Solar Water Collector Hourly Energy Output

Central Solar Water Heaters

Multi-Apartment Residential Buildings in Tel Aviv

by Joseph Nowarski, M.Sc., ME – Energy Conservation Expert

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Abstract

Calculations of solar water collector hourly thermal energy output as part of central solar water heating system with individual 150 liters storage tanks for each apartment in high rise multi-apartment residential building in Tel Aviv.
The energy output at noon is 758 kcal/hr in January and 1,221 kcal/hr in April.
Solar collectors supply 2,647 kWh/year of thermal energy to each apartment, minimum 5.41 kWh/day on an average day in December, maximum 8.53 kWh/day in August.
Hot water supply equivalent at 40°C is 30 liter/hr in December and 81 liter/hr in August at noon, 192 liter/day in January to 500 liter/day in August.

1. Versions

Version 1, 20 January 2022: Solar Collectors Hourly Energy Supply, academia.edu/69468297

2. Glossary

E	thermal energy [kcal] (not kcal/hr)
kcal	kilo-calorie, thermal energy unit
SE	Solar Energy – global solar energy on solar collector tilt angle facing south [kcal/hr,m2]
SWH	Solar Water Heater, in this work domestic solar water heater for residential building, forced circulation

3. Introduction

Solar water heaters must be installed in new buildings in Israel according to the law. Solar water heaters save 5 % of the national electricity consumption [1] and are an important component of the Israeli economy and standard of living. The solar law requires solar water heaters for 9 upper floors of the residential buildings.
The usual solution for residential buildings above 4 floors is a forced circulation system with a central collectors array and individual storage tanks separate for each apartment.
This work is for conditions in Israel/Tel Aviv.

4. Energy Units

This work is in Metric Units. Usually, metric units apply Joule as an energy unit. In this work the energy unit is kilocalorie, the energy required to heat 1 kg of water (1 liter) by 1°C. 1 kcal is equal to 4,186.8 Joule, and 1 kJ to 0.23885 kcal. Application of kcal instead of Joule is very convenient for works involving water heating, as the temperature difference indicates immediately the amount of energy in kcal.

Electric energy is expressed in kWh.

1 kWh is 859.85 kcal and 1 kcal is 1.1630 Wh.

All calculations are for winter time GMT+2 for the whole year, DST is not considered.

5. Solar Water Heater

The solar water heating system selected for this work is Chromagen and consists of the following main parts:

- central collectors array type CR12-B, 1" connections, η=0.75-4.1x = 61.8%, tilt angle 45°
- circulation pump
- individual 150 liters vertical storage tanks H=1070mm, Dia=560mm, all connections ¾", with inside 2.5kW instant backup

Location: Tel Aviv / Israel 32.0929° N, 34.8072° E

6. Tilt Angle

The tilt angle for central solar installations in residential buildings in Israel is 45° [1].

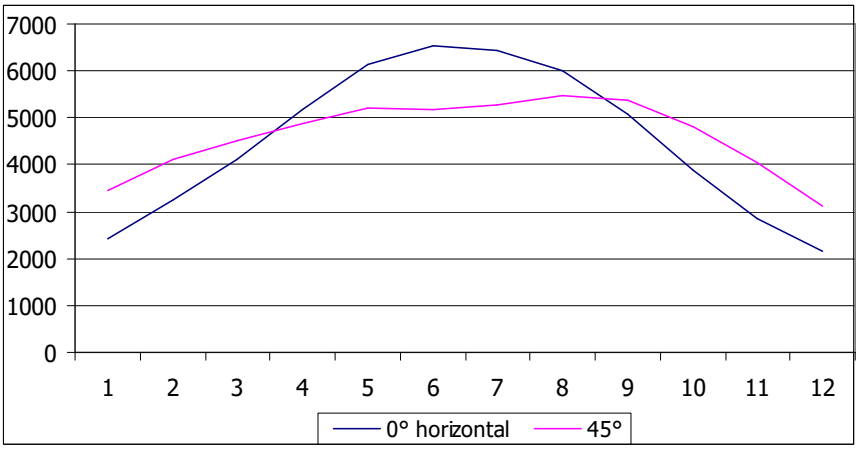
7. Solar Radiation

Solar radiation data for tilt angle 45° in Tel Aviv is from [2].

Table 1 - Solar radiation on tilt angle 45° in Tel Aviv, kcal/m2,day

Tilt	0° horizontal	45°	Δ	Δ
Month	kcal/m2,d	kcal/m2,d	kcal/m2,d	
1	2430	3450	+1,020	+42.0%
2	3260	4120	+860	+26.4%
3	4130	4520	+390	+9.4%
4	5190	4890	-300	-5.8%
5	6140	5200	-940	-15.3%
6	6520	5180	-1,340	-20.6%
7	6440	5270	-1,170	-18.2%
8	5990	5460	-530	-8.8%
9	5080	5380	+300	+5.9%
10	3890	4810	+920	+23.7%
11	2850	4060	+1,210	+42.5%
12	2160	3110	+950	+44.0%
Ave	4507	4621	+114	+2.5%

Chart 1 - Solar radiation on tilt angle 45° in Tel Aviv, kcal/m2,day



8. City Water (Cold Water) Temperature

It is assumed that city water temperature in winter (<+20°C) is 3°C above the average ambient air temperature, and in other periods equals monthly average air temperature.

Table 2 - Monthly averages of city water temperature in Tel Aviv

Month	Ta, °C	Tcold, °C
1	12.07	15.07
2	12.70	15.70
3	14.16	17.16
4	18.04	20.00
5	20.02	20.02
6	23.35	23.35
7	25.15	25.15
8	25.52	25.52
9	24.63	24.63
10	21.84	21.84
11	16.55	19.55
12	13.09	16.09

Ta ambient air temperature, month's average, °C

Tcold cold water (city water) temperature, month's average, °C

9. Heating Energy Formula

Formula 1 - Heating energy

$$E = m * c * \Delta t$$

This formula is well described in publication [2].

10. Storage Tank Stratification

According to [5] the stratification in a vertical storage tank is 10.89°C per 1 meter of the storage tank height.
The inner height of the storage tank applied in this work is 850 mm, resulting in 9.26°C stratification.

11. Selected Solar Collector

The selected solar collector for this work is Chromagen CR12-B [4].
The size of this collector is 7,005 kcal/d, net opening 2.55 m2.
The standard thermal energy output of 1m2 of this collector is 2,747 kcal/d, which according to Israeli law is suitable for 67 liters storage tank.

Table 3 - Selected solar collector

Collector	Q	V	Q/V	Opening
	kcal/d	Liter	kcal/L	m2
CR12-B	7,005	170	41	2.55
For 1 m^2 of collector	2,747	67	41	1.00
For each apartment	6,150	150	41	2.24

The area of solar collectors relevant to each apartment is 2.24 m2 net opening.

Ac = 2.24 m2

12. Hot Water Consumption Daily Pattern

In this work, it is assumed that there is no hot water consumption during solar hours, and 100% of the hot water is used after solar hours.
It is also assumed that the storage tank temperature in the morning equals the city water temperature.
The same assumptions were applied in work [6] to determine the solar collector's hourly efficiency.

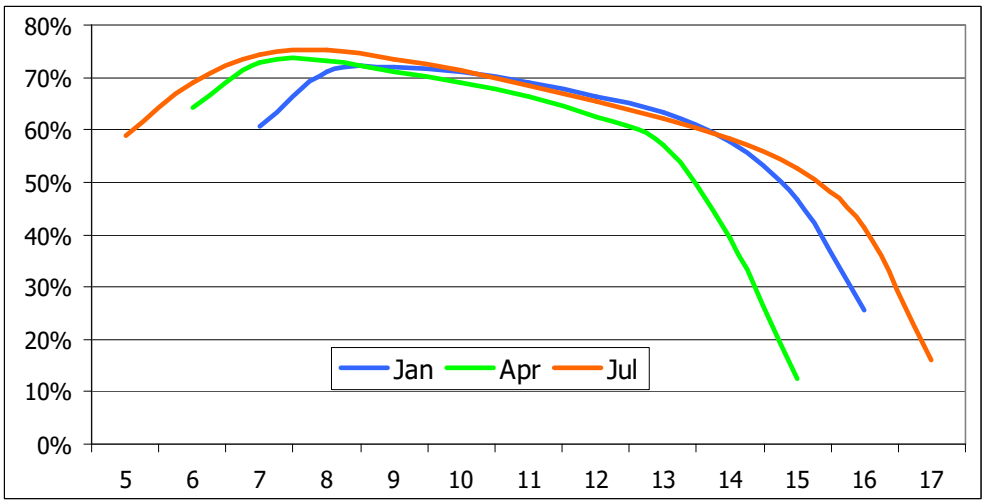
13. Hourly Efficiency of Solar Water Collector

Hourly efficiency of solar water collector is based on the publication "*Hourly Efficiency of Solar Water Collector*" [6].

Table 4 - Hourly efficiency of solar collector

hr	Jan	Apr	Jul	Ave
5			59%	
6		64%	69%	
7	61%	73%	74%	69.2%
8	71%	73%	75%	73.1%
9	72%	71%	74%	72.2%
10	71%	69%	71%	70.5%
11	69%	66%	69%	67.9%
12	66%	62%	65%	64.8%
13	63%	57%	62%	60.9%
14	58%	39%	58%	
15	47%	12%	53%	
16	26%		41%	
17			16%	

Chart 2 - Hourly efficiency of solar collector



Axis x is the hour of the day (winter time).

14. Solar Collectors Hourly Energy Output

Formula 2 - Hourly energy supplied by solar collectors

$$Ei = SEi * Ac * \eta i$$

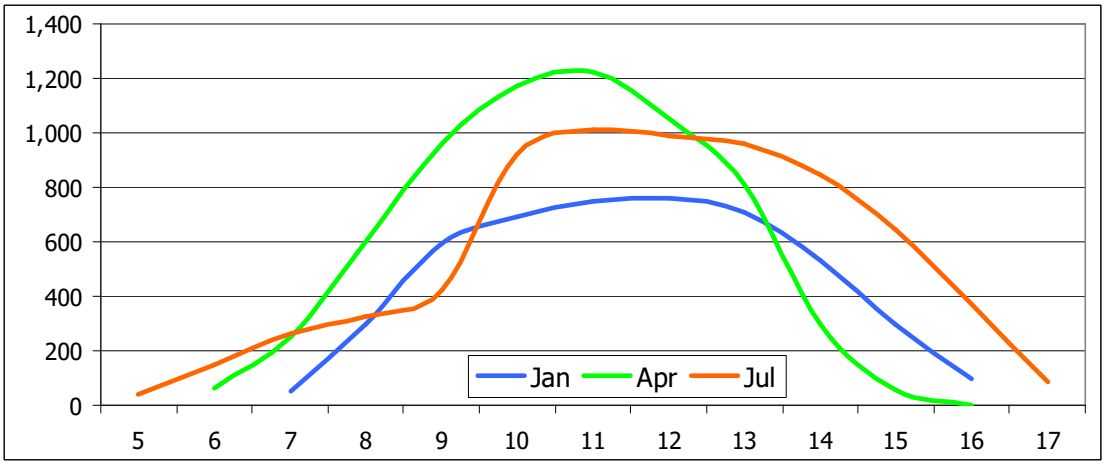
Ei	hourly thermal energy supplied by the solar collectors to one apartment [kcal/hr,apartment]
i	hour from 1 to 24
SEi	Global solar energy on collectors tilt angle facing south, in hour i [kcal/m2,hr]
Ac	collectors area relevant to each apartment = 2.24 m2
ηi	collector efficiency in hour i

Table 5 - Hourly thermal energy supplied by solar collectors, kcal/hr,apartment

hr	Jan	Apr	Jul	Ave
5			41	9
6		62	148	64
7	49	254	262	189
8	298	600	327	434
9	596	958	421	717
10	692	1,173	921	881
11	749	1,221	1,009	948
12	758	1,054	989	944
13	709	809	963	832
14	529	295	847	641
15	297	55	648	379
16	98	0	370	186
17			83	10

Ave is not an average of the selected 3 months, but the average of all months of the year.

Chart 3 - Hourly thermal energy supplied by solar collectors, kcal/hr,apartment



Axis x is the hour of the day (winter time).

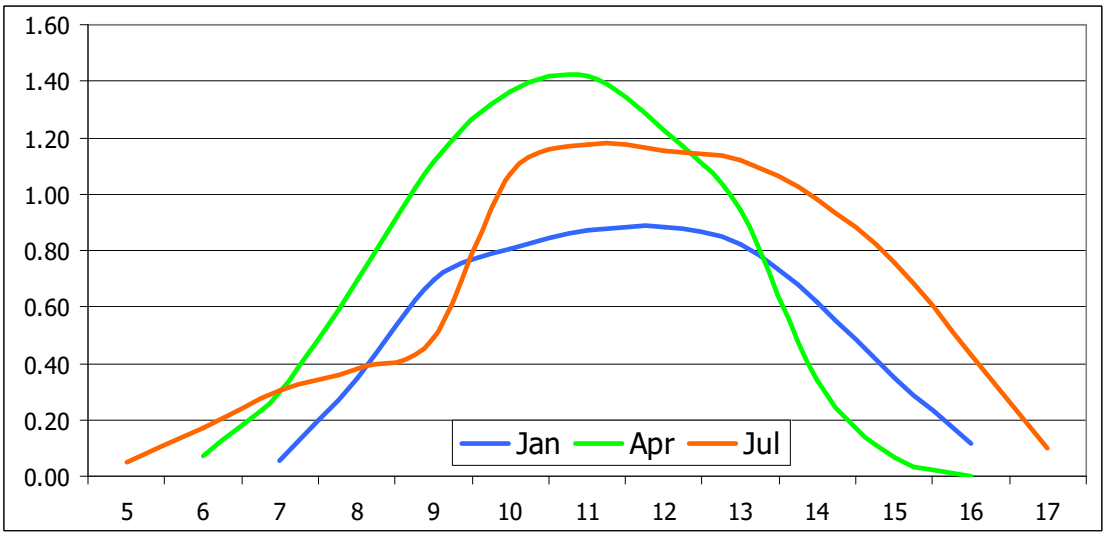
15. Power of Solar Collector Hourly Energy Output

The energy output hourly data may be expressed as energy per hour (like kWh/hr), resulting in power units (like kW).

Table 6 - Thermal energy power supplied by solar collectors, kW/apartment

hr	Jan	Apr	Jul	Ave
5			0.05	0.01
6		0.07	0.17	0.07
7	0.06	0.30	0.31	0.22
8	0.35	0.70	0.38	0.51
9	0.69	1.11	0.49	0.83
10	0.81	1.36	1.07	1.02
11	0.87	1.42	1.17	1.10
12	0.88	1.23	1.15	1.10
13	0.82	0.94	1.12	0.97
14	0.62	0.34	0.98	0.75
15	0.35	0.06	0.75	0.44
16	0.11	0.00	0.43	0.22
17			0.10	0.01
kWh/day	5.6	7.5	8.2	7.3

Chart 4 - Thermal energy power supplied by solar collectors, kW/apartment

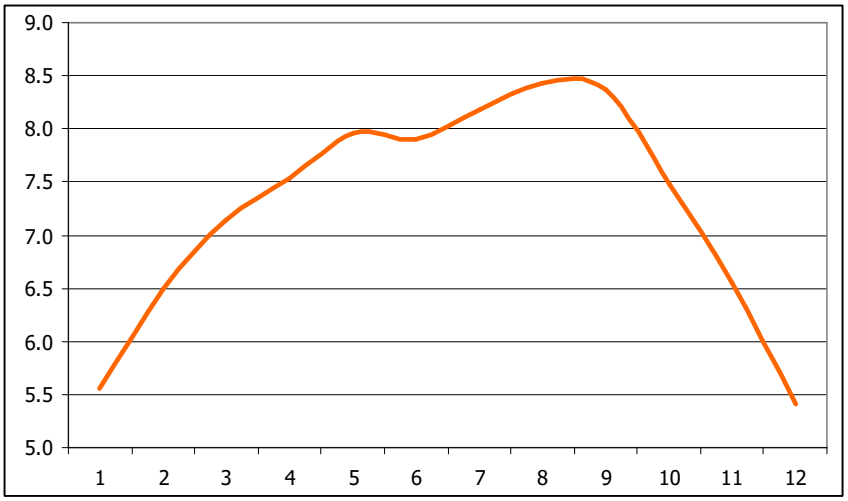


Axis x is the hour of the day (winter time).

Table 7 - Thermal energy supplied by solar collectors per day, kWh/d,apartment

Month	kWh/day
1	5.55
2	6.49
3	7.14
4	7.54
5	7.96
6	7.90
7	8.18
8	8.43
9	8.37
10	7.48
11	6.55
12	5.41
Ave	7.25

Chart 5 - Thermal energy supplied by solar collectors per day, kWh/d,apartment



Axis x is month of the year.

Solar collectors supply 2,647 kWh/year of thermal energy for each apartment having 150 liters storage tank.

16. Hot Water Supply Equivalent

Hot water supply equivalent is the amount of water that could be heated in solar collectors by solar energy, from city water temperature to 40°C.

This parameter is calculated using Formula [1] and considering specific heat of water 1 kcal/kg,°C and water density 1 kg/liter.

Formula 3 - Hourly hot water supply equivalent

$$Qei = Ei / (40°C - Tcold)$$

Qei hourly hot water supply equivalent [liter/hr,apartment]
Ei hourly thermal energy supplied by solar collectors to one apartment [kcal/hr,apartment]
Tcold city water temperature [°C]

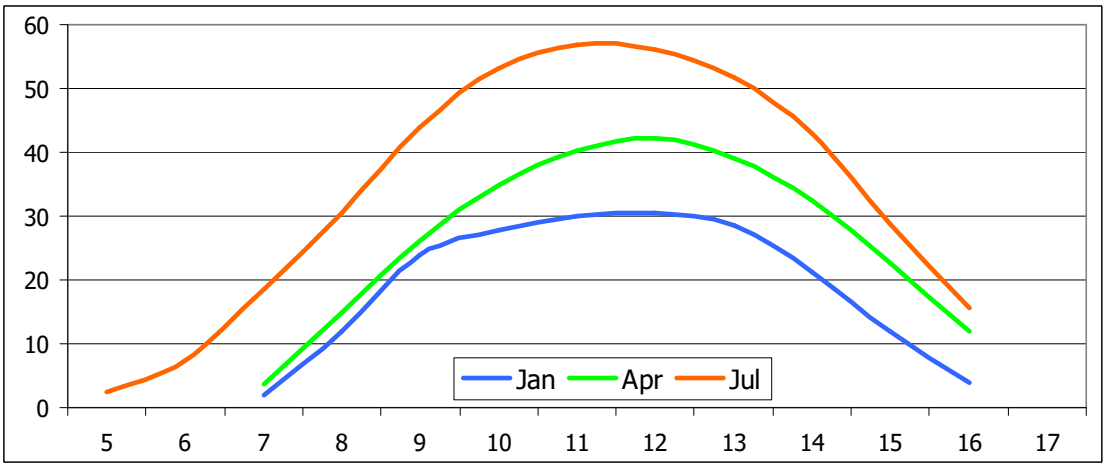
Table 8 - Hourly hot water supply equivalent, liter/hr,apartment

hr	Jan	Apr	Jul	Ave
5			3	1
6			7	4
7	2	4	18	11
8	12	15	31	23
9	24	26	44	38
10	28	35	53	47
11	30	40	57	51
12	30	42	56	51
13	28	39	52	45
14	21	32	43	35
15	12	23	29	21
16	4	12	15	10
17				
liter/day	192	268	408	336

The meaning of this parameter is that the solar collectors can supply 336 liters per day of hot water at temperature 40°C for an apartment having 150 liters storage tank, as

a yearly average, or maximum 57 liter/hr of hot water at temperature 40°C in July at noon.

Chart 6 - Hourly hot water supply equivalent, liter/hr,apartment

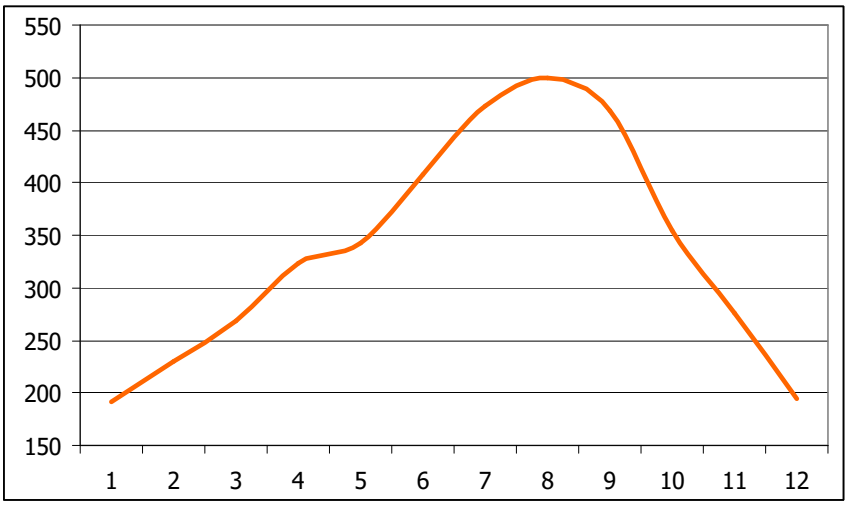


Axis x is the hour of the day (winter time).

Table 9 - Hot water supply equivalent, liter/day,apartment

Month	liter/day
1	192
2	230
3	269
4	324
5	343
6	408
7	473
8	500
9	468
10	354
11	275
12	194
Ave	336

Chart 7 - Hot water supply equivalent, liter/day,apartment



Axis x is month of the year.

17. References

1. Solar Israel – A practical and legislative model – Joseph Nowarski, Renewable Energy World, March-April 2000, p93-99

2. Energy Balance of Solar Water Heaters – Joseph Nowarski, academia.edu/34457200

3. Heat Transfer in Solar Water Heaters Pipes – Joseph Nowarski, academia.edu/34459205

4. Chromagen Solar Thermal Systems chromagen.co.il, chromagen.com

5. Experimental Measurements of Hot Water Stratification in a Heat Storage Tank iopscience.iop.org/article/10.1088/1757-899X/471/2/022014

6. Hourly Efficiency of Solar Water Collector – Joseph Nowarski, academia.edu/59825918

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