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COLORADO STATE UNIVERSITY PROGRAM FOR DEVELOPING, TESTING, EVALUATING AND OPTIMIZING SOLAR HEATING AND COOLING SYSTEMS

PROJECT STATUS REPORT FOR THE MONTHS OF DECEMBER 1994 AND JANUARY 1995

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UNIQUE SOLAR SYSTEM COMPONENTS

INTEGRATED TANK/HEAT EXCHANGER MODELING/EXPERIMENTS

A copy of a technical paper titled "Experimental Evaluation of a Simulation Model for Wrap-Around Heat Exchanger, Storage Tanks" is attached. This paper will be presented at the ASME/JSME/JSES International Solar Energy Conference in Maui, Hawaii, March 19-24, 1995. The paper summarizes the results of seven constant temperature heat input tests (reference the Aug/Sep and Oct/Nov 1994 progress reports).

Tables 1 and 2 in the progress report summarize the results of all the constant heat input tests conducted on the Rheem wrap-around heat exchanger tank. In each case, the heat transfer performance of the wrap-around heat exchanger was determined from the experimental data and compared to the results of TRNSYS simulations using the wrap-around heat exchanger tank model previously developed at CSU (Miller et al., 1993) and an attempt was been made to normalize the model to the experimental results.

Summary of Results of Constant Heat Input Tests

Tables 1 and 2 summarize the results of all of the constant heat input tests performed on the 80 gallon wrap-around heat exchanger tank. In Table 1, the tests are organized in groups of constant collector side flow rate. Flow rates of 0.5 , 1.0, 1.5, and 2.0 gpm were investigated. At each flow rate, a test was conducted with a constant heat transfer across the heat exchanger of (approximately) 1, 2, 3, and 4 kW. Note, the top of the tank was not preheated with the auxiliary heater for tests 1007_0, 1026_0, and 1031_0. Table 2 shows the same results grouped in terms of constant heat input with the collector flow rate increasing in each group.

As before (Jun/Jul 1994 Progress Report) the average log-mean temperature difference, ΔT_{lm}, and effective overall heat exchanger conductance, UA_{hx}, determined from experiment are compared to those predicted by TRNSYS simulation.

The model normalization procedure is the same as before (Aug/Sep 1994 Progress Report). The calculation of the heat exchanger UA is modified to

$$\frac{1}{\eta_0 UA_{hx,i}} = \frac{1}{\eta_1 (hA)_{coil,i}} + \frac{1}{\eta_2 (hA)_{tank,i}}$$

The parameter η_0 adjusts the overall conductance calculated by the model, and the parameters η_1 and η_2 adjust the calculated conductance on the coil-side and tank-side of the heat exchanger respectively. With $\eta_0 = \eta_1 = \eta_2 = 1$, the model remains unchanged and the results of Table 1 are obtained. For the results reported here, each parameter is modified independent of the remaining two (i.e. the remaining two are fixed at 1). In each case, the standard estimate of error (root-mean-square error) between the measured and predicted overall log-mean temperature difference (Coleman et al., 1989),

$$\mathrm{SEE} = \left(\frac{\sum_{1}^{N} (\Delta T_{\mathrm{lm,Experiment}} - \Delta T_{\mathrm{lm,Model}})^2}{N-1} \right)^{1/2}$$

is minimized to obtain the value of that parameter which gave the "best fit" between the simulation and the experiment. The standard estimate of error, SEE, is calculated over the interval starting 30 minutes after the circulation heater is enabled (to avoid the oscillations in at the beginning of the experimental data) and ending when the heater is disabled.

Tables 1 and 2 lists the values of η_0, η_1, and η_2 required to obtain agreement with the tests. Remember, each parameter was adjusted independent of the others (i.e. the remaining η's were equal to 1).

These results have not been corrected for the drift in the flow meter zero (reference Oct/Nov 1994 Progress Report). The error caused by this zero drift is small in most cases.

References:

Coleman, H. W., and W.G.Steele Jr., *Experimentation and Uncertainty Analysis for Engineers*, John Wiley and Sons, Inc., New York, NY, 1989.

Miller, J. A., and D. C. Hittle, "Yearly Simulation of a PV Pumped, Wrap-Around Heat Exchanger, Solar Domestic Hot Water System," *Solar Engineering 1993, ASME/ASES/ISES Solar Energy Conference*, Washington, D.C., April 4-9, 1993.

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Table 1. Summary of results of constant heat input tests on the 80 gallon Rheem warp-around heat exchanger tank. Results organized by collector side flow rate.

				Experiment		TRNSYS		Normalization Results					
Run	Q_{aux} kW	Q_{input} kW	Flow Rate gpm	ΔT_{lm} K	UA_{hx} W/K	ΔT_{lm} K	UA_{hx} W/K	η_0	SEE K	η_1	SEE K	η_2	SEE K
0813_0	3.2	1.4	0.3	10.8	131	6.0	243	0.42	0.43	0.32	0.42	0.19	0.39
1010_0	3.2	0.9	0.5	5.5	164	3.2	276	0.46	0.38	0.40	0.39	0.12	0.36
0929_0	3.2	2.0	0.5	10.8	188	6.4	312	0.46	0.64	0.40	0.65	0.14	0.59
1025_0	3.2	2.8	0.5	18.3	155	8.9	320	0.33	0.54	0.26	0.55	0.10	0.50
1030_0	3.1	3.7	0.5	23.8	154	11.0	336	0.30	0.56	0.24	0.57	0.10	0.56
1012_0	3.2	0.9	1.0	5.2	173	2.7	326	0.41	0.34	0.39	0.34	0.07	0.30
0511_1	3.3	1.0	1.1	6.0	174	3.0	340	0.40	0.19	0.37	0.20	0.06	0.16
1003_0	3.2	1.8	1.0	9.7	183	4.9	361	0.37	0.57	0.34	0.58	0.07	0.55
1001_0	3.3	1.8	1.0	9.9	186	5.0	367	0.37	0.56	0.34	0.57	0.07	0.53
0607_0	3.3	2.2	1.0	11.2	193	5.7	381	0.38	0.25	0.34	0.26	0.07	0.25
0517_0	3.2	2.9	1.0	16.9	173	7.4	392	0.30	0.28	0.27	0.29	0.06	0.27
0521_0	3.3	4.2	1.0	23.4	178	9.7	432	0.29	0.44	0.25	0.45	0.06	0.44
1007_0	0.0	1.8	1.0	10.7	172	5.0	367	0.34	0.56	0.31	0.57	0.06	0.52
1026_0	0.0	2.9	1.0	18.3	157	7.4	393	0.27	0.76	0.24	0.77	0.05	0.79
1031_0	0.0	3.8	0.9	24.1	156	9.2	410	0.25	0.99	0.21	0.98	0.05	1.07
1017_0	3.2	0.8	1.5	5.0	163	2.3	352	0.38	0.21	0.36	0.23	0.04	0.19
1004_0	3.2	1.8	1.5	9.4	187	4.4	396	0.36	0.50	0.34	0.50	0.05	0.47
1027_0	3.2	2.9	1.5	17.1	168	6.7	430	0.28	0.37	0.25	0.38	0.04	0.50
1101_0	3.1	3.8	1.5	22.8	165	8.4	456	0.25	0.51	0.23	0.51	0.04	0.58
1024_0	3.2	0.8	2.1	5.1	164	2.3	360	0.37	0.22	0.35	0.22	0.03	0.17
1005_0	3.2	1.8	2.2	9.4	191	4.3	413	0.36	0.42	0.34	0.42	0.04	0.36
0811_0	3.2	2.1	2.0	11.0	188	4.9	423	0.34	0.18	0.32	0.18	0.04	0.14
1028_0	3.2	2.9	2.1	16.9	171	6.4	454	0.27	0.29	0.26	0.29	0.03	0.28
1102_0	3.1	3.2	2.1	19.1	170	7.0	466	0.26	0.34	0.24	0.35	0.03	0.34

Table 2. Summary of results of constant heat input tests on the 80 gallon Rheem warp-around heat exchanger tank. Results organized by heat input.

				Experiment		TRNSYS		Normalization Results					
Run	Q_{aux} kW	Q_{input} kW	Flow Rate gpm	ΔT_{lm} K	UA_{hx} W/K	ΔT_{lm} K	UA_{hx} W/K	η_0	SEE K	η_1	SEE K	η_2	SEE K
1010_0	3.2	0.9	0.5	5.5	164	3.2	276	0.46	0.38	0.40	0.39	0.12	0.36
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1005_0	3.2	1.8	2.2	9.4	191	4.3	413	0.36	0.42	0.34	0.42	0.04	0.36
0929_0	3.2	2.0	0.5	10.8	188	6.4	312	0.46	0.64	0.40	0.65	0.14	0.59
0607_0	3.3	2.2	1.0	11.2	193	5.7	381	0.38	0.25	0.34	0.26	0.07	0.25
0811_0	3.2	2.1	2.0	11.0	188	4.9	423	0.34	0.18	0.32	0.18	0.04	0.14
0812_0	3.2	2.0	3.1	10.9	182	4.6	424	0.32	0.09	0.31	0.08	0.02	0.41
1025_0	3.2	2.8	0.5	18.3	155	8.9	320	0.33	0.54	0.26	0.55	0.10	0.50
0517_0	3.2	2.9	1.0	16.9	173	7.4	392	0.30	0.28	0.27	0.29	0.06	0.27
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1102_0	3.1	3.2	7.8	19.1	170	7.0	466	0.26	0.34	0.24	0.35	0.03	0.34

RATING AND CERTIFICATION OF DOMESTIC WATER HEATING SYSTEMS

December 1994/January 1995

Current work on this project has been to update the TRNSYS model for a previous experimental data set collected using the Solahart 180JK system mounted at CSU's Solar Simulator. The test involved a four hour constant irradiation level with a seven minute load draw at two hours. The draw volume was about one-half of the storage tank volume. An effort is being made to determine how well TRNSYS can predict the temperatures, and thus the energy, involved in the draw. Parameter values that can be adjusted to match the experimental data are considered.

1.0 TRNSYS Deck Modification

Several parameter values from the previous deck have been modified. The significant ones are described below and are included as comments in the enclosed TRNSYS deck (Appendix). The change in the tank UA value is discussed in a previous progress report [Solar Energy Applications Laboratory, 1994].

1.1 Physical Dimensions

Two of the physical dimensions of the solar storage tank were modified to better match the specifications for closed circuit fluid volume and to ensure that TRNSYS would calculate the correct gap in the heat exchanger. The inner length of the outer tank was decreased from 1.35 meters to 1.31 meters and the diameter of the outer tank was decreased from 0.447 meters to 0.436 meters. The net result of these changes was an increase of about five percent in the predicted draw energy value.

The diameter of the collector piping runs was reduced to 0.0169 meters (its inside diameter) from a value of 0.019 meters due to the fact that TRNSYS uses this number to calculate Reynolds numbers and friction factors. This change caused less than a one percent increase in the draw energy value.

1.2 Collector Pipe Loss Coefficient

Assuming that the inner pipe heat transfer coefficient is very large and that the conductivity of copper is much less than that of the insulation, the collector pipe loss coefficients are calculated based upon the following equation:

$$U=\frac{1}{\frac{r_1}{k_i}\ln\left(\frac{r_3}{r_2}\right)+\frac{r_1}{r_3}\frac{1}{h_{out}}}$$

where r_1, r_2, and r_3 are the inner pipe radius, outer pipe radius, and insulation radius, respectively, k_i is the conductivity of the insulation, and h_{out} is the heat transfer coefficient outside of the pipe-insulation system. Using a wind velocity of approximately 2 m/s at the collector (generated by a fan) and a common Nusselt number correlation, h_{out} is about 35 W/m^2-K. Using 1/2" insulation with a conductivity of 0.037 W/mK [Grainger, 1994] and the appropriate radii of the system, U becomes 17.6 kJ/hr-m^2-K which is almost twice the previous value. However, even with the significant increase in the loss coefficient for the collector piping, the draw energy dropped much less than a tenth of one percent indicating that collector piping losses are a minor part of the total system losses.

1.3 Conduction Thermal Resistance of Tank Wall per Unit Length

The conduction resistance of the storage tank wall per unit length is used by TRNSYS in the heat exchanger calculations to determine the UA value for a section of the tank. The following equation is used:

$$R=\frac{\ln(r_2/r_1)}{2\pi k_{glass}}+\frac{\ln(r_3/r_2)}{2\pi k_{steel}}$$

where r_1, r_2, and r_3 are the inner radius of the tank, the radius including the glass coating, and the radius including the steel thickness, respectively, and k_{glass} and k_{steel} are the material conductivities. This produces a resistance value with units of m-K/W or m-K-hr/kJ with a unit conversion.

Using the appropriate radii derived from the specification sheets and conductivities of 1 W/m-K for glass and 54 W/m-K for steel results in a value of 7.2E-5 m-K-hr/kJ when converted to hourly units. This is nearly three times the previous value. However, this parameter change does not affect the draw energy significantly (less than one percent).

2.0 TRNSYS Results

Figure 1 shows the average tank temperature as a function of time over the four hour test. TRNSYS predicts a much higher average tank temperature before the draw and actually drops to a lower average tank temperature after the draw. This occurs because TRNSYS predicts much more stratification in the tank than actually exists. As a result, the hottest water in the tank is drawn off and TRNSYS predicts an energy value for the fixed volume draw that is much higher than the experimental

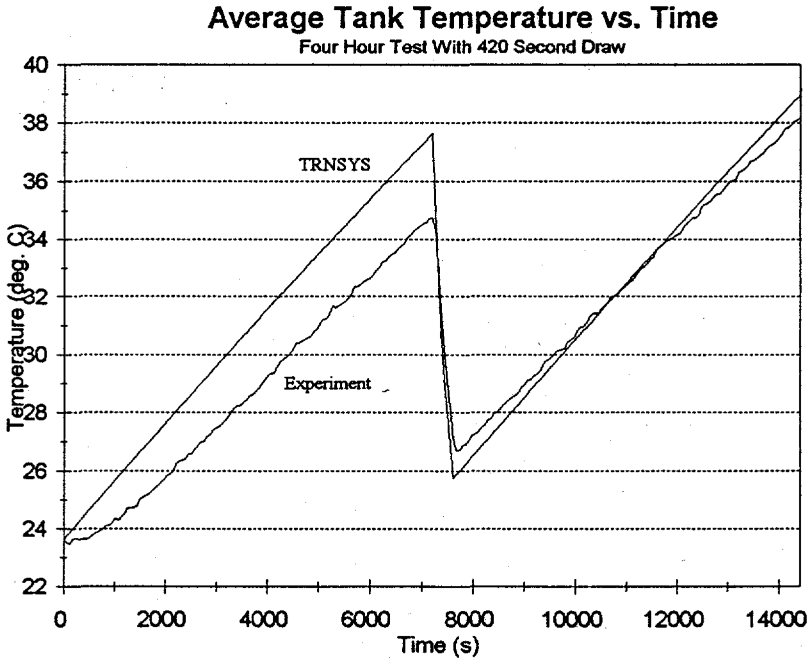

Figure 1. Average Tank Temperature vs. Time Over Four Hour Test

result. After the draw, the average tank temperature catches up to the experimental value and again surpasses it. The fact that the rate of temperature increase before and after the draw in the TRNSYS simulation is larger than in the experiment suggests that more energy is being transferred to the tank water in the model than in actuality. This suggests the use of a collector or tank loss factor adjustment which will be discussed later.

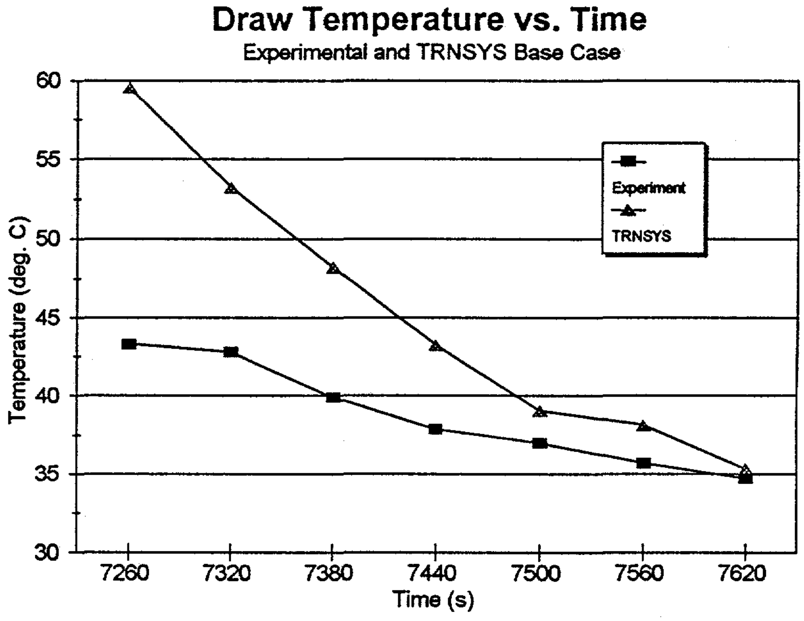

Figure 2. Draw Temperature vs. Time Over 420 Second Draw

Figure 2 shows the tank draw temperature as a function of time over the 420 second draw starting with the second data point after the start of the draw. The first data point is not included since it is experimentally recorded at the instant the draw starts and does not reveal a true draw temperature. As expected of a highly stratified tank, the TRNSYS draw temperature starts off very high and drops with a greater slope than the corresponding experimental draw temperature.

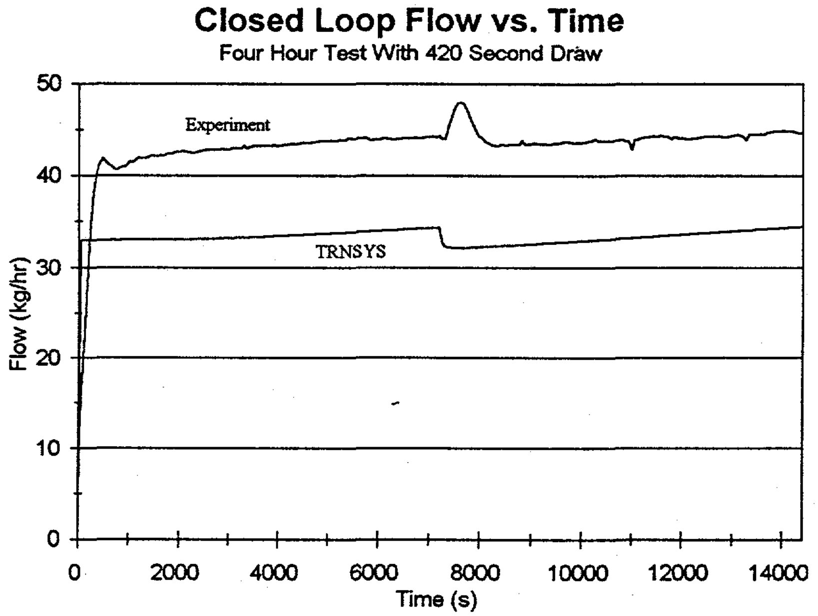

Figure 3. Closed Loop Flow Rate vs. Time Over Four Hour Test

Figure 3 shows the closed loop collector flow as a function of time for the experiment and for the TRNSYS simulation. The qualitative shapes of these curves have been discussed previously [Bickford, 1994], but note that TRNSYS predicts significantly lower flow than observed suggesting a recheck or modification of piping pressure loss factors in the collector loop.

The actual energy delivered over the mains temperature during the 420 second draw was 7412 kJ.

TRNSYS calculated an energy delivery of 9503 kJ which is 28 percent larger than the actual value. TRNSYS also predicts the useful energy from the collector over the entire four hour test to be 21053 kJ which is about seven percent larger than the experimental value of 19626 kJ. TRNSYS is not effectively modeling this four hour constant irradiation test with a fixed volume draw.

3.0 Possible Modifications to Match Temperature Profile and Energy Value

The TRNSYS model overpredicts tank stratification, overpredicts the amount of useful energy coming from the collector, and overpredicts the draw energy for a constant volume draw. This section discusses several possible methods that could be used to improve these predictions by using an adjustment factor, or knob, to vary a chosen parameter to better match the data.

3.1 Collector Loss (F_RU_L) Knob

One way to reduce the useful energy leaving the collector, and thus the energy going to the storage tank, is to multiply the collector's F_RU_L loss parameter by some factor or knob to effectively increase its value. By increasing collector losses, less energy will be delivered to the tank. This solution ignores the stratification problem, but could reduce the draw energy to a more realistic value. The table below shows several possible knobs and the resulting draw energy values.

F_RU_L Knob	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.35
Draw Energy (kJ)	9503	9162	8813	8409	8119	7903	7640	7416

The first value in the table is the result from the TRNSYS model with no adjustment and the last one is the required adjustment to achieve an energy draw close to the experimental value of 7412 kJ. The overprediction by TRNSYS of the useful energy from the collector (measured at the collector outlet) over the four hour test with no adjustment (Knob = 1) is about seven percent. However, with the knob at 4.35, the useful energy from the collector is underpredicted by twenty-six percent which indicates that the collector losses have been increased well beyond a realistic value. Using this technique, the error in the draw energy can only be corrected by reducing the total amount of energy reaching the heat exchanger to a value well below its experimental value. The size of the required knob and the resulting effect on the useful collector energy suggest that this is not a good method to match the draw energy for this particular test and draw procedure.

Figure 4 shows the TRNSYS and experimental results for the average tank temperature as a function of time with the modified collector loss factor (and one other knob to be discussed in the following section). It can be seen that the average tank temperature does not climb as high as in the experiment before the draw and has a diminished slope. The draw lowers the tank temperature significantly below the experimental value and the average tank temperature continues to fall further behind the experimental value until the end of the test. As the experiment uses only four thermocouples to measure the tank stratification, it is feasible that the calculated average value could be significantly different than the actual average tank temperature, thus a comparison between draw temperatures during the 420 second draw is also important.

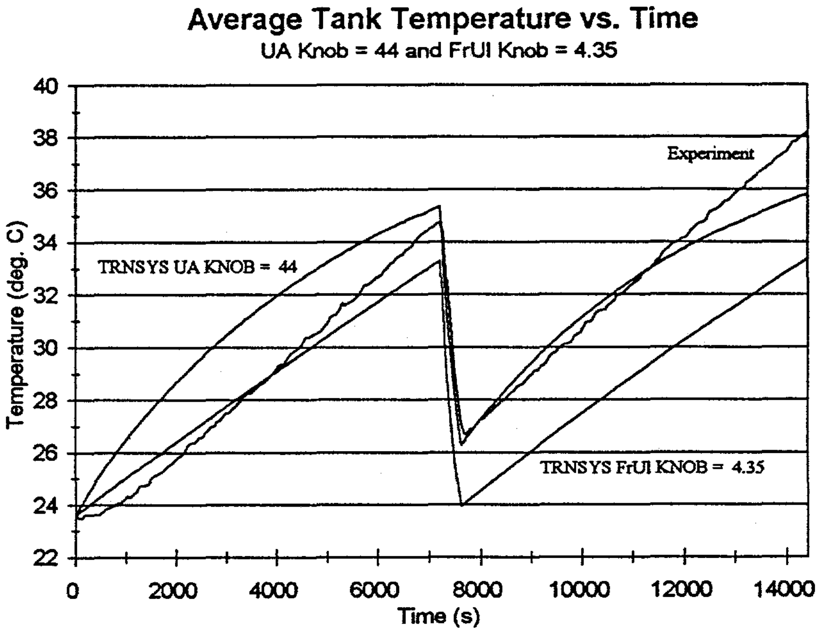

Figure 4. Average Tank Temp. vs. Time Using F_RU_L Knob and UA Knob

Draw temperature results as a function of time for the experiment and for TRNSYS using three different knob adjustments (the remaining two to be discussed in the following sections) are shown in Figure 5. The topmost curve at the left side of the figure is the result when the collector's F_RU_L value is increased by a factor of 4.35. The initial draw temperature is almost ten degrees cooler than it was in the base TRNSYS run due to the fact that less energy is available at the heat exchanger to transfer to the tank water, but is still about seven degrees higher than the experimental value. The draw temperature then drops at a faster rate than in the experiment

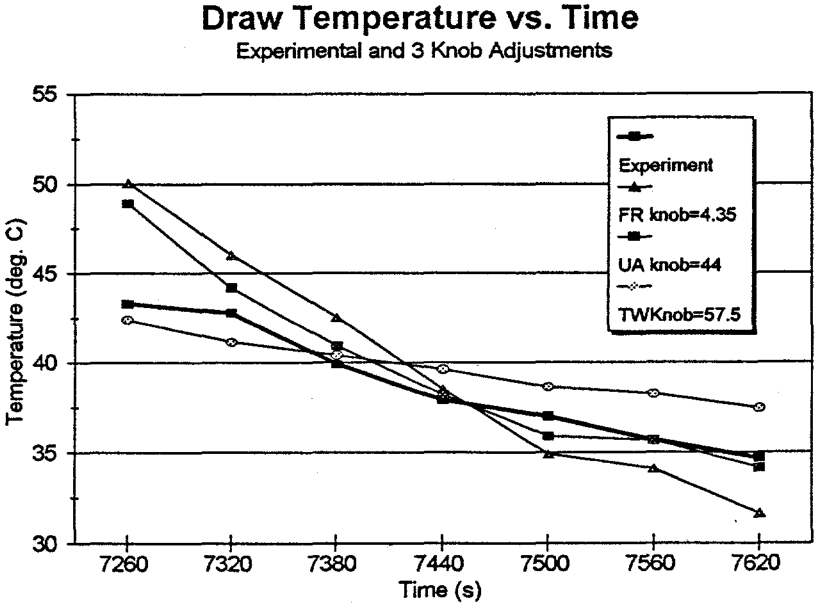

Figure 5. Draw Temperature vs. Time for Experiment and Three TRNSYS Knobs

as it did in the original run, again suggesting greater stratification in the tank than actually exists. The predicted temperature at the end of the draw is about four degrees cooler than in the experiment.

3.2 Storage Tank Heat Loss (UA) Knob

Another possible method to reduce the amount of energy reaching the storage tank is to increase the tank's heat loss or UA value. This is done in the same manner as in the previous section by multiplying the UA value in the deck by a knob. The table below shows the draw energy resulting from several different knobs.

UA Knob	1.0	5.0	10.0	15.0	20.0	44.0
Draw Energy (kJ)	9503	9226	8900	8610	8352	7421

The first value in the table is the TRNSYS result for the draw energy with no UA adjustment and the last value in the table is the knob required to achieve approximately the same draw energy as in the experiment. Increasing the UA value of the tank by a factor of 44 is an extreme adjustment and is not physically realistic. Figure 4 shows the TRNSYS and experimental results for the average tank temperature as a function of time. The huge UA value of the tank can be seen as a downward curvature of the TRNSYS data caused by increased tank losses as the temperature difference between the tank and the ambient conditions increases. Figure 5 shows the draw temperature as a function of time with the modified UA value. The draw temperature begins about six degrees higher than the experimental value, but after one time step the temperature curve follows the experimental curve fairly close, staying within two degrees of the actual draw temperature. This result suggests that losses from the tank, measured with no heat exchanger flow, may be underestimated in the model, which is plausible as tank environmental losses would be expected to increase with flow present in the heat exchanger.

3.3 Tank Thickness Times Wall Conductivity

The tank thickness times the wall conductivity term is used by TRNSYS to calculate heat transfer down the tank wall due to adjacent water layers with differing temperatures. Along with conduction heat transfer between the water layers, this parameter controls destratification of the water in the tank. As it appears that the tank model predicts more stratification than actually exits, this parameter is a qualified candidate for adjustment. The table below shows the draw energy results using several knobs for this parameter.

T_wk_w Knob	1.0	5.0	10.0	15.0	20.0	57.5
Draw Energy (kJ)	9503	9138	8747	8447	8220	7415

A knob of 57.5 is required to achieve the correct energy draw in this case. Again, the size of the knob is discouragingly large. Figure 6 shows the average tank temperature as a function of time with the knob applied compared to the experimental result. This model adjustment achieved temperature profiles that have very similar shapes, but are offset from each other by about three degrees.

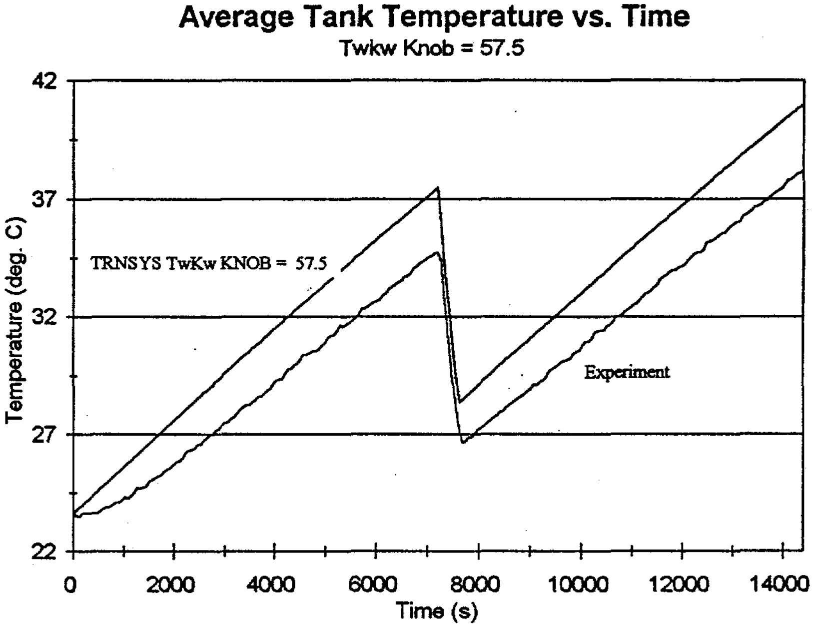

Figure 6. Average Tank Temp. vs. Time Using T_wk_w Knob

The draw temperature profile seen in Figure 5 shows a temperature at the start of the draw that is less than the experimental value and a slope over time that is less than the experimental value. This suggests that we have modified the effective conductivity to such an extent that the tank stratification has actually decreased.

4.0 Matching Draw Temperature and Energy

Based upon the above results, two of the three knobs were adjusted in an attempt to match the draw temperature profile and energy value as closely as possible. To begin, the F_RU_L knob was adjusted to 1.65 to match the useful energy output from the collector. The T_Wk_W knob was then adjusted to match the energy value for the 420 second draw. The required knob value was 31.1 and the resulting draw temperature profile is shown with the experimental result in Figure 7. The result is significantly better than the single knob results presented in figure 5. The draw temperature begins very close to the experimental value, drops slightly below it and then remains above it for the duration of the draw. The RMS temperature error over the draw is about 1.3 degrees.

Several other multiple knob adjustments were tried, but the results were never significantly better than those shown in Figure 7. An automated procedure could improve this process, but the fact remains that the required parameter adjustments are very large.

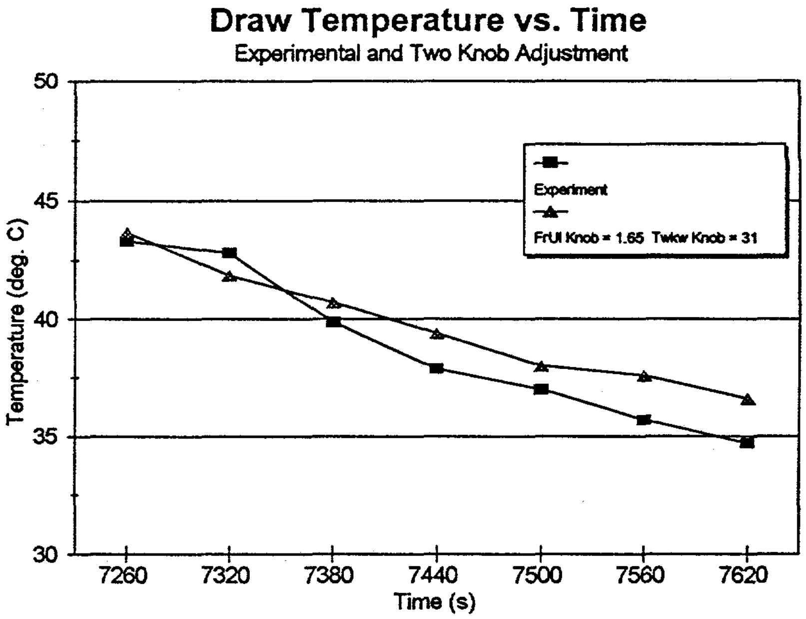

Figure 7. Draw Temperature vs. Time for Experiment and Two Knob Adjustment

5.0 Summary and Current Work

The TRNSYS Type 45 Thermosyphon is currently not effectively modeling a four hour constant irradiation test with a constant volume draw at two hours. Using parameter adjustments to achieve the experimental draw energy requires very large knob values that suggest that something fundamental is missing from the analytical calculations in the model.

The primary problems seem to be an underestimation of tank and heat exchanger losses and overstratification in the tank. Dr. Graham Morrison of the University of New South Wales, Kensington, Australia, the author of the model, has a horizontal-mantle heat exchanger apparatus that is currently being used for flow visualization in the heat exchanger portion of the tank. His eventual goal is to improve the tank destratification processes in the model.

Continued work on this project will involve modification of the thermosyphon code to allow forcing of the collector flow rate and collector inlet temperature to their experimental values every time step. The resulting predicted temperatures leaving the collector and the heat exchanger will then be compared to their experimental values. This will allow a more quantitative determination of where the model discrepancies arise.

References:

Bickford, C., "Short Term Performance Comparison Between A Solar Thermosyphon Water Heater and Two Numerical Simulations," M. S. Thesis, Colorado State University, Fort Collins, CO, 1994.

Grainger 1994 General Catalog No. 385, p. 2533, 1994.

Solar Energy Applications Laboratory, "Rating and Certification of Domestic Water Heating Systems.," *Colorado State University Program for Developing, Testing, Evaluating, and Optimizing Solar Heating and Cooling Systems - Project Status Report for the Months of October and November, 1994*, U.S. DOE grant DE-FG36-86SF16306 report, 1994.

Appendix:

```
ASSIGN DRAW4.LST 6
ASSIGN DRAW4.OUT 10
*
*       *********************************************
*       **** Solahart 180JK Thermosyphon System ****
*       *********************************************
*
*       Four hour constant irradiation with draw
*
*       Original Deck by: Carl Bickford
*       Revised by: Todd Swift
*       Date: 2/95
*
*       Parameter code (where they were obtained):
*         Carl - Carl's experiemental value or measurement
*         Todd - I remeasured or recalculated
*         Spec - Specs from Solahart
*         FSEC - FSEC data obtained from DSET or Solahart
*
*
*              ***** Simulation Parameters *****
EQUATIONS 6
START = 0
STOP = 4
STEP = 1/60
UAKNOB = 1
FRKNOB = 1.65
KWKNOB = 31.1
*  Knobs
*
*              *****Collector Parameters*****
EQUATIONS 4
A =  0.846
*  Efficiency Intercept (Fav(TA)) - Carl
B = 6.5 * 3.6 * FRKNOB
*  (Tw - Ta + R) Coefficient  [kJ/hr-m2-K] - Carl
C = 0.0 * 3.6
*  (Tw - Ta + R)^2 Coefficient [kJ/hr-m2-K]
R = 0
*  Sky Temperature Allowance [K]
*
*             *****Thermosyphon Unit Parameters*****
EQUATIONS 25
AREAPAN =  1.860
*  Single panel net area  [m2]  - Carl/Spec (Net)
NPANEL =  1.0
*  Total number of panels
```

```
AREA = AREAPAN*NPANEL
*  Total Area
SLOPE =  45
*  Test Stand Slope [deg] - Carl
RHOG =  .000001
*  Ground Reflectance - Carl
RHOTNK =  1.000000E+03
*  Collector fluid density [Kg/m3] - Todd (consistent with UA value)
CPTNK =  4.186728E+00
*  Collector Fluid Specific Heat  [KJ/kg-k] - Todd (consistent with UA)
NR =  36
*  Number of parallel collector risers
DR = 4.25E-03
*  Riser Diameter [m] - Carl (FSEC uses 5.08E-3)
LR = 1.843
*  Riser Length [m] - Carl (FSEC uses 1.93)
DH =  2.412882E-02
*  Header Diameter [m] - Spec (CSU/FSEC agree)
LH =  0.990
*  Header Length [m] - Carl (FSEC uses 1.076)
HC =  1.320
*  HC from Figure [m] - Carl
HCOLD = 0.03
*  Ht. of Cold In Above Tank Bottom [m] - Carl (FSEC - 0.01)
HO =  1.405
*  HO from Figure [m] - Carl
HR =  0.040
*  HR from Figure [m] - Carl (CSU/FSEC agree)
NX =  10
*  Nodes for Thermal Head Calculations
DI = 0.0169
DO = DI
*  Diameter of Collector Inlet and Outlet Pipes [m] - Todd (Carl had 0.019)
*                                                          (FSEC has 0.0222)
LI =  2.87
*  Length of Thermosyphon Inlet Pipe [m] - Carl
NB1 =  7.0
*  # of Right Angle Bends in Inlet Pipe - Carl (w/ flow meter)
NB2 =  2.0
*  # of Right Angle Bends in Outlet Pipe - Carl
UI = 17.6
UO=UI
*  Loss Coefficient, Collector Pipes [kJ/h-m2-K] - Todd (Carl had 10.42)
LO =  0.42
*  Length of Thermosyphon Outlet Pipe [m] - Carl
*
*              *****Solar Storage Tank*****
EQUATIONS 15
VOLSOL =  0.1779
*  Solar tank volume [m3]
HT =  0.4259
*  Inner tank diameter [m] - Carl/Spec
UASOL =  10.944 * UAKNOB
*  Solar tank UA-value [kJ/hr-C] - Todd (corrected from Carl's)
*  See the Oct/Nov 1994 DOE report for this correction
RI =  1
*  Insulation Ratio - Carl
VMAX = 0.1
*  Max Size of Tank Element During Conduction Analysis (Fraction)
TMAX = 95
*  Dump Valve Operating Temp [C]
TMIN = 94
*  Dump Valve Closing Temp [C]
DT = 0.436
*  Outer Tank Diameter [m] - Todd (was 0.4469 - changed to get correct gap)
LT = 1.31
*  Outer Tank Length [m] - Todd (was 1.35 - changed to match CC vol. better)
RB = 7.2e-05
*  Cond. Thermal Resistance of Tank Wall / Length [K-h-m/kJ]
*  (Carl had 2.53e-05 and wrong units)
TWKW = 0.4465 * KWKNOB
*  Tank Thk * Wall Conductivity [kJ/h-K] - Todd (Carl had 0.4465)
*  This assumes that heat gets through glass relatively easy (?)
*
*             *****Auxilary Heater*****
* NOTE: Auxilary is off for this test
HTH = 0.23
```

```
*  Height of thermostat above bottom of tank [m] - no effect
AUX = 6684
*  Maximum auxilary heating rate [kJ/hr] - no effect
HHEAT = 0.223
*  Height of Aux. heater above bottom of tank [m] - seems to have effect
TDBTNK = 3
*  Aux. heater deadband [K] - no effect
*
*                *****Experimental Variables*****
EQUATIONS 12
TI = 23.63
*  Initial Temperature of Preheat portion of tank (Avg) [C] - Carl (data)
TAMB = 30.94
*  Average ambient Temperature during test [C] - Carl (data)
TSET = TI
*  Set Point Temperature and temp of portion above heater [C]
TMAINS = 20.0
*  Average Mains Water Temperature during draw [C] - Carl (data)
DUMMY = 0.0
*  Value for Dummy Parameters
IREV = 0.0
*  Reverse Flow Analysis Option - no rev. flow analysis
TT = 200
*  Temp for Flow Restriction (none for TT > 100 C)
IT = 3740.4
*  Incident Radiation on Collector Aperature [kJ/hr m^2] - Carl (data)
IH = 0
*  Horizontal Total Radiation - no effect
ID = 0
*  Diffuse Radiation - assumed very small (indoor simulator)
MDOT = 0.2140*3600
*  Av. Draw Flow Rate [kg/h] - 0.2140 l/s - Carl (data)
THETA = 0
*  Angle of incidence on collector
*
*     ****************
*     SIMULATION START
*     ****************
*
SIMULATION START STOP STEP
LIMITS 25 5 25
TOLERANCES -0.01 -0.01
*
UNIT 15 TYPE 14 Collector inlet Temp Profile during draw [Deg C]
PARAMETERS 10
0,0 2,30.6 2.0167,19.5 2.0333,18.8 4,18.8
*
UNIT 14 TYPE 14 Draw Profile [kg/h]
PARAMETERS 12
0,0 2,0 2,MDOT 2.11667,MDOT 2.11667,0 4,0
*
UNIT 45 TYPE 45 G.M. Thermosyphon
PARAMETERS 55
*
*Eff Mode; Ac; Eff; 1st Coeff; 2nd Coeff; Sky Temp.; Slope; LU; # Risers; DR; LR
*DH; LH; NX; Hc; Ho; DI; LI; NB1; UI; DO; LO; NB2; UO; Tank Mode; VOLSOL
*HT; Hr; CPTNK; RHOTNK; twkw; Tank Config; UASOL; RI; TI; HCOLD; AUX
*HHEAT; HTH; TSET; TDBTNK; UAF; VMAX; TMAX; TMIN; DT; LT; RB; Dummy
*Dummy; Optical Mode; Bo; IREV; TT; FLUID (1 for pg)
*
2 AREA A B C R SLOPE -2 NR DR
LR DH LH NX HC HO DI LI NB1 UI
DO LO NB2 UO 6 VOLSOL HT HR CPTNK RHOTNK
TWKW 2 UASOL RI TI HCOLD AUX HHEAT HTH TSET
TDBTNK 0 VMAX TMAX TMIN DT LT RB DUMMY DUMMY
1 0 IREV TT 1
*
INPUTS 10
*
*It; Ih; Id; Theta; Rhog; Tamb; Tmains; Load Flow; Tenv; Aux Enable
*
0,0  0,0  0,0  0,0    0,0  0,0   0,0     14,1   0,0   0,0
IT   IH   ID   THETA  RHOG TAMB  TMAINS  0.0    TAMB  0.0
*
* Output Printer
*
UNIT 24 TYPE 24 Integrator
```

```
INPUTS 2
45,8  45,2
0.0    0.0
*
UNIT 25 TYPE 25 Printer
PARAMETERS 4
STEP 2 2.1167 10
INPUTS 4
24,1  45,12  45,5  24,2
QsupSum Ttnk  Tdel Qutot
*
END
```

ADVANCED RESIDENTIAL SOLAR DOMESTIC HOT WATER (SDHW) SYSTEMS

This report is for December, 1994 and January, 1995. Experimental tests are being conducted on three side by side systems: ASN, NEG and Thermodynamics.

The month of December was spent in isolating problems with the flow meters and re-calibrating them. The calibration was finally successful and all of the flowmeters have been re-installed. New pressure taps were installed at all locations. The old design was very fragile and would cause delays. The themocouple that was on the outlet of the NEG tank has been moved to the "to collectors" line, in line with the new location for the NEG flowmeter. An additional line with a shut off valve has been added between the "back from colletors" on the NEG system and the draw line. This allows us to determine the energy in the NEG collectors by filling them with constant temperature water and by-passing the NEG auxiliary storage tank when emptying the collectors. A new power supply was installed for the anemometer; the old one was not reliable.

Much work has been done on the IAM program and the NEG TRNSYS input deck. We are trying to match the TRNSYS output temperatures and energies with experimental ones over the entire duration of the test, not just the overall energies. Runs will be made by varying the $\tau\alpha_{normal}$ and the UA value of the collectors.

The data from previous tests will be reanalyzed with the new data reduction program.

MANAGEMENT AND COORDINATION OF COLORADO STATE/DOE PROGRAM

Coordination of research activities continued on the four technical research tasks under the DOE grant, and accounts were maintained and updated. Financial and technical reports were submitted as required.