The electric function, solar energy and efficient water heating

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1. Introduction

In Uruguay much energy is used for water heating purposes. Most frequent energy sources are Joule effect electricity (JUL) and gas combustion, while renewable energy sources are seldom used. The usual requirements on solar heating systems (generally thermo-siphon systems TS): a) collectors should face the equator, b) they should be inclined conveniently, c) shadows, when sun is on, should be minimized, are minimal barriers when compared to the daily, seasonal and weather generated variations in solar irradiance. To lift these barriers implies to have at our disposal an auxiliary source and a thermally insulated hot water storage

Less used still, than TS, are the heat pump water heating systems (HPWH or HP), although their recognized ability to extract "cold BTUs" from ambient and transform them into "hot BTUs". Two versions of the HP will be studied; the AHP with ambient air as the cold source and the SHP with ambient air preheated by the sun as the cold source.

In this paper a comparison of the four ways of heating water JUL, TS, AHP and SHP, in their electricity requirements is made. Results presented, are specific electricity consumption, economical behavior, greenhouse gas generation and lost of load probability.

Twenty cities around the world have been studied. Results from Australia are in good accord with values from [Lu Aye et al. (2002)].

2. Simulation models

A international standard [UNIT-ISO 9459-2, (2009)] was used to simulate our Solar system TS. It establishes test procedures for characterizing the performance of solar domestic water heating systems with 600 liters storage capacity or less, operated without auxiliary boosting, and for predicting annual performance in any given climatic and operating conditions, but only for one evening draw –off.

A "black box" approach is adopted which involves no assumptions about the type of system under test; the procedures are therefore suitable for testing all types of systems, including forced circulation, thermo-siphon, freon-charged and integrated collector-storage systems.

To adjust the model to our needs, an ideal auxiliary Joule effect electric heating system is added at the end of the line, that instantly complement the heat required to fulfill our temperature requirements.

Two strategies are suggested by the standard, to manage the hot water daily demand; temperature limited (MOLTEM, variable daily volume draw-off with a constant temperature) or volume limited (MOLVOL variable daily temperature draw-off with a constant volume extraction).

The MOLVOL strategy was selected, controlling the overheating temperature (Tmax) and the auxiliary heat

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activation temperature (Tctrl).

The heat pumps were modeled using the Carnot theoretical efficiency, adjusted by a technological factor (f_{HPWH}).

3. Locations and weather data

Twenty cities from all latitudes and climates were chosen. Satellite meteorological data, at our disposal, through Internet, from **Surface Meteorology and Solar Energy** [NASA; 2010] and the **Australian Government Bureau of Meteorology** [AGBM; 2010] were used. Daily series of maximum temperatures, minimum temperatures and global solar irradiation on horizontal plane, from the years 2000, 2004 and 2010 were examined and annual averages are shown in table 1.

Table 1

Satellital Meteorological Superficial Average Annual Data							
cities	latitude	longitude	Tmin (℃)	Tmax (℃)	Tm (℃)	H ($kJ/m^2/day$)	H ($kWh/m^2/day$)
Anchorage (2000)	61°13' N	149°54' W	-5	3	-1	9.891	2,75
Estocolmo (2000)	59°19' N	18°03' E	6	10	8	10.254	2,85
Edimburgo (2000)	55°57' N	3°11' W	5	12	8	8.727	2,42
Beijing (2000)	39°54' N	116°24' E	7	17	12	15.631	4,34
Sevilla (1990)	37°23' N	5°59' W	14	23	18	18.025	5,01
Jerusalen (2004)	32°00' N	35°00' E	14	24	19	18.786	5,22
Florida (2004)	28°00' N	81°00' W	20	24	22	17.486	4,86
Caracas (2000)	10°29' N	65°54' W	23	27	25	21.793	6,05
Darwin (2010)	12°27' S	130°50' E	24	33	28	22.343	6,21
BeloHorizonte (2000)	19°55' S	43°56' W	17	26	21	18.451	5 ,13
Brisbane (2000)	27°28' S	153°01' E	15	26	20	18.974	5,27
Salto (2004)	31°23' S	57°57' W	14	25	20	17.148	4,76
Perth (2010)	31°57' S	115°51' E	12	26	19	21.718	6,03
Sydney (2010)	33°51' S	151°12' E	15	23	19	18.718	5,20
Montevideo (2000)	34°53' S	56°09' W	14	21	17	16.213	4,50
Adelaide (2010)	34°55' S	138°36' E	12	22	17	20.306	5,64
Camberra (2010)	35°18' S	149°07' E	7	20	14	19.605	5,45
Melbourne (2010)	37°48' S	147°57' E	10	20	15	17.679	4,91
Hobart (2010)	42°52' S	147°19' E	8	18	13	17.286	4,80
PuntaArenas (2000)	53°08' S	70°54' W	1	6	4	9.044	2,51

4. Description of simulated systems

4.1 TS

The TS system consists of a solar collector, a hot water storage tank mounted on top, natural thermo-siphon water circulation between them and an auxiliary electric heater in the outlet.

In the MOLVOL operation, the nominal daily draw off volume Vn, is fixed. If the draw off temperature Td at night is less than the control temperature Tctrl, the auxiliary heat is turned on, until this temperature is reached and only then the volume Vn is extracted.

If a Td temperature greater than Tmax is anticipated, then Td is set to be Tmax, to prevent overheating.

The replacement water volume is equal to Vn, but its temperature is low, equal to Tmain. The storage mixture temperature Ts will depend on Vn, the storage volume Vs and the previous storage temperature Ts.

4.2 AHP

The AHP system consists of a heat pump, working between a cold source realized by ambient air, with a temperature Ta, and a hot source at a control temperature T_{HPWH}. The electricity required is calculated with a theoretical Carnot coefficient of performance COP, jointly with a technological factor f_{HPWH}. Day after day a water volume Vn, at the cold main temperature Tmain is heated to the T_{HPWH} temperature. No storage is considered

4.3 SHP

The SHP system consists of a heat pump, working between a cold source realized by ambient air heated by the sun, with a temperature Ta + 15°C, and a hot source at the control temperature T_{HPWH}. The electricity required is calculated with a theoretical Carnot coefficient of performance COP, jointly with a technological factor f_{HPWH}. Day after day a water volume Vn at the cold main temperature Tmain is heated to the T_{HPWH} temperature. No storage is considered.

4.4 JUL

The JUL system consist of an electric heater activated by Joule effect. Day after day a water volume Vn at the cold main temperature Tmain is heated to the T_{HPWH} temperature. No storage is considered.

Table 2

Reference Data for Montevideo		
optical efficiency of solar collectors	FR(τα) (%/100)	0,6967
heat loss by collectors	FRUL (W/°C/m^2)	5,6508
collectors area	Ac (m2)	6
collectors tilt angle	β (°)	35°
superficial azimuth	γ (°)	180°
storage tank volume	Vs (lt)	400
Heat loss through storage walls	Us (kW / K)	0,00338
Montevideo´s longitude	ψ	56°09' 59,15" W
Montevideo´s latitude	φ	34°53' 00,00" S
solar constant	Gsc (kW / m^2)	1,367
albedo	ρ	0,2
nominal daily consumption	Vcn (lt)	270
T control HPWH	T_{HPWH} (°C)	70
T control auxiliar	T_{ctrl} (°C)	70
Tcontrol maxímum	T_{max} (°C)	70
T mains cold water for day n and maximum and minimum temperatures in the year	$T_{main} = \frac{\left(T^a_{\max} + T^a_{\min}\right)}{2} + \frac{0.35\left(T^a_{\max} - T^a_{\min}\right)}{2} \cos\left(\frac{2\pi(n-51)}{365}\right)$	
technological factor of heat pumps AHP y SHP	f_{HPWH}	0,7

5. Specific electricity consumption

5.1 Temperature settings

Specific energy consumption of a water heating system can be defined as the ratio of the electrical energy used to the volume of water heated in the year (kWh / literH2O).

For the TS system, the draw off temperature Td is limited twice, by a maximum temperature Tmax, to avoid overheating, and a control temperature Tctrl to activate the Joule effect in the electric heater, when Td is less than Tctrl.

For the AHP and the SHP systems, the hot source temperature is made equal to the hot water supply temperature $T_{HPWH.}$

For the JUL system the maximum thermostat temperature is set equal to Tctrl and the main cold water temperature is calculated in terms of the maximum and minimum ambient temperatures, T^a_{max} and T^a_{min}, by the formula shown in Table 2.

So a comparison can be carried out Tmax = Tctrl = T_{HPWH}.

5.2 Results and Discussion

In figure 6 and in table 3, our MOLVOL results are displayed. As expected and according to the simplified model adopted, AHPs, not being sun assisted, have a higher specific electricity consumption than the SHPs. On the other hand TS specific electricity consumption may be less, may be in between or may be greater than values for AHP and SHP according to latitude and climatic conditions.

The Uruguayan cities Salto and Montevideo TS consumptions, have higher values than AHP and SHP, escaping a somehow latitude dependent behaviour, as shown in table 3.

Figure 1

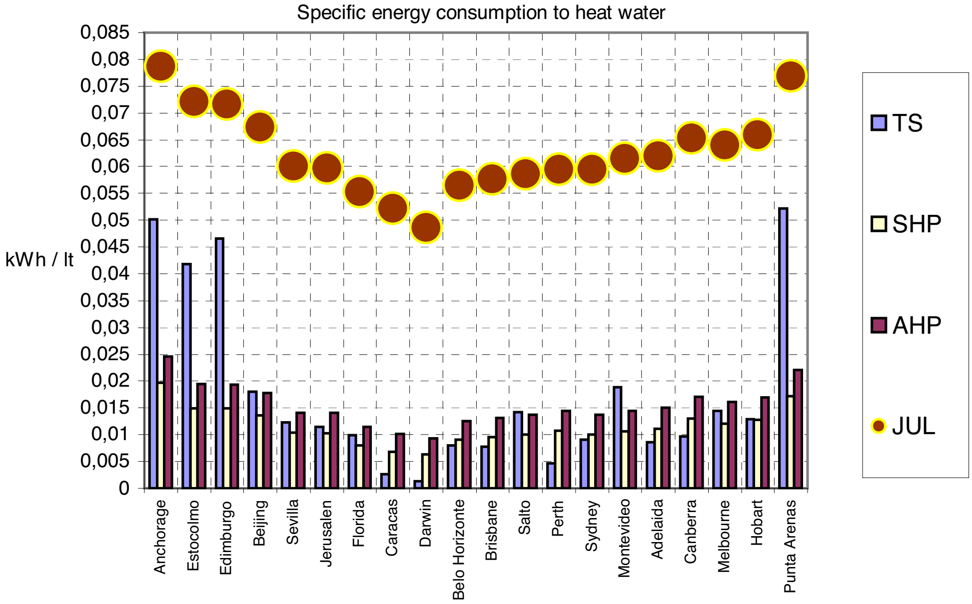

Table 3

Specific energy consumption to heat water (kWh / liter H_2O)

	TS	SHP	AHP	JUL
Anchorage	0,05017	0,01971	0,02463	0,07871
Stockholm	0,04176	0,01491	0,01941	0,07207
Edinburgh	0,04652	0,01490	0,01938	0,07167
Beijing	0,01799	0,01360	0,01781	0,06729
Sevilla	0,01226	0,01034	0,01408	0,06002
Jerusalem	0,01150	0,01032	0,01405	0,05970
Miami	0,00986	0,00800	0,01145	0,05532
Caracas	0,00260	0,00685	0,01011	0,05213
Darwin	0,00128	0,00629	0,00932	0,04855
Belo Horizonte	0,00798	0,00903	0,01256	0,05649
Brisbane	0,00772	0,00959	0,01319	0,05768
Salto	0,01422	0,01007	0,01373	0,05860
Perth	0,00461	0,01075	0,01446	0,05942
Sydney	0,00908	0,00999	0,01370	0,05947
Montevideo	0,01887	0,01060	0,01444	0,06143
Adelaide	0,00858	0,01116	0,01502	0,06191
Canberra	0,00962	0,01299	0,01707	0,06527
Melbourne	0,01445	0,01207	0,01607	0,06404
Hobart	0,01286	0,01283	0,01694	0,06589
Punta Arenas	0,05218	0,01725	0,02205	0,07690

6. Economic evaluation

The following battery of economic methods, that take into account the time value of money, will be used [Rosalie T. Ruegg, et al, (1981)]:

- VA – present value of life-cycle costs method in electricity.
- VAN – present value of net savings method in electricity of TS, AHP and SHP respect to JUL in life cycle.
- VANP – annual value of net savings method in electricity of TS, AHP and SHP respect to JUL in life cycle.
- TIR – internal rate of return method.
- PBK – payback method.
- B / C – benefit/cost method (savings to investment ratio).
- LPC – levelized production cost

Reference calculation was made for a life cycle of 20 years, discount rate of 7.5%, inflation rate of 7.5% and a salvage of 35% at the end of the life-cycle. The price of kWh is 1,6763 URU / kwh for a quotation price of 20 URU / USD. To level the very difficult task of assigning initial costs all over the world, all unit prices were set equal to USD 2000 and its installation cost was estimated in 10% of the unit cost.

The present value of net savings of TS, AHP and SHP respect to JUL, are displayed in Figure 7. In table 4 calculated values with different economic methods are compared for all cities, using a colour code. The technological factor adopted is $f_{HPWH} = 0.7$, which is a reasonable value for this comparison and will be explained in Section 10.4.

The Uruguayan cities Salto and Montevideo have higher HP VANs values than TS, revealing the convenience of using HPs.

Figure 2

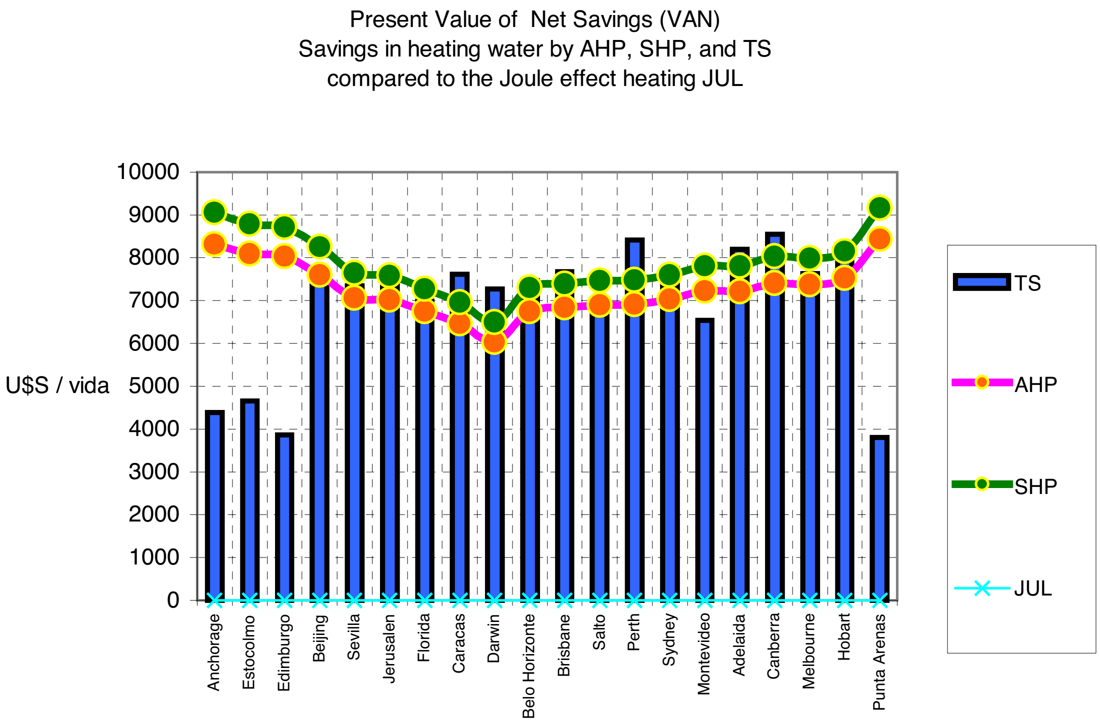

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Table 4

Economical pointers in the water heating process

ciudad	TIR (%)			PBK (años)			Beneficio/ Costo			VA - total actualizado - (U$S/vida)				VAN - actualizado neto - (U$S/vida)			VANP - actualizado neto promedio - (U$S/año)			precio nivelado - U$S/kWh			
	TS	AHP	SHP	TS	AHP	SHP	TS	AHP	SHP	TS	AHP	SHP	JUL	TS	AHP	SHP	TS	AHP	SHP	TS	AHP	SHP	JUL
Anchorage (2000)	17%	32%	32%	11	4	4	2	4,1	4,5	9924	6006	5251	14317	4393	8311	9066	431	815	889	0,069	0,042	0,036	0,099
Estocolmo (2000)	18%	32%	32%	10	5	5	2	4,0	4,3	8638	5204	4512	13296	4658	8092	8784	457	794	862	0,065	0,039	0,034	0,101
Edimburgo (2000)	15%	32%	32%	12	5	5	2	3,9	4,3	9370	5199	4512	13234	3864	8035	8723	379	788	856	0,071	0,040	0,034	0,101
Beijing (2000)	26%	32%	32%	6	5	5	4	3,7	4,1	4986	4958	4312	12561	7575	7604	8249	743	746	809	0,040	0,040	0,035	0,102
Sevilla (1990)	26%	30%	30%	7	5	5	4	3,5	3,8	4106	4386	3810	11444	7339	7059	7634	720	692	749	0,037	0,040	0,035	0,104
Jerusalen (2004)	26%	30%	30%	6	5	5	4	3,4	3,7	3988	4381	3808	11396	7408	7016	7589	727	688	744	0,036	0,040	0,035	0,104
Florida (2004)	24%	29%	29%	7	6	6	3	3,3	3,6	3736	3981	3450	10723	6987	6742	7273	685	661	713	0,037	0,039	0,034	0,106
Caracas (2000)	26%	27%	27%	6	6	6	4	3,2	3,4	2621	3774	3274	10232	7611	6458	6958	747	633	683	0,027	0,039	0,034	0,107
Darwin (2010)	26%	26%	26%	7	6	6	4	3,0	3,2	2417	3654	3188	9682	7265	6028	6494	713	591	637	0,027	0,041	0,036	0,109
BeloHorizonte (2000)	26%	29%	29%	6	6	6	4	3,3	3,6	3447	4151	3609	10903	7455	6752	7294	731	662	715	0,033	0,040	0,035	0,105
Brisbane (2000)	26%	29%	29%	6	6	6	4	3,4	3,6	3407	4248	3695	11086	7678	6837	7391	753	671	725	0,032	0,040	0,035	0,105
Salto (2004)	23%	30%	24%	7	5	7	3	3,3	2,8	4556	4331	4364	10216	5660	5886	5852	555	577	574	0,042	0,040	0,041	0,095
Perth (2010)	29%	30%	30%	6	5	5	4	3,4	3,7	2930	4443	3873	11352	8422	6909	7479	826	678	734	0,027	0,041	0,036	0,104
Sydney (2010)	26%	30%	30%	6	5	5	4	3,5	3,7	3617	4327	3757	11361	7744	7033	7604	760	690	746	0,033	0,040	0,034	0,104
Montevideo (2000)	23%	24%	27%	7	7	6	3	3,5	3,8	5121	4440	3850	11662	6541	7222	7812	642	708	766	0,045	0,039	0,034	0,104
Adelaide (2010)	27%	30%	30%	6	5	5	4	3,5	3,8	3540	4530	3936	11736	8196	7205	7800	804	707	765	0,031	0,040	0,035	0,103
Camberra (2010)	29%	32%	32%	6	5	5	4	3,6	3,9	3699	4844	4218	12252	8553	7408	8034	839	727	788	0,031	0,040	0,035	0,102
Melbourne (2010)	26%	32%	32%	6	5	5	4	3,6	3,9	4441	4691	4076	12062	7621	7372	7986	748	723	783	0,038	0,040	0,035	0,103
Hobart (2010)	27%	32%	32%	6	5	5	4	3,7	4,0	4198	4825	4192	12347	8148	7522	8154	799	738	800	0,035	0,040	0,035	0,102
PuntaArenas (2000)	15%	32%	32%	12	4	4	2	4,1	4,5	10240	5610	4872	14038	3799	8428	9166	373	827	899	0,073	0,040	0,035	0,100
LOGICA DE COLORES	🟨			🟨			🟨			0,5	1	2		0,5	2	1	1	2	1	1	1	1	
	🟨			🟨			🟨			1,5	1	2		1,5	2	1	2	2	1	0,5	1	1	
	🟨			🟨			🟨			2,5	1	2		2,5	2	1	🟪	2	1	1,5	1	1	

7. Greenhouse gas generation

The greenhouse gas generation of a water heating system relies on an estimation of greenhouse gases produced over the lifetime of the system. The total equivalent warming impact (TEWI) is used as an indicator, based in the use of the global warming potential (GWP)(GWP CO_2 = 1),

TEWI = GWP x L x n + GWP x m x (1-α) + n x E x β.

Where L is the leakage rate per year = 10% of m (kg / year), n is the system operating time = 20 years, m is the working fluid charge = 1.5 kg, α is the recycling factor = 70%, E is the energy consumption per year (kWh /year), β is the CO_2 emission per kWhe (kg CO_2/kWhe) (in table 5).

The TEWI high value for Melbourne, results from an elevated emission β = 1,5085 kg CO_2 / kWhe, related certainly with an electric energy generation based in carbon combustion.

The TEWI value for Uruguayan cities Salto and Montevideo were calculated using the CO_2 emission value for Uruguay, β = 0,47 kg CO_2 / kWhe [Claudia Cabal el al., 2007]. It is a low value due to a country´s extensive hydraulic electric generation.

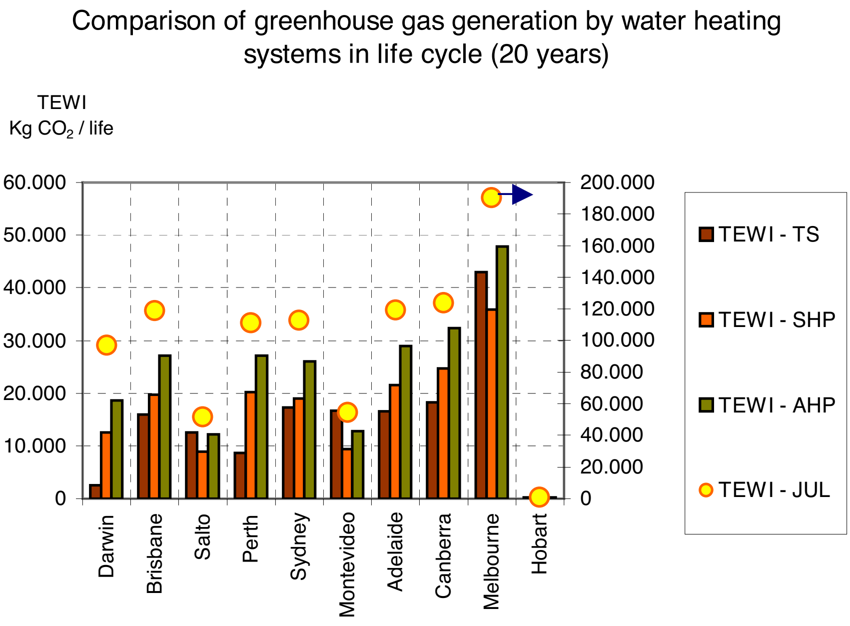
Hobart on the other side has an extremely low value β = 0,072 kg CO_2 / kWhe.

The first two terms indicate direct global warming potential, while the third term indicates indirect global warming potential from the electric energy generation. In general, the highest proportion of the global warming effect of a water heating system, can be attributed to the indirect carbon dioxide emission from the electric energy generation

Tabla 5

Greenhouse gas generation by water heating systems - kg CO_2 / vida					
β (kg de CO_2 / kWhe)		**TEWI - TS**	**TEWI - AHP**	**TEWI - SHP**	**TEWI - JUL**
1,0116	Darwin	2.586	18.633	12.588	96.843
1,044	Brisbane	15.921	27.184	19.772	118.736
0,447	Salto	12.568	12.135	8.910	51.672
0,9504	Perth	8.676	27.123	20.173	111.340
0,9612	Sydney	17.247	26.005	18.969	112.715
0,447	Montevideo	16.667	12.760	9.380	54.165
0,9756	Adelaide	16.541	28.932	21.498	119.093
0,9612	Canberra	18.257	32.375	24.653	123.701
1,5084	Melbourne	42.990	47.815	35.926	190.430
0,0072	Hobart	224	282	223	976

Figure 3



8. Lost of load probability by the sun

The daily TS model allows to count the days, from the 365 of the year, in which Td does not reach the control temperature Tctrl and therefore the electric auxiliary heater has to be turned in. Some hints to understand results shown in figure 11 and table 6 are the following:

- thermostat temperature is Tctrl = 70 °C, hence higher temperatures are never reached,
- latitude influence is clearly seen,
- only draw offs Vn less than the storage volume Vs allow some solar heat collected in the day to be used in the next day, reducing the need to light the auxiliary the next day.

The auxiliary heat is evaluated summing for those days, the heat required to reach Tctrl from Td. The different electric energy needed for this purpose, according the method used, is a result of the different energy mixture required as shown in table 5.

Table 6

TS	Electricity & Sun	Only electricity if sun is off	Similar to JUL
AHP	Electricity & Ambient		
SHP	Electricity & Ambient & Sun	Only electricity & Ambient if sun is off	Similar a AHP
JUL	Electricity		

Table 7

Number of days in the year when auxiliary is turned on

Temperatura Td	Anchorage	Estocolmo	Edimburgo	Beijing	Sevilla	Jerusalen	Miami	Caracas	Darwin	BeloHorizonte	Brisbane	Salto	Perth	Sydney	Montevideo	Adelaide	Canberra	Melbourne	Hobart	PuntaArenas
0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	57	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
10	88	29	17	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42
15	112	89	72	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	95
20	147	119	122	12	0	0	0	0	0	0	0	1	0	0	12	2	3	1	1	141
25	175	153	160	19	15	18	2	0	0	1	1	12	1	3	36	4	7	9	10	201
30	213	177	208	30	33	34	9	0	0	6	5	37	5	8	55	8	13	16	14	253
35	232	201	243	44	65	50	23	1	0	11	9	56	6	18	80	14	23	33	22	285
40	261	220	268	64	98	82	32	2	2	20	21	77	11	32	100	23	33	48	37	313
45	289	238	291	95	119	96	41	5	3	29	34	89	15	43	116	36	49	72	49	331
50	318	270	315	126	142	113	54	11	5	50	52	106	22	58	131	53	59	98	74	347
55	340	289	338	163	161	137	77	17	10	68	74	117	38	83	148	73	79	131	111	358
60	354	311	346	201	184	155	111	31	15	93	96	137	61	118	181	97	102	169	161	359
65	362	346	354	240	192	165	161	52	24	131	117	165	81	156	210	142	148	213	204	362
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

9. Sensitivity Analysis

The system to be selected, will depend on geographic location, available technology and design.

Location is not relevant for Uruguay, as can be seen from similarities between Montevideo and Salto.

However the quality of the heat pumps and the relation between the storage volume Vs and the draw off volume Vn is important.

The quality of the heat pump is modeled by a technological factor defined with the following equations:

$$COP_{HPWH} = \frac{Q^+}{W} = \frac{Q^+}{Q^+ - Q^-} \leq \frac{T^+}{T^+ - T^-} = COP_{HPWH}^{Carnot} \qquad COP_{HPWH} = f_{HPWH} * COP_{HPWH}^{CARNOT} \tag{1}$$

According the value of the technological factor, the dilemma between TS, AHP and SHP is resolved. The JUL option is always rejected.

An election is made between the different options, TS, AHP or SHP, counting the number of economical methods that give the best value to the different solutions.

The winners in the polls are shown in table 7. When the technological factor increases the TS system is slowly being substituted by the SHP, although some cities as Caracas, Darwin and Perth never change.

In our reference calculation, the daily draw off is Vcn = 270 lt,, that implies an equal volume of cold water coming in, to the Vs = 400 liter storage, causing a drop in its temperature by mixture.

In figures 4, 5 and 6 the effect of a variable storage volume Vs is studied for a fixed draw off Vcn = 270 lt.

Singularities occur for Vs near Vd:

- Td has a maximum value
- The energy left in tank for the following day appears (green colour).
- The number of days in which electricity has to be turned in takes a minimum value.

Figure 4

Montevideo´s annual temperature averages as funtion of storage volume Vs
for a constant daily draw off, Vn = 270 lt.

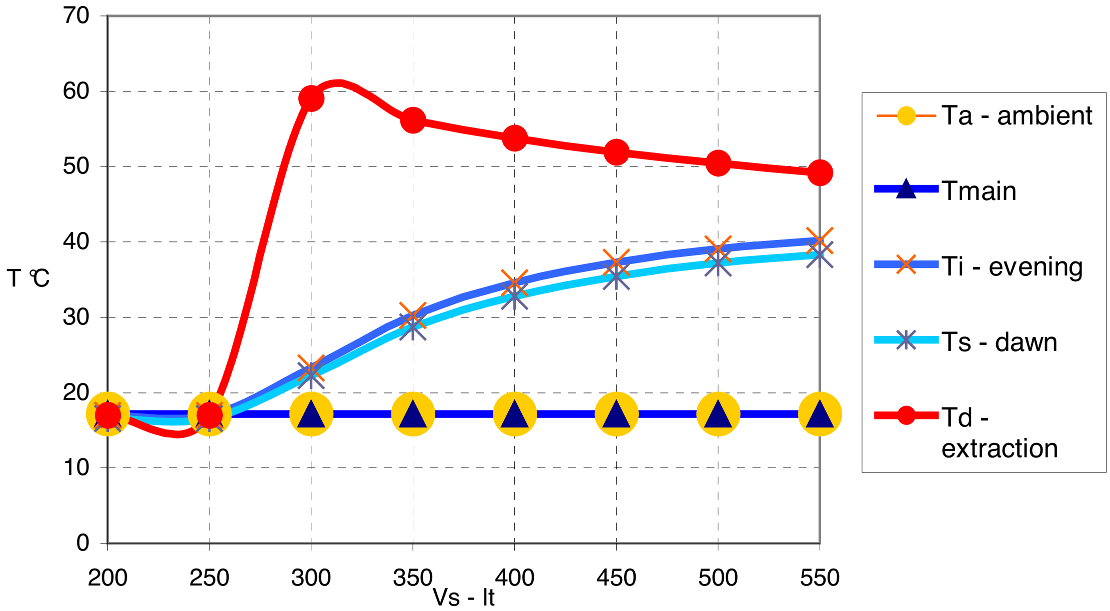


Figure 5

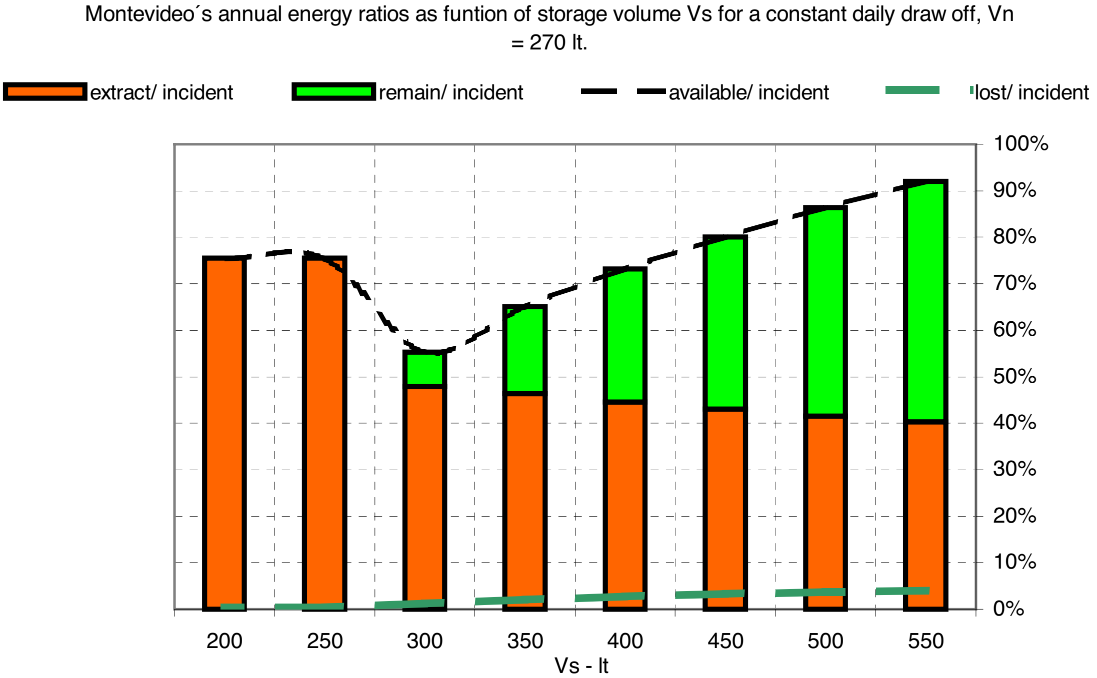

Montevideo´s annual energy ratios as funtion of storage volume Vs for a constant daily draw off, Vn = 270 lt.

Figure 6

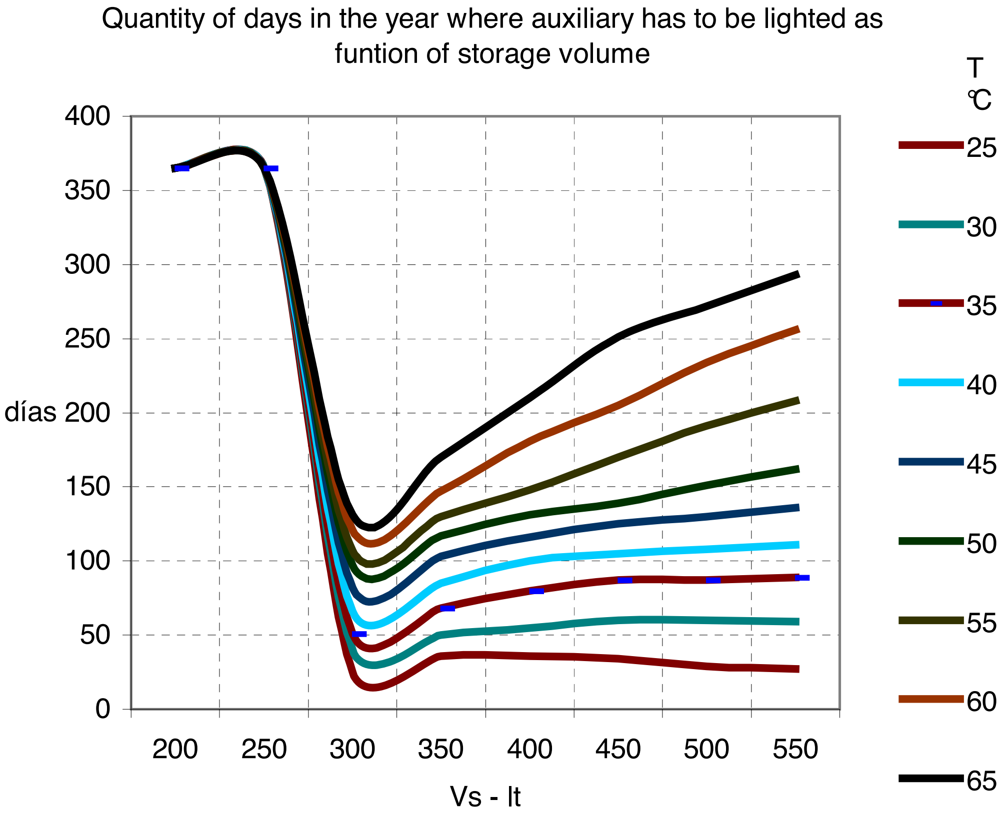

Quantity of days in the year where auxiliary has to be lighted as funtion of storage volume

Table 8

OptimumSolutions according F_{HPWH} (TS - 1 SHP = 4)										
FACTOR - HPWH	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1.0
Anchorage	1	1	4	4	4	4	4	4	4	4
Stockholm	1	1	4	4	4	4	4	4	4	4
Edinburgh	1	1	4	4	4	4	4	4	4	4
Beijing	1	1	1	1	1	4	4	4	4	4
Sevilla	1	1	1	1	4	4	4	4	4	4
Jerusalem	1	1	1	1	1	4	4	4	4	4
Miami	1	1	1	1	1	4	4	4	4	4
Caracas	1	1	1	1	1	1	1	1	1	1
Darwin	1	1	1	1	1	1	1	1	1	1
Belo Horizonte	1	1	1	1	1	1	1	4	4	4
Brisbane	1	1	1	1	1	1	1	1	4	4
Salto	1	1	1	1	4	4	4	4	4	4
Perth	1	1	1	1	1	1	1	1	1	1
Sydney	1	1	1	1	1	1	1	4	4	4
Montevideo	1	1	1	4	4	4	4	4	4	4
Adelaide	1	1	1	1	1	1	1	1	1	4
Canberra	1	1	1	1	1	1	1	1	1	4
Melbourne	1	1	1	1	1	4	4	4	4	4
Hobart	1	1	1	1	1	1	4	4	4	4
Punta Arenas	1	1	4	4	4	4	4	4	4	4

10. Conclusions

10.1 Comparison with Australian cities.

The reference case with $f_{HPWH} = 0.7$, is in good accord with results in the paper by [Lu Aye et al. (2002)]:

- For Darwin, where solar radiation and temperature are high and uniform through out the whole year, the TS system is the most suitable.
- For Melbourne and Hobart the transition between TS and SHP occurs just when f_{HPWH} changes from 0.5 to 0.7. The SHP system is the most suitable.
- For Perth, Canberra, Brisbane, Sydney and Adelaide, TS system is the most suitable.

10.2 Results for other cities.

- For Caracas and Belo Horizonte the situation is the same as for Darwin and Perth and TS is the choice.
- For Anchorage, Stockholm, Edinburgh and Punta Arenas, from as low a value as $f_{HPWH} = 0.3$ the SHP is the most adequate system.
- For Beijing, Seville, Jerusalem and Miami the SHP recommendation begins from a $f_{HPWH} = 0.6$ value.

10.3 Results for Salto and Montevideo.

- The transition from TS to a SHP for Uruguayan cities occur for $f_{HPWH} = 0.4$ to 0.5, a relatively low value, less than the equivalent value for Australian cities of the same latitude.

10.4 The technological factor of heat pumps.

The formulae in (1) define our technological factor based on a Carnot scale going from 0 to 1, where 1 is the ultimate theoretical limit. A more practical situation, shown in figure 7, would be to consider an ideal heat pump, working in a Rankine cycle with an isentropic compressor, with fluid R-134a, operating between a maximum of 70°C and a minimum extending from 0°C up to 40°C. This gives an average $f_{HPWH} = 0.79$ for the Rankine cycle with an uncertainty of 0.06. For that reason our assumption of $f_{HPWH} = 0.7$, for the reference state, equal for AHP and for SHP, seems reasonable.

In regard to the use of R-134a refrigerant, it is considered environmentally friendly and is the natural replacement of R-22.

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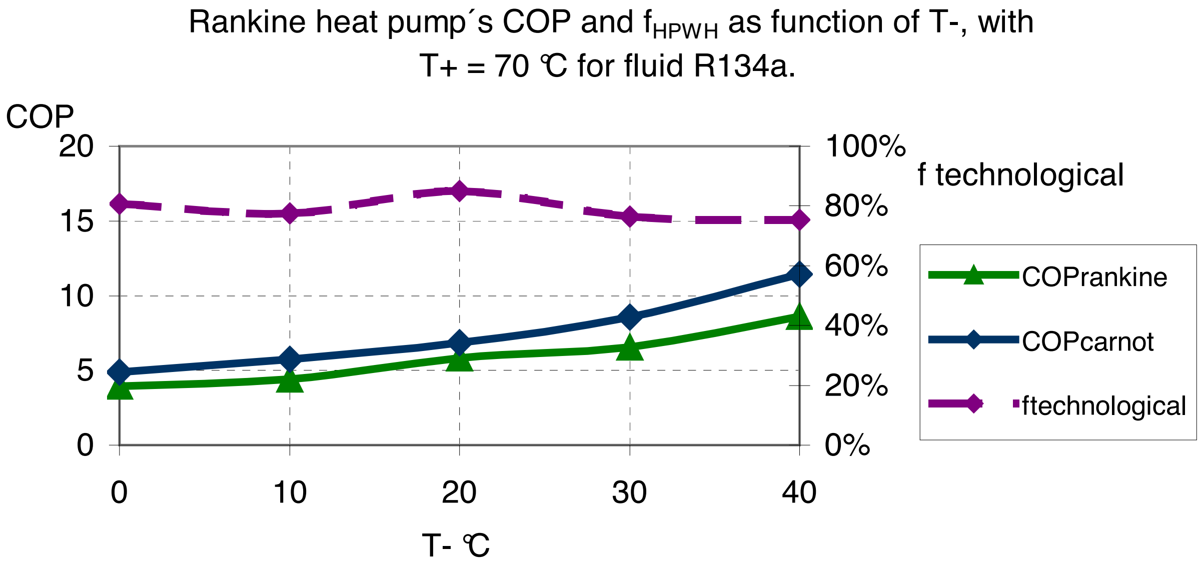
Figure 7



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