ESL-TR-12-04-03

COMPARISONS BETWEEN TRNSYS SOFTWARE SIMULATION AND F-CHART PROGRAM ON POOL HEATING SYSTEM

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April 2012

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EXECUTIVE SUMMARY

The purpose of this report is to test the accuracy of TRNSYS simulation of Solar Pool Heating System by comparing with F-Chart program which is an authoritative tool to analyze solar system and was developed in 1970s.

This report is organized in nine sections. It begins with a brief introduction of Solar Pool Heating System which includes a basic diagram explaining the composition of the system. The detailed simulations of Solar Pool Heating System by TRNSYS and F-Chart are followed with the system input parameter tables and system output results related to system performance. In the next section, the comparison results between TRNSYS and F-Chart are well presented in term of summary tables and plots. To further test the reliability of TRNSYS simulation, four different cases are studied by changing the primary system input parameters. The conclusions and references are listed in Section 5 and 6. Last but not least, Appendix A-C present the detailed the TRNSYS output data for each TRNSYS component in the Solar Pool Heating System, the TRNSYS model by TESS modeling Group and their summary report as well as the working principles of TRNSYS outdoor/indoor swimming pool model type 344.

1 SOLAR POOL HEATING SYSTEM INTRODUCTION

With solar energy widely used as one of primary renewable energy resources, Solar Pool Heating System is adopted by both residential and commercial owners. Figure 1-1 shows a diagram of Solar Pool heating System including solar collectors, pumps, auxiliary heater and controllers, etc. In order to simplify the system, two loops are decided to use, which are solar collector loop and swimming pool loop. The first loop is consist of solar collectors, heat exchanger, controller and one single speed pump while the other loop include auxiliary heater, aquastat (a controlling device), pumps and swimming pool. The algorithm of Solar Pool Heating System is referred to F-Chart manual which says that algorithms for estimating pool monthly energy loss was based on the one developed by Sigworth *et al* in 1979.

In the Solar Pool Heating System, the solar energy is collected by solar collector and delivered through heater exchanger under the temperature difference control from the controller. The delivered useful energy first goes through a diverter and then either enters the auxiliary heater or bypass to the mixer depending on whether the temperature of the flow meets the set point temperature. If the flow temperature is lower than the set point temperature, it will enter the auxiliary heater to be heated up to the set point and then flow out to the mixer. Two flows mixing together from the mixer enter the swimming pool eventually.

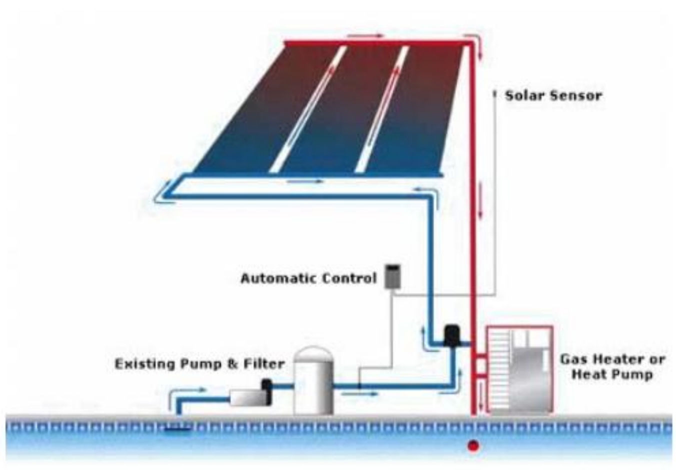

Figure 1-1Solar Pool Heating System Diagram

(Source: http://www.warmwater.com/how_solar_pool_heating_works.aspx.htm)

2 SOLAR POOL HEATING SYSTEM SIMULATION

2.1 F-Chart Simulation

F-Chart is an authoritative computer program which is used to design and analyze solar heating systems including Domestic Water Heating Systems, Pebble Bed Storage Space and Domestic Water Heating Systems, Water Storage Space and Domestic Water Heating Systems, Active Collection with building Storage Space heating Systems, Direct-gain Passive Systems, Collector-Storage Wall Passive Systems, Pool heating Systems, general Solar Heating Systems and integral Collector-Storage Domestic Water Heating Systems (*F-Chart Manual Window Version*). F-Chart method was original developed by Klein in 1976 in his Ph.D. dissertation *(Haberl and Cho, 2004*) which was also the basis for TRNSYS software.

Figure 2-1 reveals Pool Heating System in the F-Chart Manual without detailed information. Therefore, the system diagram was selected based on the descriptions in Section 1.

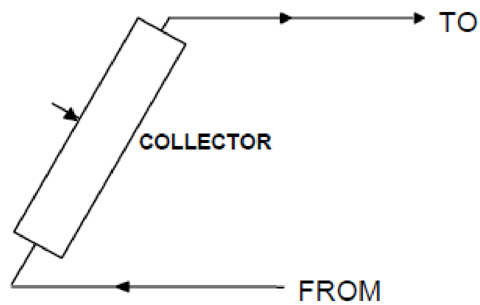

Figure 2-1 Pool Heating System Diagram in F-Chart Manual.

2.1.1 F-Chart input

Table 2-1 shows the input values for an F-Chart Simulation. The weather file for Houston city is selected as the location of the pool system. However, the modified weather file is used instead of original one installed in F-Chart. The reason for that is to minimize the simulation discrepancy due to different weather file in TRNSYS and F-Chart, which can be referred in Solar Domestic Hot Water System report for Comparing TRNSYS software and F-Chart program.

The flat-plate collector and pool system are selected in F-Chart simulation. The detailed input information is listed in Table 2-1 in terms of SI unit. The solar collector is assumed to face south with water inside the collector tubes and the pool is assumed to be outdoor pool without any cover during the simulation period from January to December.

Table 2-1F-Chart Input Values for Pool Heating System

F-CHART INPUT			
Flat-Plate Collector	Number of collector panels	-	1.00
	Collector panel area	m^2	50
	FR*UL (Test slope)	W/m^2 C	6.075
	FR*TAU*ALPHA (Test intercept)	-	0.78
	Collector slope	degree	29.8
	Collector azimuth (South=0)	degree	0
	Incidence angle modifier calculation	-	Values
	Collector flowrate/area	kg/s m^2	0.005
	Collector fluid specific heat	kJ/kg C	4.19
	Modify test values	-	No
Pool Heating System	Location	-	Houston
	Pool Surface Area	m^2	50
	Pool Temperature	C	26.7
	First Month of Season	-	Jan
	Last Month of Season	-	Dec
	Cover	-	None
	Average Pool Depth	m	1.5
	Pool Loacation	-	Outdoor
	% Time Shaded	-	0
	Fuel	-	Elec
	Heater Capacity	kW	23
	Efficiency of Fuel Usage	%	70
	Pipe Heat Loss	-	No

2.1.2 F-Chart output

Figure 2-2 shows the output results from F-Chart simulation for Pool Heating System, which includes the analysis for monthly collected solar energy (Q Coll), monthly solar energy directly absorbed by the pool (Q Pool), monthly load (Load), monthly auxiliary heating energy (Aux), f factor (f) and pool temperature (Pool T).

Thermal Output

	Q Coll [GJ]	Q Pool [GJ]	Load [GJ]	Aux [GJ]	f [ ]	Pool T [C]
Jan	10.02	12.96	59.67	49.65	0.168	26.7
Feb	10.18	14.47	54.13	43.95	0.188	26.7
Mar	14.92	20.45	43.37	28.44	0.344	26.7
Apr	16.56	22.77	26.12	9.56	0.634	26.7
May	13.58	26.85	13.58	0.00	1.000	26.7
Jun	3.86	28.35	3.86	0.00	1.000	26.7
Jul	0.00	28.16	0.00	0.00	1.000	26.9
Aug	3.73	26.46	3.73	0.00	1.000	26.7
Sep	13.25	22.69	13.25	0.00	1.000	26.7
Oct	18.47	20.29	27.31	8.85	0.676	26.7
Nov	13.40	14.77	42.76	29.36	0.313	26.7
Dec	8.74	11.60	61.71	52.97	0.142	26.7
Year	126.72	249.81	349.50	222.78	0.363	

Figure 2-2 Pool Heating System Simulation Resutls by F-Chart.

2.2 TRNSYS Simulation

TRNSYS is a Transient System Simulation tool which can simulate not only instantaneous thermal systems but also building simulations. It is consist of simulation studio and TRNBuild as well as TRNSYS Add-ons, such as TRNFlow, COMIS 3.2, TESS Libraries and TRNSYS 3d for Google SketchUp^{TM} (*TRNSYS 17 Manual*, *2010*). This is user-friendly software, which provides modular image for each TRNSYS component so that the user can easily pick module graphically.

The Solar Pool Heating System is modeled as shown in Figure 2-3. As it mentioned before, the system contains two loops: solar collector and swimming pool loops. The detailed settings for each TRNSYS simulation are shown as follows.

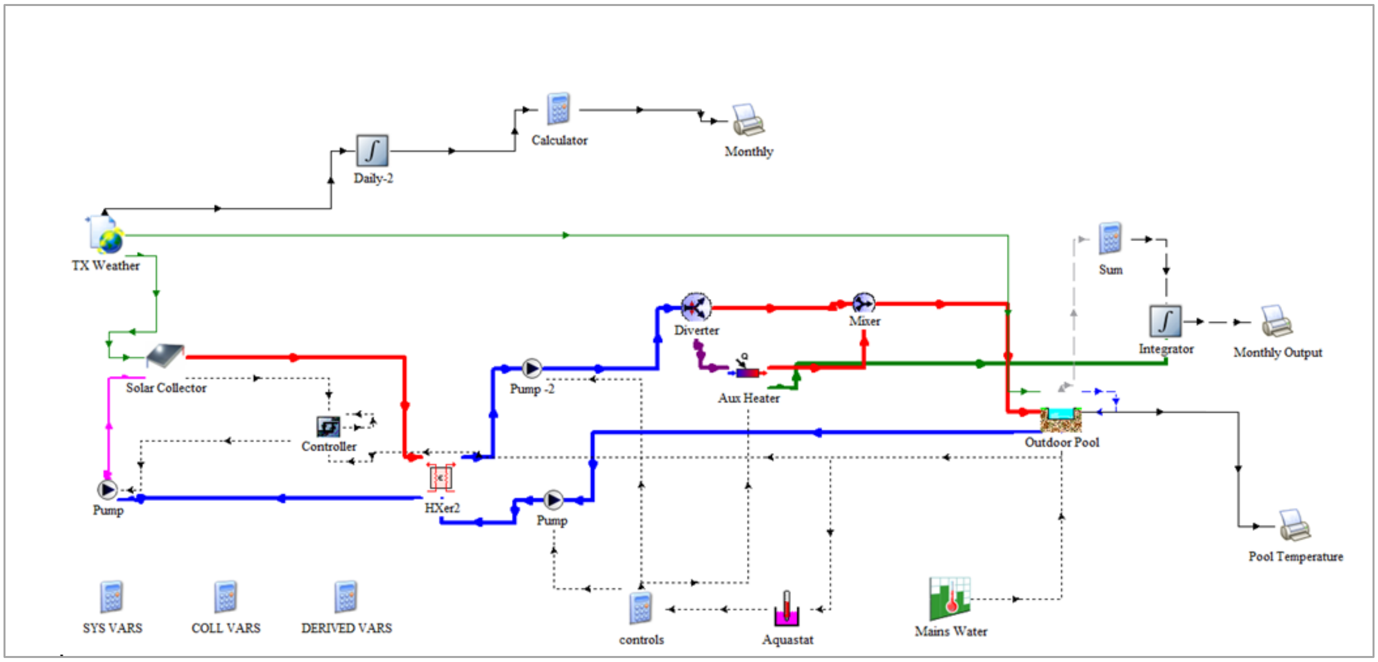

Figure 2-3 Pool Heating System Simulation by TRNSYS

2.2.1 Weather

TMY2 Houston weather file is uploaded and its data is output by TRNSYS Type 15-2 which includes dry bulb temperature, solar radiation, humidity, etc. All the parameters are shown in Table 2-2.

Table 2-2 Weather Input Summary for Type 15-2

Parameter	Value	Unit	Remarks
File Type	2	-	2=TMY2 format
Logical Unit	35	-	The logical unit through which the data reader will read the external weather file
Tilted Surface Radiation Mode	3	-	3=Reindl Model
Ground Reflectance - no snow	0.2	-	
Ground Reflectance - snow	0.7	-	
Number of Surface	1	-	The number of surfaces for which titlted surface radiation calculations will be performed
Tracking Mode	1	-	1=fixed surface (no tracking)
Slope of Surface	29.8	degree	
Azimuth of Surface	0	degree	

2.2.2 Solar collector

The quadratic efficiency solar collector, TRNSYS Type 1-b, is selected with the collector area 50 m^2. The incidence angle modifier data needs to be uploaded through external text file which is 1, 0.999, 0.998, 0.998, 0.981, 0.953, 0.882, 0.7, 0.35, 0 for incidence angle 0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°, respectively. The settings are shown in Table 2-3.

Table 2-3 Collector Input Summary for Type 1-b

Parameter	Value	Unit	Remarks
Number in Series	1	-	How many collectors are hooked up in a series arrangement
Collector Area	50	m^2	
Fluid Specific Heat	4.19	kJ/kg K	
Efficiency Mode	1	-	1=the efficiency parameters are given as a function of the inlet temperature
Tested Flow Rate	0	kg/hr m2	
Intercet Efficiency	0.78	-	
Efficiency Slope	21.87	W/m^2 K	
Efficiency Curvature	0	$W/m^2 K^2$	
Optical Mode	3	-	The incidence angle modifiers are to be read from an external data file
Input	**Value**	**Unit**	
Inlet Temperature	20	C	
Inlet flow rate	Linked	kg/kJ	
Ambient Temperature	10	C	
Incident Radiation	Linked	kJ/hr m^2	
Total Horizontal Radiation	Linked	kJ/hr m^2	
Horizontal Diffuse Radiation	Linked	kJ/hr m^2	
Ground refelctance	0.2	-	
Incidence Angle	Linked	degree	
Collector Slope	Linked	degree	

2.2.3 Heat exchanger

Heat Exchanger is modeled as a constant effectiveness heat exchanger which is TRNSYS Type 91. The fluids used for both hot side and cold side are water. There is no need to put antifreeze into the heat exchanger due to Houston climate features. The settings are shown in Table 2-4.

Table 2-4 Heat Exchanger Input Summary for Type 91

Parameter	Value	Unit
Heat Excahnger Effectiveness	0.5	-
Specific Heat of Source Side Fluid	4.19	kJ/kg K
Specific Heat of Load Side Fluid	4.19	kJ/kg K
Input	**Value**	**Unit**
Source Side Inlet Temperature	Linked	C
Source Side Flow Rate	Linked	kg/kJ
Load Side Inlet Temperature	Linked	C
Load Side Flow Rate	Linked	kg/kJ

2.2.4 Controller

The temperature difference controller is modeled by TRNSYS Type 2b to control the pump behavior based on temperature difference between flow temperature output by solar collector and pool temperature. It will generate control signal either 0 or 1. The pump works when control signal equals to 1 while it stops working when control signal equals to 0. The settings are shown in Table 2-5.

Table 2-5 Controller Input Summary for Type 2b

Parameter	Value	Unit	Remarks
No. of Oscillations	5	-	The number of control oscillations allow ed in one timestep before the controller is "stuck" so that the calculations can be solved
High Limit Cut-Out	60	C	
Input	**Value**	**Unit**	
Upper Input Temperature Th	20	C	
Low er Input Temperature Tl	15	C	
Monitoring Temperature Tin	20	C	
Input Control Function	0	-	
Upper Dead Band dT	2	Temp.Difference	
Low er Dead Band dT	2	Temp.Difference	

2.2.5 Pumps

All pumps are modeled as a single-speed pump which is represented by TRNSYS Type 3d. However, in the current simulation, the pump model comes from TRNSYS 16 which has the same functions. The settings are shown in Table 2-6.

Table 2-6 Pump1, 2 and 3 Input Summary for Type 3d

Parameter	Value	Unit	Remarks
Maximum Flow Rate	1000	kJ/hr	
Fluid Specific Heat	4.19	kJ/kg K	
Maximum Pow er	1	HP	
Conversion Coefficient	0	-	The fraction of pump pow er that is converted to fluid thermal energy
Input	**Value**	**Unit**	
Inlet Fluid Temperature	20	C	
Inlet Fluid Flow Rate	Linked	kg/hr	
Control Signal	1	-	1=pump w orks

2.2.6 Diverter

Diverter is a device to separate coming flow into two streams with the same flow temperature and flow rate, which is modeled by TRNSYS Type 11f. The settings are shown in Table 2-7.

Table 2-7 Diverter Input Summary for Type 11f

Parameter	Value	Unit	Remarks
Controlled Flow Diverter Mode	2	-	
Input	**Value**	**Unit**	
Inlet Fluid Temperature	Linked	C	
Inlet Fluid Flow Rate	Linked	kg/hr	
Control Signal	0.5	-	The control signal sets the position of a damper controlling the proportion of fluid to each exit

2.2.7 Mixer

Mixer is a device to mix the coming flows into one stream which follows the rules in thermodynamics. It is modeled by TRNSYS Type 11d. The settings are shown in Table 2-8.

Table 2-8 Mixer Input Summary for Type 11d

Parameter	Value	Unit
Tee Piece Mode	1	-
Input	**Value**	**Unit**
Temperature at Inlet 1	Linked	C
Flow Rate at Inlet 1	Linked	kg/hr
Temperature at Inlet 2	Linked	C
Flow Rate at Inlet 2	Linked	kg/hr

2.2.8 Auxiliary heater

Auxiliary Heater is used to add auxiliary heating energy into the coming flow with set point temperature 60°, which is modeled by TRNSYS Type 6. The overall loss coefficient is set to zero in order to ignore the heat loss energy from the heater itself. The settings are shown in Table 2-9.

Table 2-9 Auxiliary Heater Input Summary for Type 6

Parameter	Value	Unit
Maximum Heating Rate	23	kW
Specific Heat of Fluid	4.19	kJ/kg K
Overall Loss Coefficient for Heating Operation	0	W/K
Efficiency of Auxilary Heater	1	-
Input	**Value**	**Unit**
Inlet Fluid Temperature	Linked	C
Fluid Mass Flow Rate	Linked	kg/kJ
Control Function	1	-
Set Point Temperature	60	C
Temperature of Surroundings	20	C

2.2.9 Aquastat

Aquastat is a control device and used to control pumps and auxiliary heater, which is modeled by TRNSYS Type 502. This type belongs to TESS library. The settings are shown in Table 2-10.

Table 2-10 Aquastat Input Summary for Type 502

Parameter	Value	Unit
No. of Oscillations Permitted	5	-
1st Stage Heating in 2nd stage?	1	-
2nd Stage Heating in 3rd stage?	1	-
1st Stage Heating in 3rd stage?	1	-
Temperature Dead Band	1	delta C
Input	**Value**	**Unit**
Fluid Temperature	20	C
1st Stage Heating Temperature	60	C
2nd Stage Heating Temperature	18	C
3rd Stage Heating Temperature	16	C

2.2.10 Pool

Swimming Pool in the system is an outdoor pool without any cover, which is modeled by TRNSYS Type 344 by TRNSSOLAR. It can output the pool temperature and heat loss from evaporation, convection and long-wave/short-wave radiation, which helps calculating direct solar energy absorbed by pool (Q Pool) and the load (Load). The settings are shown in Table 2-11.

Table 2-11 Pool Input Summary for Type 344

Parameter	Value	Unit
Initial Temperature of Pool Water	20	C
Pool Surface Area	50	m^2
Pool Volume	75	m^3
Cover Thickness	0	m
Input	**Value**	**Unit**
Air Temperature	Linked	C
Ambient Air RH	Linked	-
Wind Velocity	1	m/s
Total Solar Radiation on Horizontal	Linked	kJ/hr m^2
Effective Sky Temperature	18	C
Temperature of Enclosure Surfaces	20	C
Short Wave Radiation		kJ/hr
Water Surface Activity	1	-
Mass Flow rate of Fresh Water	Linked	kg/hr
Temperature of Fresh Water	Linked	C
Pool Opening Time	8	hr
Pool Closing Time	20	hr
Maximum Pool Occupancy	20	-
Covered Pool Fraction	0	-
Mass Flow rate of Heated Water	Linked	kg/hr
Temperature of Heated Water	Linked	C

2.2.11 Mains water temperature

Mains water temperature is the temperature of the supplied water, which is modeled by forcing function TRNSYS Type 14e. Figure 2-4 shows the temperature pattern of the supplied water which is the same data from monthly weather file shown in F-Chart.

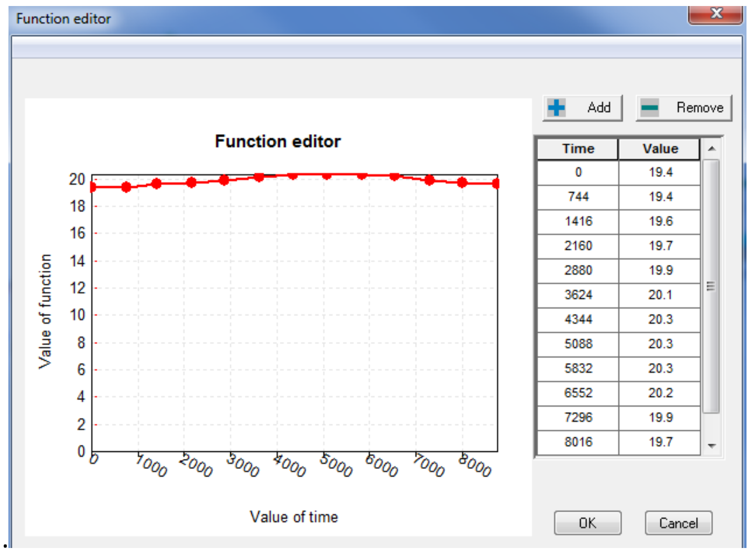

Figure 2-4 Mains Water Temperature Profile for Type 14e

2.2.12 TRNSYS Results

The monthly simulation results of TRNSYS are obtained by TRNSYS Type 24 which can integrate the value for each timestep into monthly value. Three outputs are obtained: solar energy direct absorbed by the Pool (Q Pool), heat losses from evaporation, convection and radiation, auxiliary heating energy (Aux). The QColl, Load and f factor are manually calculated based on energy balance on the Solar Pool heating System. The detailed results of Solar Pool Heating System are shown in Table 2-12 in term of SI unit. Compared with the results of F-Chart simulation shown in Figure 2-2, there are large differences, which are thought to be due to the different heat balance algorithms used by the simulation software.

Table 2-12 TRNSYS Simulation Results in SI Unit

	TRNSYS				
	Qcoll (GJ)	**Q Pool (GJ)**	**Load (GJ)**	**AUX (GJ)**	**f**
Jan	6.271	13.599	52.379	46.108	0.120
Feb	6.496	15.200	48.435	41.939	0.134
Mar	7.938	21.454	43.074	35.136	0.184
Apr	3.313	23.895	24.460	21.147	0.135
May	1.602	28.192	11.406	9.805	0.140
Jun	0.000	29.748	0.047	0.820	1.000
Jul	0.000	29.552	0.000	0.000	1.000
Aug	0.000	27.759	1.728	1.731	1.000
Sep	2.036	23.817	9.475	7.439	0.215
Oct	4.880	21.293	25.557	20.676	0.191
Nov	8.403	15.494	41.889	33.486	0.201
Dec	7.012	12.175	54.937	47.925	0.128
Year	47.951	262.176	313.387	266.213	0.153

3 SOLAR POOL HEATING SYSTEM SIMULATION COMPARISONS

3.1 Overview

In this section, a Solar Pool Heating System is simulated by TRNSYS software as well as F-Chart by using the results shown in Section 2. The comparisons of Q Coll, QPool, Load Aux and f factor are shown as follows.

3.2 Comparisons of TRNSYS and F-Chart for Solar Pool Heating System Simulations

Figure 3-1 - Figure 3-4 show the detail comparisons of these two simulations on monthly total solar energy (Q Coll), monthly total water heating demand (Load), monthly total auxiliary energy (Aux) , monthly total solar energy absorbed directly by the pool (QPool) and the f factor. Figure 3-1 details the comparison data for two simulations. The difference percentages are well presented.

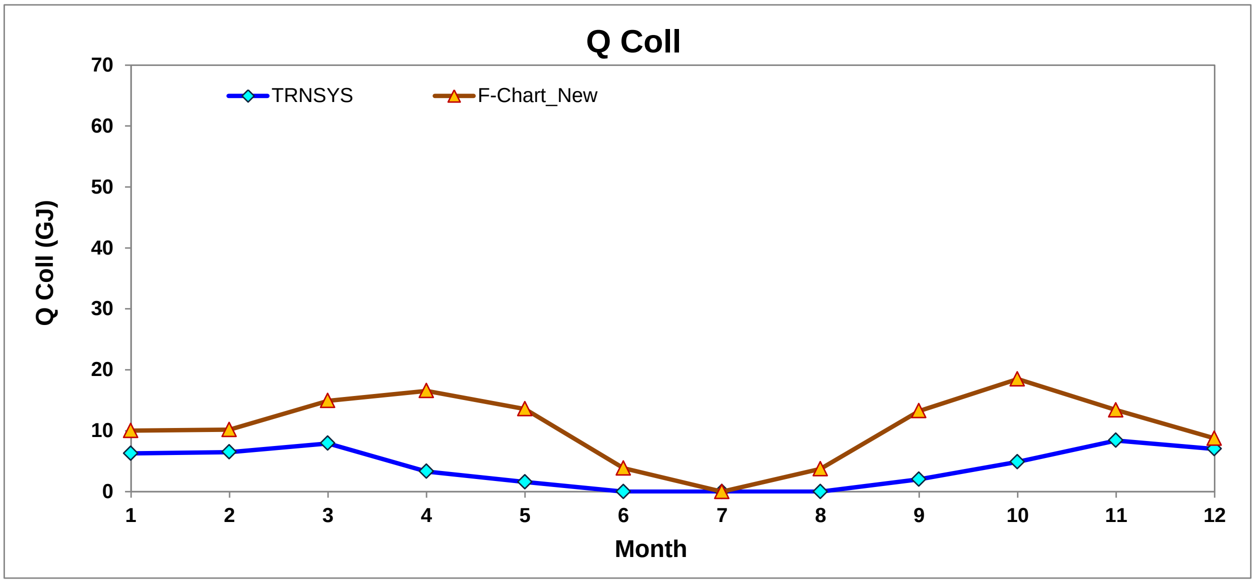

Figure 3-1 Monthly Solar Energy delivered by the Solar Collectors to the Pool.

As it shown in Figure 3-1, the pattern difference is quite large, which results in annual difference is 62.2%. The one from F-chart appears two peak values around April and October and zero value from June to August for the monthly solar energy. The other one from TRNSYS shows the needed solar energy is quite low in summer and peak values occur in winter, which is more reasonable.

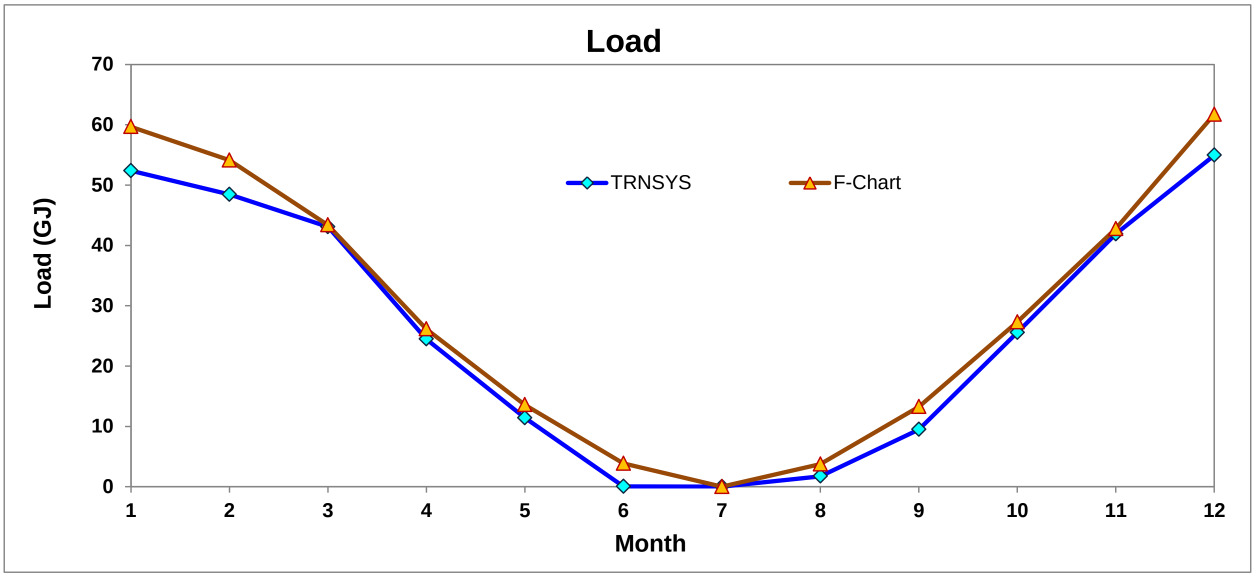

Figure 3-2 Monthly Load Demand.

As it is shown in Figure 3-2, the water heating demand calculated by TRNSYS is matching well with the one from F-Chart whose annual difference is 10.33%. The load demand is calculated from the total pool heat loss by evaporation, convection, radiation minus the solar energy directly absorbed by the pool.

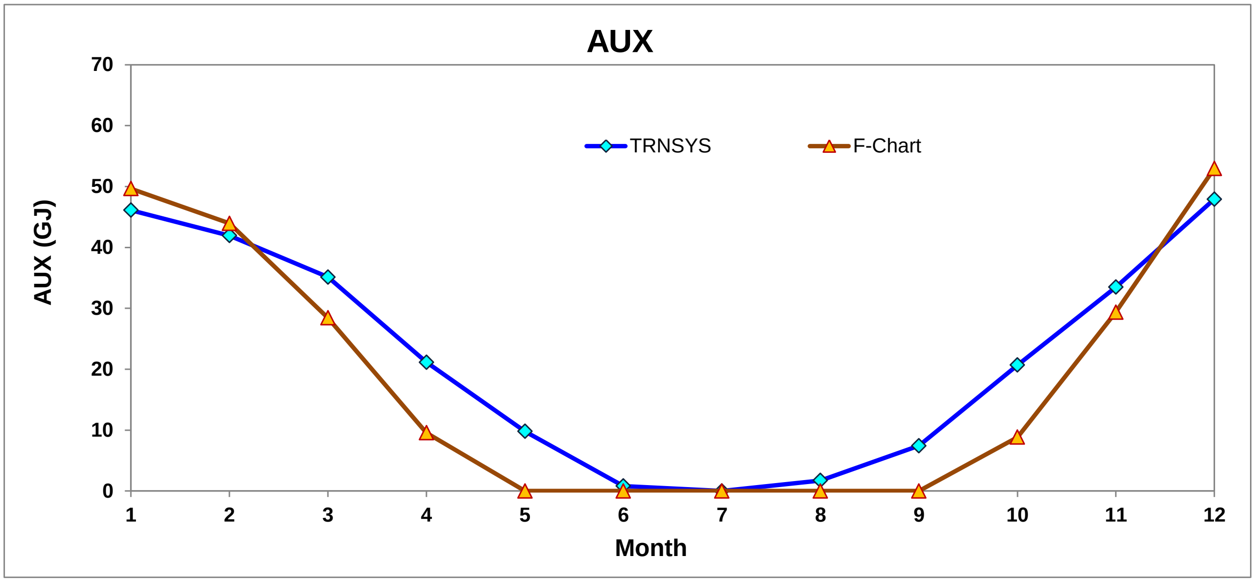

Figure 3-3Monthly Energy Supplied by the Backup Pool Heater

Seen in Figure 3-3, the monthly total auxiliary energy comparisons based on various mains temperatures show a large difference between the TRNSYS simulation and F-Chart Program results. The annual difference is -19.5%.

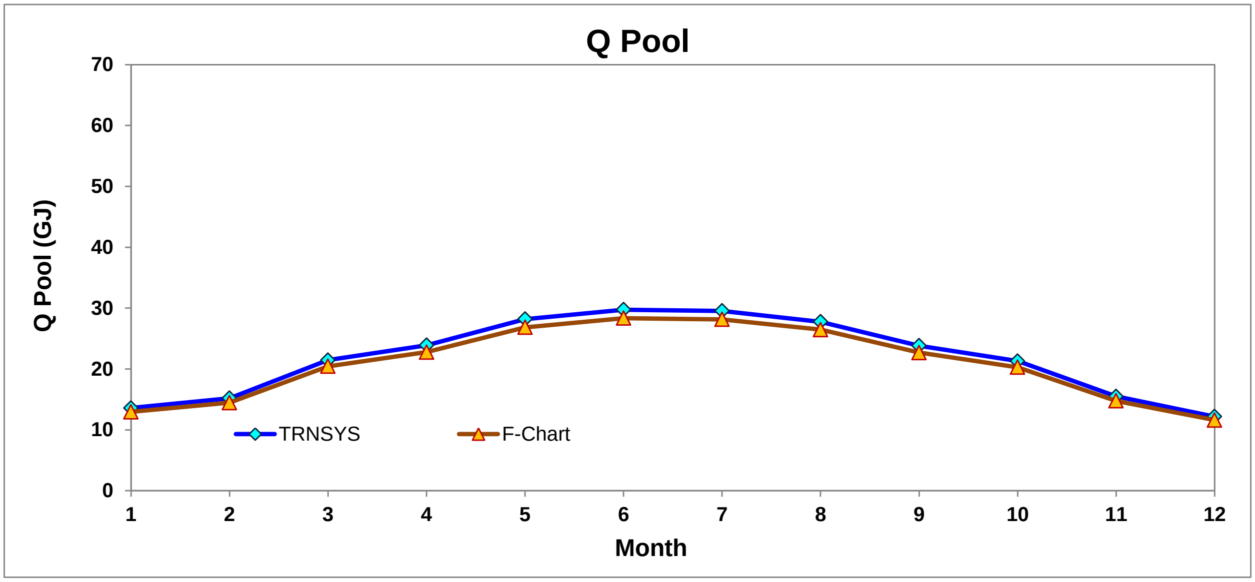

Figure 3-4 Monthly Solar Energy Directly Absorbed by the Pool

Figure 3-4 shows the monthly total useful solar energy supplied by the solar energy system. It is output by the collector component, which means the useful energy collected by the solar collectors to be used for water heating. The annual difference is -4.95%.

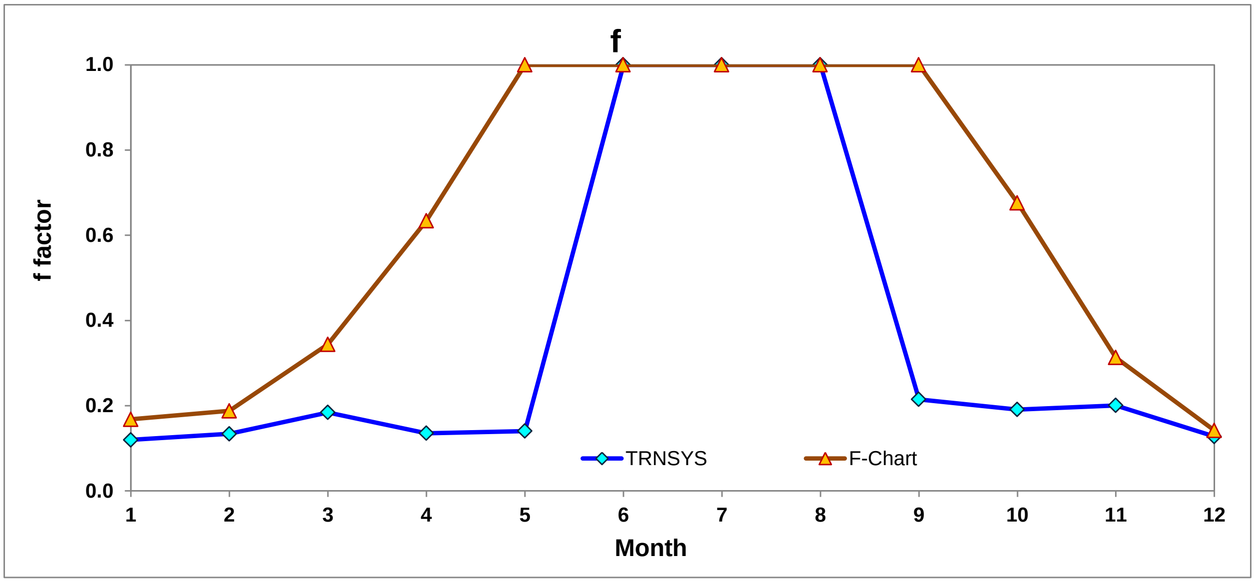

Figure 3-5 f Factor

Figure 3-5 shows the f factor comparison between TRNSYS and F-Chart simulations, which indicates that only from June to August, f-factor matches well. The annual difference is 57.85%

Table 3-1 Comparisons Data between TRNSYS and F-Chart

	TRNSYS					F-Chart (New weaher)						Diff				
	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Cal. from Eqns	Qcoll (%)	Q Pool (%)	Load (%)	AUX (%)	f
Jan	6.271	13.599	52.379	46.108	0.120	10.020	12.960	59.670	49.650	0.168	0.168	59.78%	-4.70%	13.92%	7.68%	28.73%
Feb	6.496	15.200	48.435	41.939	0.134	10.180	14.470	54.130	43.950	0.188	0.188	56.70%	-4.80%	11.76%	4.80%	28.66%
Mar	7.938	21.454	43.074	35.136	0.184	14.920	20.450	43.370	28.440	0.344	0.344	87.97%	-4.68%	0.69%	-19.06%	46.43%
Apr	3.313	23.895	24.460	21.147	0.135	16.560	22.770	26.120	9.560	0.634	0.634	399.84%	-4.71%	6.79%	-54.79%	78.64%
May	1.602	28.192	11.406	9.805	0.140	13.580	26.850	13.580	0.000	1.000	1.000	747.85%	-4.76%	19.06%	-100.00%	85.96%
Jun	0.000	29.748	0.047	0.820	1.000	3.860	28.350	3.860	0.000	1.000	1.000	-	-4.70%	8200.83%	-100.00%	0.00%
Jul	0.000	29.552	0.000	0.000	1.000	0.000	28.160	0.000	0.000	1.000	1.000	-	-	-	-	-
Aug	0.000	27.759	1.728	1.731	0.000	3.730	26.460	3.730	0.000	1.000	1.000	-	-4.68%	115.89%	-100.00%	100.00%
Sep	2.036	23.817	9.475	7.439	0.215	13.250	22.690	13.250	0.000	1.000	1.000	550.79%	-4.73%	39.83%	-100.00%	78.51%
Oct	4.880	21.293	25.557	20.676	0.191	18.470	20.290	27.310	8.850	0.676	0.676	278.45%	-4.71%	6.86%	-57.20%	71.75%
Nov	8.403	15.494	41.889	33.486	0.201	13.400	14.770	42.760	29.360	0.313	0.313	59.47%	-4.67%	2.08%	-12.32%	35.91%
Dec	7.012	12.175	54.937	47.925	0.128	8.740	11.600	61.710	52.970	0.142	0.142	24.65%	-4.72%	12.33%	10.53%	10.12%
Year	47.951	262.176	313.387	266.213	0.153	126.720	249.810	349.500	222.780	0.363	0.363	**62.16%**	**-4.95%**	**10.33%**	**-19.50%**	**57.85%**

Table **3-1** show the details comparisons of Pool Heating System simulation by TRNSYS and F-Chart. The tables include the results from TRNSYS, F-chart with modified Houston weather.

4 DIFFERENT CASES OF POOL HEATING SYSTEM SIMULATION

The purpose of this section is to compare the Pool Heating System between F-Chart program and TRNSYS simulation. Four variables are selected to test the difference percentages between those two softwares. The base case is the one shown in Section 3.

4.1 Case 1: Change solar collector area

4.1.1 Setting solar collector area equals to 1 m^2

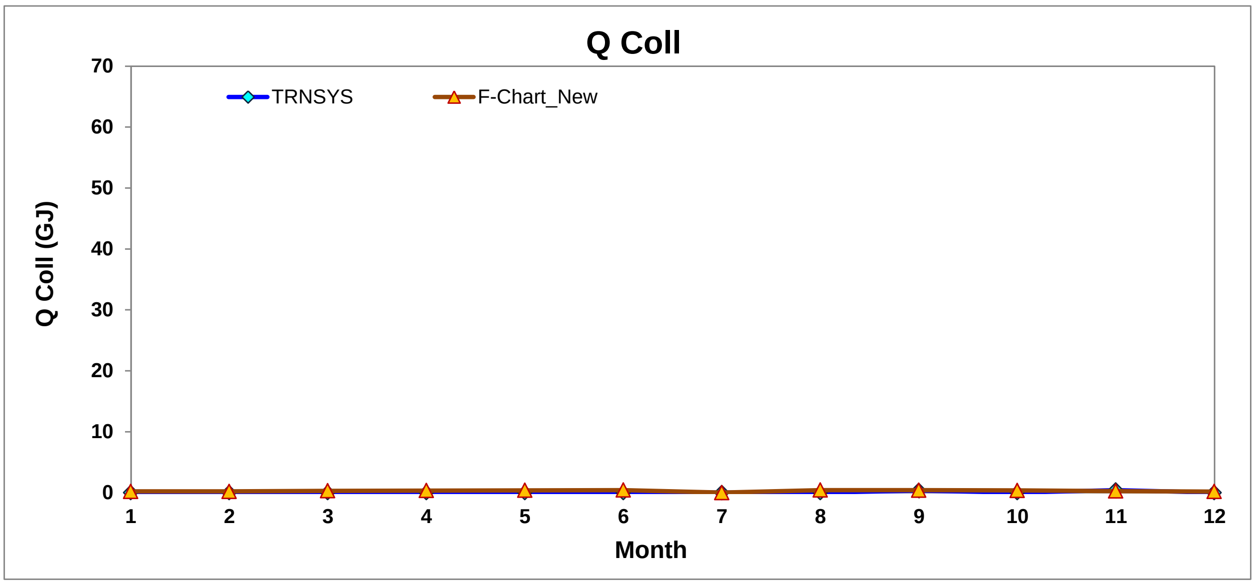

Figure 4-1 Monthly Solar Energy delivered by the Solar Collectors to the Pool (A_{coll}=1m^2)

Seen from Figure 4-1, the delivered solar energy is almost zero for TRNSYS and F-Chart, which appears a flat pattern. This is due to the small solar collector area. The annual difference percentage is 78.12%. The auxiliary heater will provide most required heating load to the outdoor swimming pool.

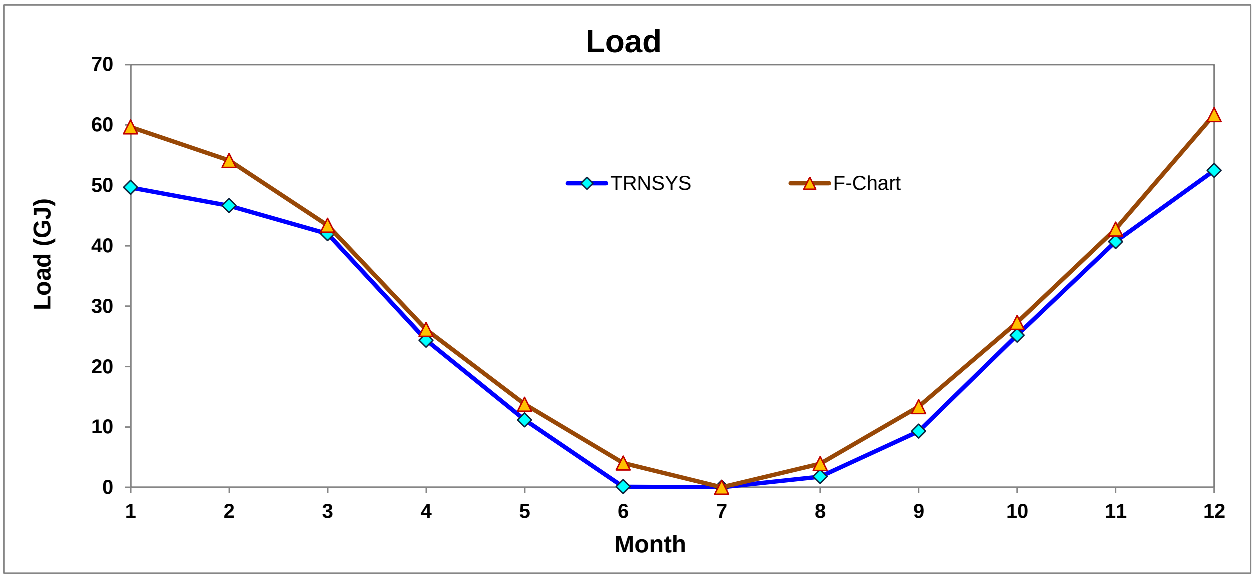

Figure 4-2 Monthly Load Demand (A_{coll}=1m^2)

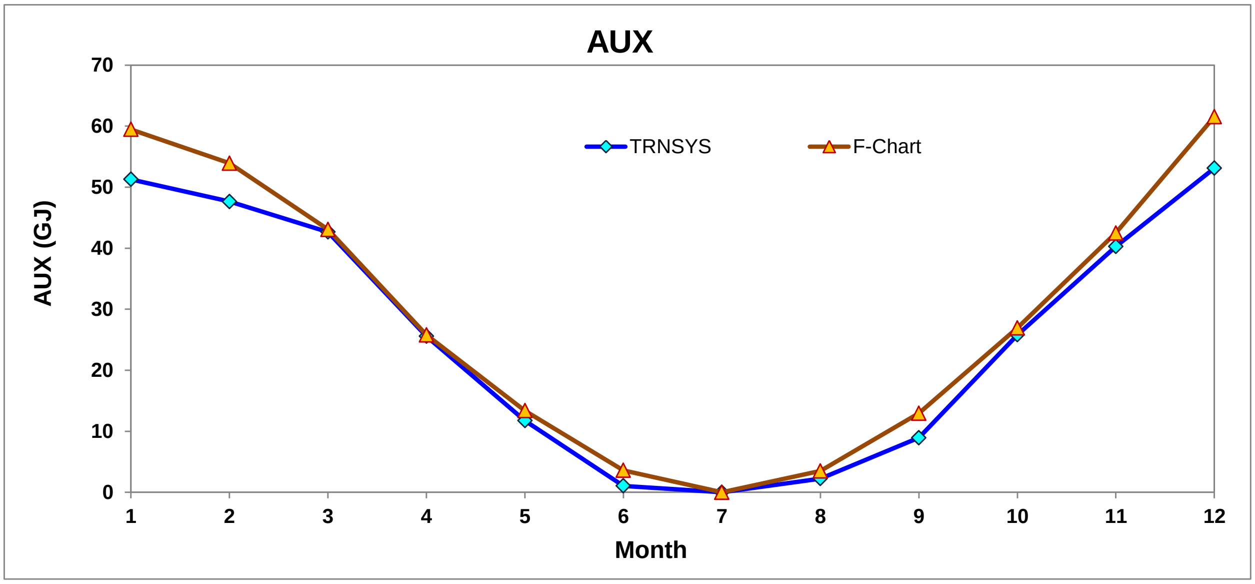

Figure 4-3Monthly Energy Supplied by the Backup Pool Heater (A_{coll}=1m^2)

Figure 4-2 and Figure 4-3 show the monthly load and auxiliary energy, respectively. In July, both loads achieve zero which means the direct solar gain absorbed by the pool can maintain the pool temperature during the summer. The difference percentages are 13.37% and 10.48%, respectively.

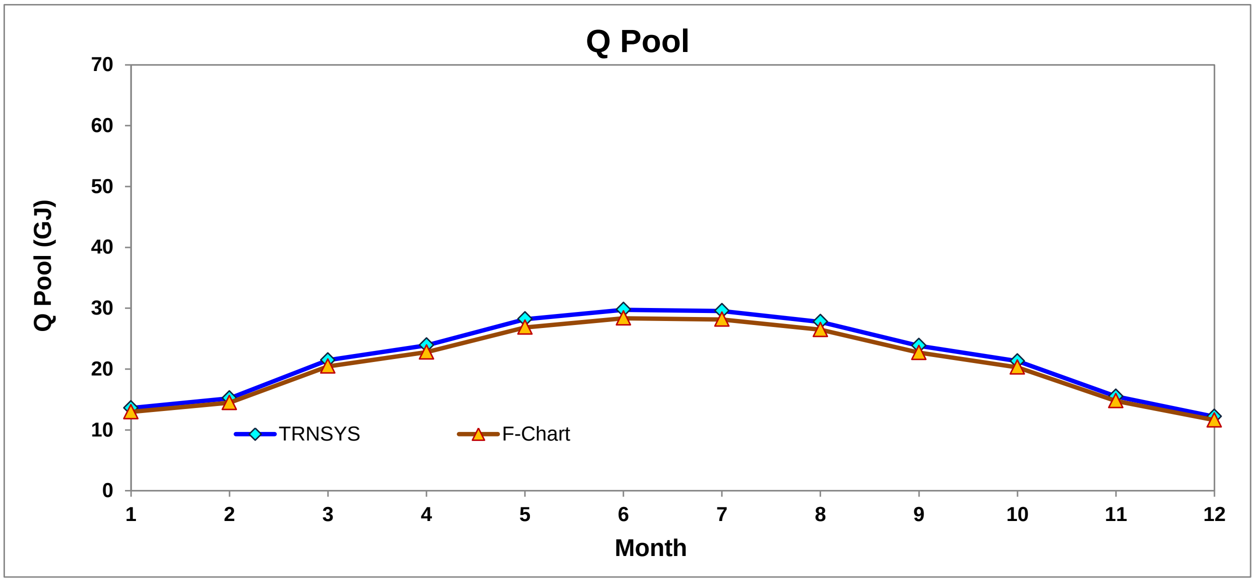

Figure 4-4 Monthly Solar Energy Directly Absorbed by the Pool (A_{coll}=1m^2)

Figure 4-4 reveals the solar energy absorbed directly by the pool. The comparison results indicate both simulations are quite close. The difference percentage is -4.95%.

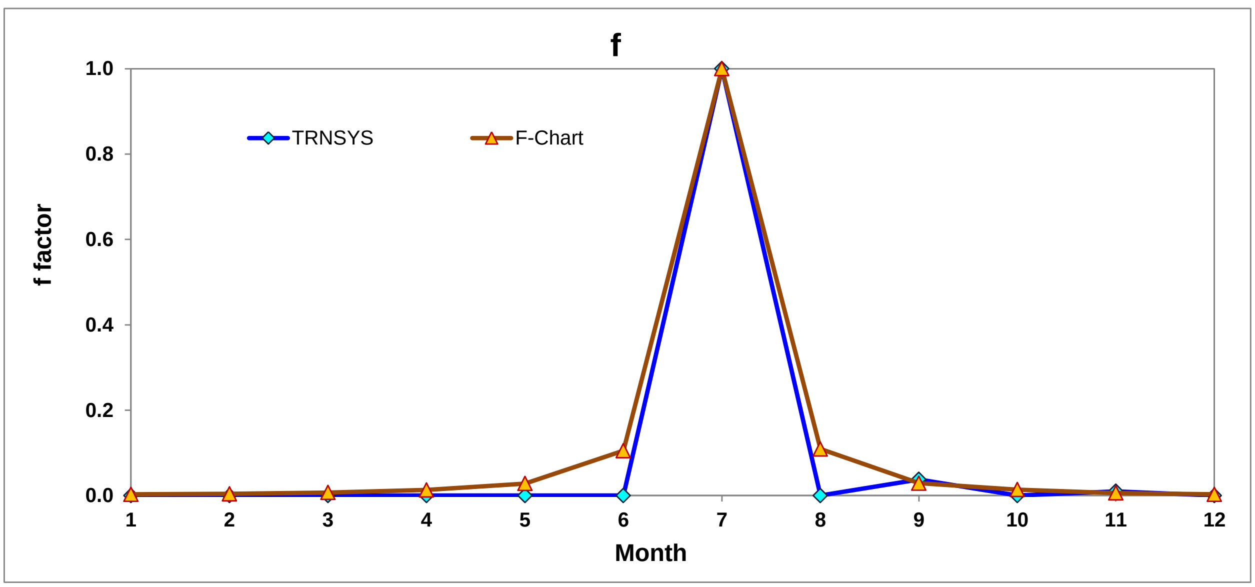

Figure 4-5 f Factor (A_{coll}=1m^2)

Table 4-1 Comparisons Data between TRNSYS and F-Chart (A_{coll}=1m^2)

	TRNSYS					F-Chart (New weaher)						Diff				
	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Cal. from Eqns	Qcoll (%)	Q Pool (%)	Load (%)	AUX (%)	f
Jan	0.000	13.599	49.652	51.279	0.000	0.200	12.960	59.670	59.470	0.003	0.003	-	-4.70%	20.18%	15.97%	100.00%
Feb	0.000	15.200	46.632	47.644	0.000	0.204	14.470	54.130	53.930	0.004	0.004	-	-4.80%	16.08%	13.19%	100.00%
Mar	0.000	21.454	41.988	42.660	0.000	0.298	20.450	43.370	43.070	0.007	0.007	-	-4.68%	3.29%	0.96%	100.00%
Apr	0.000	23.895	24.367	25.568	0.000	0.331	22.770	26.120	25.790	0.013	0.013	-	-4.71%	7.19%	0.87%	100.00%
May	0.000	28.192	11.161	11.747	0.000	0.388	26.850	13.760	13.370	0.028	0.028	-	-4.76%	23.28%	13.81%	100.00%
Jun	0.000	29.748	0.093	1.048	1.000	0.421	28.350	4.010	3.590	0.105	0.105	-	-4.70%	4204.70%	242.47%	-852.38%
Jul	0.000	29.552	0.000	0.000	1.000	0.000	28.160	0.000	0.000	1.000	1.000	-	-	-	-	-
Aug	0.000	27.759	1.768	2.243	0.000	0.428	26.460	3.920	3.490	0.109	0.109	-	-4.68%	121.71%	55.58%	100.00%
Sep	0.350	23.817	9.283	8.934	0.038	0.393	22.690	13.350	12.950	0.029	0.029	12.43%	-4.73%	43.80%	44.95%	-29.84%
Oct	0.000	21.293	25.201	25.817	0.000	0.369	20.290	27.310	26.940	0.014	0.014	-	-4.71%	8.37%	4.35%	100.00%
Nov	0.411	15.494	40.687	40.276	0.010	0.268	14.770	42.760	42.490	0.006	0.006	-34.77%	-4.67%	5.10%	5.50%	-68.29%
Dec	0.000	12.175	52.467	53.114	0.000	0.175	11.600	61.710	61.540	0.003	0.003	-	-4.72%	17.62%	15.86%	100.00%
Year	0.760	262.176	303.301	310.329	0.003	3.476	249.810	350.120	346.640	0.010	0.010	**78.12%**	**-4.95%**	**13.37%**	**10.48%**	**74.93%**

Table 4-1 details the monthly comparisons between two softwares when collector area equals to 1 m^2.

4.1.2 Setting solar collector area equals to 1000 m^2

In this case, the solar collector area is set as a quite large number.

From Figure 4-6 - Figure 4-10, load and pool energy are quite similar for TRNSYS and F-Chart comparison while the solar energy and auxiliary energy are quite different. Their difference percentages are 78.5%, -4.95%, 8.48%, shown in Table 4-2.

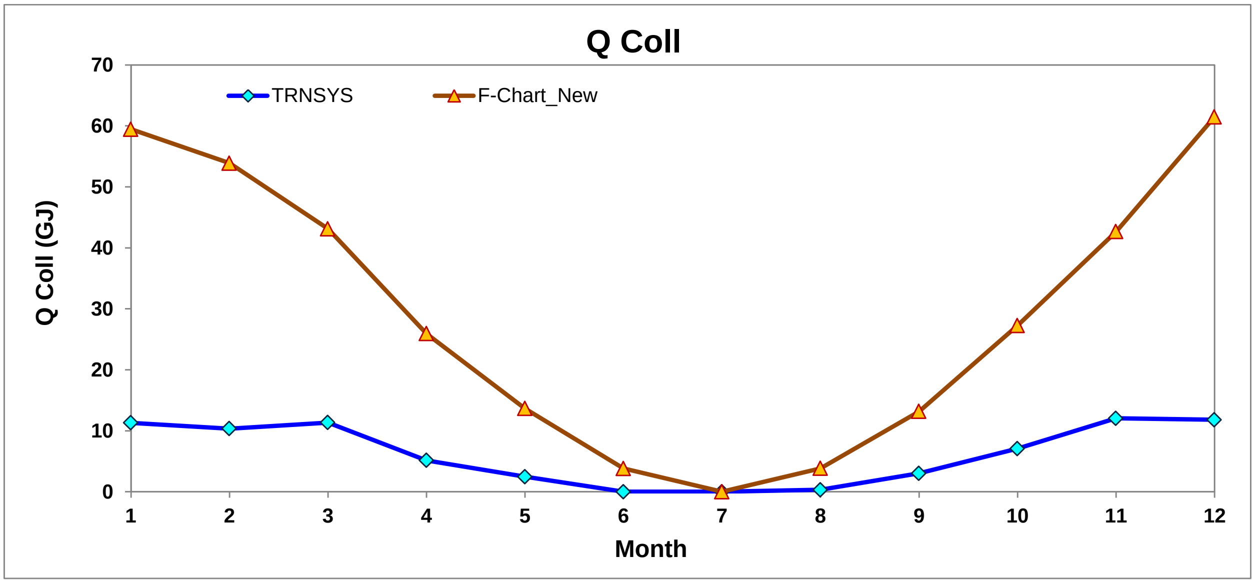

Figure 4-6 Monthly Solar Energy delivered by the Solar Collectors to the Pool (A_{coll}=1000 m^2)

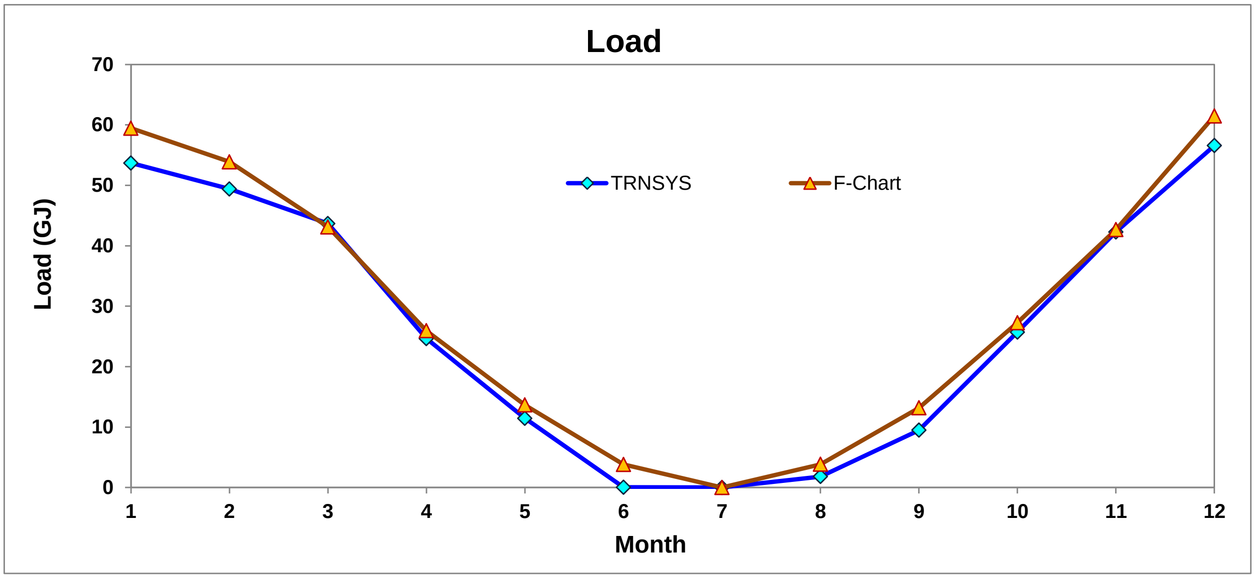

Figure 4-7 Monthly Load Demand (A_{coll}=1000 m^2)

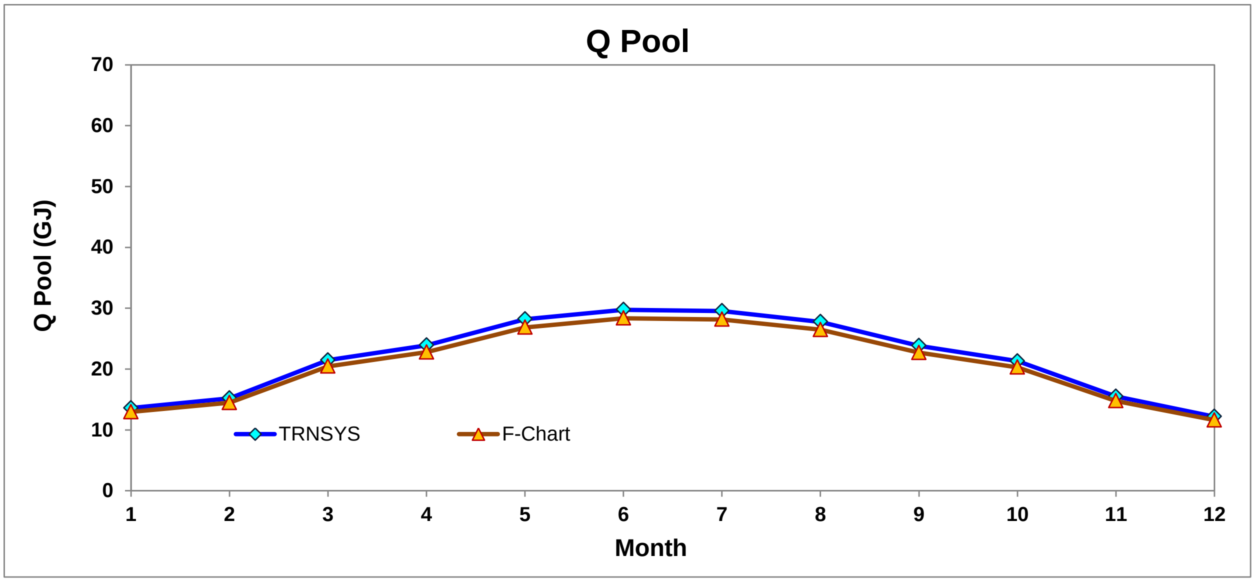

Figure 4-8 Monthly Solar Energy Directly Absorbed by the Pool (A_{coll}=1000 m^2)

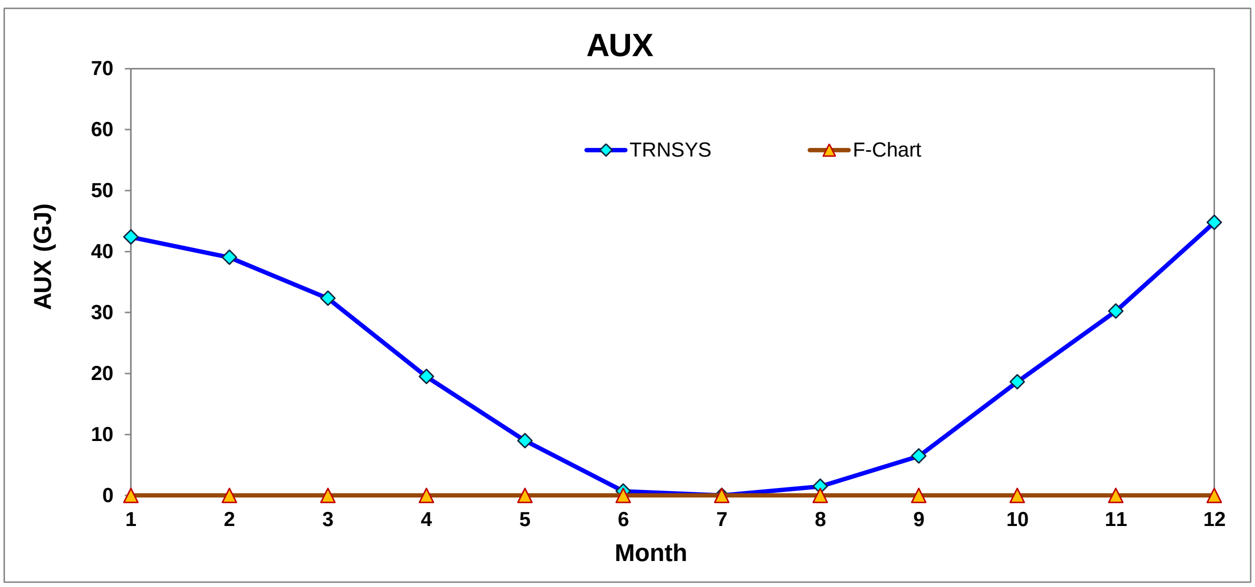

Figure 4-9Monthly Energy Supplied by the Backup Pool Heater (A_{coll}=1000 m^2)

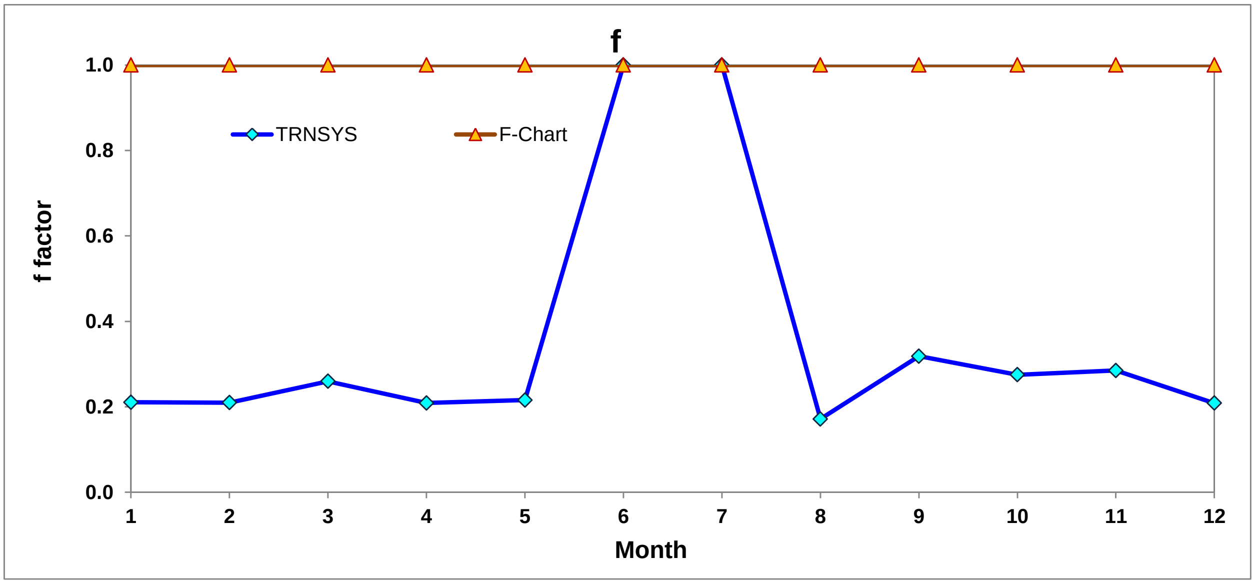

Figure 4-10 f Factor (A_{coll}=1000 m^2)

Table 4-2 Comparisons Data between TRNSYS and F-Chart (A_{coll}=1000 m^2)

	TRNSYS					F-Chart (New weaher)						Diff				
	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Cal. from Eqns	Qcoll (%)	Q Pool (%)	Load (%)	AUX (%)	f
Jan	11.309	13.599	53.687	42.378	0.211	59.440	12.960	59.440	0.000	1.000	1.000	425.61%	-4.70%	10.72%	-100.00%	78.94%
Feb	10.359	15.200	49.403	39.045	0.210	53.890	14.470	53.890	0.000	1.000	1.000	420.24%	-4.80%	9.08%	-100.00%	79.03%
Mar	11.339	21.454	43.670	32.331	0.260	43.120	20.450	43.120	0.000	1.000	1.000	280.26%	-4.68%	-1.26%	-100.00%	74.03%
Apr	5.152	23.895	24.643	19.491	0.209	25.940	22.770	25.940	0.000	1.000	1.000	403.51%	-4.71%	5.27%	-100.00%	79.09%
May	2.468	28.192	11.445	8.977	0.216	13.650	26.850	13.650	0.000	1.000	1.000	453.10%	-4.76%	19.26%	-100.00%	78.44%
Jun	0.000	29.748	0.038	0.690	1.000	3.810	28.350	3.810	0.000	1.000	1.000	-	-4.70%	9954.27%	-100.00%	0.00%
Jul	0.000	29.552	0.000	0.000	1.000	0.000	28.160	0.000	0.000	1.000	1.000	-	-	-	-	-
Aug	0.311	27.759	1.813	1.502	0.171	3.840	26.460	3.840	0.000	1.000	1.000	-	-4.68%	111.84%	-100.00%	82.85%
Sep	3.018	23.817	9.478	6.460	0.318	13.180	22.690	13.180	0.000	1.000	1.000	336.70%	-4.73%	39.06%	-100.00%	68.16%
Oct	7.073	21.293	25.703	18.630	0.275	27.260	20.290	27.260	0.000	1.000	1.000	285.39%	-4.71%	6.06%	-100.00%	72.48%
Nov	12.050	15.494	42.281	30.231	0.285	42.650	14.770	42.650	0.000	1.000	1.000	253.95%	-4.67%	0.87%	-100.00%	71.50%
Dec	11.804	12.175	56.562	44.758	0.209	61.470	11.600	61.470	0.000	1.000	1.000	420.76%	-4.72%	8.68%	-100.00%	79.13%
Year	74.883	262.176	318.722	244.491	0.235	348.240	249.810	348.240	0.000	1.000	1.000	**78.50%**	**-4.95%**	**8.48%**	**-**	**76.51%**

4.2 Case 2: Change swimming pool area

4.2.1 Setting pool area equals to 1 m^2

As pool are is set very small, from Figure 4-11 - Figure 4-15, solar energy, auxiliary energy and pool energy are quite similar for TRNSYS and F-Chart comparison while the load is quite different. Their difference percentages are shown in Table 4-3.

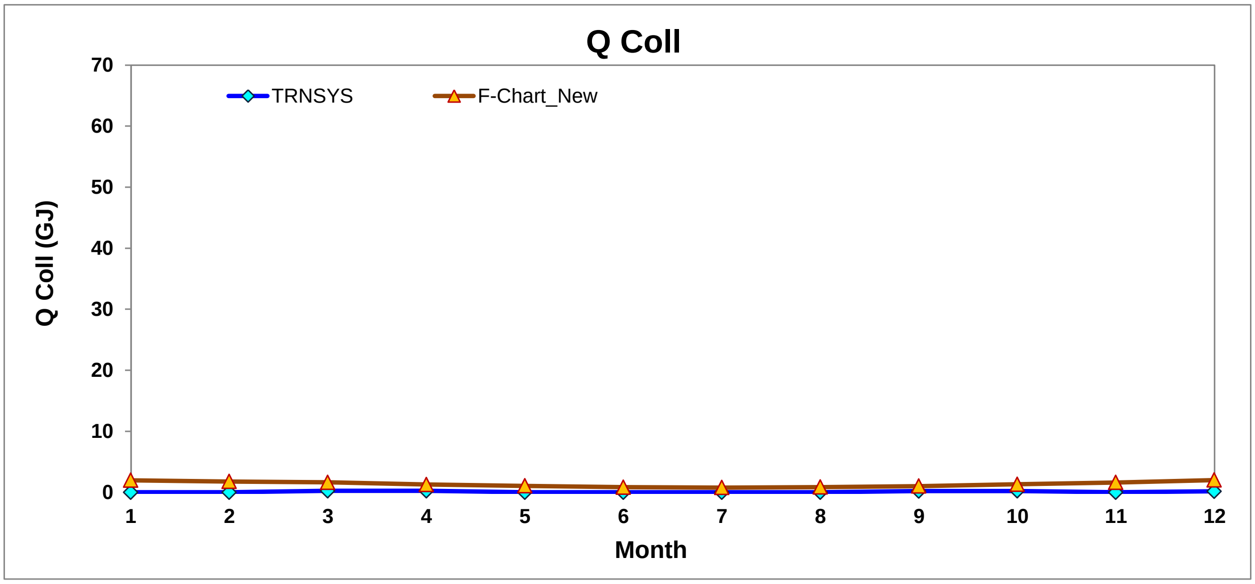

Figure 4-11 Monthly Solar Energy delivered by the Solar Collectors to the Pool (A_{pool}=1m^2)

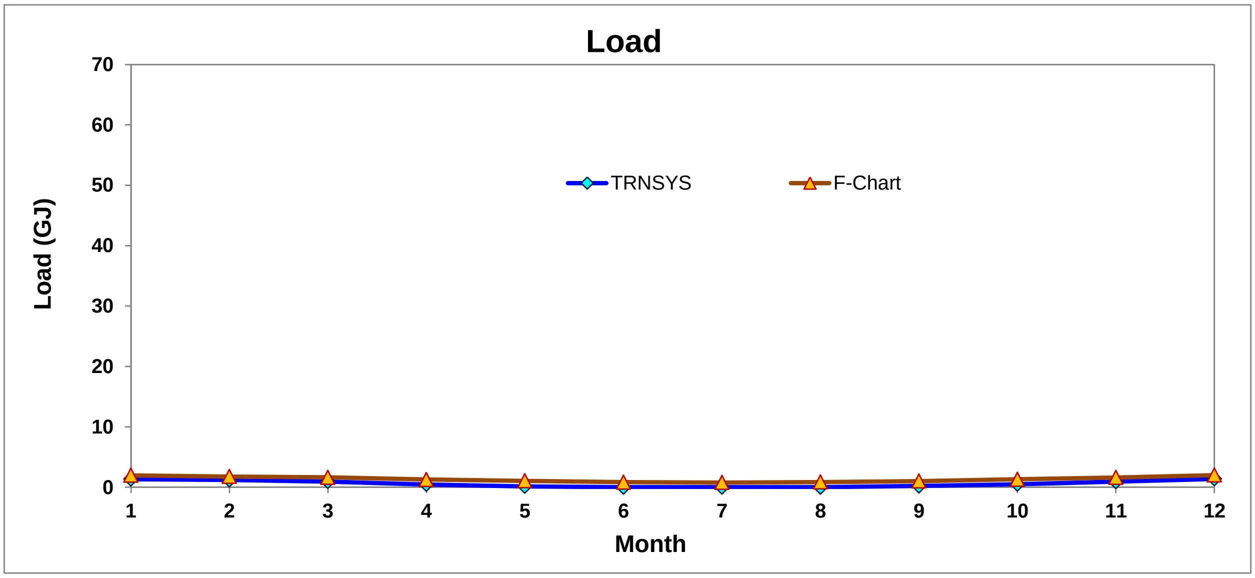

Figure 4-12 Monthly Load Demand (A_{pool}=1m^2)

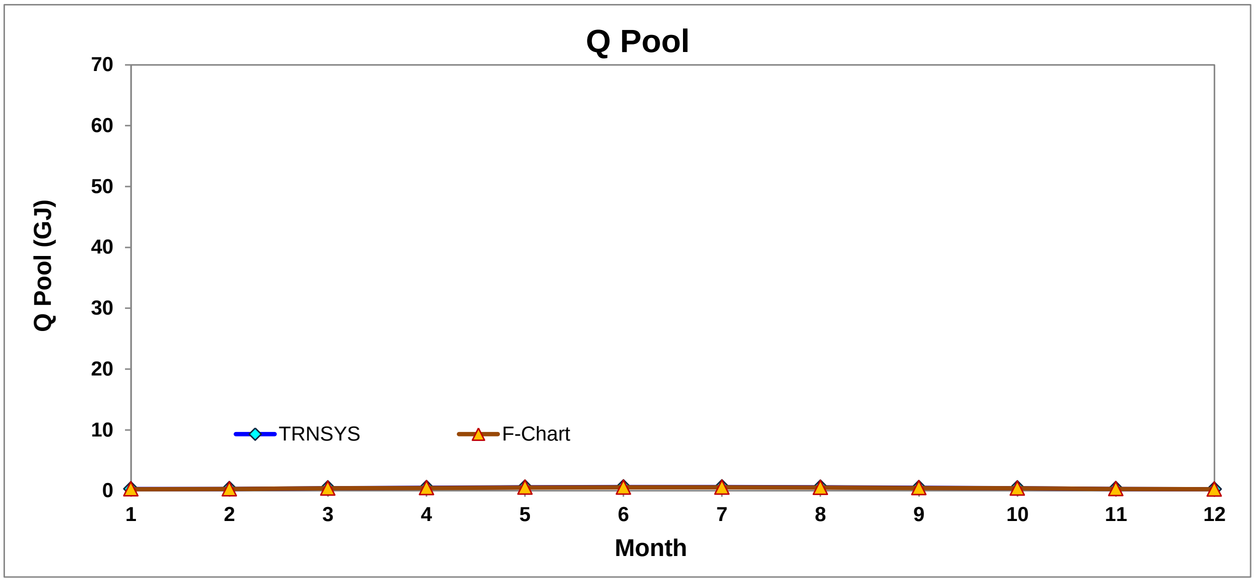

Figure 4-13 Monthly Solar Energy Directly Absorbed by the Pool ($A_{pool}=1m^2$)

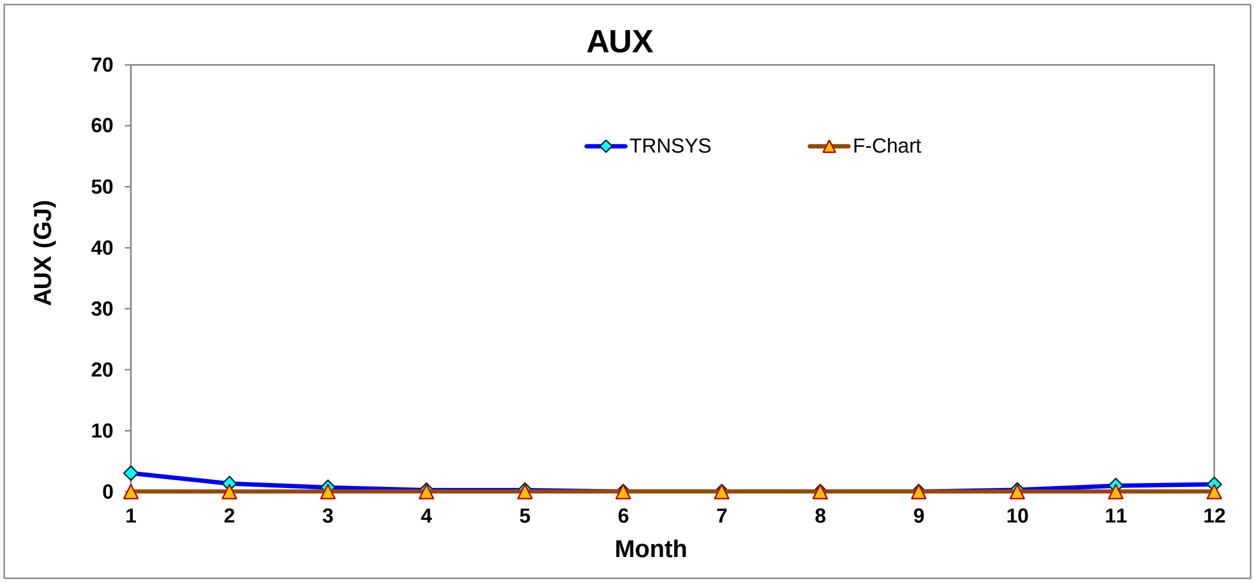

Figure 4-14Monthly Energy Supplied by the Backup Pool Heater ($A_{pool}=1m^2$)

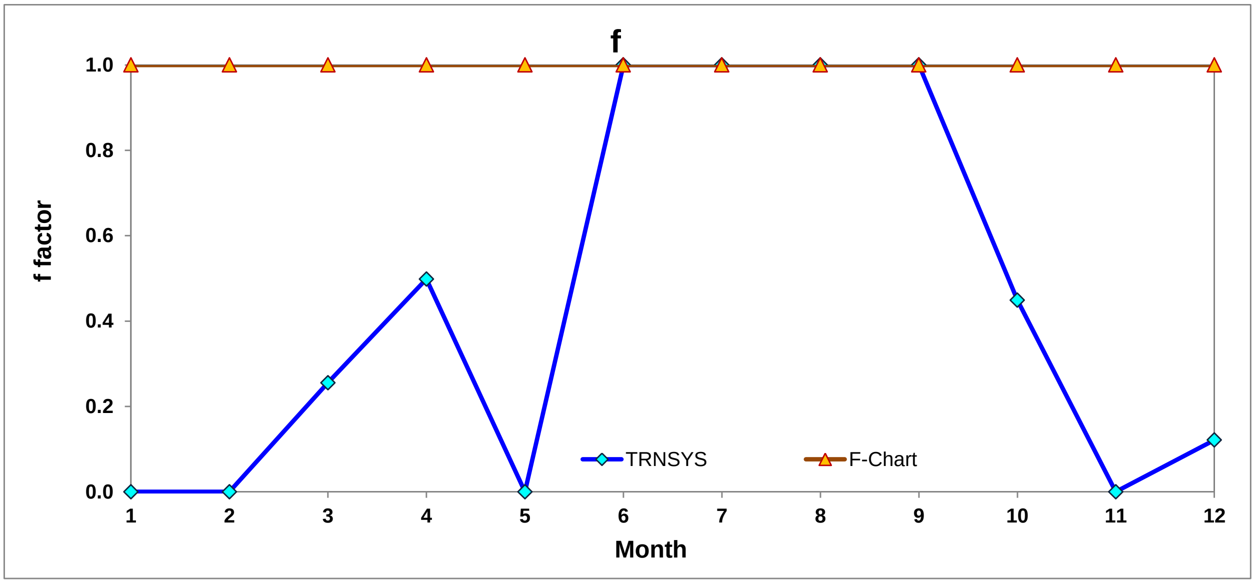

Figure 4-15f Factor (A_{pool}=1m^2)

Table 4-3 Comparisons Data between TRNSYS and F-Chart (A_{pool}=1m^2)

	TRNSYS					F-Chart (New weaher)						Diff				
	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Cal. from Eqns	Qcoll (%)	Q Pool (%)	Load (%)	AUX (%)	f
Jan	0.000	0.272	1.326	3.021	0.000	1.967	0.258	1.967	0.000	1.000	1.000	-	-5.14%	48.34%	-100.00%	100.00%
Feb	0.000	0.304	1.195	1.309	0.000	1.779	0.288	1.779	0.000	1.000	1.000	-	-5.26%	48.88%	-100.00%	100.00%
Mar	0.241	0.429	0.945	0.703	0.255	1.641	0.408	1.641	0.000	1.000	1.000	580.30%	-4.91%	73.74%	-100.00%	74.46%
Apr	0.231	0.478	0.464	0.233	0.498	1.273	0.454	1.273	0.000	1.000	1.000	450.00%	-5.00%	174.11%	-100.00%	50.16%
May	0.000	0.564	0.146	0.249	0.000	1.060	0.535	1.060	0.000	1.000	1.000	-	-5.12%	628.42%	-100.00%	100.00%
Jun	0.000	0.595	0.000	0.000	1.000	0.832	0.565	0.832	0.000	1.000	1.000	-	-5.03%	-	-	0.00%
Jul	0.000	0.591	0.000	0.000	1.000	0.769	0.561	0.769	0.000	1.000	1.000	-	-	-	-	-
Aug	0.000	0.555	0.000	0.000	1.000	0.856	0.527	0.856	0.000	1.000	1.000	-	-5.08%	-	-	-
Sep	0.209	0.476	0.209	0.000	1.000	1.017	0.452	1.017	0.000	1.000	1.000	386.51%	-5.11%	386.51%	-	0.00%
Oct	0.225	0.426	0.503	0.277	0.449	1.320	0.405	1.320	0.000	1.000	1.000	485.45%	-4.90%	162.66%	-100.00%	55.13%
Nov	0.000	0.310	0.910	0.967	0.000	1.612	0.294	1.612	0.000	1.000	1.000	-	-5.13%	77.16%	-100.00%	100.00%
Dec	0.166	0.243	1.370	1.204	0.121	2.007	0.231	2.007	0.000	1.000	1.000	1109.14%	-5.13%	46.47%	-100.00%	87.89%
Year	1.073	5.244	7.067	7.964	0.152	16.133	4.980	16.133	0.000	1.000	1.000	**93.35%**	**-5.29%**	**56.20%**	**-**	**84.81%**

4.2.2 Setting pool area equals to 1000 m^2

As pool are is set very large, from Figure 4-16 - Figure 4-20, Only pool energy is similar for TRNSYS and F-Chart comparison while the rest of the results are quite different. Their difference percentages are shown in Table 4-4.

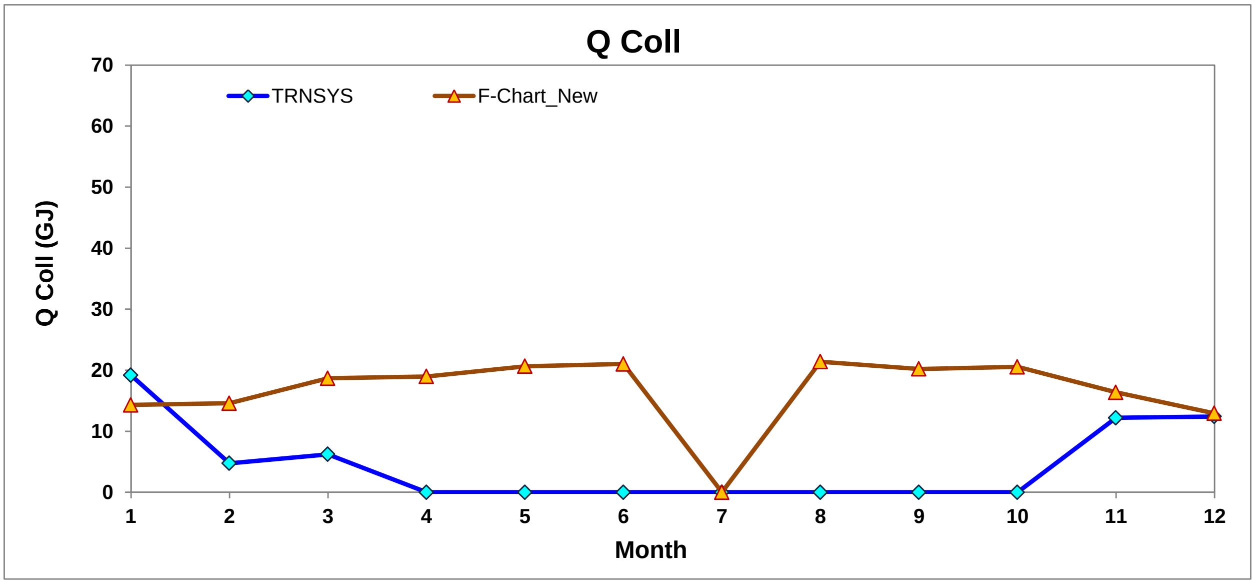

Figure 4-16 Monthly Solar Energy delivered by the Solar Collectors to the Pool (A_{pool}=1000 m^2)

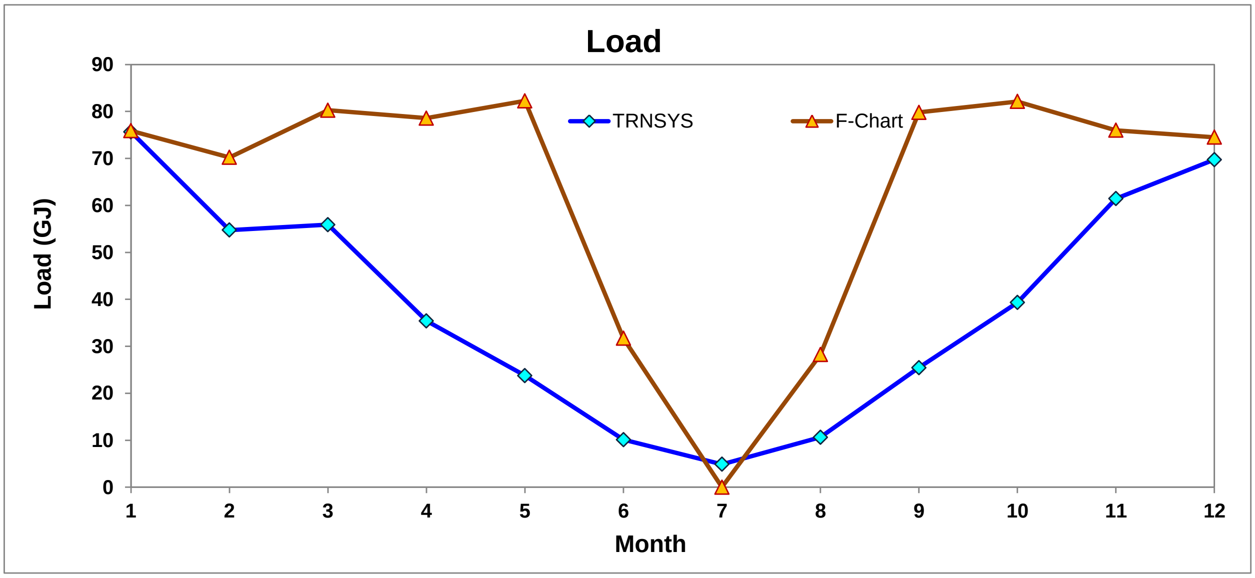

Figure 4-17 Monthly Load Demand (A_{pool}=1000 m^2)

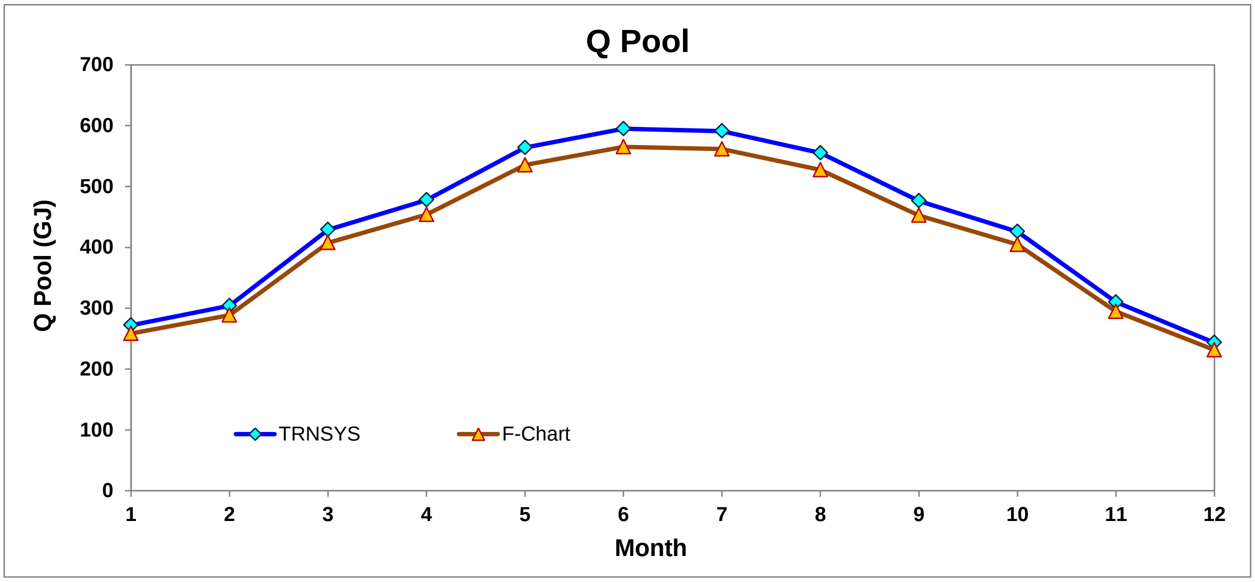

Figure 4-18 Monthly Solar Energy Directly Absorbed by the Pool (A_{pool}=1000 m^2)

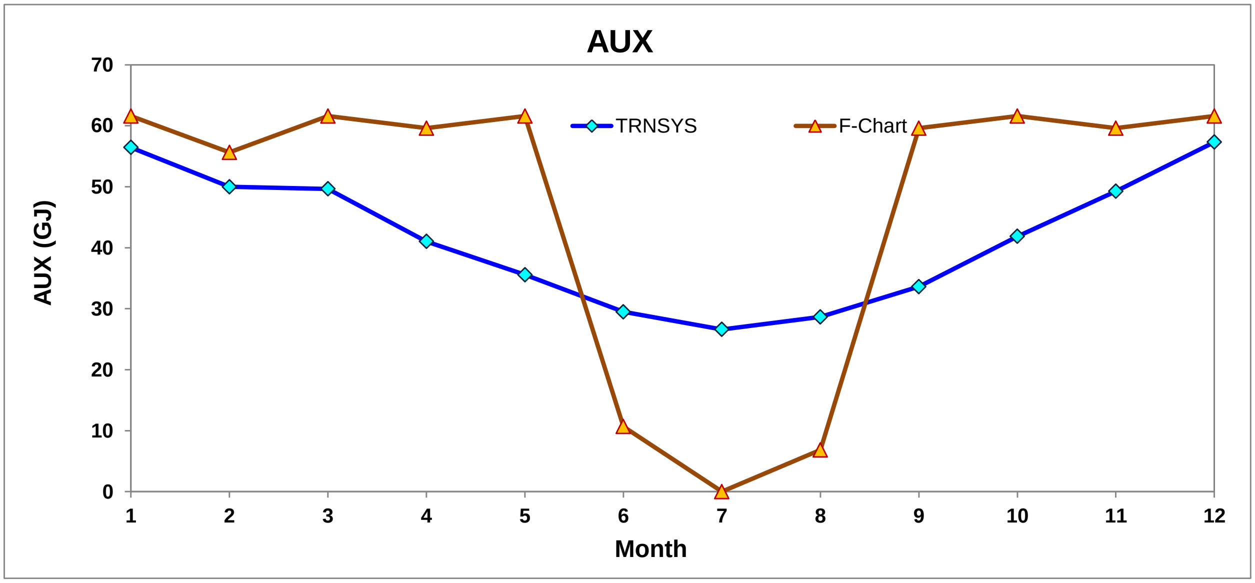

Figure 4-19Monthly Energy Supplied by the Backup Pool Heater (A_{pool}=1000 m^2)

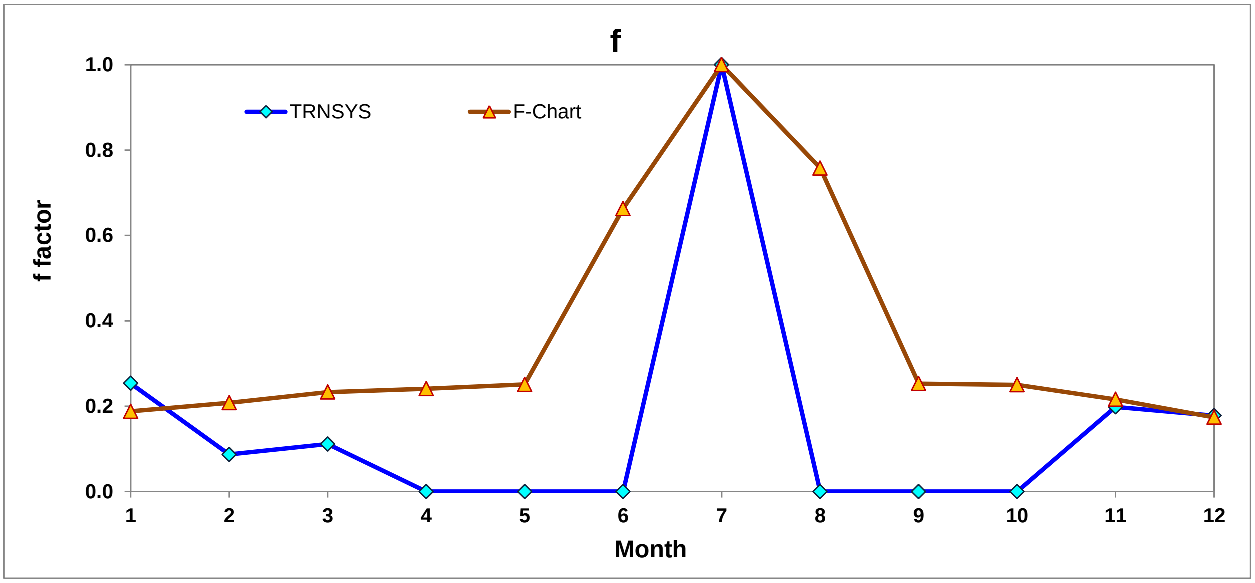

Figure 4-20f Factor (A_{pool}=1000 m^2)

Table 4-4 Comparisons Data between TRNSYS and F-Chart (A_{pool}=1000 m^2)

	TRNSYS					F-Chart (New weaher)						Diff				
	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Cal. from Eqns	Qcoll (%)	Q Pool (%)	Load (%)	AUX (%)	f
Jan	19.183	271.972	75.633	56.450	0.254	14.300	258.300	75.890	61.590	0.188	0.188	-25.45%	-5.03%	0.34%	9.11%	-34.91%
Feb	4.756	303.996	54.741	49.985	0.087	14.590	288.500	70.230	55.630	0.208	0.208	206.74%	-5.10%	28.29%	11.29%	58.23%
Mar	6.226	429.073	55.886	49.660	0.111	18.670	407.600	80.260	61.590	0.233	0.233	199.85%	-5.00%	43.61%	24.02%	52.18%
Apr	0.000	477.892	35.407	41.023	0.000	18.970	453.800	78.570	59.610	0.241	0.241	-	-5.04%	121.91%	45.31%	100.00%
May	0.000	563.847	23.750	35.564	0.000	20.650	535.200	82.250	61.590	0.251	0.251	-	-5.08%	246.31%	73.18%	100.00%
Jun	0.000	594.951	10.119	29.482	1.000	21.030	565.100	31.710	10.670	0.663	0.663	-	-5.02%	213.36%	-63.81%	-50.83%
Jul	0.000	591.038	4.873	26.602	1.000	0.000	561.400	0.000	0.000	1.000	1.000	-	-	-	-	-
Aug	0.000	555.188	10.620	28.658	0.000	21.410	527.300	28.240	6.830	0.758	0.758	-	-5.02%	165.92%	-76.17%	100.00%
Sep	0.000	476.338	25.455	33.620	0.000	20.200	452.400	79.810	59.610	0.253	0.253	-	-5.03%	213.54%	77.30%	100.00%
Oct	0.000	425.853	39.304	41.871	0.000	20.550	404.500	82.140	61.590	0.250	0.250	-	-5.01%	108.98%	47.10%	100.00%
Nov	12.192	309.884	61.442	49.250	0.198	16.380	294.500	75.990	59.610	0.216	0.216	34.35%	-4.96%	23.68%	21.04%	8.13%
Dec	12.413	243.492	69.739	57.325	0.178	12.940	231.200	74.530	61.590	0.174	0.174	4.24%	-5.05%	6.87%	7.44%	-2.30%
Year	54.771	5243.525	462.096	472.888	0.119	199.700	4979.700	759.630	559.920	0.263	0.263	**72.57%**	**-5.30%**	**39.17%**	**15.54%**	**54.93%**

4.3 Case3: Change heater capacity

4.3.1 Setting heater capacity equals to 1 kW

Shown in Figure 4-21 - Figure 4-25, the pool energy and auxiliary energy are similar for TRNSYS and F-Chart comparison while the rest of the results are quite different. Their difference percentages are shown in Table 4-5.

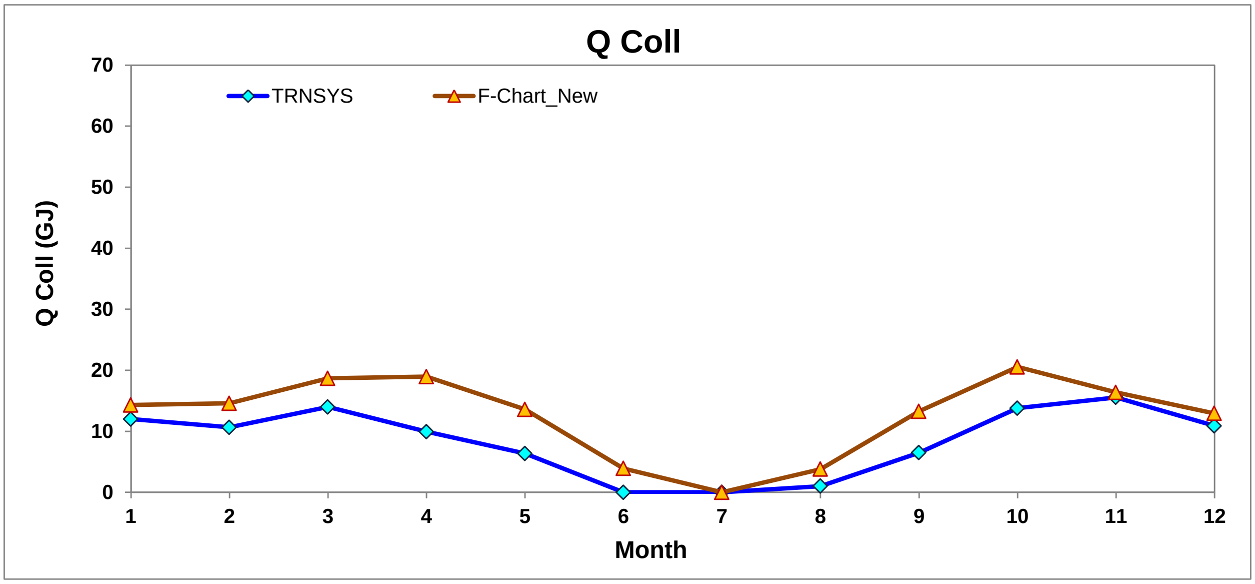

Figure 4-21 Monthly Solar Energy delivered by the Solar Collectors to the Pool (Heater Cap.=1kw)

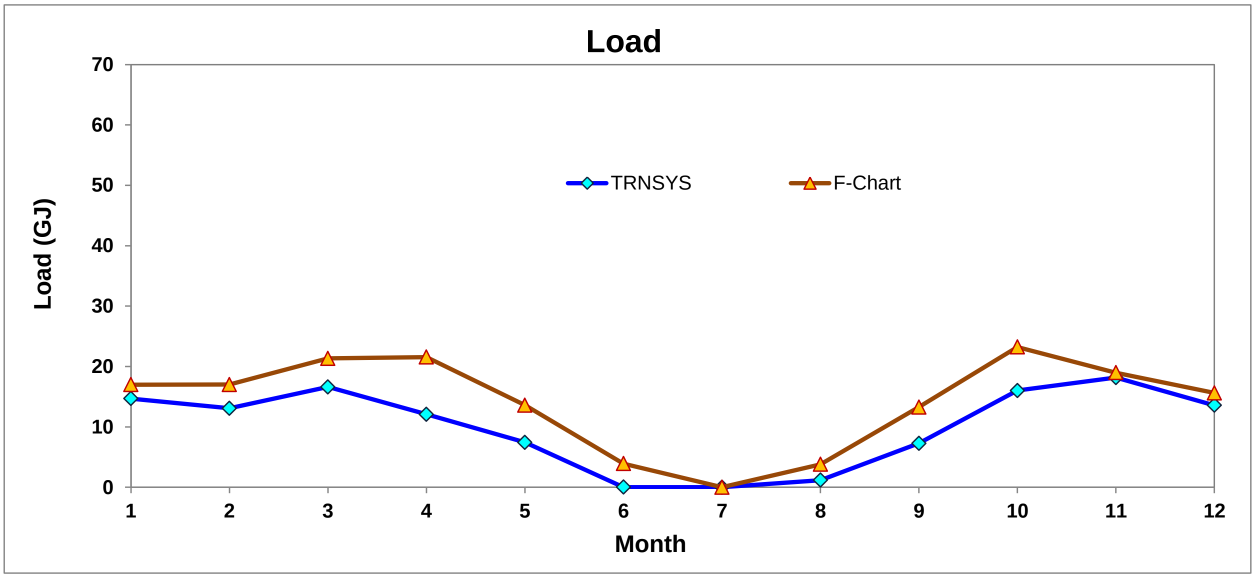

Figure 4-22 Monthly Load Demand (Heater Cap.=1kw)

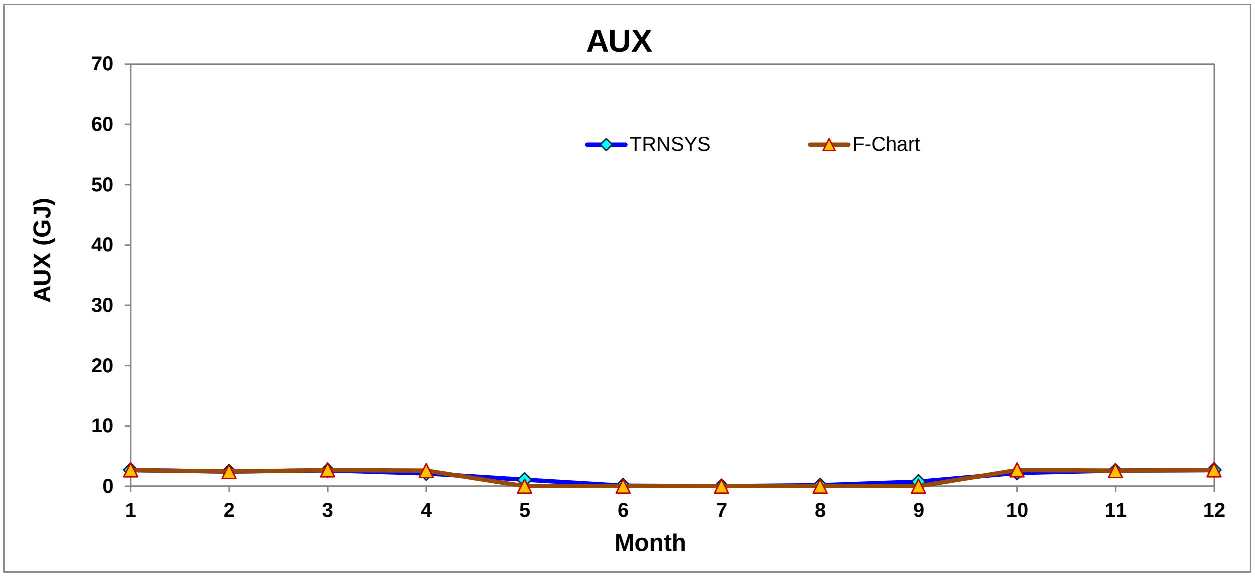

Figure 4-23Monthly Energy Supplied by the Backup Pool Heater (Heater Cap.=1kw)

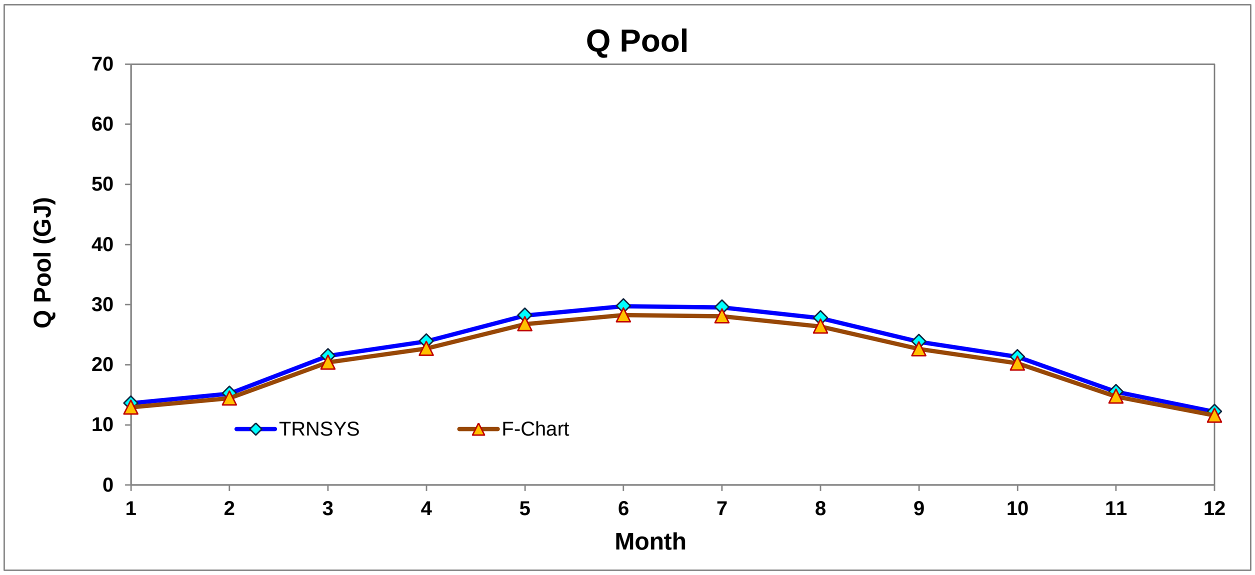

Figure 4-24 Monthly Solar Energy Directly Absorbed by the Pool (Heater Cap.=1kw)

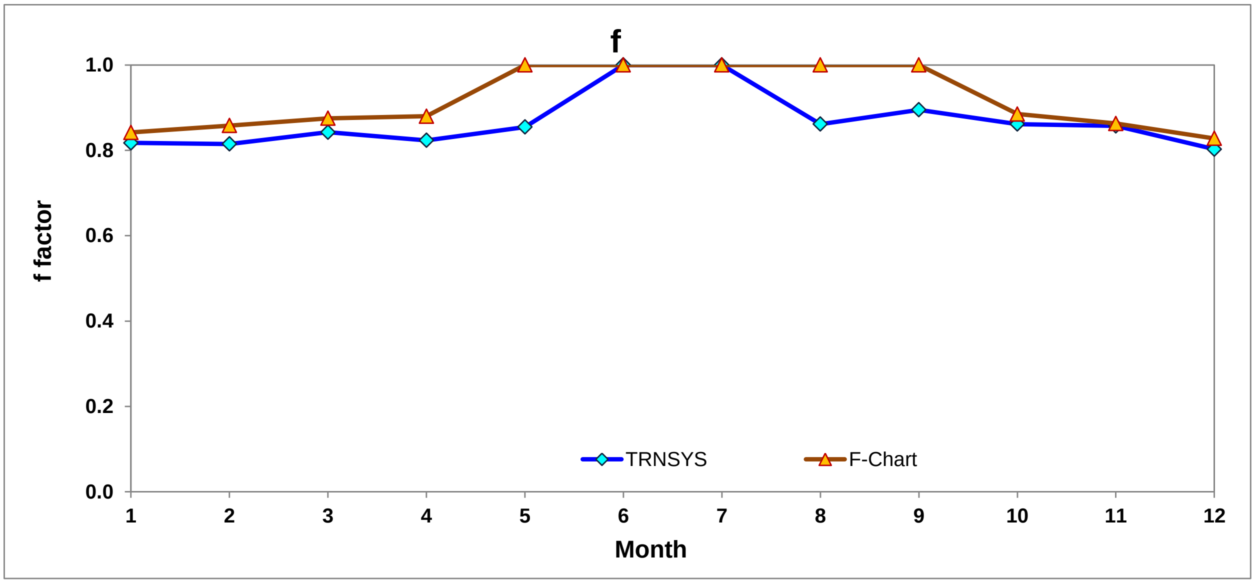

Figure 4-25 f Factor (Heater Cap.=1kw)

Table 4-5 Comparisons Data between TRNSYS and F-Chart **(**Heater Cap.=1kw)

	TRNSYS					F-Chart (New weaher)						Diff				
	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Cal. from Eqns	Qcoll (%)	Q Pool (%)	Load (%)	AUX (%)	f
Jan	11.998	13.599	14.676	2.678	0.818	14.300	12.910	16.980	2.678	0.842	0.842	19.19%	-5.06%	15.70%	-0.01%	2.91%
Feb	10.655	15.200	13.074	2.419	0.815	14.590	14.420	17.010	2.419	0.858	0.858	36.93%	-5.13%	30.11%	-0.01%	5.02%
Mar	13.988	21.454	16.605	2.617	0.842	18.670	20.380	21.340	2.678	0.875	0.875	33.47%	-5.00%	28.52%	2.32%	3.73%
Apr	9.944	23.895	12.075	2.131	0.824	18.960	22.690	21.560	2.592	0.880	0.879	90.67%	-5.04%	78.55%	21.62%	6.42%
May	6.352	28.192	7.432	1.080	0.855	13.600	26.760	13.600	0.000	1.000	1.000	114.11%	-5.08%	82.99%	-100.00%	14.53%
Jun	0.000	29.748	0.024	0.094	1.000	3.910	28.260	3.910	0.000	1.000	1.000	-	-5.00%	15872.03%	-100.00%	0.00%
Jul	0.000	29.552	0.000	0.000	1.000	0.000	28.070	0.000	0.000	1.000	1.000	-	-	-	-	-
Aug	1.006	27.759	1.168	0.162	0.861	3.790	26.370	3.790	0.000	1.000	1.000	-	-5.01%	224.43%	-100.00%	13.87%
Sep	6.503	23.817	7.266	0.763	0.895	13.270	22.620	13.270	0.000	1.000	1.000	104.05%	-5.03%	82.62%	-100.00%	10.50%
Oct	13.789	21.293	16.007	2.218	0.861	20.550	20.230	23.220	2.678	0.885	0.885	49.03%	-4.99%	45.06%	20.76%	2.66%
Nov	15.562	15.494	18.154	2.592	0.857	16.380	14.720	18.970	2.592	0.863	0.863	5.26%	-5.00%	4.50%	0.00%	0.67%
Dec	10.896	12.175	13.574	2.678	0.803	12.930	11.560	15.610	2.678	0.828	0.828	18.67%	-5.05%	15.00%	-0.01%	3.06%
Year	100.693	262.176	120.056	19.433	0.839	150.940	248.980	169.250	18.314	0.892	0.892	**33.29%**	**-5.30%**	**29.07%**	**-6.11%**	**5.97%**

4.3.2 Setting heater capacity equals to 1000 kW

Shown in Figure 4-26 - Figure 4-30, the pool energy and load are similar for TRNSYS and F-Chart comparison while the rest of the results are quite different. Their difference percentages are shown in Table 4-6.

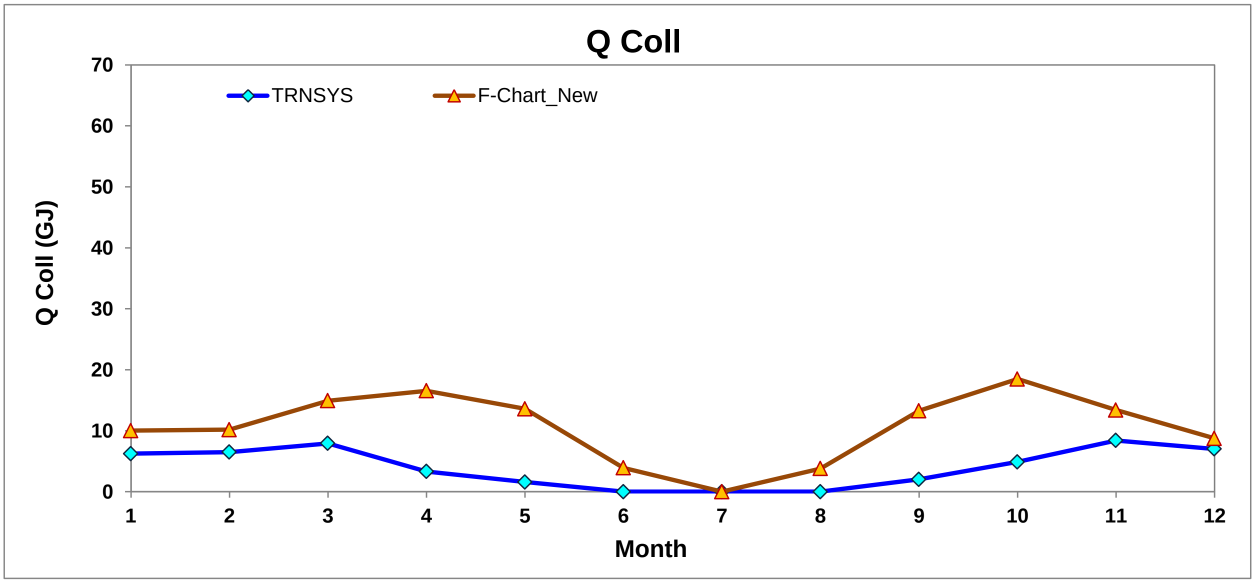

Figure 4-26 Monthly Solar Energy delivered by the Solar Collectors to the Pool (Heater Cap.=1000kw)

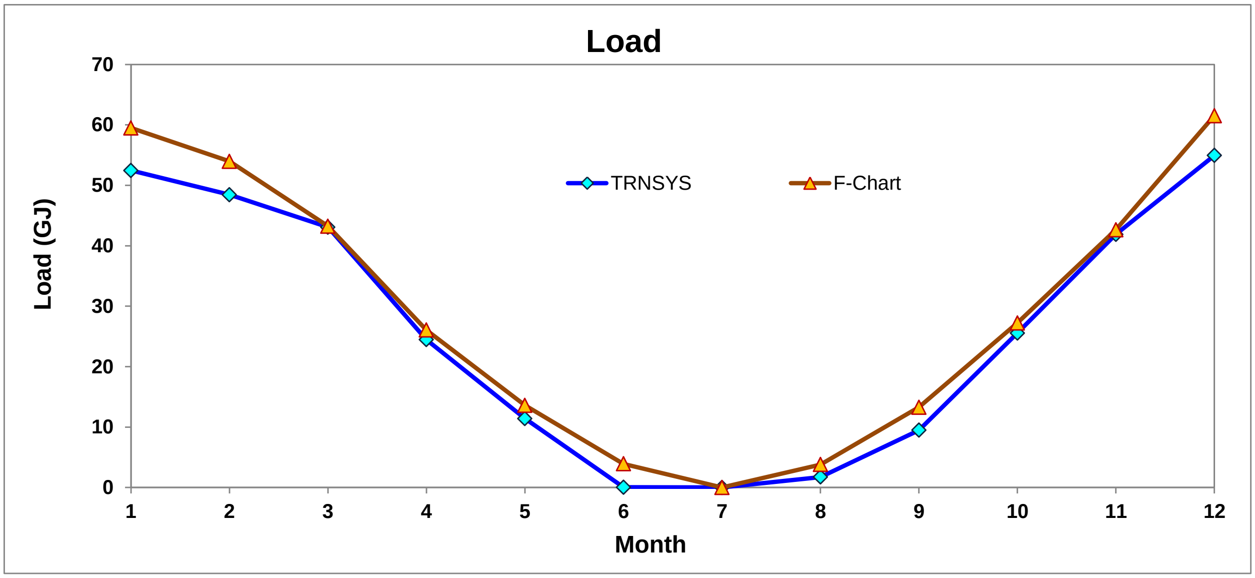

Figure 4-27 Monthly Load Demand (Heater Cap.=1000 kw)

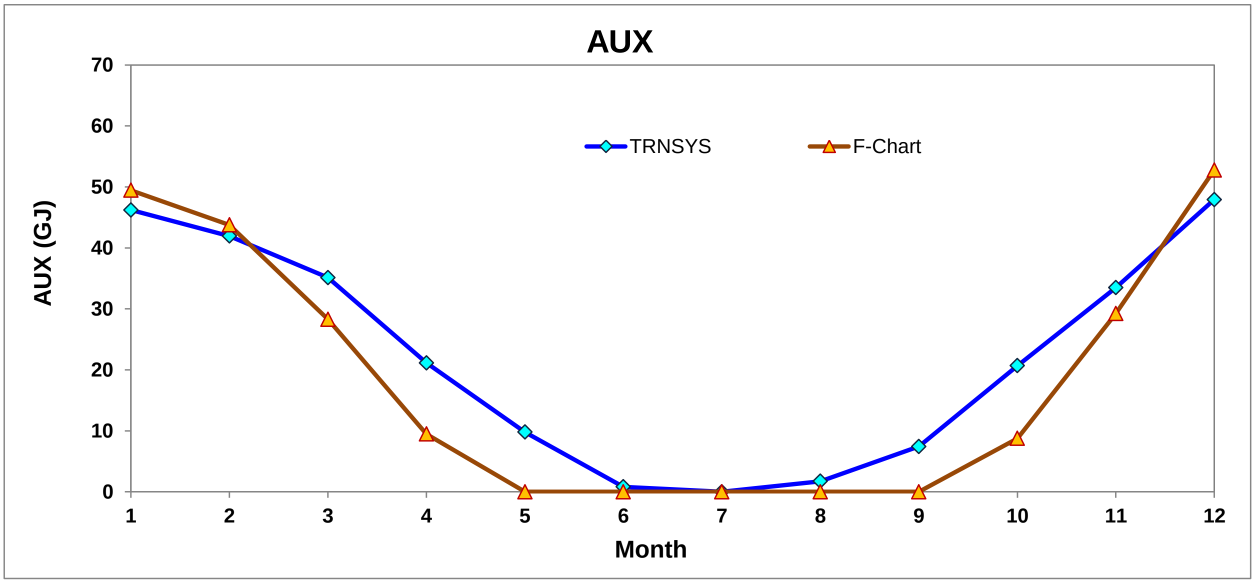

Figure 4-28Monthly Energy Supplied by the Backup Pool Heater (Heater Cap.=1000 kw)

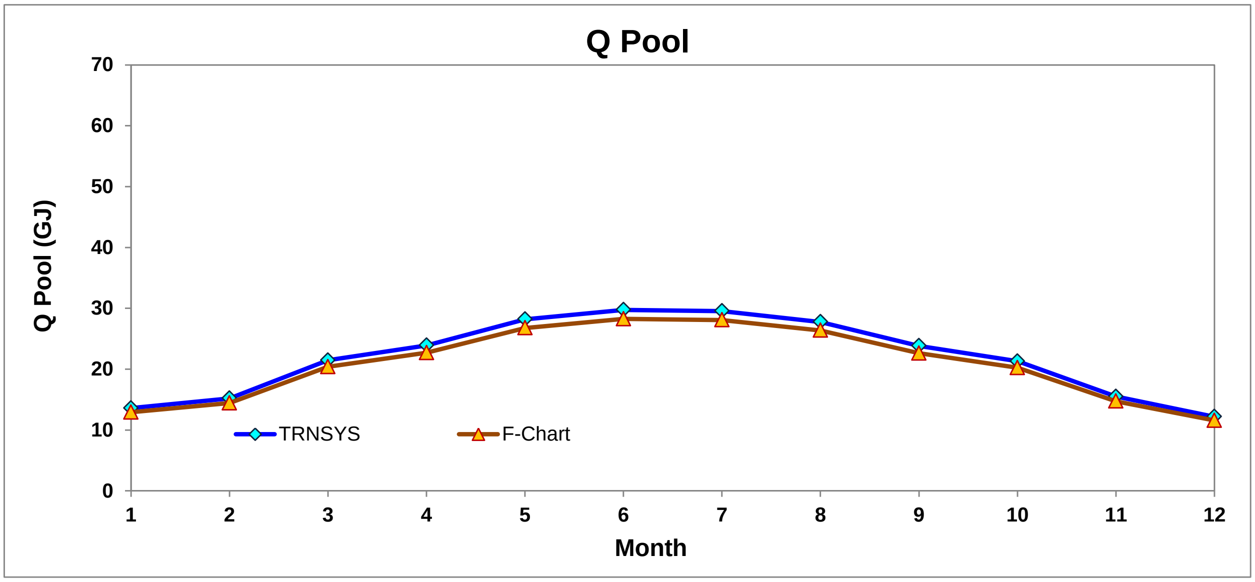

Figure 4-29 Monthly Solar Energy Directly Absorbed by the Pool (Heater Cap.=1000 kw)

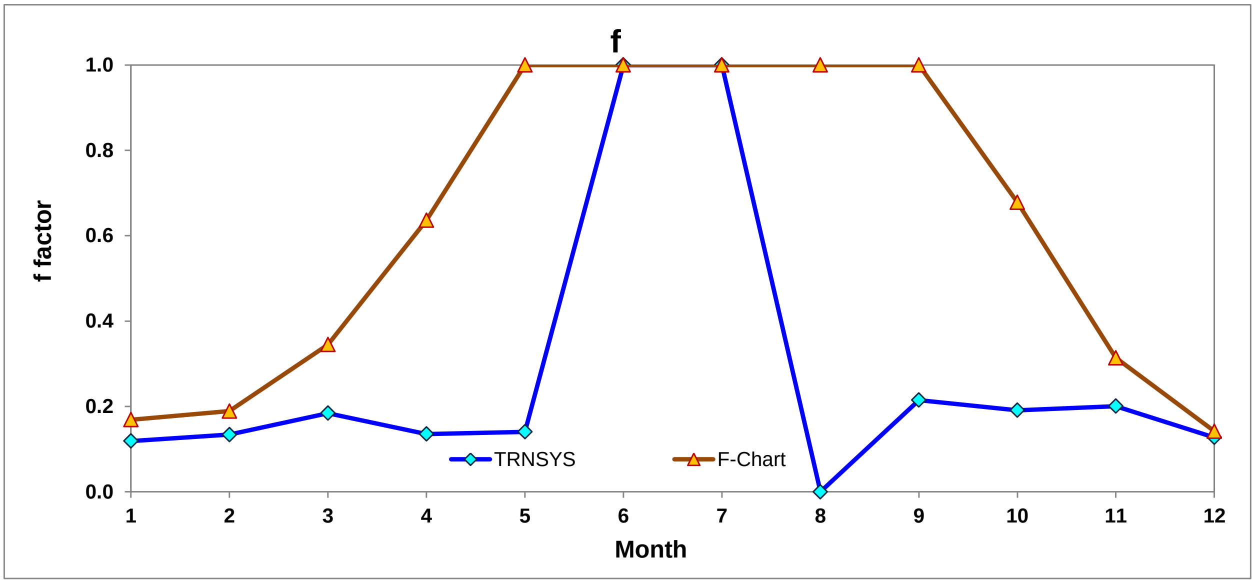

Figure 4-30 f Factor (Heater Cap.=1000 kw)

Table 4-6 Comparisons Data between TRNSYS and F-Chart (Heater Cap.=1000 kw)

	TRNSYS					F-Chart (New weaher)						Diff				
	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Cal. from Eqns	Qcoll (%)	Q Pool (%)	Load (%)	AUX (%)	f
Jan	6.245	13.599	52.456	46.211	0.119	10.020	12.910	59.480	49.460	0.169	0.168	60.46%	-5.06%	13.39%	7.03%	29.56%
Feb	6.496	15.200	48.435	41.939	0.134	10.180	14.420	53.960	43.780	0.189	0.189	56.70%	-5.13%	11.41%	4.39%	29.03%
Mar	7.938	21.454	43.074	35.136	0.184	14.920	20.380	43.230	28.300	0.345	0.345	87.97%	-5.00%	0.36%	-19.46%	46.59%
Apr	3.313	23.895	24.460	21.147	0.135	16.560	22.690	26.040	9.480	0.636	0.636	399.84%	-5.04%	6.46%	-55.17%	78.70%
May	1.602	28.192	11.406	9.805	0.140	13.600	26.760	13.600	0.000	1.000	1.000	749.10%	-5.08%	19.23%	-100.00%	85.96%
Jun	0.000	29.748	0.047	0.820	1.000	3.910	28.260	3.910	0.000	1.000	1.000	-	-5.00%	8308.35%	-100.00%	0.00%
Jul	0.000	29.552	0.000	0.000	1.000	0.000	28.070	0.000	0.000	1.000	1.000	-	-	-	-	-
Aug	0.000	27.759	1.728	1.731	0.000	3.790	26.370	3.790	0.000	1.000	1.000	-	-5.01%	119.36%	-100.00%	100.00%
Sep	2.036	23.817	9.475	7.439	0.215	13.270	22.620	13.270	0.000	1.000	1.000	551.77%	-5.03%	40.05%	-100.00%	78.51%
Oct	4.880	21.293	25.557	20.676	0.191	18.470	20.230	27.230	8.760	0.678	0.678	278.45%	-4.99%	6.55%	-57.63%	71.83%
Nov	8.403	15.494	41.889	33.486	0.201	13.400	14.720	42.630	29.220	0.314	0.314	59.47%	-5.00%	1.77%	-12.74%	36.11%
Dec	7.011	12.175	54.945	47.934	0.128	8.740	11.560	61.520	52.780	0.142	0.142	24.65%	-5.05%	11.97%	10.11%	10.13%
Year	47.924	262.176	313.471	266.324	0.153	126.860	248.980	348.630	221.780	0.364	0.364	**62.22%**	**-5.30%**	**10.08%**	**-20.08%**	**58.00%**

4.4 Case4: Change ratio of flow rate over collector area

4.4.1 Setting ratio equals to 0.03

Shown in Figure 4-31 - Figure 4-35Figure 4-34, the pool energy and load are similar for TRNSYS and F-Chart comparison while the rest of the results are quite different. Their difference percentages are shown in Table 4-7.

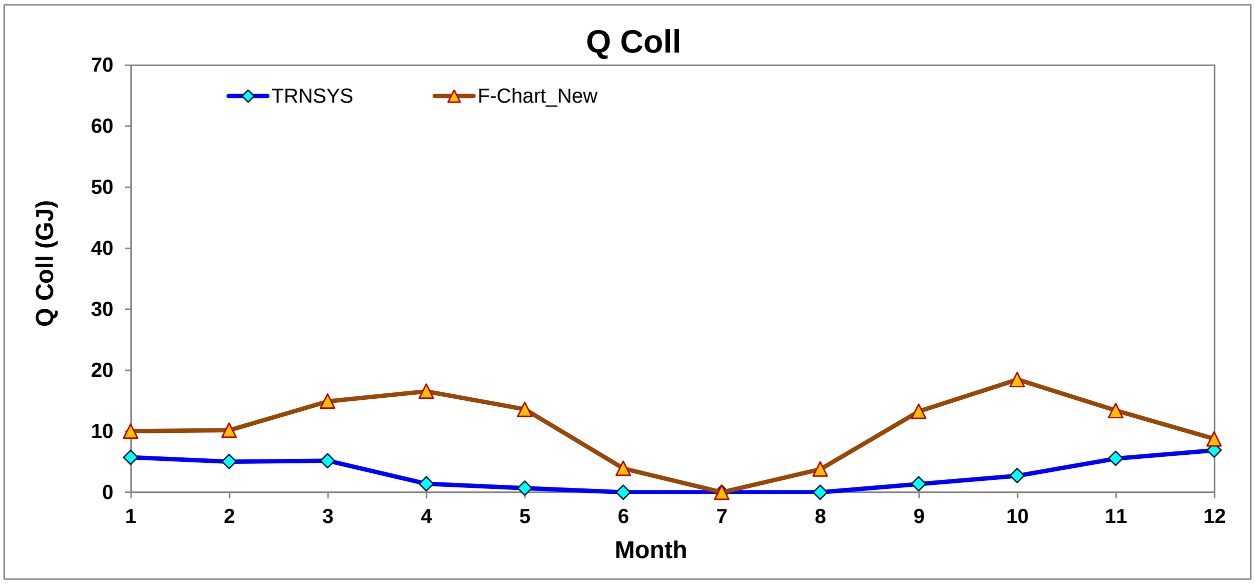

Figure 4-31 Monthly Solar Energy delivered by the Solar Collectors to the Pool (Ratio =0.03)

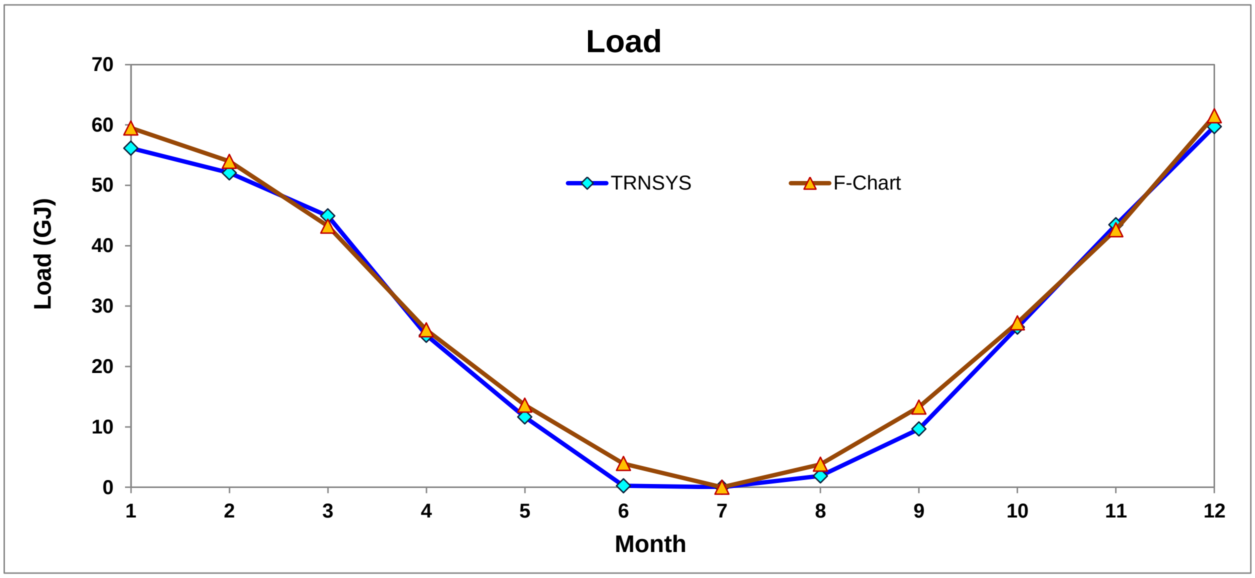

Figure 4-32 Monthly Load Demand (Ratio =0.03)

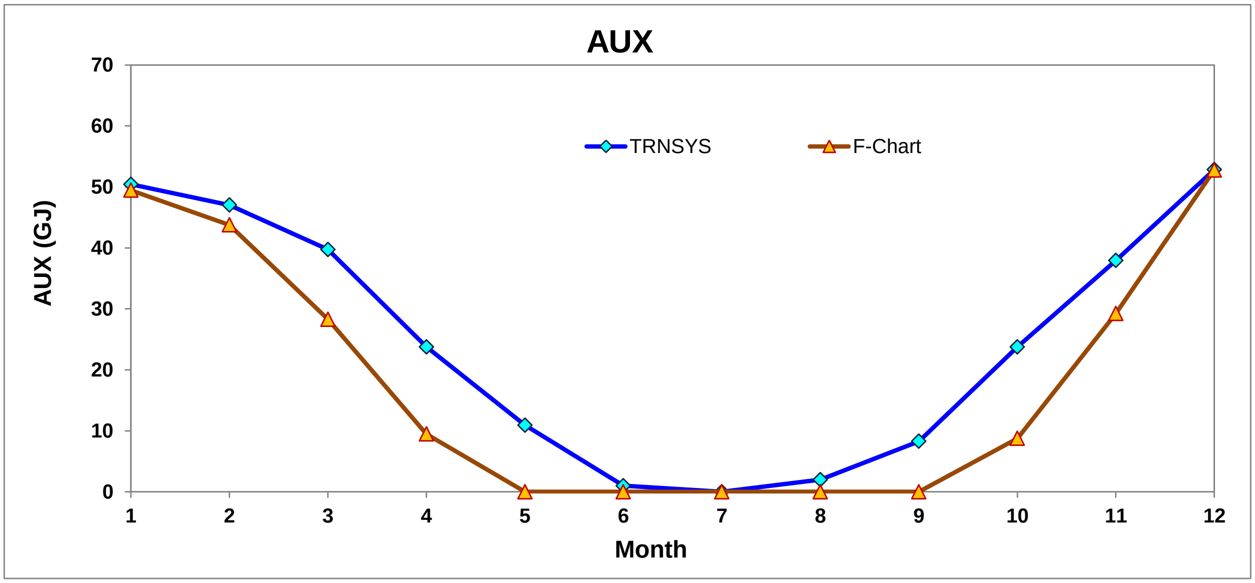

Figure 4-33Monthly Energy Supplied by the Backup Pool Heater (Ratio =0.03)

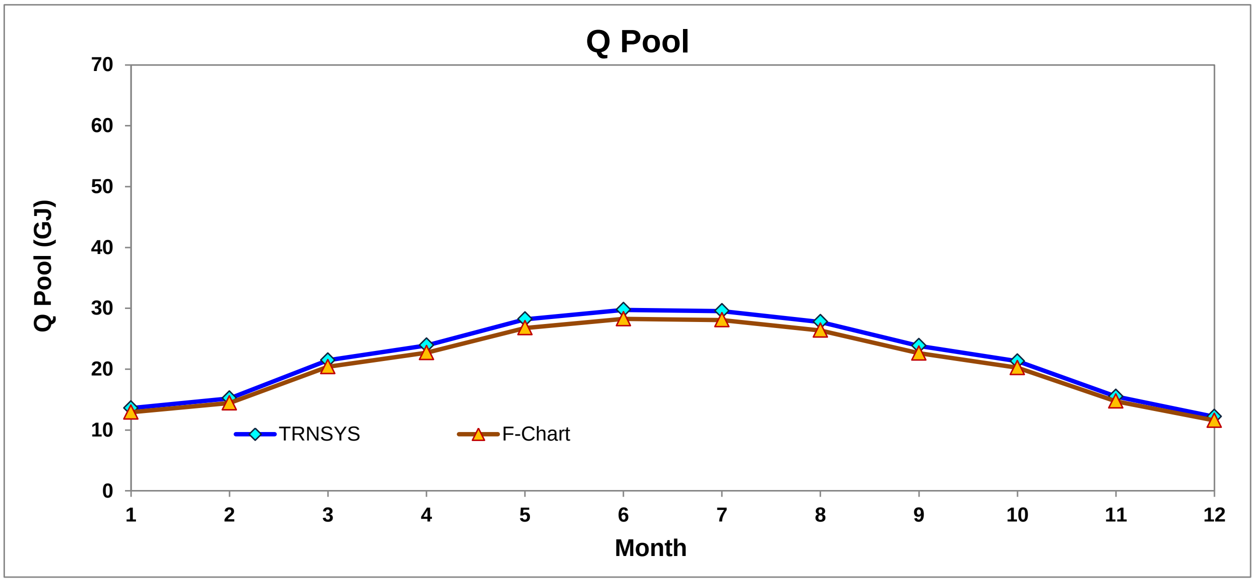

Figure 4-34 Monthly Solar Energy Directly Absorbed by the Pool (Ratio =0.03)

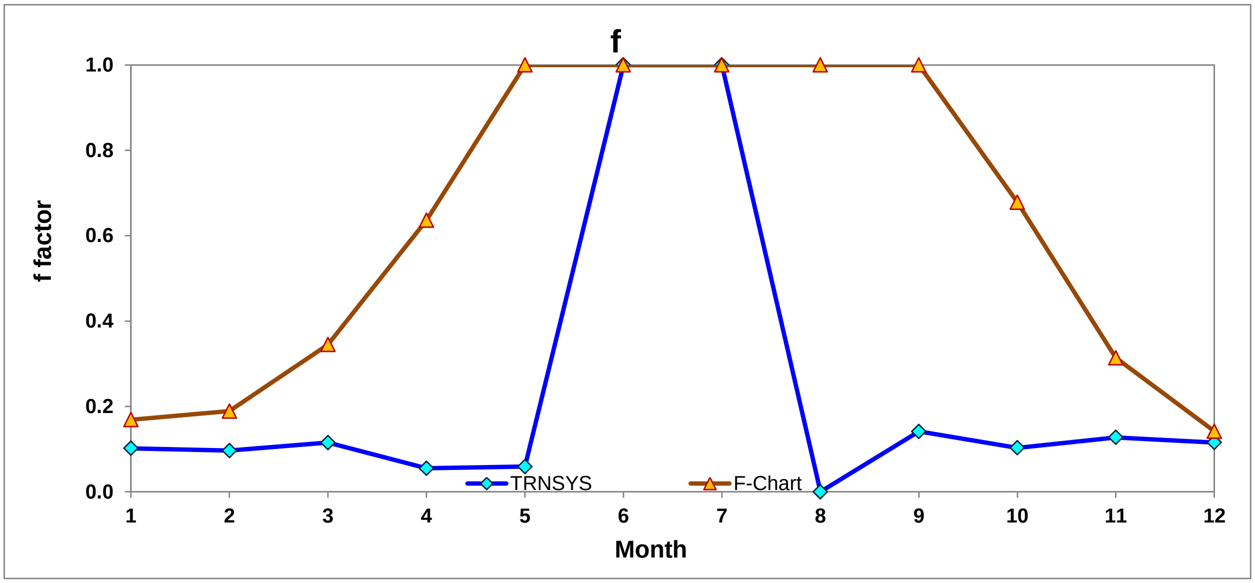

Figure 4-35 f Factor (Ratio =0.03)

Table 4-7 Comparisons Data between TRNSYS and F-Chart (Ratio =0.03)

	TRNSYS					F-Chart (New weaher)						Diff				
	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Cal. from Eqns	Qcoll (%)	Q Pool (%)	Load (%)	AUX (%)	f
Jan	5.718	13.599	56.143	50.425	0.102	10.020	12.910	59.480	49.460	0.169	0.168	75.25%	-5.06%	5.94%	-1.91%	39.74%
Feb	5.021	15.200	52.051	47.030	0.096	10.180	14.420	53.960	43.780	0.189	0.189	102.74%	-5.13%	3.67%	-6.91%	48.96%
Mar	5.177	21.454	44.921	39.744	0.115	14.920	20.380	43.230	28.300	0.345	0.345	188.20%	-5.00%	-3.76%	-28.79%	66.60%
Apr	1.387	23.895	25.150	23.764	0.055	16.560	22.690	26.040	9.480	0.636	0.636	1094.24%	-5.04%	3.54%	-60.11%	91.33%
May	0.686	28.192	11.616	10.930	0.059	13.600	26.760	13.600	0.000	1.000	1.000	1882.40%	-5.08%	17.08%	-100.00%	94.09%
Jun	0.000	29.748	0.246	0.994	1.000	3.910	28.260	3.910	0.000	1.000	1.000	-	-5.00%	1488.38%	-100.00%	0.00%
Jul	0.000	29.552	0.000	0.000	1.000	0.000	28.070	0.000	0.000	1.000	1.000	-	-	-	-	-
Aug	0.000	27.759	1.869	1.987	0.000	3.790	26.370	3.790	0.000	1.000	1.000	-	-5.01%	102.83%	-100.00%	100.00%
Sep	1.365	23.817	9.645	8.280	0.142	13.270	22.620	13.270	0.000	1.000	1.000	872.30%	-5.03%	37.59%	-100.00%	85.85%
Oct	2.731	21.293	26.494	23.764	0.103	18.470	20.230	27.230	8.760	0.678	0.678	576.37%	-4.99%	2.78%	-63.14%	84.80%
Nov	5.540	15.494	43.463	37.922	0.127	13.400	14.720	42.630	29.220	0.314	0.314	141.87%	-5.00%	-1.92%	-22.95%	59.40%
Dec	6.906	12.175	59.732	52.826	0.116	8.740	11.560	61.520	52.780	0.142	0.142	26.56%	-5.05%	2.99%	-0.09%	18.58%
Year	34.530	262.176	331.330	297.666	0.104	126.860	248.980	348.630	221.780	0.364	0.364	**72.78%**	**-5.30%**	**4.96%**	**-34.22%**	**71.37%**

4.4.2 Setting ratio equals to 0.05

Shown in Figure 4-36 - Figure 4-40, the pool energy and load are similar for TRNSYS and F-Chart comparison while the rest of the results are quite different. Their difference percentages are shown in Table 4-8.

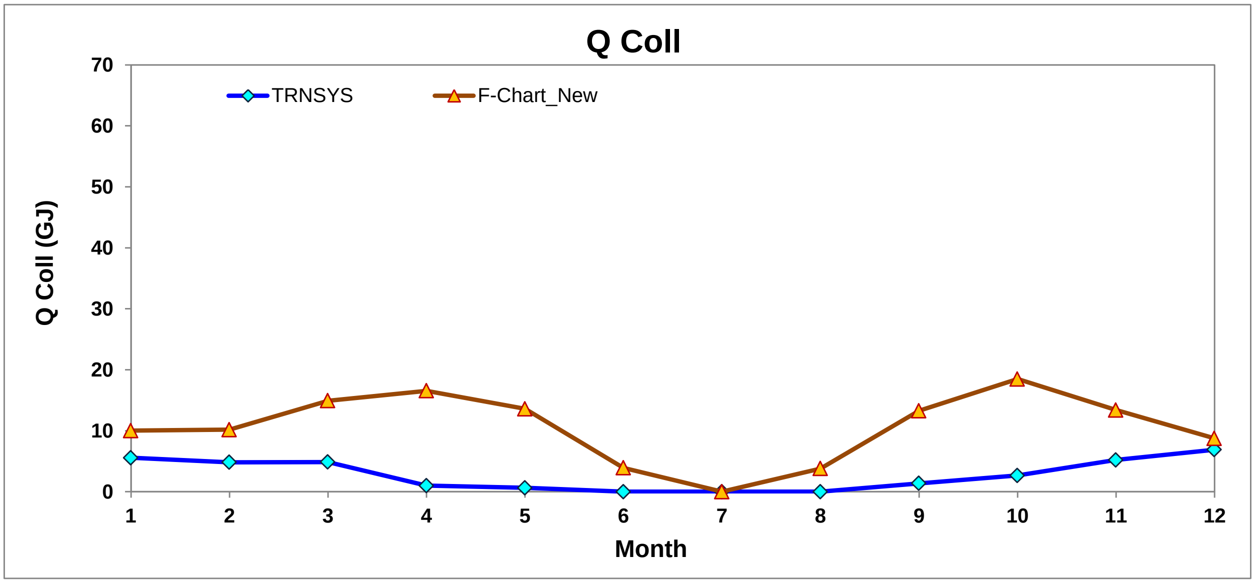

Figure 4-36 Monthly Solar Energy delivered by the Solar Collectors to the Pool (Ratio =0.05)

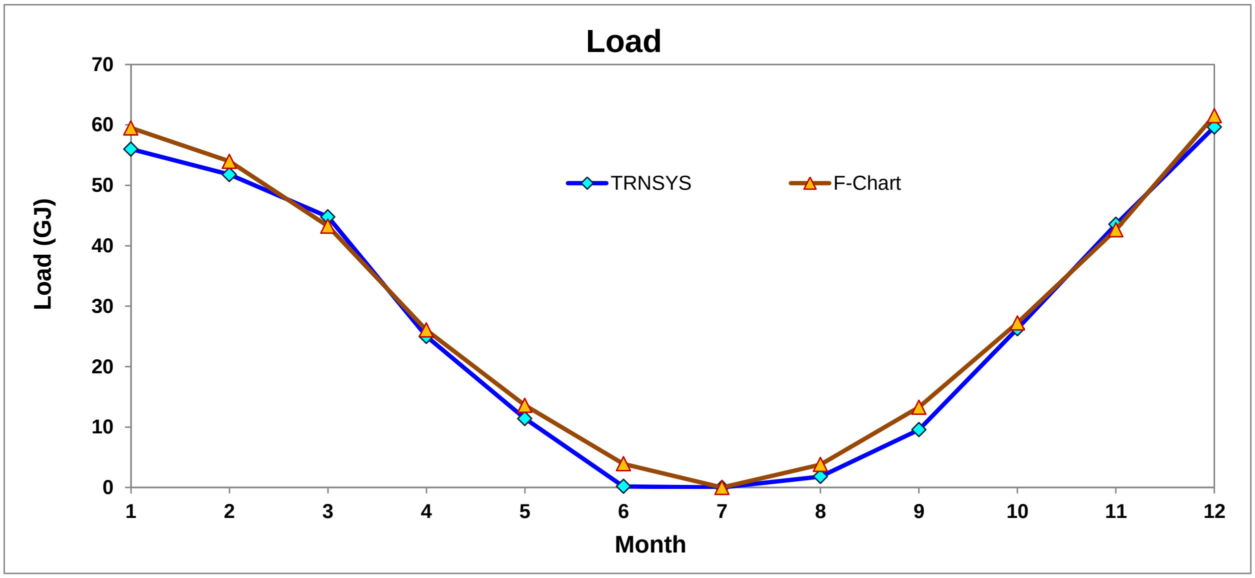

Figure 4-37 Monthly Load Demand (Ratio =0.05)

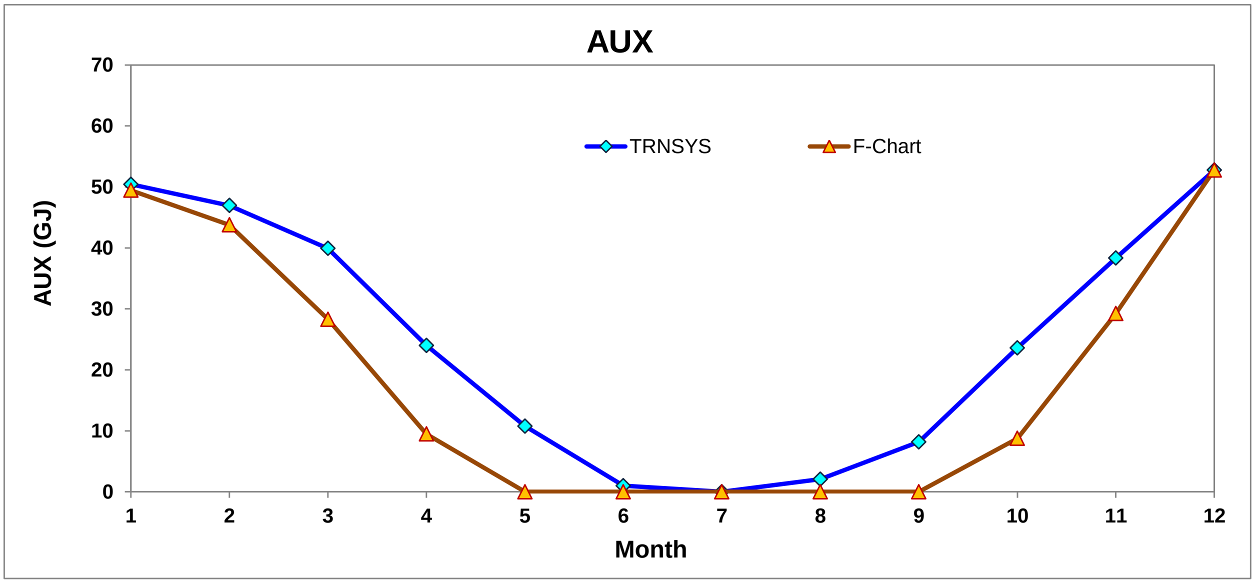

Figure 4-38Monthly Energy Supplied by the Backup Pool Heater (Ratio =0.05)

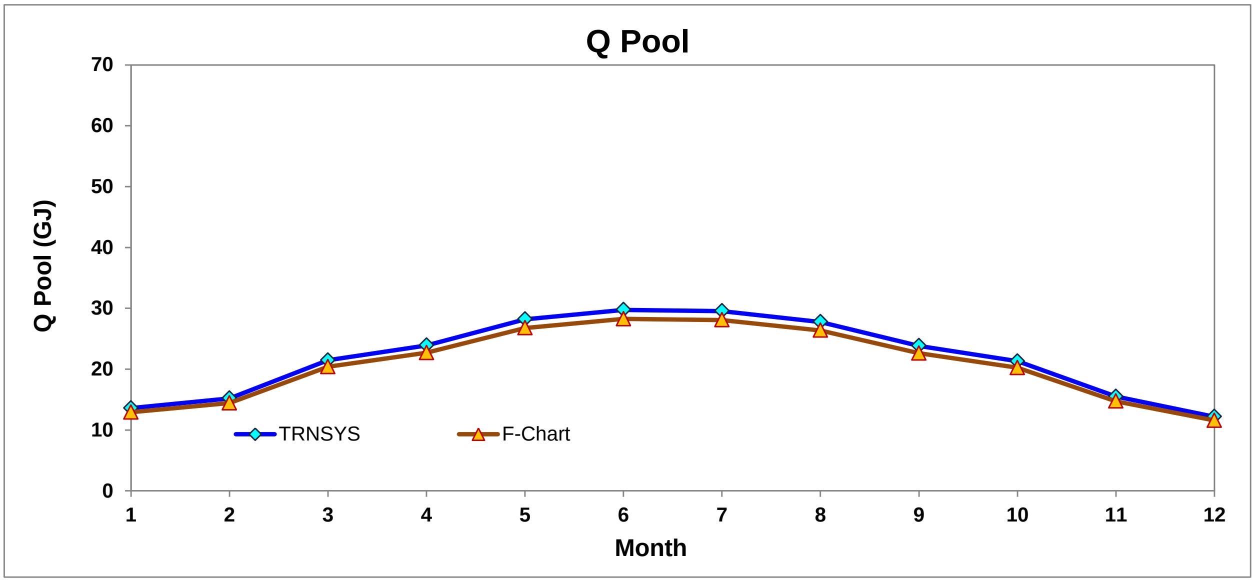

Figure 4-39 Monthly Solar Energy Directly Absorbed by the Pool (Ratio =0.05)

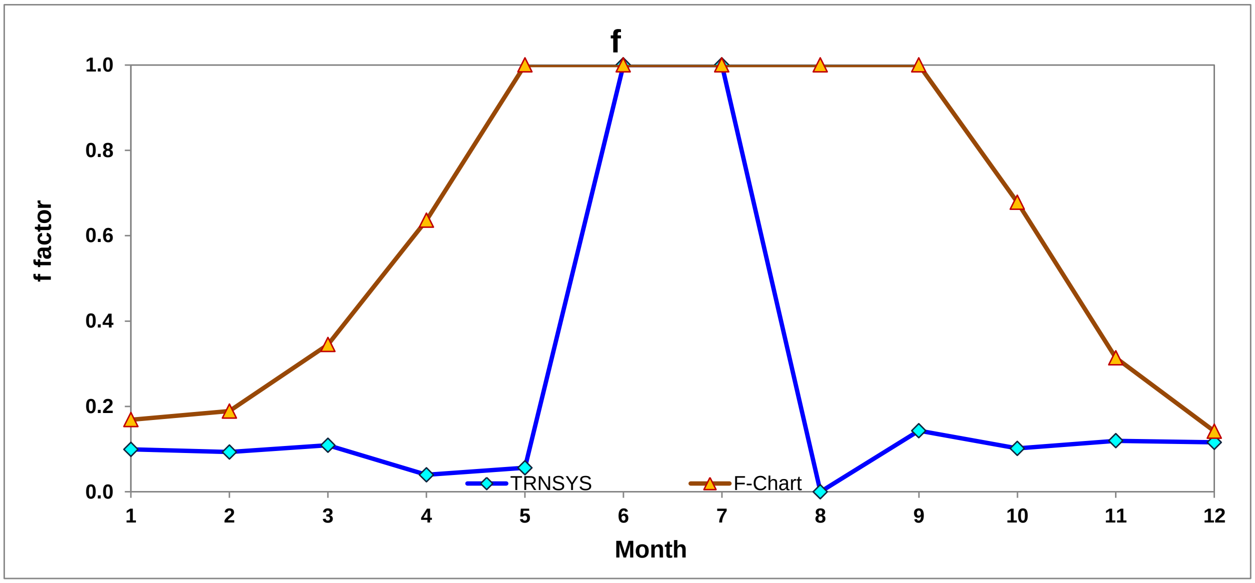

Figure 4-40 f Factor (Ratio =0.05)

Table 4-8 Comparisons Data between TRNSYS and F-Chart (Ratio =0.05)

	TRNSYS					F-Chart (New weaher)						Diff				
	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Qcoll (GJ)	Q Pool (GJ)	Load (GJ)	AUX (GJ)	f	Cal. from Eqns	Qcoll (%)	Q Pool (%)	Load (%)	AUX (%)	f
Jan	5.570	13.599	55.995	50.425	0.099	10.020	12.910	59.480	49.460	0.169	0.168	79.89%	-5.06%	6.22%	-1.91%	41.14%
Feb	4.823	15.200	51.770	46.948	0.093	10.180	14.420	53.960	43.780	0.189	0.189	111.09%	-5.13%	4.23%	-6.75%	50.71%
Mar	4.878	21.454	44.787	39.910	0.109	14.920	20.380	43.230	28.300	0.345	0.345	205.87%	-5.00%	-3.48%	-29.09%	68.43%
Apr	0.994	23.895	25.006	24.012	0.040	16.560	22.690	26.040	9.480	0.636	0.636	1566.37%	-5.04%	4.14%	-60.52%	93.75%
May	0.642	28.192	11.406	10.764	0.056	13.600	26.760	13.600	0.000	1.000	1.000	2018.56%	-5.08%	19.24%	-100.00%	94.37%
Jun	0.000	29.748	0.190	0.994	1.000	3.910	28.260	3.910	0.000	1.000	1.000	-	-5.00%	1958.16%	-100.00%	0.00%
Jul	0.000	29.552	0.000	0.000	1.000	0.000	28.070	0.000	0.000	1.000	1.000	-	-	-	-	-
Aug	0.000	27.759	1.814	2.070	0.000	3.790	26.370	3.790	0.000	1.000	1.000	-	-5.01%	108.95%	-100.00%	100.00%
Sep	1.370	23.817	9.567	8.197	0.143	13.270	22.620	13.270	0.000	1.000	1.000	868.96%	-5.03%	38.71%	-100.00%	85.68%
Oct	2.666	21.293	26.264	23.598	0.102	18.470	20.230	27.230	8.760	0.678	0.678	592.71%	-4.99%	3.68%	-62.88%	85.03%
Nov	5.204	15.494	43.540	38.336	0.120	13.400	14.720	42.630	29.220	0.314	0.314	157.50%	-5.00%	-2.09%	-23.78%	61.94%
Dec	6.903	12.175	59.647	52.744	0.116	8.740	11.560	61.520	52.780	0.142	0.142	26.60%	-5.05%	3.14%	0.07%	18.49%
Year	33.049	262.176	329.987	297.997	0.100	126.860	248.980	348.630	221.780	0.364	0.364	**73.95%**	**-5.30%**	**5.35%**	**-34.37%**	**72.49%**

5 CONCLUSION

For comparisons of F-Chart and TRNSYS Simulations on Pool Heating System, the results from two softwares do not match well on monthly results. The differences of annual total solar energy, annual solar radiation absorbed by the pool, annual load demand, annual auxiliary heating energy and f factor are 62.16%, -4.95%, 10.33%, -19.5%, 57.85%, respectively. The mains temperature varies based on the input profile. The different cases studies are covered, which still indicates that TRNSYS and F-Chart simulations do not match well by showing large annual differences among the comparisons.

The calculation algorithms of TRNSYS and F-Chart for Pool Heating System are doubted to be quite different, which results in the large result variations.

Therefore, for IC3 development, Pool Heating System model by TESS modeling group is recommended, which is shown in APPENDIX B.

6 REFERENCE

S.A., Klein and W.A., Beckman, 2001, F-Chart User’s Manual.

Solar Energy Laboratory, 2010, TRNSYS 17 Manual.

Pohl, S.E. 1999. Use of Air Conditioner Heat Rejection for Swimming Pool Heating. Master's Thesis, University of Wisconsin-Madison.

Auer, T., 1996. TRNSYS-TYPE 344: Assessment of an Indoor or Outdoor Swimming Pool,

7 APPENDIX A: TRNSYS OUTPUT FOR POOL HEATING SYSTEM

The purpose of this section is to present all TRNSYS output plots for each TRNSYS primary components shown in Pool Heating System for further demonstrating working principle of TRNSYS system.

7.1 Weather

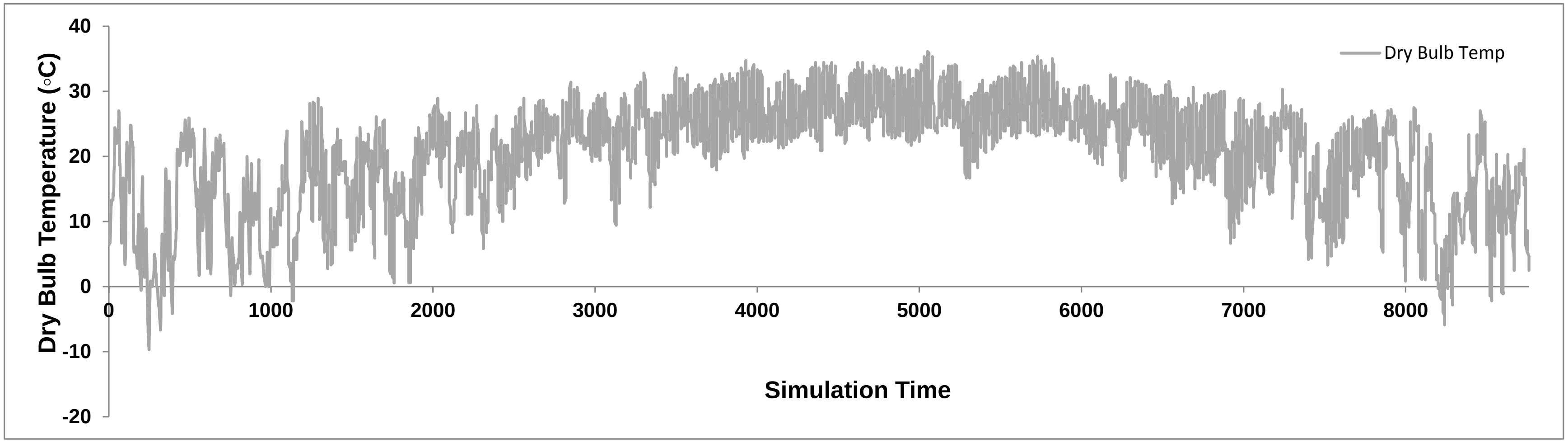

Figure 7-1 Dry Bulb Temperature

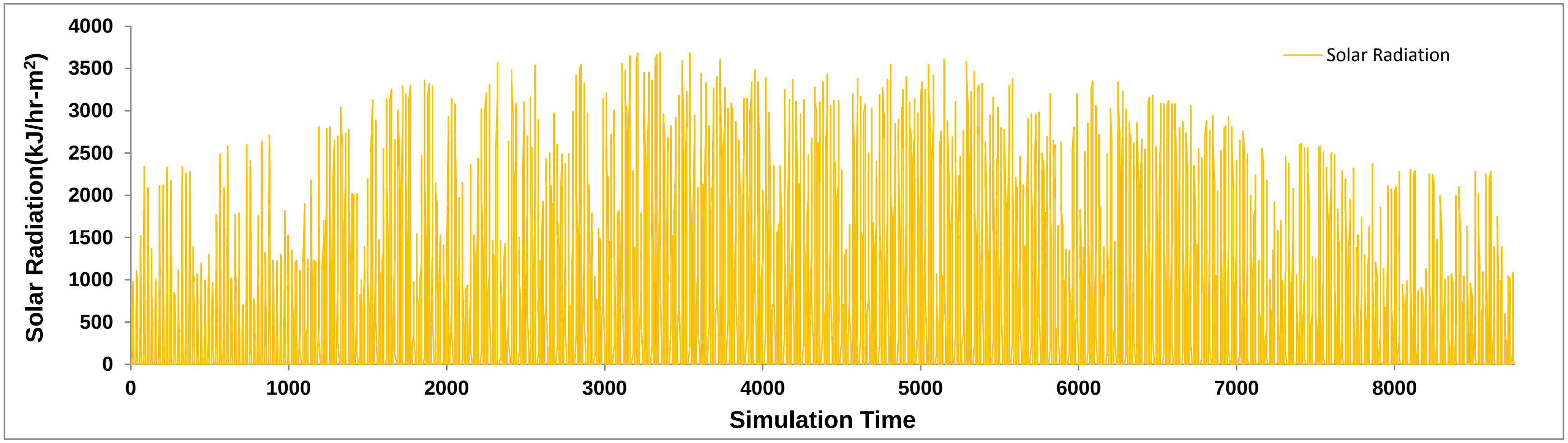

Figure 7-2 Solar Radiation

7.2 Solar Collector

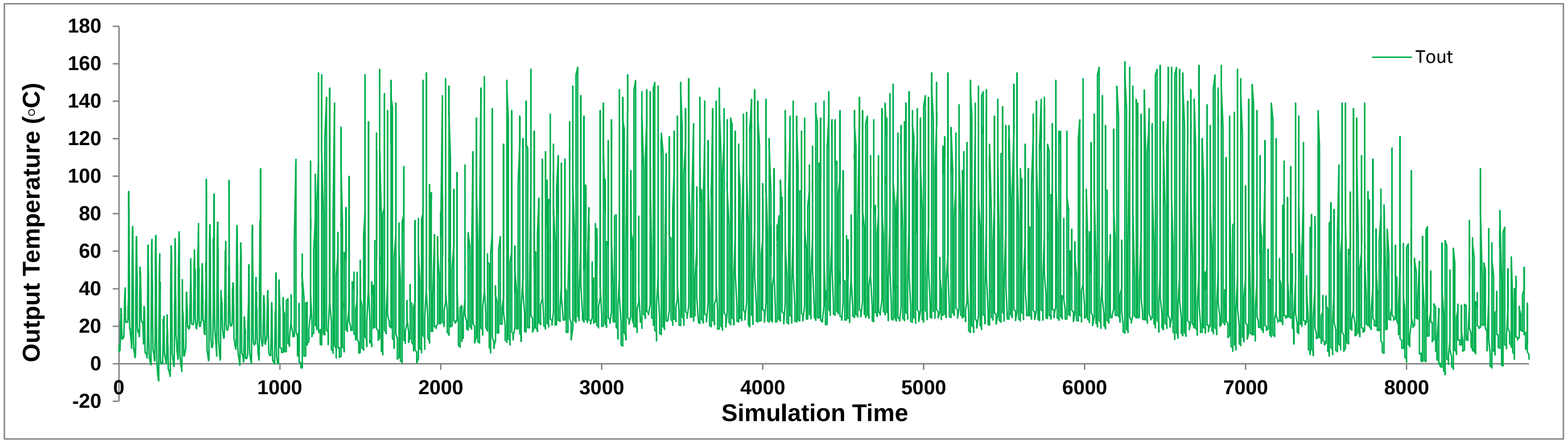

Figure 7-3 Output Temperatures of Solar Collector

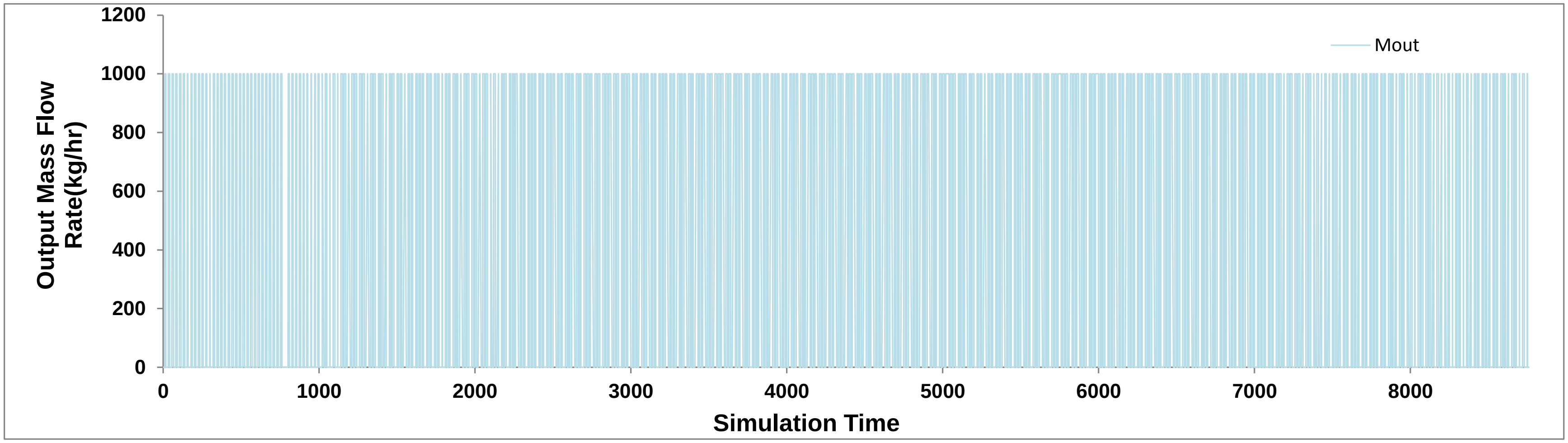

Figure 7-4 Output Mass Flow Rate of Solar Collector

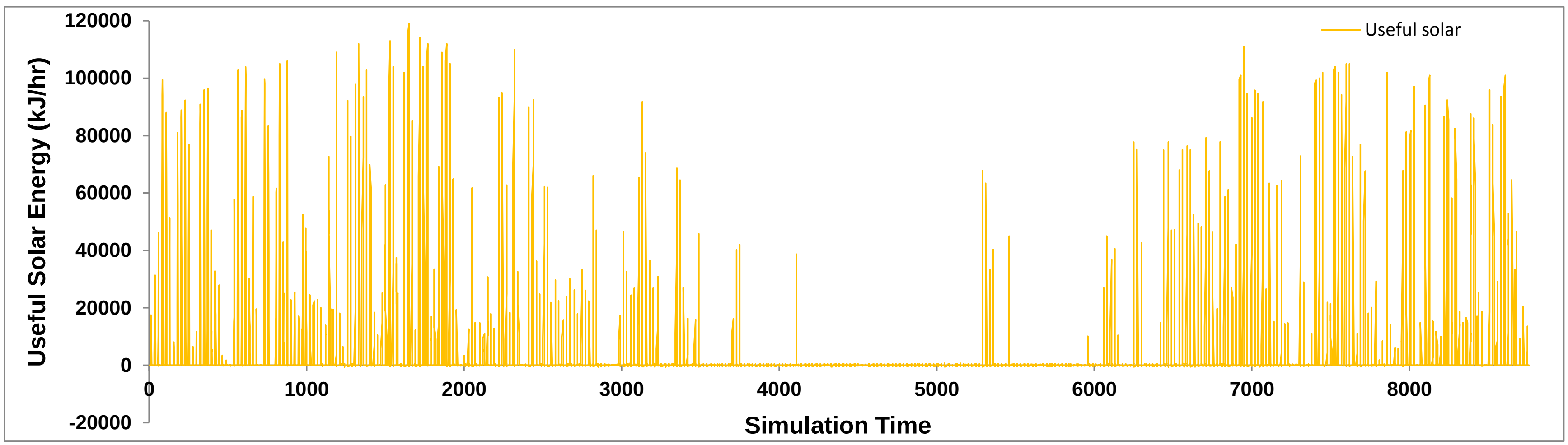

Figure 7-5 Useful Gain of Solar Collector

7.3 Pump 1

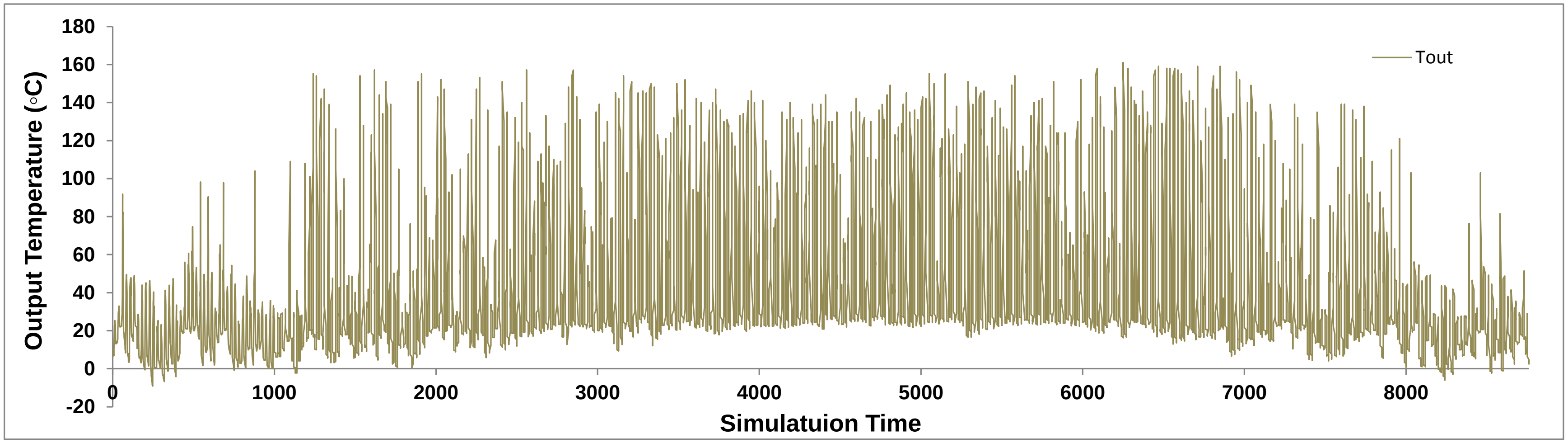

Figure 7-6 Output Temperature of Pump 1

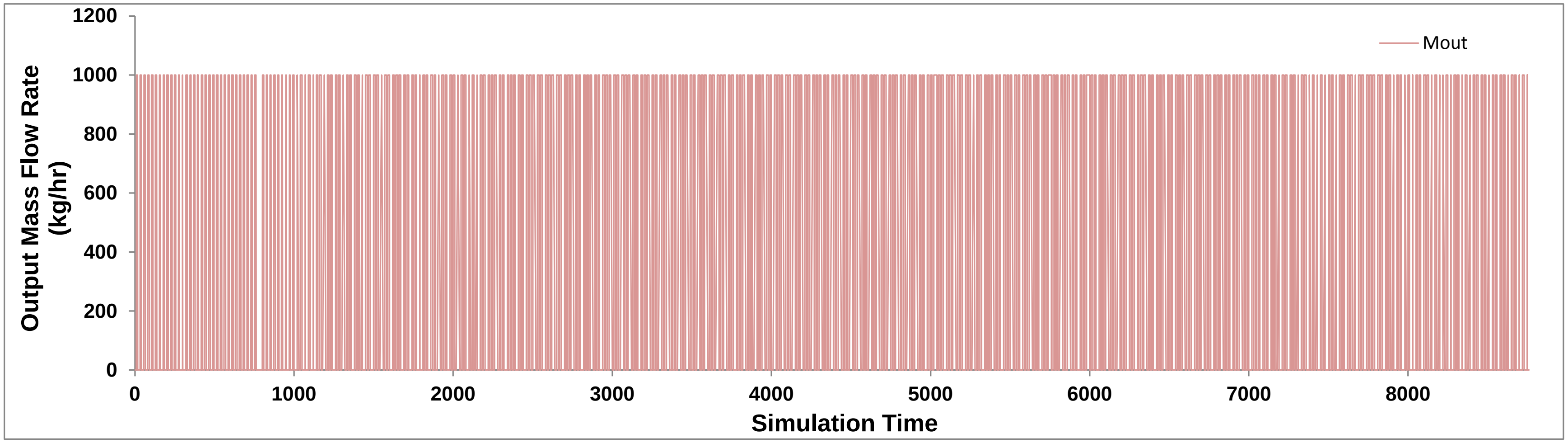

Figure 7-7 Output Mass Flow Rate of Pump 1

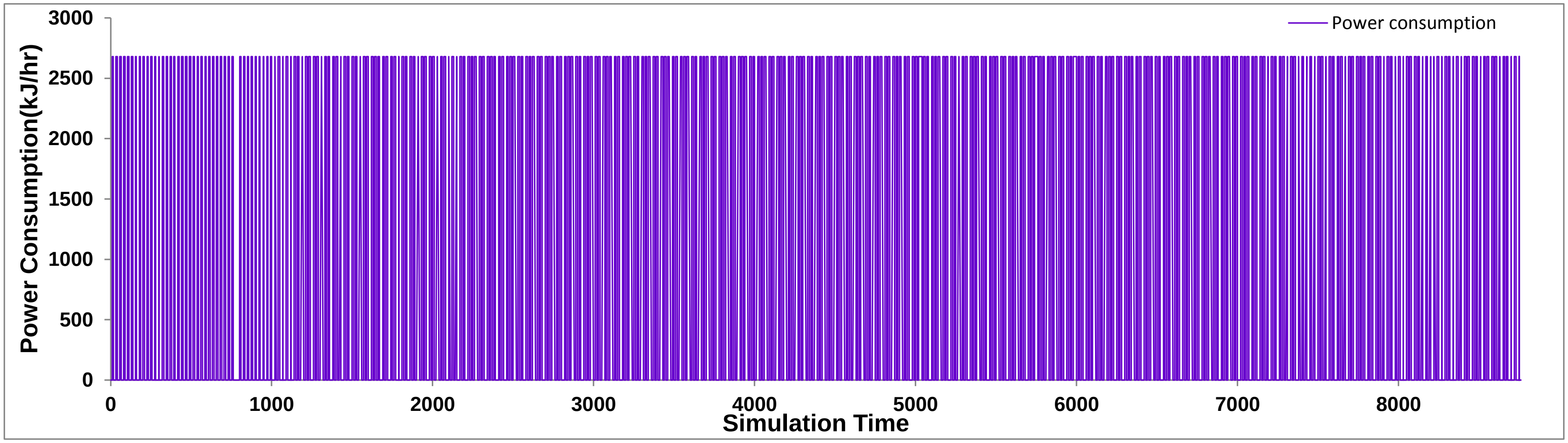

Figure 7-8 Power Consumption of Pump 1

7.4 Controller

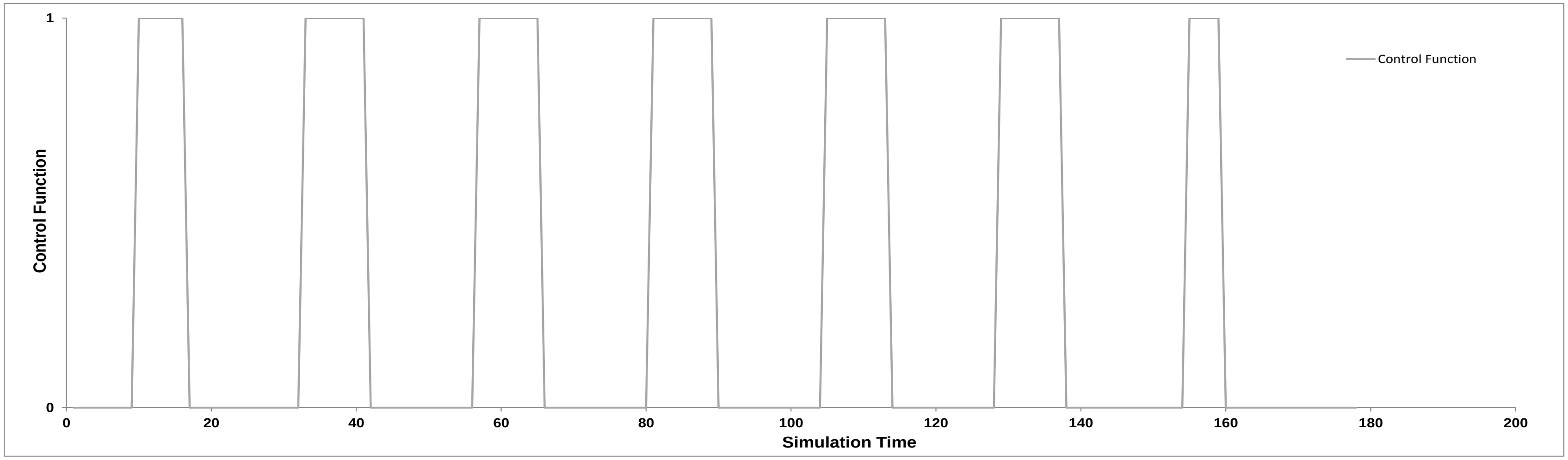

Figure 7-9 Controller in Solar Collector Loop

7.5 Pump 2

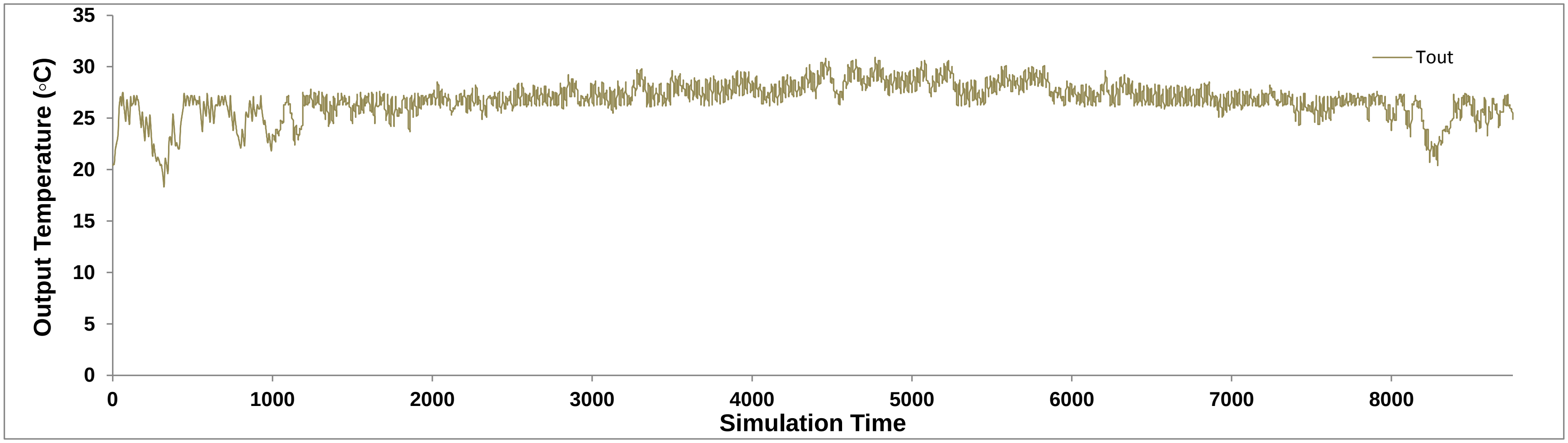

Figure 7-10 Output Temperature of Pump 2

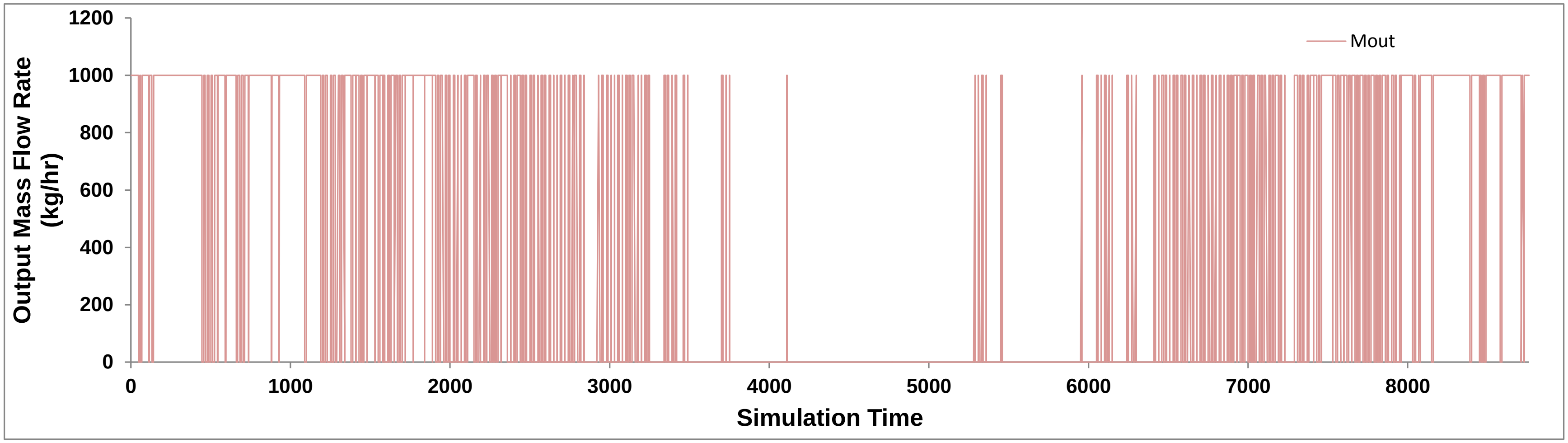

Figure 7-11 Output Mass Flow Rate of Pump 2

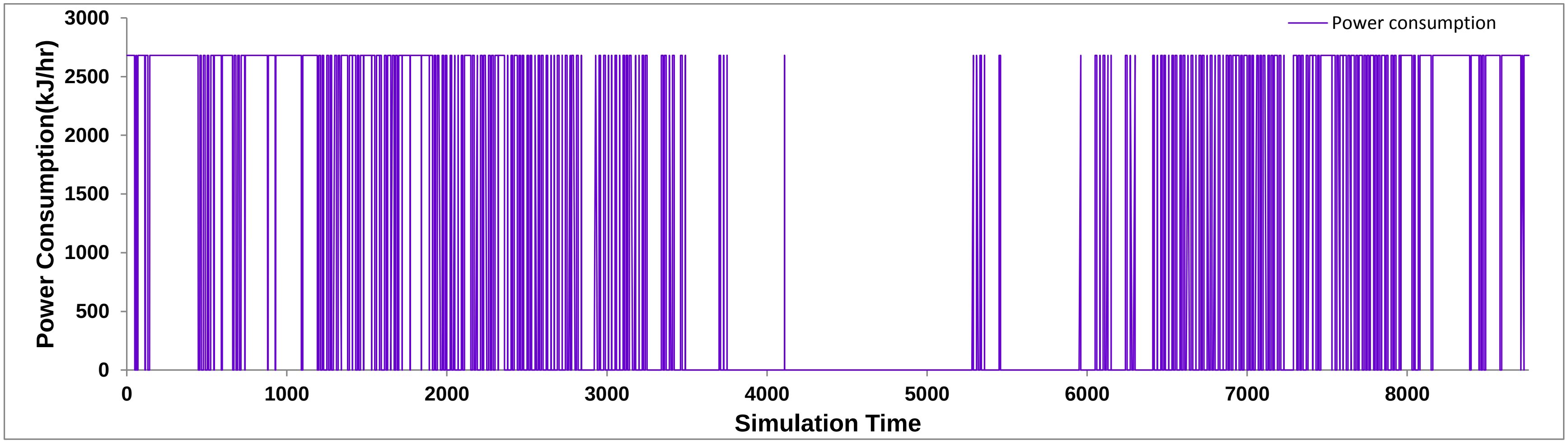

Figure 7-12 Power Consumption of Pump 2

7.6 Pump 3

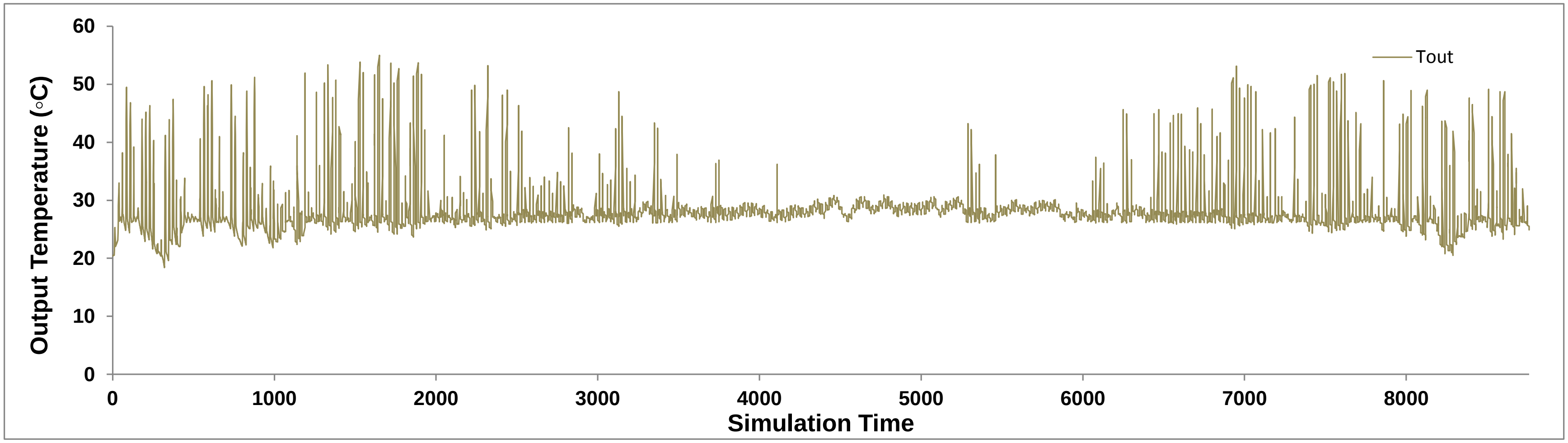

Figure 7-13 Output Temperature of Pump 3

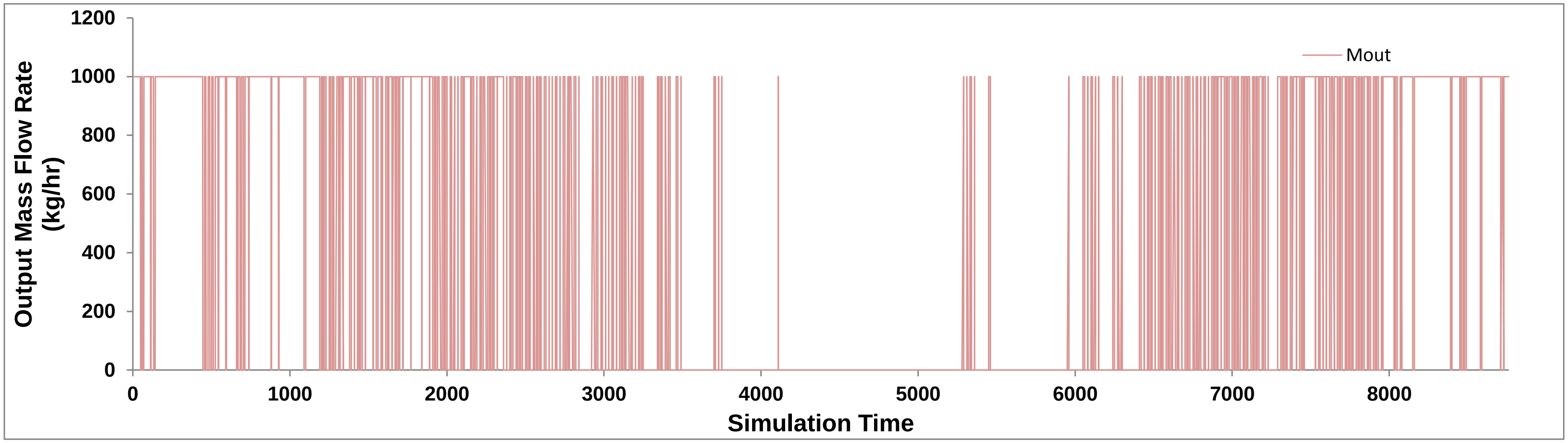

Figure 7-14 Output Mass Flow Rate of Pump 3

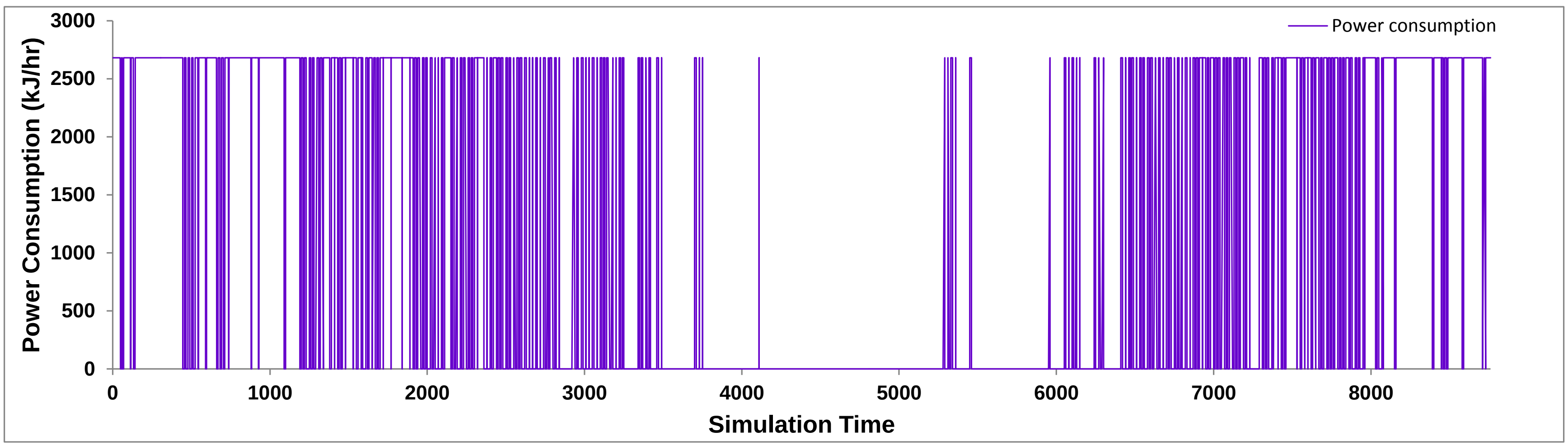

Figure 7-15 Power Consumption of Pump 3

7.7 Aquastat

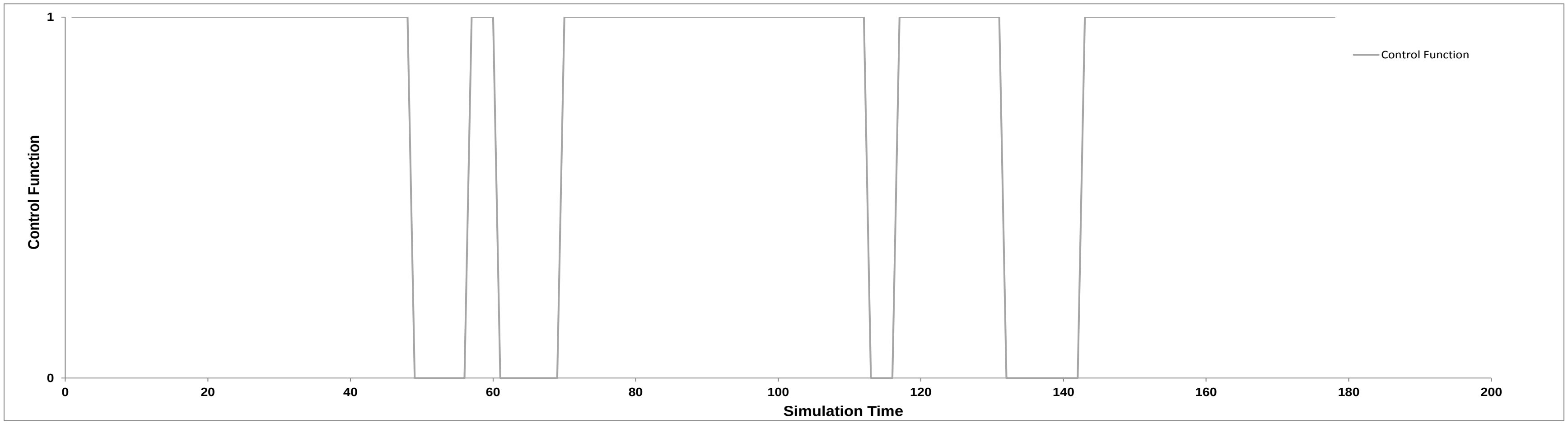

Figure 7-16 Aquastat in Swimming Pool Loop

7.8 Diverter

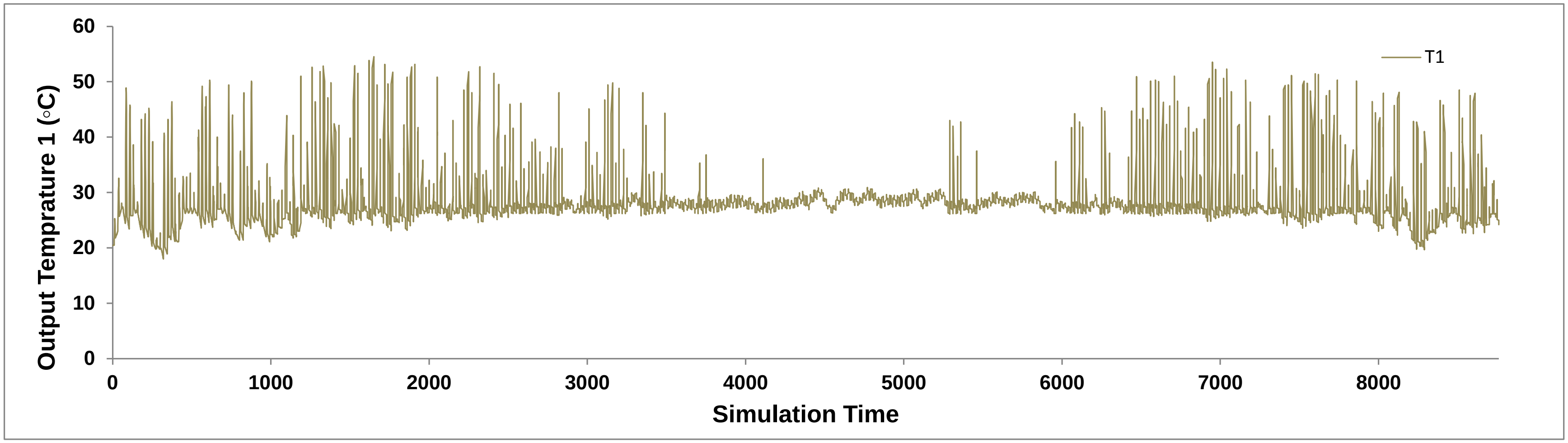

Figure 7-17 Output Temperature for Outlet 1

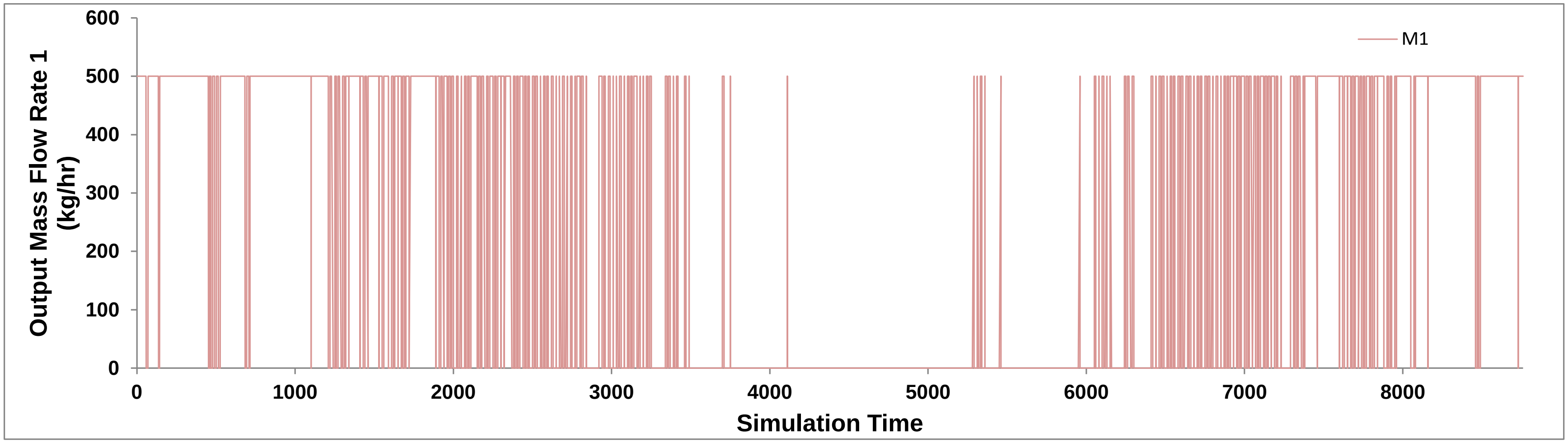

Figure 7-18 Output Mass Flow Rate for Outlet 1

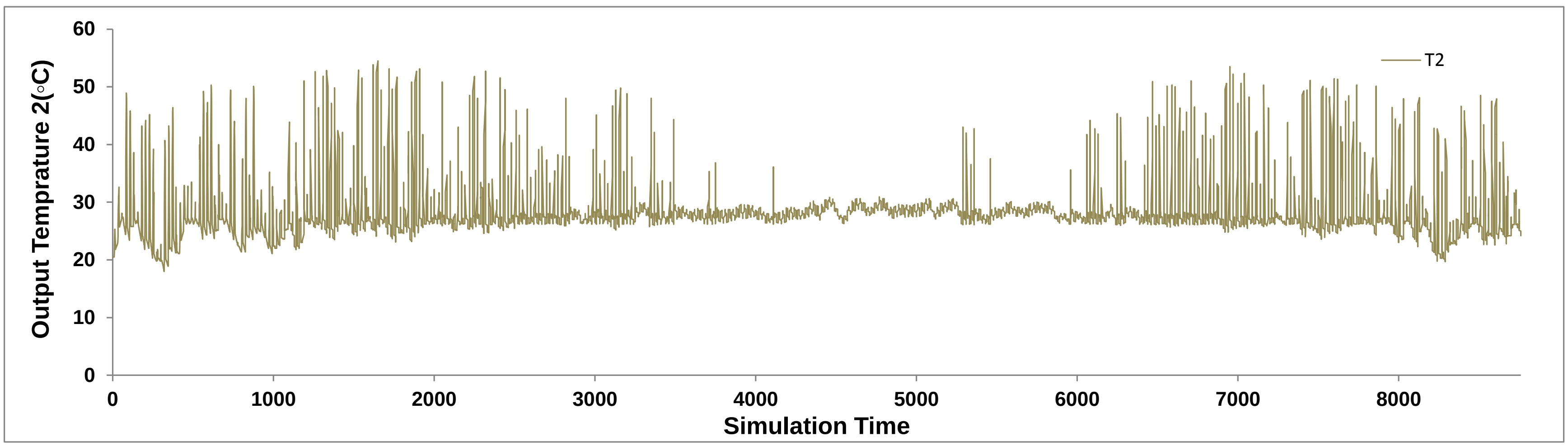

Figure 7-19 Output Temperature for Outlet 2

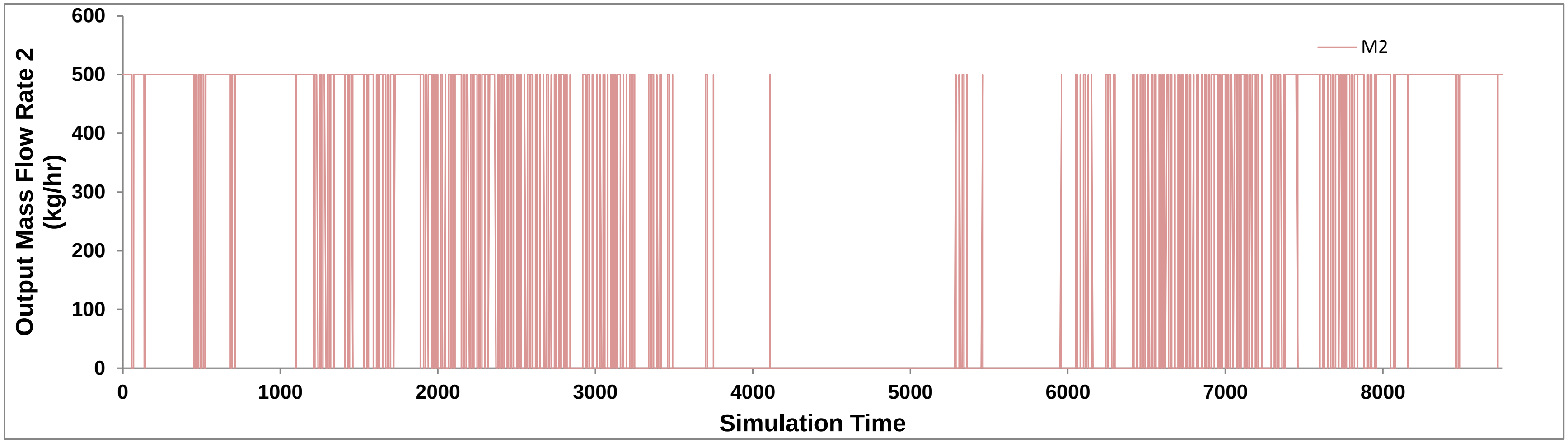

Figure 7-20 Output Mass Flow Rate for Outlet 2

7.9 Heater

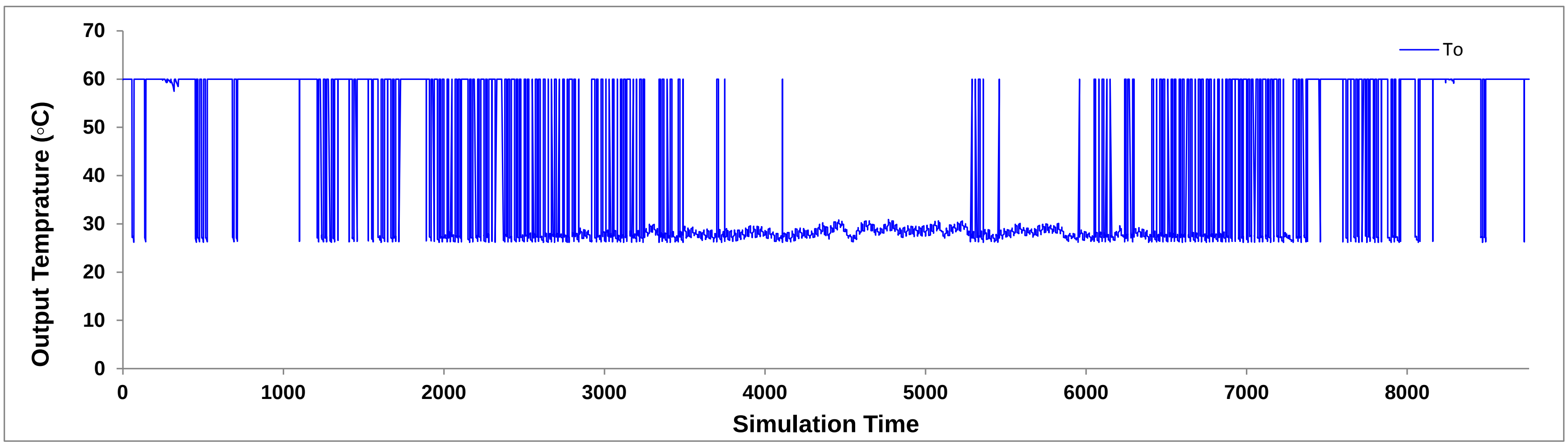

Figure 7-21 Output Temperature for Heater

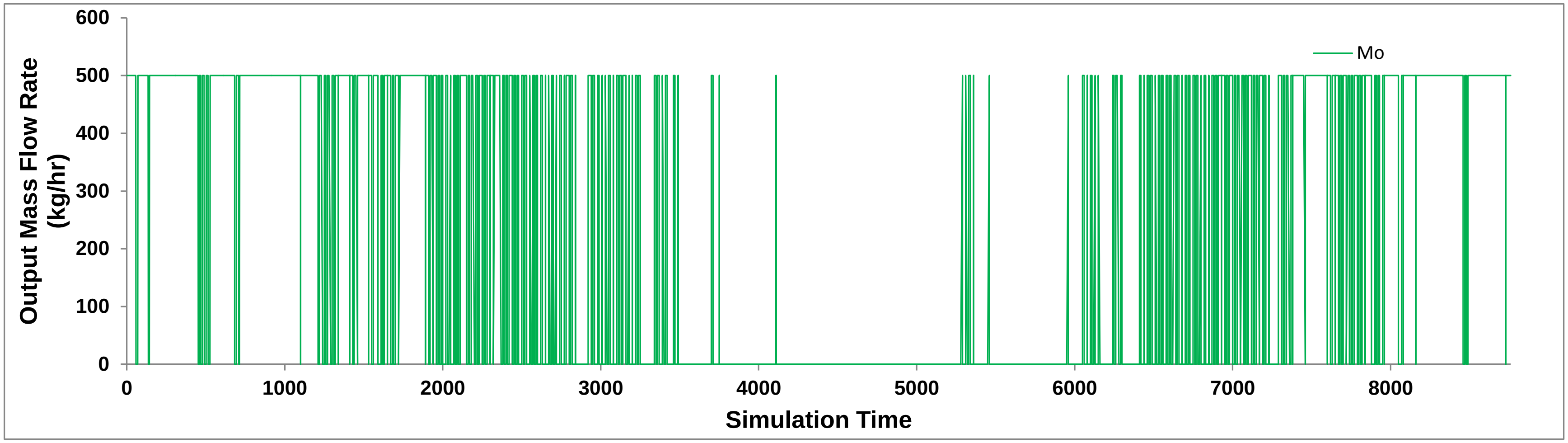

Figure 7-22 Output Mass Flow Rate for Heater

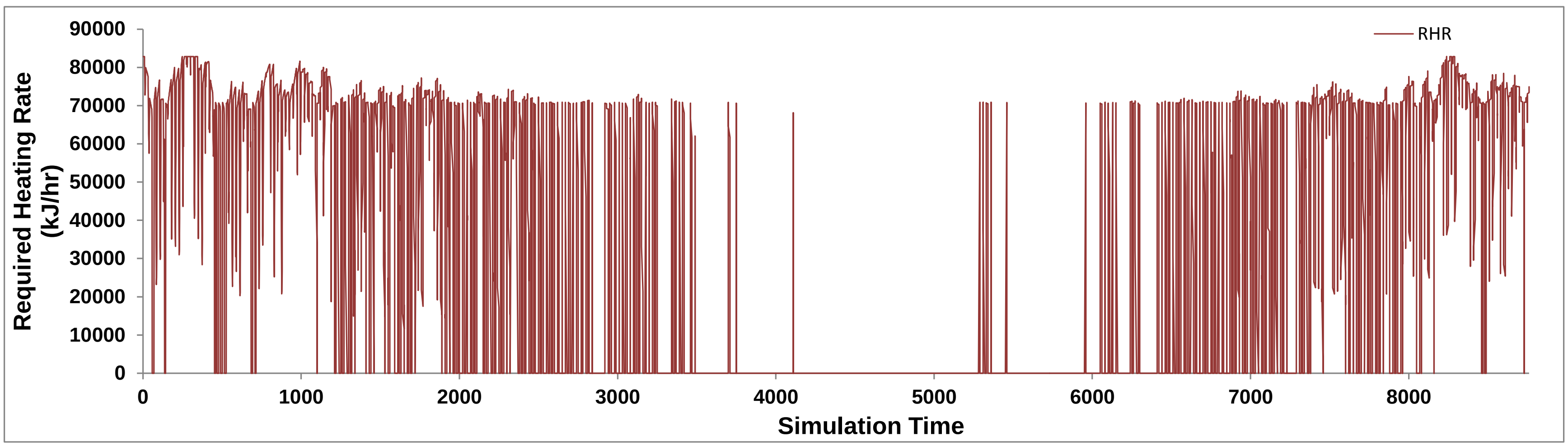

Figure 7-23 Required Heating Rate for Heater

7.10 Mixer

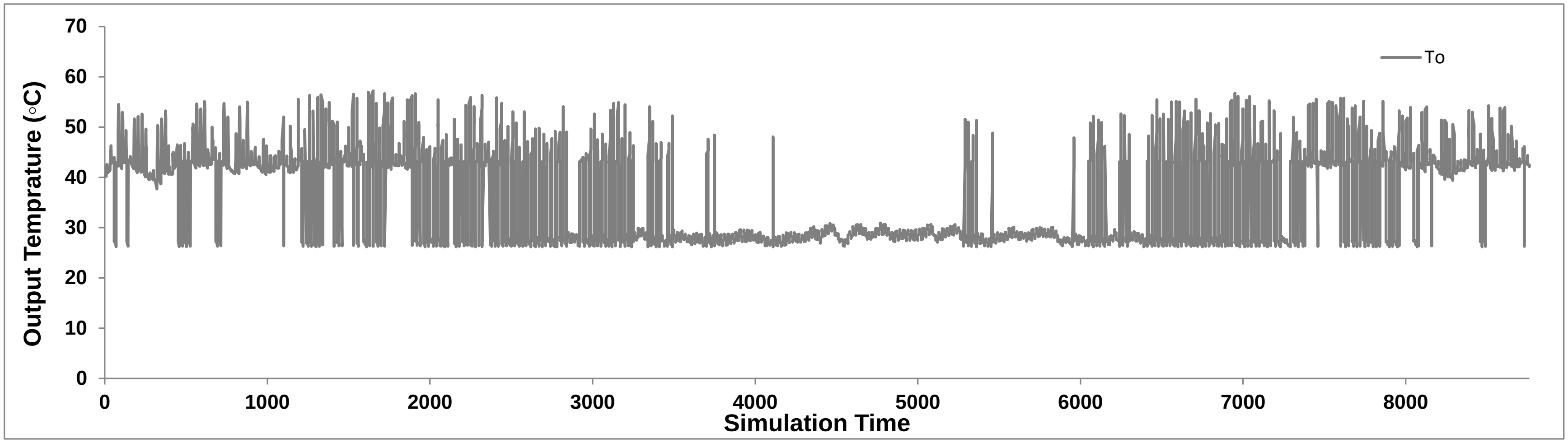

Figure 7-24 Output Temperature for Mixer

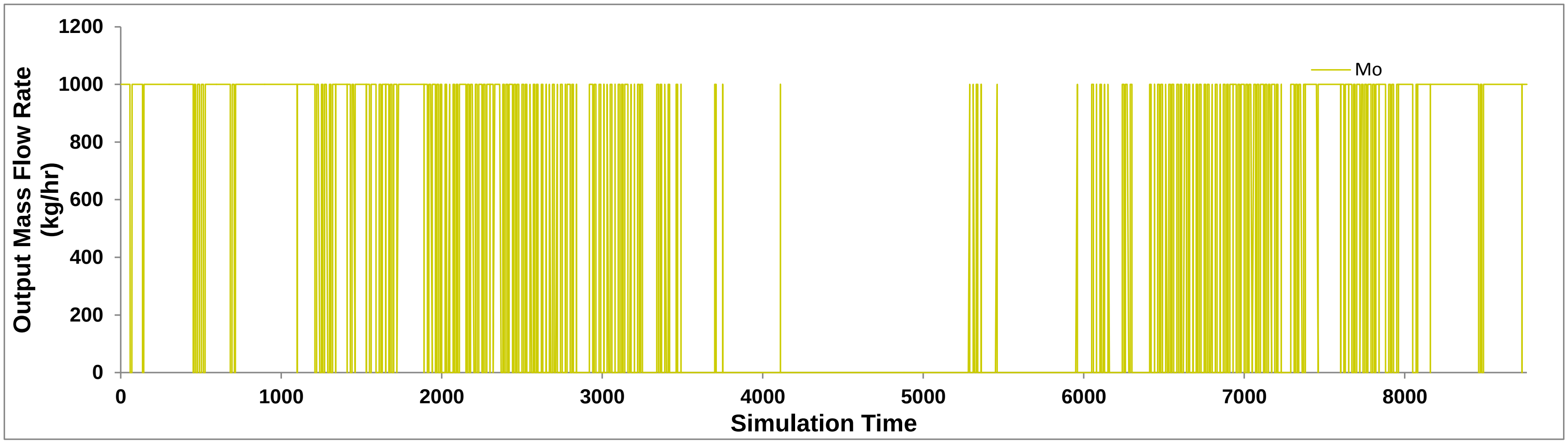

Figure 7-25 Output Mass Flow Rate for Mixer

7.11 Swimming Pool

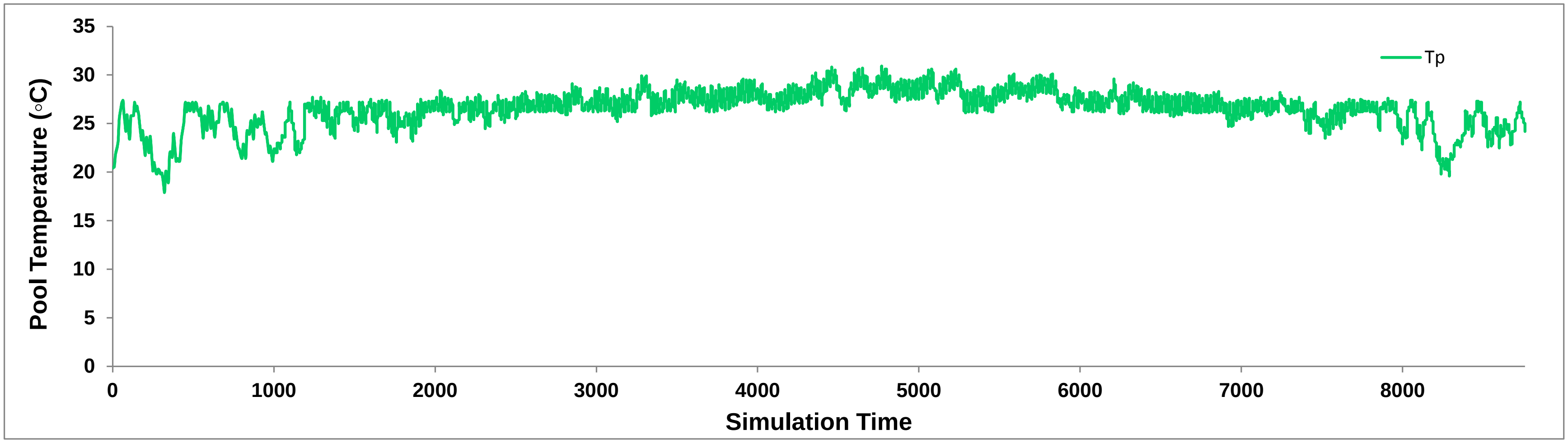

Figure 7-26 Pool Temperature

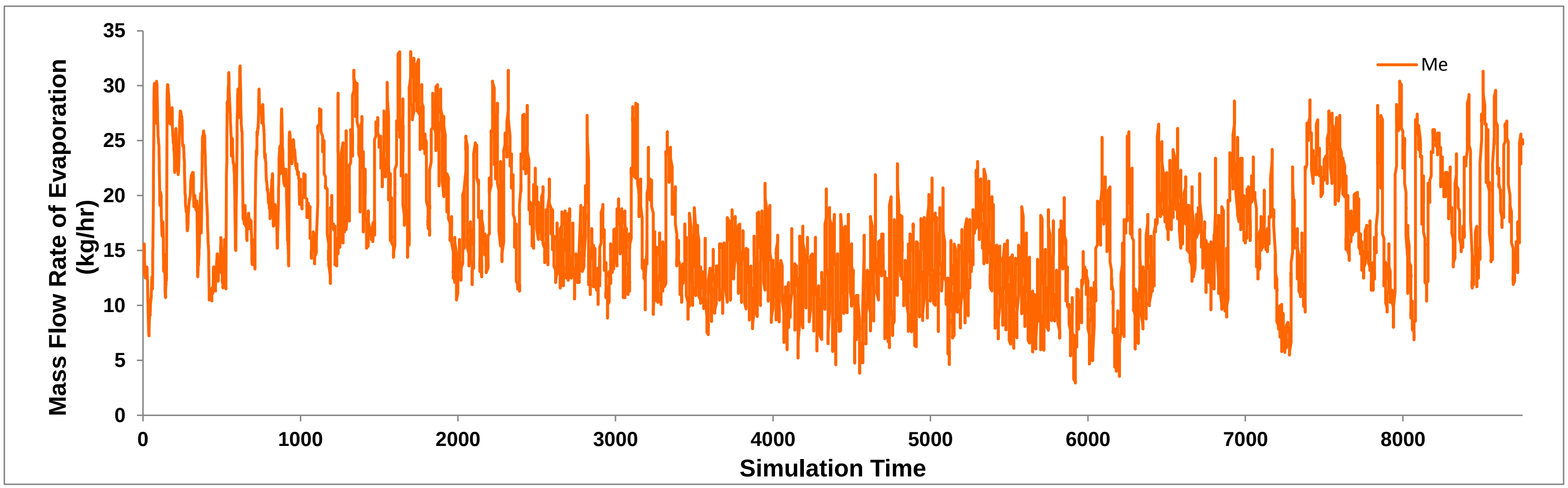

Figure 7-27 Mass Flow Rate of Pool Evaporation

8 APPENDIX B: TRNSYS AND F-CHART COMPARISON REPORT FROM TESS MODELING GROUP

The TESS Modeling Group Simulated the Pool Heating System by completely separating two loops apart, shown in Figure 8-1. There is no connection between the upper and lower loop. The reason for that was given as a not "matching results" compared with results by F-Chart if adding solar system directly to the pool system. The detailed report is shown below.

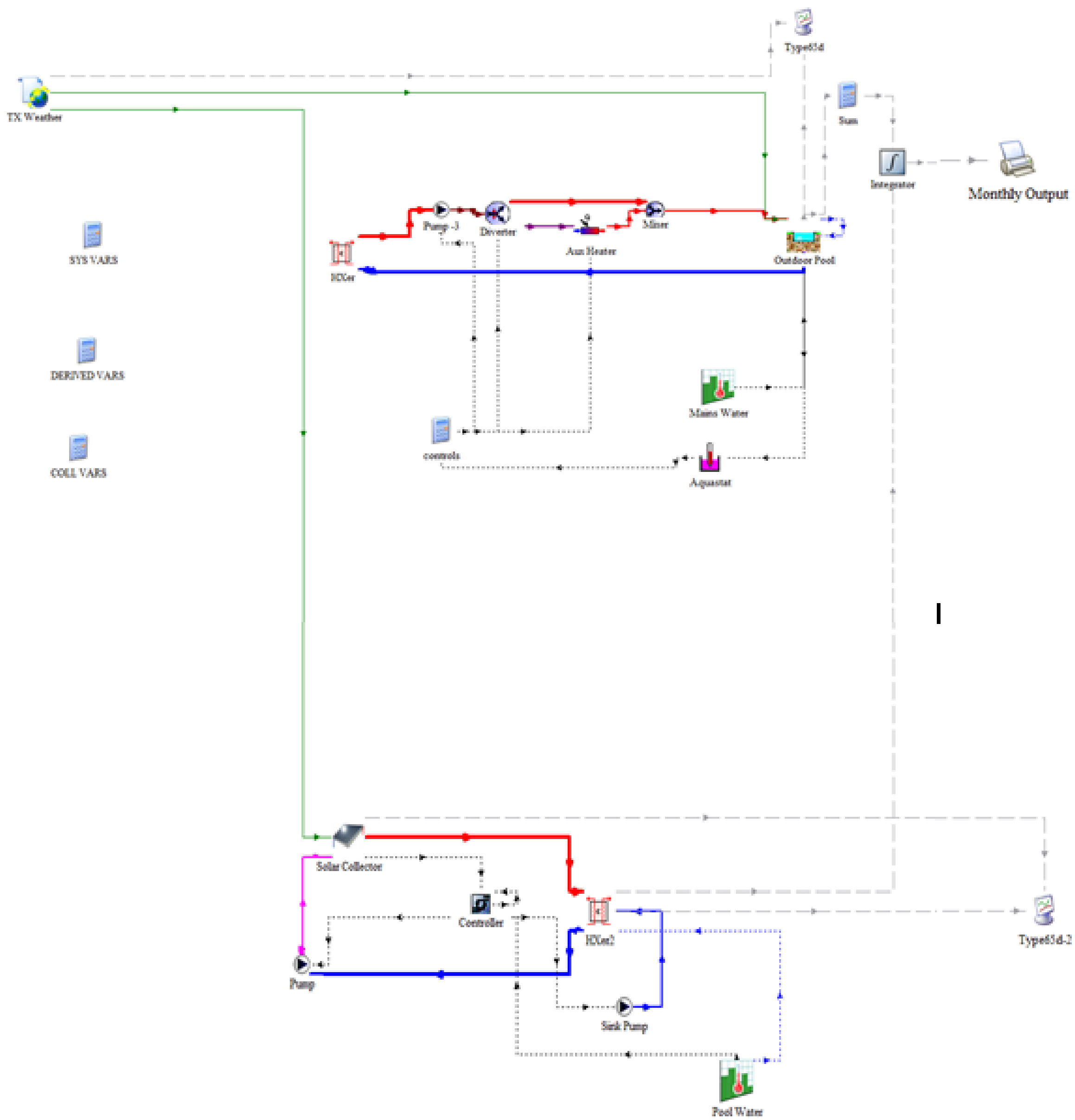

Figure 8-1 Pool Heating System Model by TESS

Introduction

In order to match the FChart results, the calculations had to be done as you saw in the Trnsys Project file (*outdoor_pool.tpf*). If adding the solar thermal system energy directly to the pool, it causes wildly different results from FChart. For example, when the temperature increases even slightly, it causes the evaporation rate to increase dramatically and temperatures to fluctuate dramatically – as would an actual outdoor pool system. Since FChart is a quick and macro approach, the FChart method simplifies the calculations of the systems such as assuming a constant operating temperature. Thus, the TRNSYS project needed to be developed to reflect these quick simulations.

FChart Method

Let us first break down the FChart Output list for the default Pool Heating System in Austin, TX.

Thermal Output

	Q Coll [GJ]	Q Pool [GJ]	Load [GJ]	Aux [GJ]	f [ ]	Pool T [C]
May	12.98	25.85	12.98	0.000	1.000	26.7
Jun	5.26	28.00	5.26	0.000	1.000	26.7
Jul	2.01	29.76	2.01	0.000	1.000	26.7
Aug	4.14	27.73	4.14	0.000	1.000	26.7
Sep	13.03	22.25	13.03	0.000	1.000	26.7
Oct	18.58	19.12	24.18	5.597	0.769	26.7
Year	56.01	152.70	61.60	5.597	0.909	

Figure-1: FChart Results for Pool Simulation For Austin, TX

The output variables from FChart are defined as the following.

Table 1: FChart Pool System Outputs

Q Coll	[GJ]	The monthly solar energy delivered by the solar collectors to the pool.
Q Pool	[GJ]	The amount of solar (short wave) absorbed by the pool.
Load	[GJ]	The monthly energy loss from the pool by evaporation, convection, thermal radiation, and ground conduction at the monthly average pool temperature minus QPool, the absorbed solar radiation.
Aux	[GJ]	The monthly energy that must be supplied by the backup pool heater to maintain the pool temperature at the specified value.
f	[0..1]	The fraction of the pool heating demand which is supplied by the solar collector system. Direct absorption of solar radiation (for outdoor pools) is considered as a reduction to the pool heating load.
Pool T	[C]	The monthly average temperature of the pool. If the heater capacity is sufficiently large, then the pool temperature will be equal to the second parameter, the Pool temperature. If the heater capacity is not sufficient to maintain the pool temperature at the desired setting then the pool will reach an equilibrium temperature which balances the input energy from the sun and solar system with the pool losses.

TRNSYS Simulations

The TRNSYS simulation project was constrained by the parameters that the simulation matched the FChart Results and also required a fast simulation time (under 3 seconds). To meet the simulation time requirements, a large timestep of 1 hour would be required. This would also imply a broad, macro approach to the problem similar to FChart. Thus, the calculations of the pool losses/gains at a constant temperature, and the integration of the solar energy were done as separate calculations (as separate subsystems) in TRNSYS to match the FCHart results. A directly-coupled, detailed solar thermal simulation that would be coupled directly to the pool would require a timestep on the scale of 1-3 minutes, and thus making the simulation time much longer. On the other hand, leaving the simulation at one hour with the solar collector and pool systems coupled together caused the pool temperature and losses to vary wildly.

The outputs of the TRNSYS Solar Thermal Pool System from the Type25 "Printer" component are outlined in the following table.

Table 2: TRNSYS Simulation Printer Outputs

Q_Coll	[kJ]	The heat transfer across the heat exchanger of the solar collector subsystem (hot side of the heat exchanger) and the constant temperature of the pool (cold side of the heat exchanger).
Q_Pool	[kJ]	The amount of solar (short wave) absorbed by the pool.
Load	[kJ]	The monthly energy loss from the pool by evaporation, convection, and longwave radiation.
Aux	[kJ]	Not implemented in the simulation.
f	[0..1]	Not implemented in the simulation.

The results will also have to be post-processed with logical functions as done with the FChart results. The following table explains the post-processed results with the logical functions.

Table 3: Post-Processing Logical Corrections Values and Outputs for TRNSYS Results

Q_Coll_Corrected	[kJ]	The minimum value of **Q_Coll** versus **Load_Corrected**.
Load_Corrected	[kJ]	This value is the **Load** minus **Q_Pool** if **Load** is indeed greater than **Q_Pool**. Otherwise, if **Q_Pool** is greater than **Load**, this value is zero.
Aux_Corrected	[kJ]	This value is zero if **Q_Coll** is greater than **Load_Corrected**. Otherwise, this value is **Load_Corrected** minus **Q_Coll**.
f_Corrected	[0..1]	This value is 1 if **Q_Coll_Corrected** is greater than or equal to **Load_Corrected**. Otherwise, this value is the product of **Q_Coll_Corrected** and **Load_Corrected**.

Applying the logical corrections the following table contains the final TRNSYS simulations results after post-processing.

Table 4: Final TRNSYS Results after Post-Processing

TIME	Q_COLL _Corrected	Q_POOL	LOAD_Corrected	AUX_Corrected	f_Corrected
	[GJ]	[GJ]	[GJ]	[GJ]	[]
May	15.33	29.70	15.33	0.00	1.00
June	3.35	32.12	3.35	0.00	1.00
July	0.00	34.01	0.00	0.00	1.00

August	0.00	31.54	0.00	0.00	1.00
Sept	12.85	25.48	12.85	0.00	1.00
October	22.20	22.66	34.05	11.85	0.65
Year	53.72	175.52	65.57	11.85	0.94

FChart and TRNSYS Comparisons

The final TRNSYS post-processed results are very close and exhibit very similar trends to the FChart results. However, the shortwave radiation gains by the pool are consistently higher than that in FChart. This is likely due to the hardcoded assumptions that both of the pool models make internally about the absorbance of solar energy by the pool water. The differences of the pool models are outlined in *Use of Air Conditioning Heat Rejection for Swimming Pool Heating* by S. Pohl. Assumptions surrounding the times in which the pool is covered by the FChart method also may be a factor as well.

Conclusion

Meeting the project stipulations of simulation times and matching the FChart Simulation results are achieved by the TRNSYS simulation, *outdoor_pool.tpf*, executable TRNSYS Project File.

For future consideration if simulation speed was not a requirement, a more realistic approach to the problem would be to implement an actual coupled system. This would require a much smaller timestep as the controllers in TRNSYS make either an on or off decision for the simulation timestep. This would also prevent the large temperature and loss variations.

9 APPENDIX C: ASSESSMENT OF AN INDOOR OT OUTDOOR SWIMMING POOL REPORT

TRNSYS-TYPE 344

Assessment of an indoor or outdoor swimming pool

TRANSSOLAR
Energietechnik GmbH
Strategies for energy efficient design and thermal comfort in buildings

Thomas Auer

November 21, 1996

Contents

Symbols

Latin Symbols

A	Area
a	Thermal diffusivity
c_p	Specific heat
D	Diffusion coefficient
dE	Change of internal energy (form start of simulation till end of simulation)
$E_{Glob,H}$	Total solar radiation on a horizontal surface
H	Enthalpy
Δh_{Evap}	Enthalpy of evaporation
m	Mass
$\dot{m}$	Mass flow rate
p	Pressure
$\dot{Q}$	Rate of heat transfer
T	Absolute temperature
t	Time
c_p	Specific heat
V	Volume

Greek Symbols

α	Heat transfer coefficient
α_{Evap}	Evaporation coefficient
β	Mass transfer coefficient
δ	Thickness
ε	Total evaporation coefficient
ε^*	Emissivity
φ	Relative humidity
λ	Thermal conductivity
ρ	Density
σ	Stefan-Boltzmann constant
ϑ	Temperature

Subscripts

Amb	Ambient
P	Pool
Cov	Cover
$Cond$	Conductivity
St	Steam
Fr	Fresh water
$total$	Total
In	Input
Con	Convection
$Pipe$	Piping
Air	Air
Out	Output
Rad	Long-wave radiation
Sat	Saturation
Sol	Solar
$Evap$	Evaporation
W	Water
aux	auxiliary
0	Initial value

1 Basic Physical Principles

It is assumed that the water in the swimming pool is ideally mixed so that the first law of thermodynamics can be expressed as follows:

$$\frac{dH}{dt} = \sum\left(\dot{Q}_{In} - \dot{Q}_{Out}\right) \quad (1)$$

It can also be assumed that a liquid is incompressible and that density and thermal conductivity are constants. Equation (1) can then be expressed as follows:

$$\rho_W \cdot c_{p,w} \cdot V_P \cdot \frac{dT}{dt} = \sum\left(\dot{Q}_{In} - \dot{Q}_{Out}\right) \quad (2)$$

When drawing up the model, it was further assumed that there is a constant amount of water in the pool.

The following figure shows a schematic view of all heat flow rates:

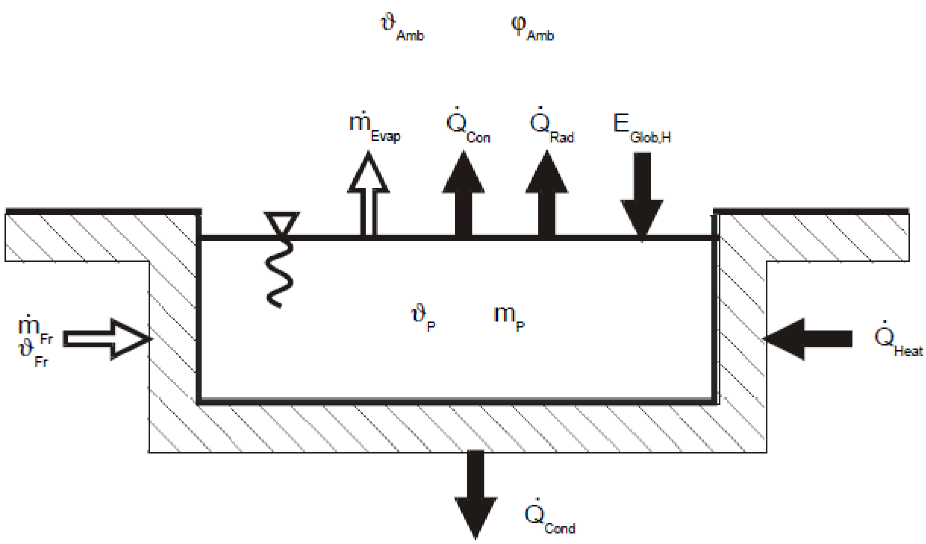

Figure 1: Heat and Mass Flow Rates of a Pool in Exchange with the Ambient

The heat exchange with the surroundings includes the following:

- Heat flow rate by evaporation
- Heat flow rate by convection
- Heat flow rate by short-wave radiation
- Heat flow rate by long-wave radiation
- Heat loss by fresh water supply
- Heat flow rate from heating
- Thermal conduction to the ground

The heat flow rate to the ground is negligible for this assessment. Indoor pools are normally surrounded by engineering rooms in the basement with ambient temperatures generally higher than 30℃ so that the heat flow rate is virtually zero. For outdoor pools this aspect may be ignored, because, on the one hand it has only a minor influence on the overall energy assessment (<1 %) and on the other, because it cannot be calculated accurately ($\dot{Q}_{Cond}$ = f (*thermal insulation*, *composition of the ground*).

In the following section each heat flow rate is calculated in detail.

1.1 Calculation of Heat Flow Rate by Evaporation

The heat loss by evaporation can be calculated on the basis of the evaporated mass flow rate with the following expression:

$$\dot{Q}_{Evap} = \dot{m}_{Evap} \cdot \Delta h_{Evap} \tag{3}$$

The evaporated mass flow rate can be determined with a formula for the calculation of a motive force. The driving force is the difference in pressure of the water steam between the water surface and the surroundings, and it is assumed that a layer directly above the water surface, at the pool water temperature, has a relative humidity of 100 %. For an indoor pool the evaporated mass flow rate can be calculated with the following equation:

$$\dot{m}_{Evap} = \varepsilon \cdot A_{total} \cdot \left(p_{Sat}(\vartheta_P) - p_{St}(\vartheta_{Amb})\right) \tag{4}$$

The steam pressure in ambient conditions can be calculated using the relative humidity determined by the following formula:

$$p_{St} = \varphi_{Amb} \cdot p_{Sat}(\vartheta_{Amb}) \tag{5}$$

The total evaporation coefficient ε for a choppy water surface is taken from the VDI[1)] Guideline 2089 [2]. Calculations for a pool without swimmers are based on measurements of an indoor pool at Schalmtal carried out by Biasin. From these measurements, Biasin concluded and documented the theoretical principles for the calculation of the total evaporation coefficient [1].

The evaporation relation for an outdoor pool is based on an empirical formula whereby the total evaporation coefficient and the evaporation enthalpy are combined so that the heat flow rate by evaporation can be calculated with the following equation:

$$\dot{Q}_{Evap} = A_{total} \cdot \alpha_{Evap} \cdot \left(p_{Sat}\left(\vartheta_P \right) - p_{St}\left(\vartheta_{Amb} \right) \right) \tag{6}$$

According to D. Richter [4] the modified evaporation coefficient can be calculated as follows:

$$\alpha_{Evap} = 50.58 + 66.9 \cdot w_{Amb}^{0.5} \tag{7}$$

This equation gare goot results for reproducing the change of temperature for the outdoor pool at Leonberg (based on calculations carried out by the Institut für Thermodynamik und Wärmetechnik der Universität Stuttgart (Institute for Thermodynamics and Heat Technology at Stuttgart University/Germany) [5].

BASIC PHYSICAL PRINCIPLES

1.2 Calculation of Heat Flow Rate by Convection

The heat flow rate by convection can be calculated on the basis of Newton's formula:

$$\dot{Q}_{Con} = \alpha \cdot A_{total} \cdot \left(\vartheta_P - \vartheta_{Amb} \right) \tag{8}$$

According to Biasin's measurements, Lewis's formula for mass and heat transfer can be used for indoor pools so that the relation between the heat and mass transfer coefficients can be determined with the following equation:

$$\frac{\alpha}{\beta} = c_{pl} \cdot p_l \cdot \left(\frac{a}{St} \right) \tag{9}$$

The heat transfer coefficient for an outdoor pool can be calculated on the basis of the following formula, found by J. T. Czarnecki [6]:

$$\alpha = 3.1 + 4.1 \cdot w_{Amb} \tag{10}$$

1.3 Calculation of Heat Flow Rate by Long-Wave Radiation

The heat transfer rate by long-wave radiation exchange with the walls (indoor pools) or the sky (outdoor pools) can be calculated on the basis of the Stefan-Boltzmann law. For the indoor pool it can be assumed that the pool is completely enclosed, and for the outdoor pool we assume that the surface area of the "sky" is large compared to that of the pool. Thus, in both cases, the heat flow rate by long-wave radiation is reduced to the heat flow rate to a full radiator. Therefore the relation can be expressed by the following formula:

$$\dot{Q}_{Rad} = A_{total} \cdot \varepsilon_w^* \cdot \sigma \cdot \left(T_P^4 - T_X^4 \right) \tag{11}$$

Where *X* can stand for *Wall* as well as for *Sky*.

The constants have the following values:

$$\varepsilon_W^* = 0.9$$

$$\sigma = 5.67 \cdot 10^{-8} \frac{W}{m^2 \cdot K^4}$$

1.4 Calculation of Heat Loss by Fresh Water Supply

The heat loss by fresh water supply can be calculated using the first law of thermodynamics under the assumption of an incompressible liquid as follows:

$$\dot{Q}_{Fr} = m_{Fr} \cdot c_{p,W} \cdot (\vartheta_P - \vartheta_{Fr}) \tag{12}$$

1.5 Calculation of Heat Flow Rate by Short-Wave Thermal Gain

The short-wave thermal gain from total solar radiation on a horizontal surface for an outdoor pool can be calculated as follows:

$$\dot{Q}_{Sol} = \varepsilon_w^* \cdot A_{total} \cdot E_{Glob,H} \tag{13}$$

The short-wave thermal gain for an indoor pool have to be determined differently. When this TYPE is combined with TYPE 56, the solar gain striking at the pool surface can be determined and used.

1.6 Calculation of Heat Flow Transfer of the Auxiliary Heating

Analogous to the heat loss by fresh water supply the heat flow rate of the auxiliary heating can be calculated with the following formula:

$$\dot{Q}_{In} = m_{In} \cdot c_{p,W} \cdot (\vartheta_P - \vartheta_{In}) \tag{14}$$

1.7 Calculation of Stored Energy

For a complete energy balance, the temperature difference between initial and final conditions must be considered. The stored energy can be calculated as follows:

$$dE = m_P \cdot c_{P,w} \cdot (\vartheta_{P,0} - \vartheta_P) \tag{15}$$

1.8 Heat Loss of a Covered Pool

If the water surface of a pool is covered, the heat loss is reduced, mainly because evaporation is prevented by the cover. Figure 2 shows a schematic view of all heat flow rates.

The heat flow rate for a covered water surface is reduced to a convective share, a short-wave and a long-wave heat flow rate resulting in a given temperature on top of the cover. We can assume that a stationary temperature profile is formed at any time, because of the small mass of the cover. Therefore the thermal slow rate balance of the cover can be reduced to the following formula:

$$0=\dot{Q}_{Con}+\dot{Q}_{Rad}+\dot{Q}_{cond}-\dot{Q}_{Sol} \qquad (16)$$

BASIC PHYSICAL PRINCIPLES

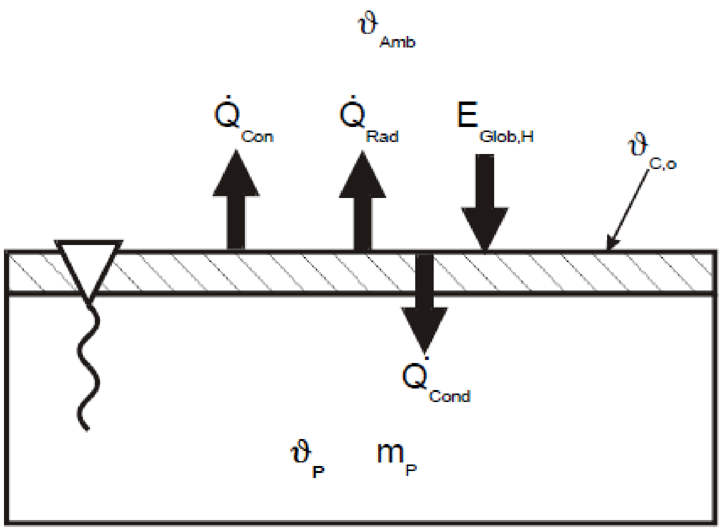

Figure 2: Heat Flow Rates of a Pool Cover

With regard to the temperature on top of the cover each heat flow rate can be expressed as follows:

$$\dot{Q}_{Con}=\alpha\cdot A_{Cov}\cdot\left(\vartheta_{C,0}-\vartheta_{Amb}\right) \qquad (17)$$

$$\dot{Q}_{Rad}=A_{cov}\cdot\varepsilon^{*}_{Cov}\cdot\sigma\cdot\left(T^{4}_{C,0}-T^{4}_{X}\right) \qquad (18)$$

$$\dot{Q}_{Cond}=\frac{\lambda_{Cov}}{\delta_{Cov}}\cdot A_{Cov}\cdot\left(\vartheta_{C,0}-\vartheta_{P}\right) \qquad (19)$$

$$\dot{Q}_{Sol}=A_{Cov}\cdot\varepsilon^{*}_{Cov}\cdot E_{glob,H} \qquad (20)$$

The heat transfer coefficient required for the calculation of the heat flow rate by convection can be calculated with equation (10). For the heat flow rates by short-wave and long-wave radiation it was assumed that the Kirchhoff law is valid, which states that absorption values equal emission values.

2 Description of TYPE 344 for the Calculation of an indoor or outdoor pool

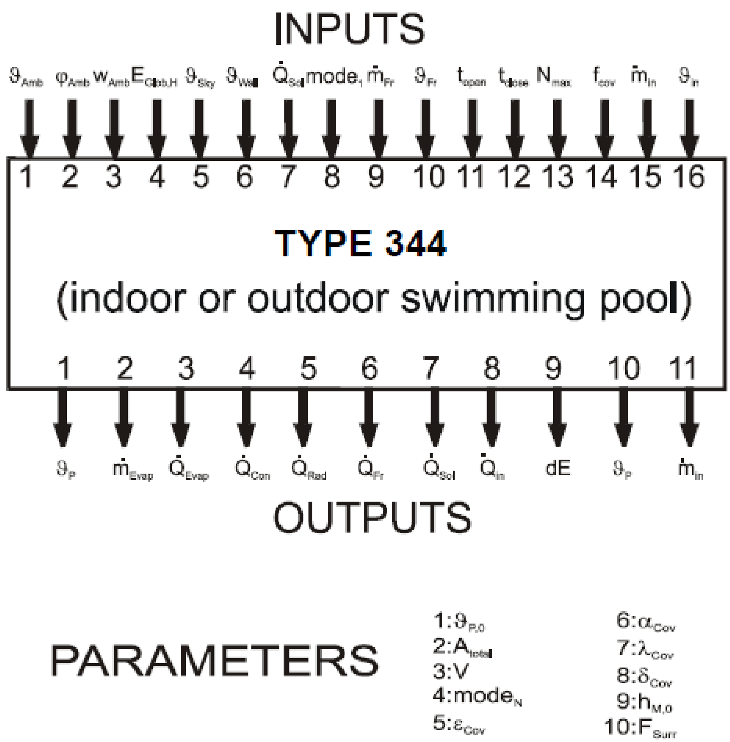

Figure 3: Parameter, Input and Output Data of Type 344

2.1 Description of Parameters

The following parameters can be used for the calculation of indoor or outdoor pools:

Parameter No	Symbol	Description	Unit
1	$\vartheta_{P,0}$	Initial Temperature of Pool Water	°C
2	A_{total}	Total Surface Area of the Pool	m²
3	V	Pool Water Volume	m³
4	$mode_N$	Distinction between indoor and outdoor pool	-
5	ε_{Cov}	Emissivity of the Cover	-
6	α_{Cov}	Absorption coefficient of the Cover	-
7	λ_{Cov}	Thermal Conductivity of the Cover	kJ/(h·m·k)
8	δ_{Cov}	Thickness of the Cover	m
9	$h_{M,0}$	Height of Wind Velocity Measurements	m
10	F_{Surr}	Factor of Surroundings	-

Table 1: List of Parameters

DESCRIPTION OF TYPE 144

1. Initial Temperature of Pool Water ($\vartheta_{P,0}$)
Pool water temperature at the beginning of the simulation.

2. Total Surface Area of the Pool (A_{total})
Surface area of the pool including the overflow-pipe system.

3. Pool water volume (V)
Water content of the pool.

4. Distinction between indoor and outdoor pools ($mode_N$)
The parameter $mode_N$ shows the distinction between the calculation for an indoor and an outdoor pool:

$mode_N = 0 \Rightarrow$ indoor pool

$mode_N > 1 \Rightarrow$ outdoor pool

5. Emissivity of the Cover (ε_{Cov})

6. Absorption coefficient of cover (α_{Cov})

7. Thermal Conductivity of the Cover (λ_{Cov})

8. Thickness of the Cover (δ_{Cov})

9. Height of Wind Velocity Measurements ($h_{M,0}$)
(see Parameter 10)

10. Factor of Surroundings (F_{Surr})
The heat loss of an outdoor pool (by evaporation and convection) depends largely on the wind velocity (see "Basic Physical Principles"). The relations used in the calculation are based on wind velocity measured at a height of 3 m. As this is not the height at which wind velocity is normally measured for weather data, a correction factor needs to be introduced. The correction factor depends on the surroundings. Figure 5 shows the graphs for different wind velocities under the influence of the correction factor and depending on the factor of surroundings (F_{Surr}).

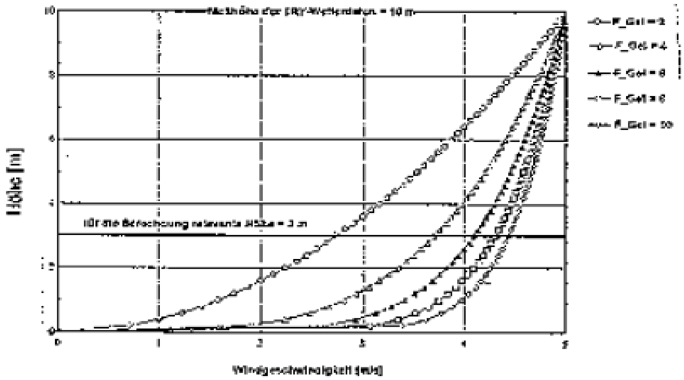

Figure 4: Wind Velocity Depending on the Height and on the Factor of Surroundings (F_{Surr}) on the Basis of a Wind Velocity of 5 m/s Measured at a Height of 10 m.

The calculation is based on the following equation:

$$\frac{w}{w_0} = \left(\frac{z}{z_0}\right)^{\frac{1}{F_{Surr}}} \qquad (21)$$

The following guideline values can be assumed for the factor of surroundings:

Area with high building density	2
Town with moderate building density	2..4
Area with forests or hills	3..6
Free plains	6..8
Free water surfaces	8..10

Table 2: Guideline Values for Factor of Surroundings

2.2 Description of Inputs

The following input values can be used for calculating the thermal assessment of an indoor or outdoor pool:

Input No	Symbol	Description	Unit
1	ϑ_{Amb}	Ambient Air Temperature	°C
2	φ_{Amb}	Relative Humidity of Ambient Air	%
3	W_{Amb}	Wind velocity of Ambient Air	m/s
4	$E_{Glob,H}$	Total Solar Radiation on a Horizontal Surface	kJ/hm²
5	ϑ_{Sky}	Temperature of the "Sky"	°C
6	ϑ_{Wall}	Temperature of Enclosing Surfaces (Walls)	°C
7	$\dot{Q}_{Sol}$	Short-Wave Radiation Gain	kJ/h
8	$mode_1$	Expressing the Activity of the Water Surface	-
9	$\dot{m}_{Fr}$	Mass Flow Rate of Fresh Water Supply	kg/h
10	ϑ_{Fr}	Temperature of Fresh Water	°C
11	t_{open}	Swimming Pool Opening Time	h
12	t_{close}	Swimming Pool Closing Time	h
13	$N_{\max}$	Maximum Pool Occupancy on a Given Day	-
14	f_{Cov}	Relative Covering of Water Surface	-
15	$\dot{m}_{In}$	Mass Flow Rate of Supply from Heating	Kg/h
16	ϑ_{In}	Temperature of Supply	°C

Table 3: List of Inputs

1. Ambient Air Temperature (ϑ_{Amb})

When calculating an outdoor pool, use the ambient air temperature outdoors, and for an indoor pool use the ambient air temperature indoors.

2. Relative Humidity of Ambient Air (φ_{Amb})

Use the relative humidity of the outdoor air (outdoor pools) and of the indoor air (indoor pools).

3. Wind velocity of Ambient Air (w_{Amb})

This parameter is only relevant for the calculation of outdoor pools. Since the wind velocity is a function of the height above ground and also depends closely on the microclimate, two additional parameters were introduced for a more accurate calculation (see table 1: List of parameters).

4. Total Solar Radiation on a Horizontal Surface ($E_{Glob,H}$)

The total solar radiation on a horizontal surface is required to calculate the short-wave radiation gain of an outdoor pool (not used for an indoor pool).

5. Temperature of the "Sky" (ϑ_{Sky})

To calculate the heat flow rate by long-wave radiation, use a fictitious sky temperature, which can be calculated with TYPE 69 (for handling see User's Manual).

6. Temperature of enclosing surfaces (ϑ_{Wall})

The average temperature of the enclosing surfaces is required to calculate the heat flow rate by long-wave radiation of an indoor pool. When this TYPE is combined with TYPE 56, the average internal surface temperatures has to be used (See NTYPE 24 of TYPE 56).

7. Short-wave radiation gain ($\dot{Q}_{Sol}$)

Input 7 is only used for the assessment of indoor pools. The short-wave radiation gain is that solar gain which is directed through the window glazing to the water surface (when this TYPE is combined with TYPE 56, this short-wave radiation gain in relation to the surface area equals NTYPE 21 of TYPE 56).

8. Expressing the calmness of the water surface ($mode_1$)

Since the activity of the water surface greatly affects the rate of evaporation and convection, it is taken into account in the form of a factor, which is very similar to the VDI[1)] values. The factors stand for the following conditions:

$mode_1$ = 0 ⇒ calm water surface

$mode_1$ = 1 ⇒ slightly choppy water surface (private pool)

$mode_1$ = 2 ⇒ slightly choppy water surface (public indoor pool, normal pool occupancy)

$mode_1$ = 3 ⇒ moderately choppy water surface (fun pool)

$mode_1$ = 4 ⇒ very choppy water surface (artificially induced waves)

$mode_1$ = -1 ⇒ function of pool occupancy

The function of pool occupancy ($mode_1$ = -1) produces a parabolic graph with the maximum value in the middle, for which inputs 11, 12 and 14 are required. Figure 5 shows the graph of the function of pool occupancy for different maximum values of pool occupancy.

9. Mass Flow Rate of Fresh Water Supply ($\dot{m}_{Fr}$)

Input 9 only expresses the water exchange required for reasons of hygieny (or the water exchange resulting from filtered water coming back from the filter). Water loss due to evaporation is automatically compensated internally.

10. Temperature of Fresh Water (ϑ_{Fr})

Temperature of the water supply mass flow rate of Input 9. The supply of water, as compensation for water loss due to evaporation, is included in the calculation at the same temperature.

11. Swimming Pool Opening Time (t_{open})

The swimming pool opening time is required for the function of pool occupancy (see Input 8).

12. Swimming Pool Closing Time (t_{close})

(see Input 11 and 8)

13. Maximum Pool Occupancy on a Given Day ($N_{\max}$)

Input 13 is also required for the calculation of the function of pool occupancy (Input 8). The maximum pool occupancy in the pool on a given day has to be entered. If, for example, a pool with a surface of 100 m^2 is assigned a maximum number of swimmers of 100, the function of pool occupancy reaches a factor of 4 as its maximum value (see Figure 5).

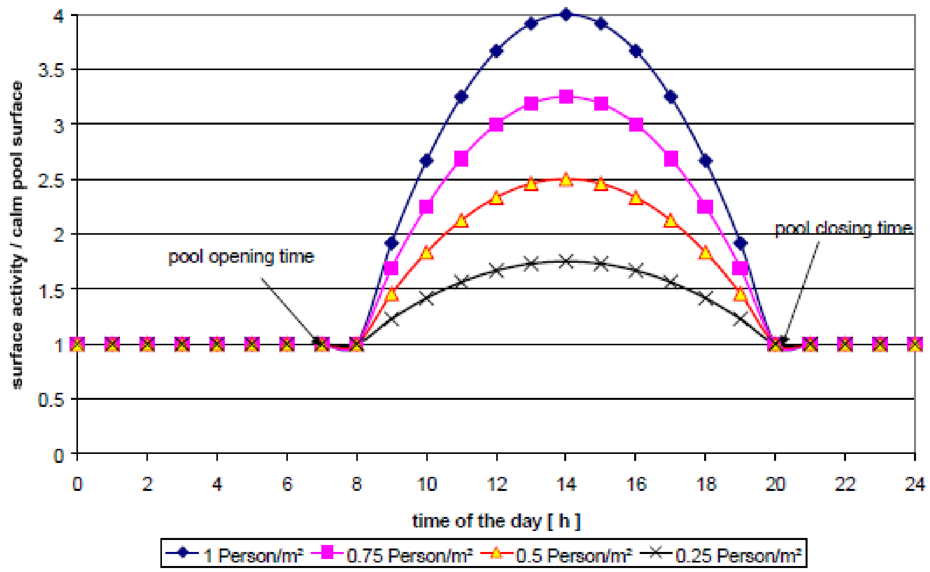

Figure 5: Change of the Function of Pool Occupancy over the Course of the Day for Different Maximum Values of Pool Occupancy. Opening time 8 a.m., closing time 8 p.m.

14. Relative Covering of Water Surface (f_{Cov})
Percentage of water surface covered ($f_{Cov} = 0\ldots1$).

15. Mass Flow Rate of Supply from Heating ($\dot{m}_{In}$)
Mass flow rate of the supply coming from the heating circuit.

16. Temperature of Supply (ϑ_{In})
Temperature of the supply coming from the heating circuit.

2.3 Description of Outputs

For the calculation of an indoor or outdoor pool the following output values can be used:

Output No	Symbol	Description	Unit
1	ϑ_P	Temperature of Pool Water	°C
2	$\dot{m}_{Evap}$	Mass Flow Rate of Evaporation	kg/h
3	$\dot{Q}_{Evap}$	Heat Flow Rate by Evaporation	kJ/h
4	$\dot{Q}_{Con}$	Heat Flow Rate by Convection	kJ/h
5	$\dot{Q}_{Rad}$	Heat Flow Rate by Long-Wave Radiation	kJ/h
6	$\dot{Q}_{Fr}$	Heat Loss by Fresh Water Supply	kJ/h
7	$\dot{Q}_{Sol}$	Short-Wave Radiation Gain	kJ/h
8	$\dot{Q}_{In}$	Auxiliary Heat Flow Rate from Heating	kJ/h
9	dE	Internal energy change from the start of the simulation	kJ
10	ϑ_P	Temperature of Pool Water	°C
11	$\dot{m}_{In}$	Mass Flow Rate from Heating Circuit	kg/h

Table 4: List of Outputs

References

[1] K. Biasin,
Die Wasserverdunstung nichtbenutzter Becken im Hallenbad
Fortschritt-Bericht, VDI-Reihe 19, Nr. 17
Düsseldorf: VDI-Verlag
1987

[2] VDI 2089
Wärme-, Raumlufttechnik, Wasserver- und -entsorgung in Hallen- und Freibäder Hallenbäder
Juli 1994

[3] D. Richter
Temperatur- und Wärmehaushalt des thermisch belasteten Stechlin- und Nehmitzsees
Akademie-Verlag, Berlin

[4] D. Richter
Ein Beitrag zur Bestimmung der Verdunstung von freien Wasserflächen dargestellt am Beispiel des Stechlinsees
Abhandlung des Meteorologischen Dienstes der DDR
Nr. 88, Band XI

[5] F. Guidati,
Überprüfung von Wärme- und Stoffübergangsbeziehungen an der Oberfläche von Freischwimmbecken mittels Meßdaten
Studienarbeit Nr. 9133
Universität Stuttgart
Institut für Thermodynamik und Wärmetechnik
1992

[6] J. T. Czarnecki,
Swimming Pool Heating by Solar Energy
CSIRO Division of Mechanical Engineering
Technical Report TR 19, 1978

[1)] Verein Deutscher Ingenieure (Association of German Engineers)