little or no choice but to develop alternative energy sources which can either supplement or replace the conventional energy sources, as well as reduce dependence on the unreliable fossil fuels.

Likewise, the present energy demands for the developing countries cannot be satisfied by the present conventional energy resources. The energy crisis in the developing countries is further magnified because of their non-competitive nature with the industrialized countries in terms of their purchasing power. Whereas both the industrialized and the developing countries compete for the same fuel commodity, the industrialized countries have greater purchasing power than the developing countries. Therefore, if the developing countries need to survive the energy crisis, they will have to develop cheap and reliable alternative energy sources in order to supplement or to replace the conventional energy sources.

Furthermore, the developing countries depend on the plant and forest material as the major sources of energy in rural areas. The demand for firewood and charcoal for the rapidly increasing population can no longer be satisfied without the destruction of the general environment. Therefore, there is need to conserve the environment by introducing energy alternatives which can compare favorably with firewood and charcoal, in order to meet the basic fuel requirements for cooking, lighting and heating in the rural areas. Thus solar energy could be the answer.

The aim of the project was to design and construct and solar cooking device (solar oven) which could be adapted to the rural communities to provide the basic energy for cooking in order to relieve the already scarce vegetation. In this design, consideration was made for the following:

(i) Adequate insolation is assured for the most part of the year;

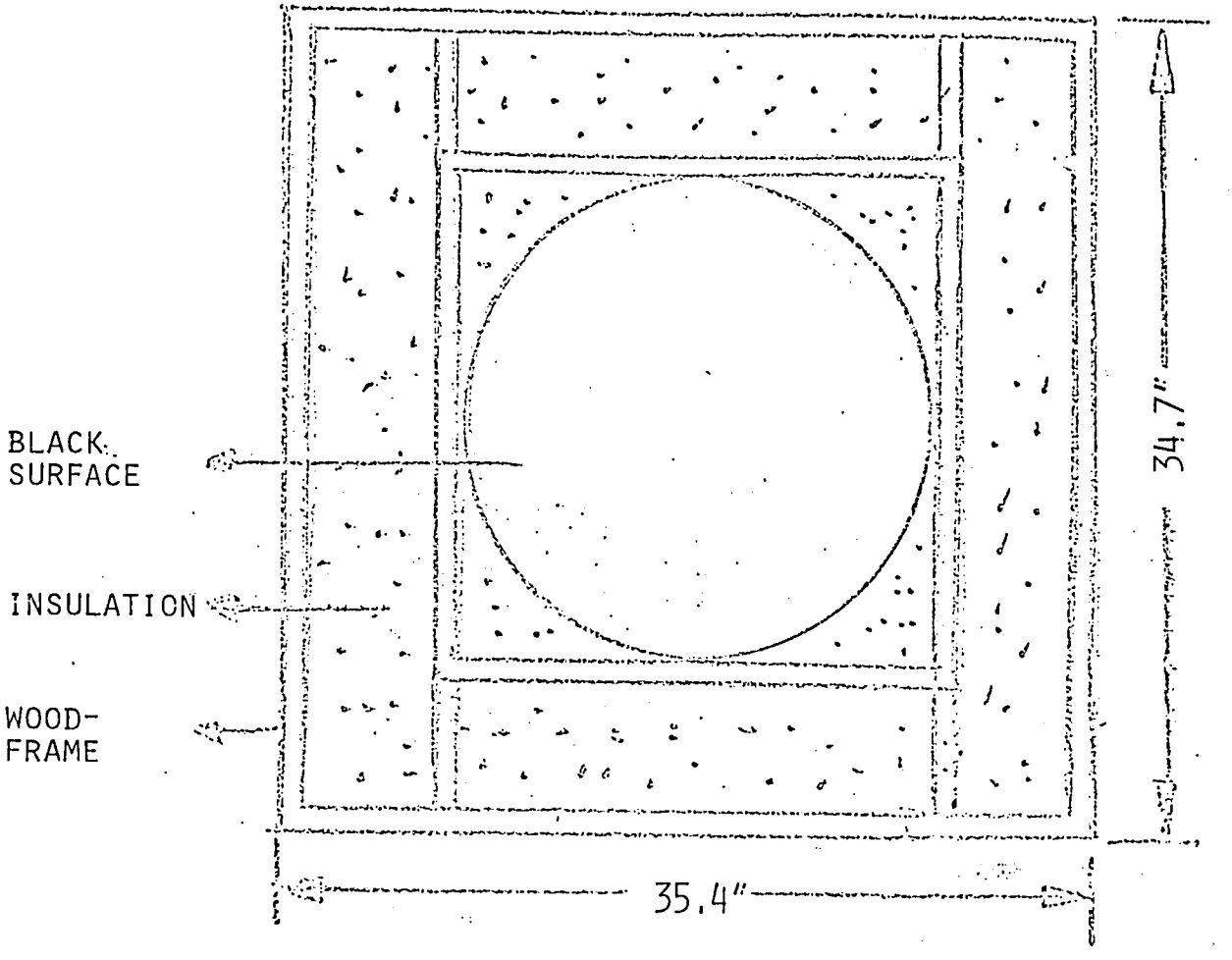
(ii) The cooker (solar oven) can be manufactured from locally available materials and at a reasonable cost;

(iii) It has to compare favorably with the conventional energy sources if it is to be accepted in the existing social structure.

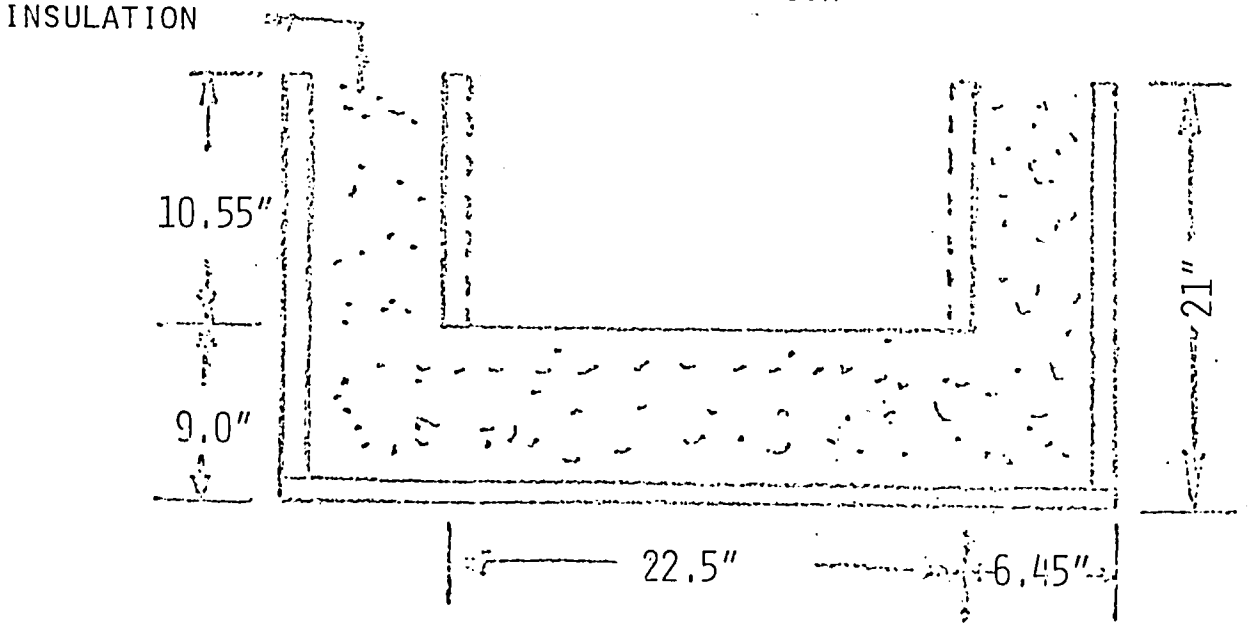
DEVELOPMENT PHASE

DESIGN:

TOP VIEW



CROSS SECTION



2. Measurements and Diagrams

The following tables and diagrams show the temperature evolution due May 4th, May 7th and May 18th, in Gainesville, Florida.

The meaning of the symbols used are:

T_a	ambient temperature
Gl	glass
Ins	inside
Outs., o	outside
Pl	plate
Fr	frame
Bott	bottom

The first two days were relatively cloudy, the last one was a clear [illegible].

The solar radiation was measured with a pyranometer, calibration factor [illegible]. The pyranometer was plugged in a recording [illegible].

The temperatures were measured with 9 thermocouples.

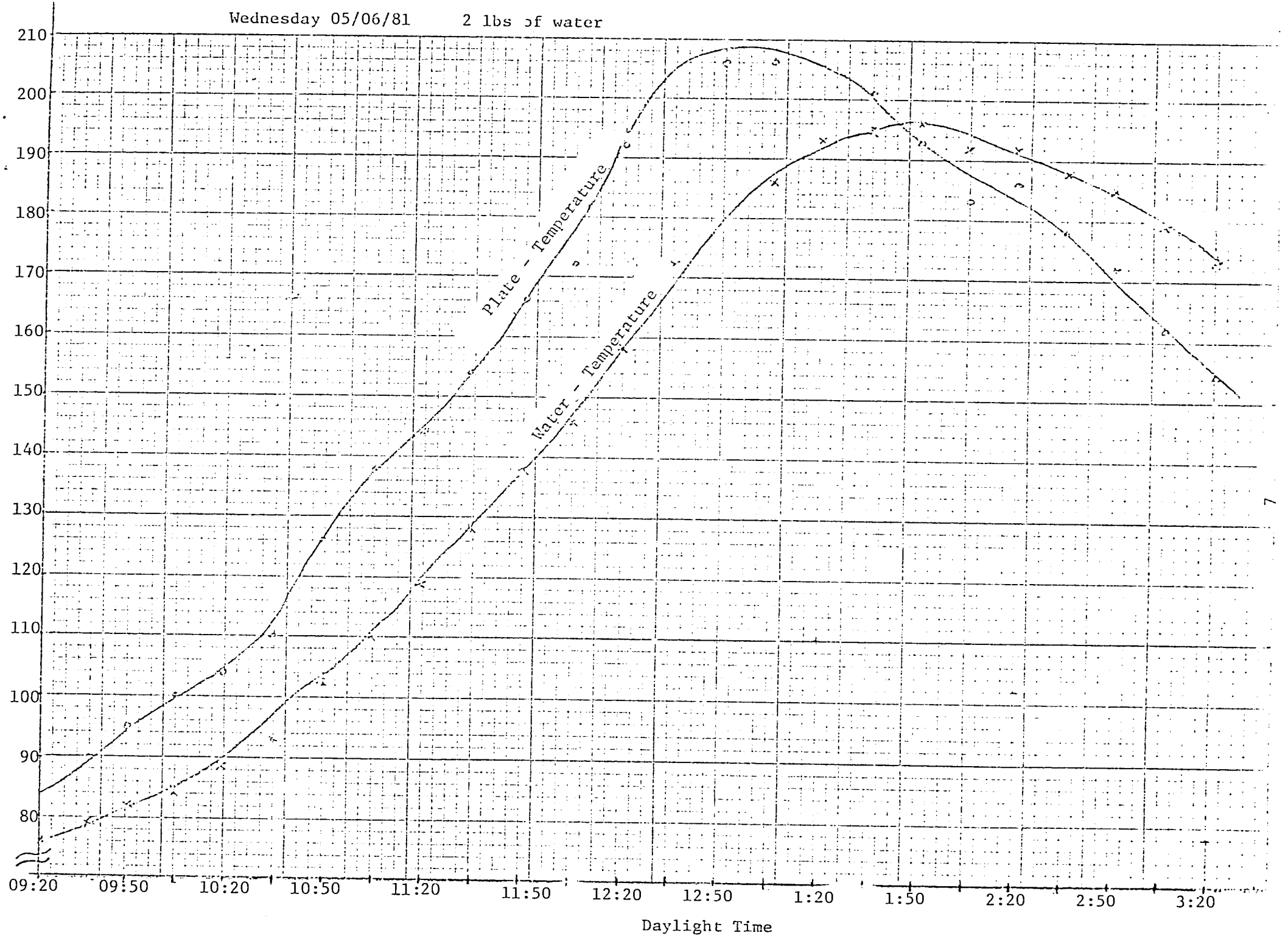
Used Materials

Oil Drum	D = 22.5" (Diameter) L = 10.55" (Height) S = 0.05" (Thickness)
Insulation	Fiberglass "Certain Teed", manufactured by Certain Teed Corporation Valley Forge, PA 19482 USA
Black Paint	"Hi-Heat Resistant" Spray-paint, withstands temperatures up to 1200°F, manufactured by Seymour of Sycamore Inc. 917 Crosby Ave., Sycamore Illinois 60178 USA
Silicone Rubber	60°F up to 450°F
Coverglass	Double glazing, 24.5" X 24.5", non-tempered Air gap between glasses 0.20" Glass thickness 0.125" Pieces of wood 0.75" X 0.75"
Wood frame	Pieces of wood 1.5" X 1.5"
Plywood	0.25" thick, double plywood on top
Nails & Hinges	

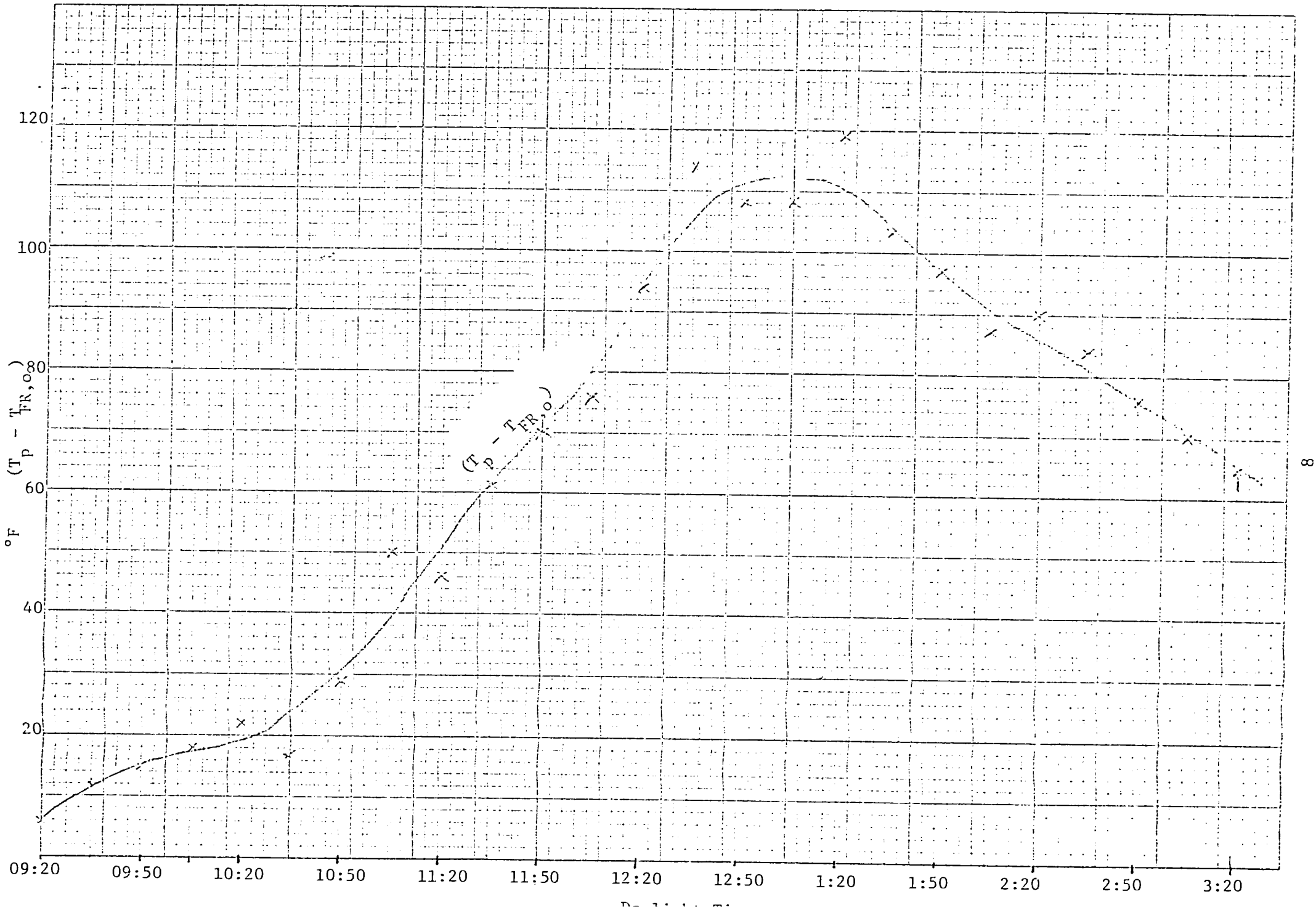
Wednesday 05/06/81
2 lbs of water

Daylight Time	T_A 0	GL ins 1	PL side 2	PL bottom 3	POT outs 4	GL outs 5	POT ins 6	FR bott 7	FR side 8
09:20	74	77	84	84	75	75	76	74	78
09:35	76	84	91	90	78	76	79	76	78
09:50	77	89	96	95	80	78	82	76	80
10:05	79	92	100	100	82	80	84	77	82
10:20	78	96	106	104	86	82	88	77	82
10:35	83	108	128	110	91	88	93	79	93
10:50	86	124	148	126	98	96	102	81	97
11:05	84	128	149	138	108	96	110	81	88
11:20	94	133	154	144	115	103	119	82	98
11:35	85	140	163	154	124	101	128	83	93
11:50	90	148	172	166	134	108	138	84	96
12:05	89	154	77	172	142	110	146	84	96
12:20	98	164	89	192	153	116	158	87	98
12:35	96	176	201	212	168	121	172	88	98
12:50	90	175	201	206	176	119	180	87	98
01:05	94	172	199	206	184	120	186	88	98
01:20	93	180	204	219	190	122	193	88	100
01:35	96	170	198	201	194	120	195	91	98
01:50	94	164	193	193	196	114	196	91	96
02:05	94	158	184	183	193	113	192	90	96
02:20	94	159	184	186	192	113	192	90	96
02:35	92	153	178	178	190	110	188	90	94
02:50	92	148	171	172	186	109	185	90	94
03:05	88	142	162	162	181	107	179	89	92
03:20	87	135	153	154	175	103	173	88	89

Remarks - very cloudy
- very windy

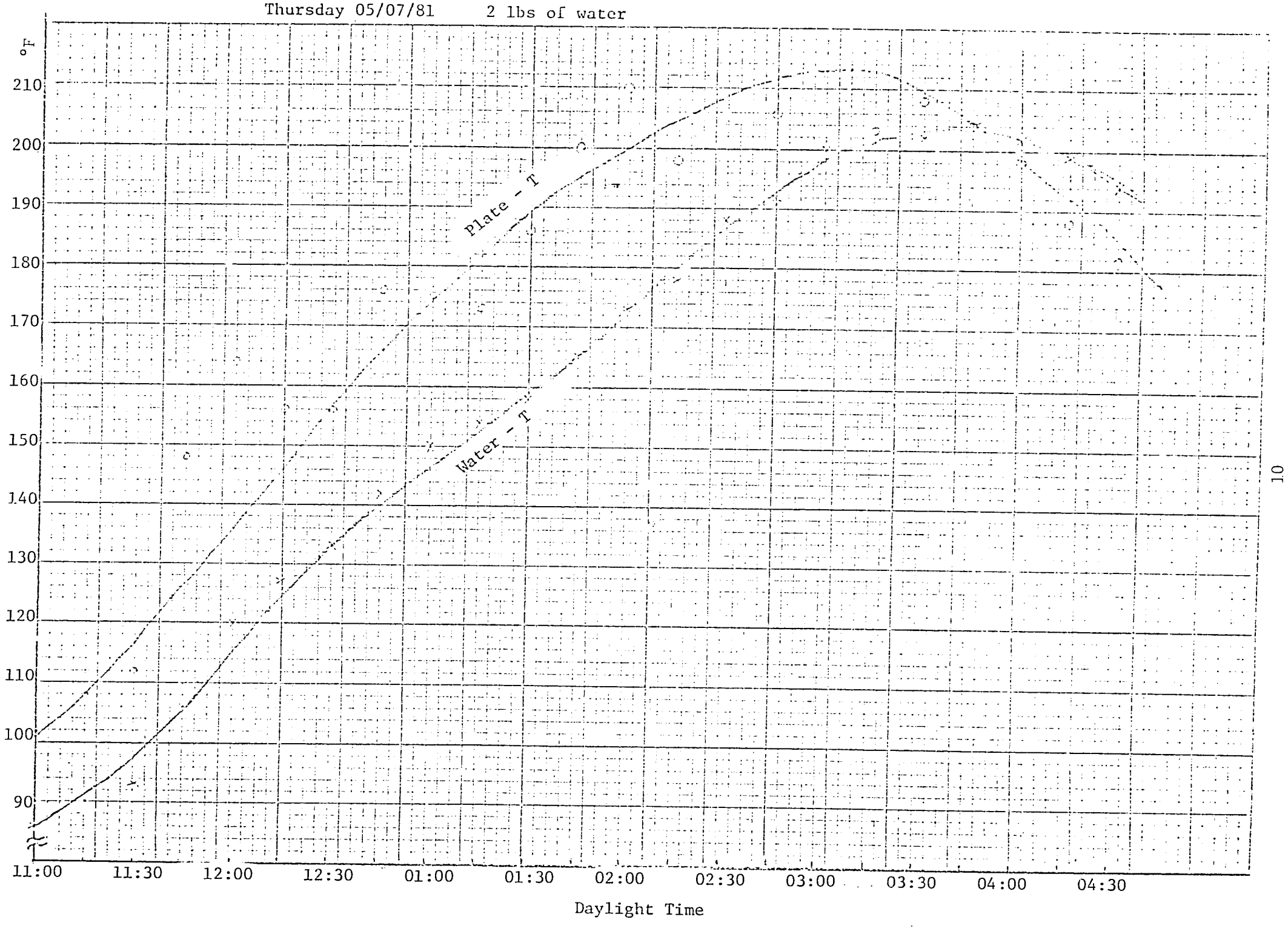

Wednesday 05/06/81 2 lbs of water
Plate - Temperature
Water - Temperature
°F
210
200
190
180
170
160
150
140
130
120
110
100
90
80
09:20
09:50
10:20
10:50
11:20
11:50
12:20
12:50
1:20
1:50
2:20
2:50
3:20
Daylight Time

Wednesday 05/06/81 418.25 °F hr 33.46 sq in

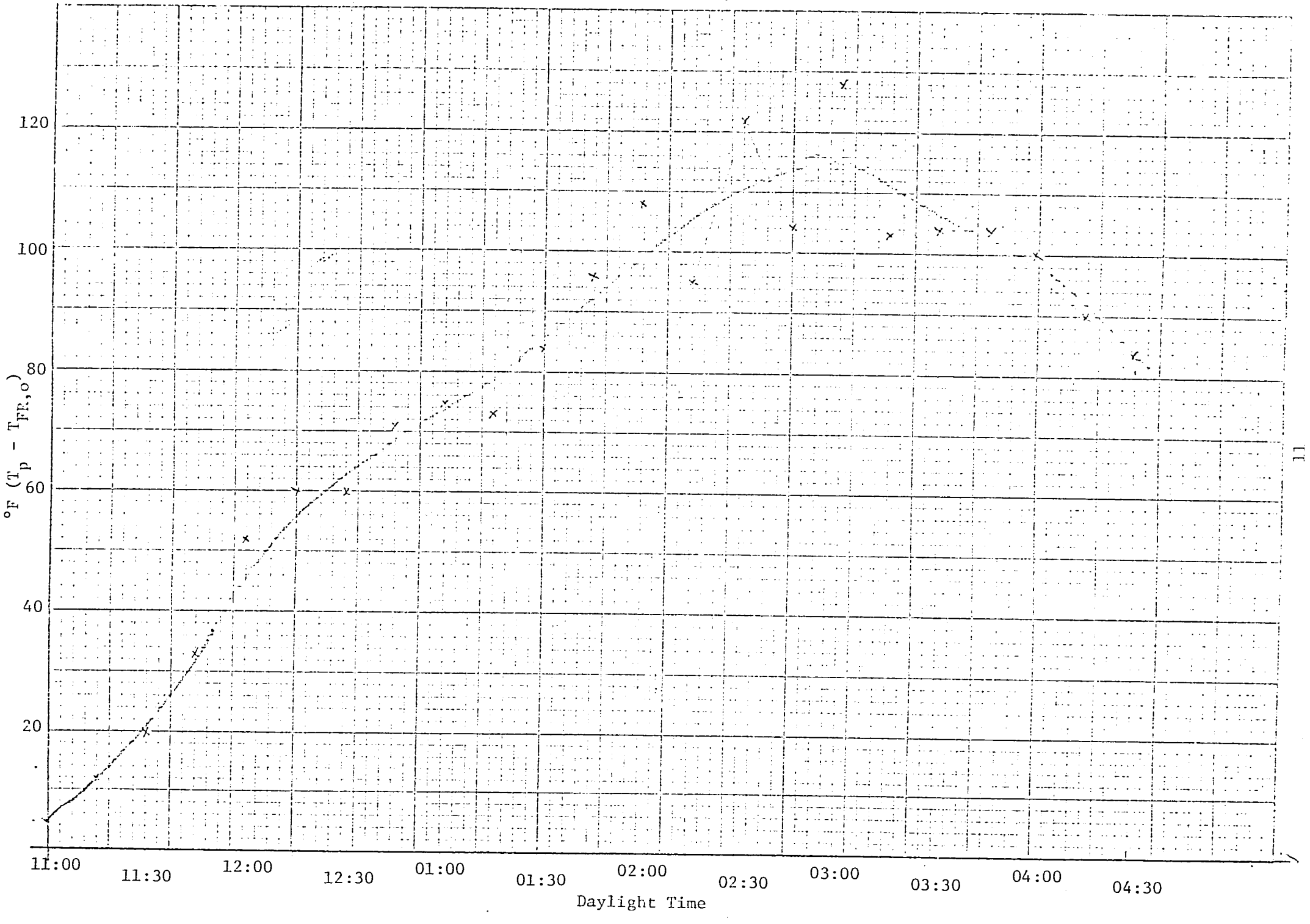


Thursday 05/07/81
2 lbs of water

Time	T_A 0	GL ins 1	PL side 2	PL bottom 3	POT outs 4	GL outs 5	POT ins 6	FR bott 7	FR side 8	T_p-T_{FR}
11:00	82	95	110	101	84	87	86	83	96	5
11:15	86	100	112	108	88	88	90	82	96	12
11:30	83	102	117	112	91	88	93	82	92	20
11:45	90	133	170	148	102	105	106	84	115	33
12:00	88	145	175	164	114	112	120	84	112	52
12:15	84	140	162	156	125	108	127	84	96	60
12:30	88	136	158	156	130	107	133	84	96	60
12:45	96	147	171	176	136	114	142	86	105	71
01:00	90	152	176	175	146	115	150	86	100	75
01:15	90	150	174	173	152	113	154	86	100	73
01:30	96	155	176	186	156	114	158	86	102	84
01:45	104	162	181	200	162	120	165	87	104	96
02:00	108	170	190	210	169	123	173	90	102	108
02:15	94	167	190	198	176	123	178	92	103	95
02:30	110	180	198	226	184	132	188	92	104	122
02:45	90	176	199	206	180	126	192	92	102	104
03:00	100	189	206	232	197	132	200	92	104	128
03:15	90	174	198	203	200	125	201	94	100	103
03:30	108	176	194	208	200	130	202	96	104	104
03:45	90	176	200	204	203	126	204	94	100	104
04:00	90	170	184	198	203	122	202	94	98	100
04:15	90	162	185	188	201	120	199	94	98	90
04:30	91	158	181	182	197	118	194	94	98	84


Thursday 05/07/81 2 lbs of water
°F
210
200
190
180
170
160
150
140
130
120
110
100
90
Plate - T
Water - T
11:00
11:30
12:00
12:30
01:00
01:30
02:00
02:30
03:00
03:30
04:00
04:30
Daylight Time

Thursday 05/07/81 432.5°F hr 34.60 sq in



Monday 05/18/1981, 2lbs of water

Time	T_A	GL ins	PL side	PL bott	POT outs	GL outs	POT ins	FR bott	FR side	$T_p - T_o$	$T_{GL_{in}} - T_{GL_o}$
	°C	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(3)-(8)	(1)-(5)
09:30	80	105	136	107	92	88	93	81	101	6	17
10:00	85	119	155	123	103	89	105	81	105	18	30
:30	87	136	175	142	120	103	122	85	110	32	33
11:00	96	150	192	162	139	113	142	87	116	46	37
:30	98	164	207	185	160	120	163	89	117	68	44
12:00	100	177	220	217	180	127	184	92	116	101	50
:30	97	190	230	227	198	132	202	93	112	115	58
01:00	103	198	236	242	214	140	217	95	112	130	58
:30	105	205	239	248	215	143	219	95	110	138	62
02:00	98	198	219	229	214	131	215	95	106	143	67
:30	98	197	221	235	215	139	218	96	109	126	58
03:00	100	184	212	219	214	131	215	95	106	113	53
:30	103	194	215	235	214	134	216	95	107	128	60
04:00	105	197	214	230	215	136	216	100	108	122	61
:30	100	193	211	224	214	133	215	103	106	118	60

Remarks: very beautiful weather

almost no wind

It took about (12:45 - 09:30) = 3 hr 15' to boil 2 lbs of water.

$$\int_T (T_T - T_o)\, dt = 640°F\ hr$$

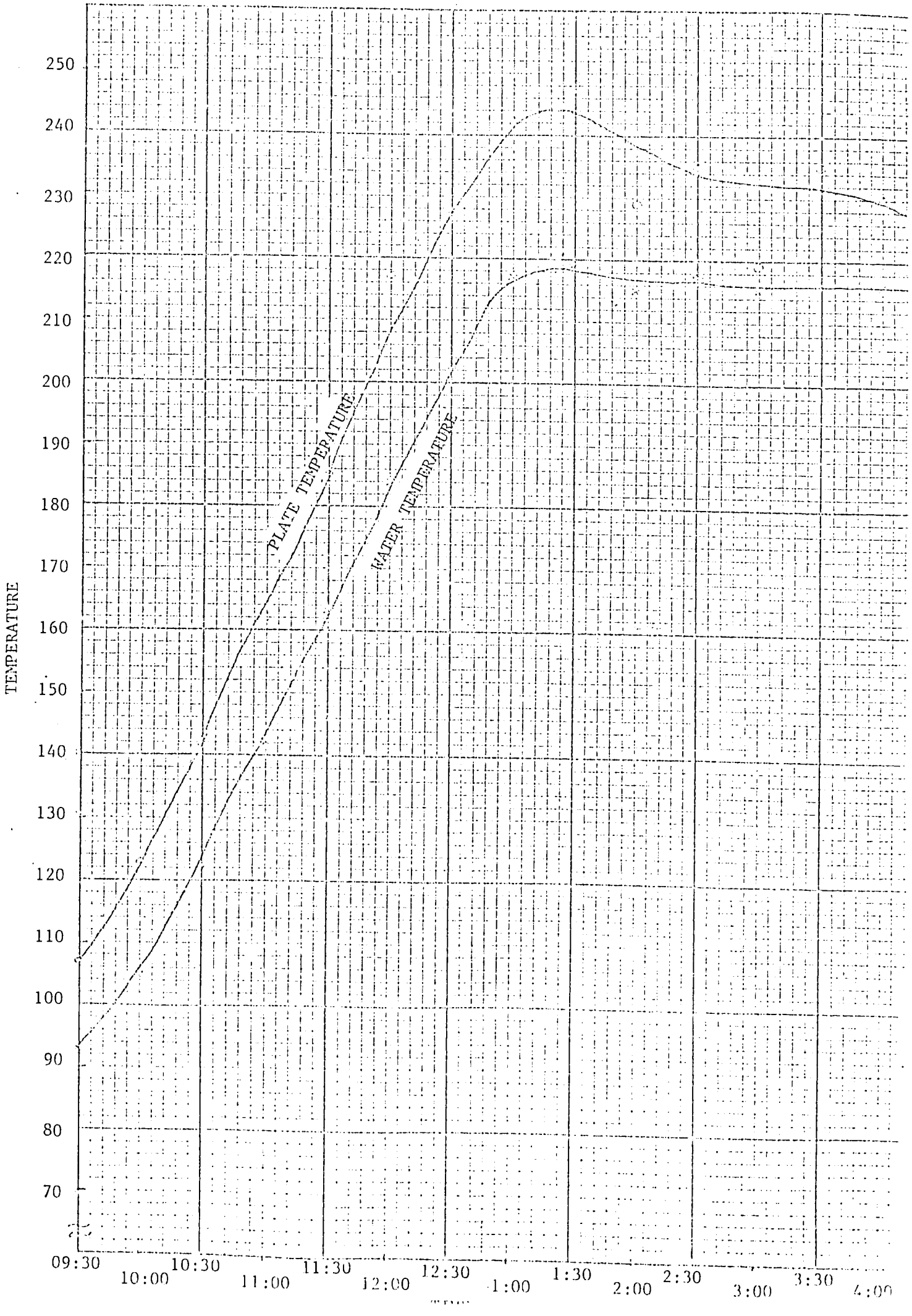
$$\int_T (T_{GL\,i} - T_{GL\,o})\, dt = 360°F\ hr$$

Amount of evaporated water: 2 lbs 11 oz 15/16

- 2 lbs 8 oz 2/16

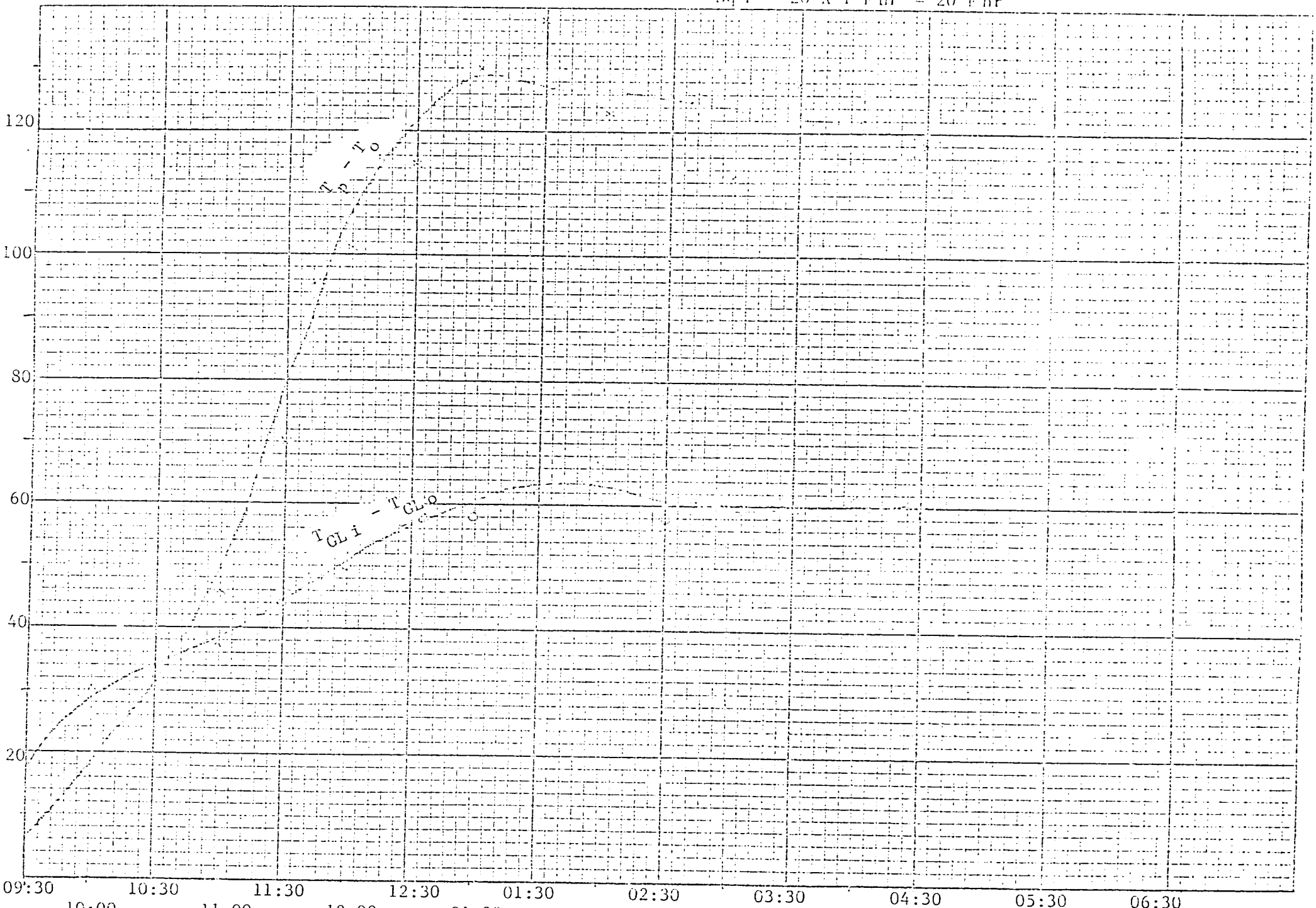
3 oz 13/16

Monday 05/18/81 2 lbs water



Monday 05/18/81 2 lbs water

sq i = 20 X 1°F hr = 20°F hr

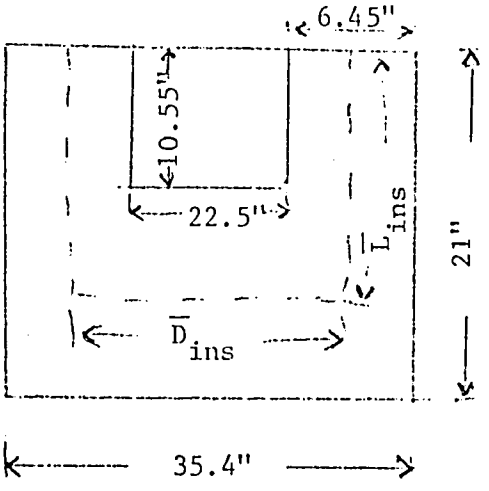


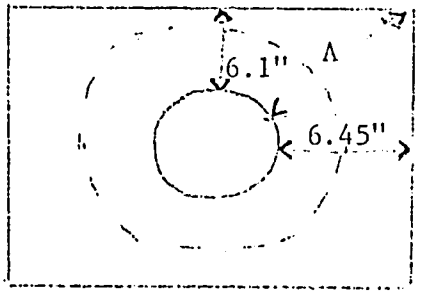
$\int (T_{GL\,i} - T_{GL\,o})dt = 18.0$ sq i

$\int (T_p - T_o)dt = 32.0$ sq i

4. <u>Calculation of the Efficiency</u>

*Average surfaces used





$$\bar{A}_{ins} = \bar{A}(\text{sides} + \text{bottom})$$

$$\bar{A}_{sides} = \pi \bar{D}_{ins}\, \bar{L}_{ins}$$

$$\bar{D}_{ins} = 22.5'' + 2 \times \left(\frac{6.45''}{2}\right) = 28.95''$$

$$\bar{L}_{ins} = 10.55'' + 1/2(21'' - 10.55'')$$

$$= 15.77$$

$$\bar{A}_{sides} = \pi \frac{28.95}{12} \times \frac{15.775}{12} = 9.963 \text{ ft}^2$$

$$\bar{A}_{bottom} = \frac{\pi}{4} \bar{D}^2_{ins}$$

$$= \frac{\pi}{4} \times \frac{28.95^2}{144} = 4.57 \text{ ft}^2$$

$$\bar{A}_{ins} = (9.963 + 4.57) = 14.534 \text{ ft}^2$$

$$\overline{\Delta X}_{ins} = \frac{1}{3} \cdot \frac{1}{12} (6.1 + A + 6.45) \text{ ft}$$

$$\text{with } A = \left(\sqrt{35.4^2 + 21^2} - 22.5\right) / 2$$

$$A = 9.33''$$

$$\overline{\Delta X}_{ins} = \frac{1}{3} \cdot \frac{1}{12} (6.1 + 9.33 + 6.45) \text{ ft}$$

$$\overline{\Delta X}_{ins} = 0.60778 \text{ ft}$$

*The calculations are based on the data of Monday 05/18.

Calculation of Efficiency, η, According to the Data of Monday 05/18/81

Pyranometer used: $11.27 \times 10^{-6}\ V/Wm^{-2} \simeq 88.73\ \frac{Wm^{-2}}{mV}$

$$1\ Wm^{-2} = 0.317\ \frac{Btu}{ft^2\ hr}$$

$$\longrightarrow\ 88.73 \times 0.317 \longrightarrow 28.1278\ \frac{Btu}{ft^2\ hr}\ /\ mV$$

Energy Input

$\overline{Q}_{in} = \overline{9}_s \times A_c \times \tau_{2\ g}$, where $\overline{9}_c$ = average solar radiation (integration with planimeter over the pyranometer graph)

A_c = collecting surface

= $2.76\ ft^2$

τ_{2g} = transmissivity of double glazing,

$\tau_{2g} \simeq 0.8$

The integration yields 64.6 mV hr for the curve over 7 hr 30'

$$\longrightarrow\ \overline{9}_s = \frac{64.6\ mV\ hr}{7.5\ hr} \times 28.1278\ \frac{Btu}{ft^2 hr\ mV} = 242.27\ \frac{Btu}{ft^2 hr}$$

$$\overline{Q}_{in} = \overline{9}_s \times A_c \times \tau_{2g} = 242.27 \times 2.76 \times 0.8 = 534.94\ \frac{Btu}{hr}$$

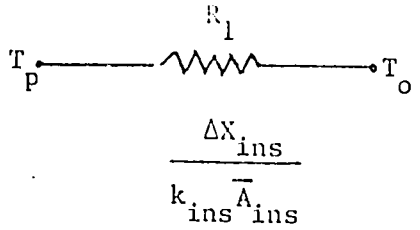
Energy Losses

$\overline{Q}_L = \overline{Q}_{La)} + \overline{Q}_{Lb)}$, where $\overline{Q}_{La)}$ = losses through sides and bottom

$\overline{Q}_{Lb)}$ = losses through front

a) Losses through sides and bottom

Assuming that the black plate temperature T_p inside the stove is uniform, we have the following circuit (T_o = outside temperature, measured on the frame).



$\bar{Q}_{La)} = UA/_{a)}\ \overline{\Delta T}_{a)}$ with

$UA/_{a)} = \frac{1}{R_1} = \frac{k_{ins}\bar{A}_{ins}}{\overline{\Delta X}_{ins}}$

$\overline{\Delta T}_{a)} = \frac{1}{T}\int_o^T (T_p - T_o)\,dt$

$$\left.\begin{aligned} k_{ins} &= 0.033\ \frac{Btu}{hr\ ft\,^\circ F} \\ \bar{A}_{ins} &= 14.534\ ft^2 \\ \overline{\Delta X}_{ins} &= 0.60778\ ft \end{aligned}\right\} \longrightarrow \underline{UA/_{a)} = 0.789\ \frac{Btu}{hr\,^\circ F}}$$

$\overline{\Delta T}_{a)} = \frac{1}{T}\int_o^T (T_p - T_o)\,dt$; $T = 7$ hr

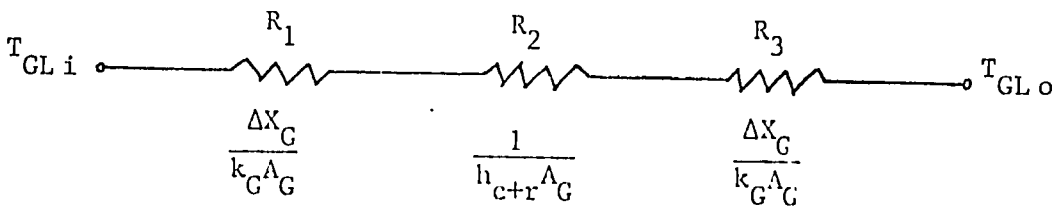
$\int_o^T (T_p - T_o)\,dt =$ (from planimeter)

32.0 sq i $\times\ 20\frac{^\circ F\ hr}{sq\ i} = 640\ ^\circ F\ hr$

$\overline{\Delta T}_{a)} = \frac{640}{7}\ ^\circ F = 91.43\ ^\circ F$ $\bar{Q}_{La)} = 0.789 \times 91.43 = 72.14\ \frac{Btu}{hr}$

b) <u>Losses through the coverglazing</u>

Assuming the losses through front surface = 2.76 ft



Assuming we have no air-leakage, the losses between the inside glass and the outside glass are due to:

- conductivity of the underglass $\longrightarrow R_1$
- free convection between the glasses $\longrightarrow R_2$
- conductivity of the upper glass $\longrightarrow R_3$

$$\overline{Q}_{Lb)} = UA/_{b)} \times \Delta T/_{b)} \text{ , with } \quad UA/_{b)} = \frac{1}{R_1 + R_2 + R_3}$$

$$\Delta T_{b)} = \frac{1}{T} \int_o^T (T_{GL\,i} - T_{GL\,o})\, dt$$

$$\left.\begin{aligned} k\,GL &= 0.59 \frac{Btu}{hr\ ft^\circ F} \\ \overline{A}_{GL} &= \frac{\pi D^2}{4} = 2.76\ ft^2 \\ \Delta\overline{X}_{GL} &= \frac{0.125}{12}\ ft = 0.01042\ ft \end{aligned}\right\} \rightarrow R_1 = R_3 = \frac{0.01042}{0.59 \times 2.76} = 0.006397 \frac{hr^\circ F}{Btu}$$

$$R_2 = \frac{1}{h_{c+r}\ A_G} \quad ; \quad \text{with } h_{c+r} = 2 \frac{Btu}{ft^{2\circ} F\ hr}$$

$$R_2 = \frac{1}{2 \times 2.76} = 0.1811 \frac{hr^\circ F}{Btu}$$

$$UA/_{b)} = \frac{1}{2 \times 0.006397 + 0.1811} = 5.1574 \frac{Btu}{hr^\circ F}$$

$$\Delta T_{b)} = \frac{1}{T} \int_o^T (T_{GL\,i} - T_{GL\,o})\, dt$$

$$\text{Planimeter} \longrightarrow \int_o^T (T_{GL\,i} - T_{GL\,o})\, dt = 18.0\ sq\ i \times 20 \frac{^\circ F\ hr}{sp\ i}$$

$$= 360^\circ F\ hr \text{ , with } T = 7\ hr$$

$$\Delta T_{b)} = \frac{360}{7}\ ^\circ F = 51.43^\circ F$$

$$\overline{Q}_{Lb)} = UA/_{b)} \times \Delta T/_{b)} = 5.1574 \times 51.43 = 265.2377 \ \frac{Btu}{hr}$$

$$\overline{Q}_L = \overline{Q}_{La)} + \overline{Q}_{Lb)} = (72.14 + 265.2377) = 337.378 \ \frac{Btu}{hr}$$

(Losses through coverglazing = 78.6%)

$$\eta = \frac{\overline{Q}_{in} - \overline{Q}_L}{\overline{Q}_{in}} = \frac{534.94 - 337.378}{534.94} = 36.93\%$$

5. Interpretation of the Results

The water - temperature follows the increasing temperature of the black plate. Since water is more inertial than the steel plate, by decreasing radiation, the plate will cool down more quickly than the water. This explains the crossing of the curves of the plate - temperature and of the plate - temperature for May 6th and May 7th.

On May 18th we reached the boiling point of water at about 01:00 p.m. Since the good weather conditions held on, the black plate remained warmer than the water.

The efficiency, $\eta = 36.9\%$ is based on $\overline{Q}_{in} = 5.34.94$ Btu/hr, falling through the double-glazing. If we compute with the energy <u>before</u> going through the double-glazing, we get: $\overline{Q}_{in} = 668.7$ Btu/hr;

$$\eta = \frac{668.7 - 337.38}{668.7} = 49\%$$

6. Rough Cost Estimation

We designed the cooker, using the cheapest and the most easily available materials. These materials should be interchangeable, according to the local features. Hence, the following estimation is valid for Florida/USA.

1/2 Oil drum	$5.--
Insulation (fiberglass)	$8.--
Black paint	$1.--
Silicone rubber	$5.--
Coverglazing, (24.5" X 24.5") X 2	$12.--
Woodframe	$3.--
Plywood	$8.--
Nails, hinges	$3.--
Material cost	$45 ≃ $50.

In this estimation, we didn't include the involved labor cost. This should be made for each country, according to the availability of machines and tools, which may reduce the labor costs.

Conclusion

We have tried to describe the technical features of the solar cooker. We feel that the costs of the cooker should be estimated later in our own countries. The analysis of the fitting - or not - in the social structure of TANZANIA and BURUNDI will follow, as soon as the authors are back in their countries.

We were very pleased with the performance of the cooker. We think that some improvements, like shortening the length of the drum (in order to avoid shadings) or making a bigger air-gap between the glasses, should be tried.

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3. Kreith, Frank and Jan F. Kreider, Principles of Solar Engineering.