APPENDIX D-1. WATSIM-DOE TEST.XLS

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APPENDIX D-1. WATSIM-DOE TEST.XLS

This Appendix describes the spreadsheet tool "WATSIM-DOE Test.xls", which was developed to calculate the energy efficiency characteristics of electric storage water heaters according to the specifications of the DOE test procedure[1] from a standard WATSIM output file.

D-1.1 BACKGROUND

The WATSIM electric water heating simulation program contains two simulation algorithms: one for the detailed simulation of the energy performance of water heater tanks and a second for controlling water draw profiles for use with the tank model. The output of WATSIM does not, however, include EF, RE, and UA values, which are specific to the DOE test procedure.

Since the simulation analysis must be performed according to the requirements of the DOE test procedure, the water draw profile is specified to the 64.3 gallon (243.4 liter). The specified draw profile is provided in a standard WATSIM draw file (machine.643). WATSIM provides detailed temperature profiles for the water in the water heater tank during the simulation run. The temperature profiles are specified in the WATSIM input file (baseline.dat). The draw file and input file are available in the DOE's Office of Codes and Standards' web-site. The temperature profile is provided in a standard WATSIM output file called *tw_vs_t1.out*. These temperature readings are used by the "WATSIM-DOE Test.xls" to determine EF, RE, and UA.

"WATSIM-DOE Test.xls" was developed using Microsoft Excel and is a workbook file consisting of three individual worksheets: 1) *results*, 2) *tw_vs_t1*, and 3) *EF_calc*. (Note that at the bottom of the screen view are the names of all three individual Worksheets.) This is a customized analysis tool developed specifically for this analysis and, as such, it has certain limitations, descriptions of which are provided in the detailed explanation of the procedure.

D-1.2 PROGRAM DESCRIPTION

D-1.2.1 Introduction

The following requirements must be satisfied before performing the procedure:

1) "WATSIM-DOE Test.xls" works in conjunction with the standard WATSIM output file *tw_vs_t1.out.* The two files need to be in the same directory.

2) The tool is customized to work with a set of parameters required by the DOE test procedure. It is necessary to supply values for the following variables used for the actual simulation:

- water heater rated input, V_{st},
- average inlet water temperature, $T_{in,1}$,
- average ambient temperature during the total standby period, $T_{a,stby}$,
- average ambient temperature after the last draw to the end of the 24-hour test, $T_{s,stby}$.

The input cells for those variables are located in the *tw_vs_t1* worksheet.

D-1.2.2 ***"Results"*** **Worksheet**

The purpose of the *"results"* worksheet is to load WATSIM's *tw_vs_t1.out* file into the spreadsheet tool. The user simply needs to "click" on the Load Data File button to activate a macro, which loads the *tw_vs_t1.out* file into the spreadsheet tool. Figure D-1.1 shows an Excel screen view of the spreadsheet tool's *results* worksheet.

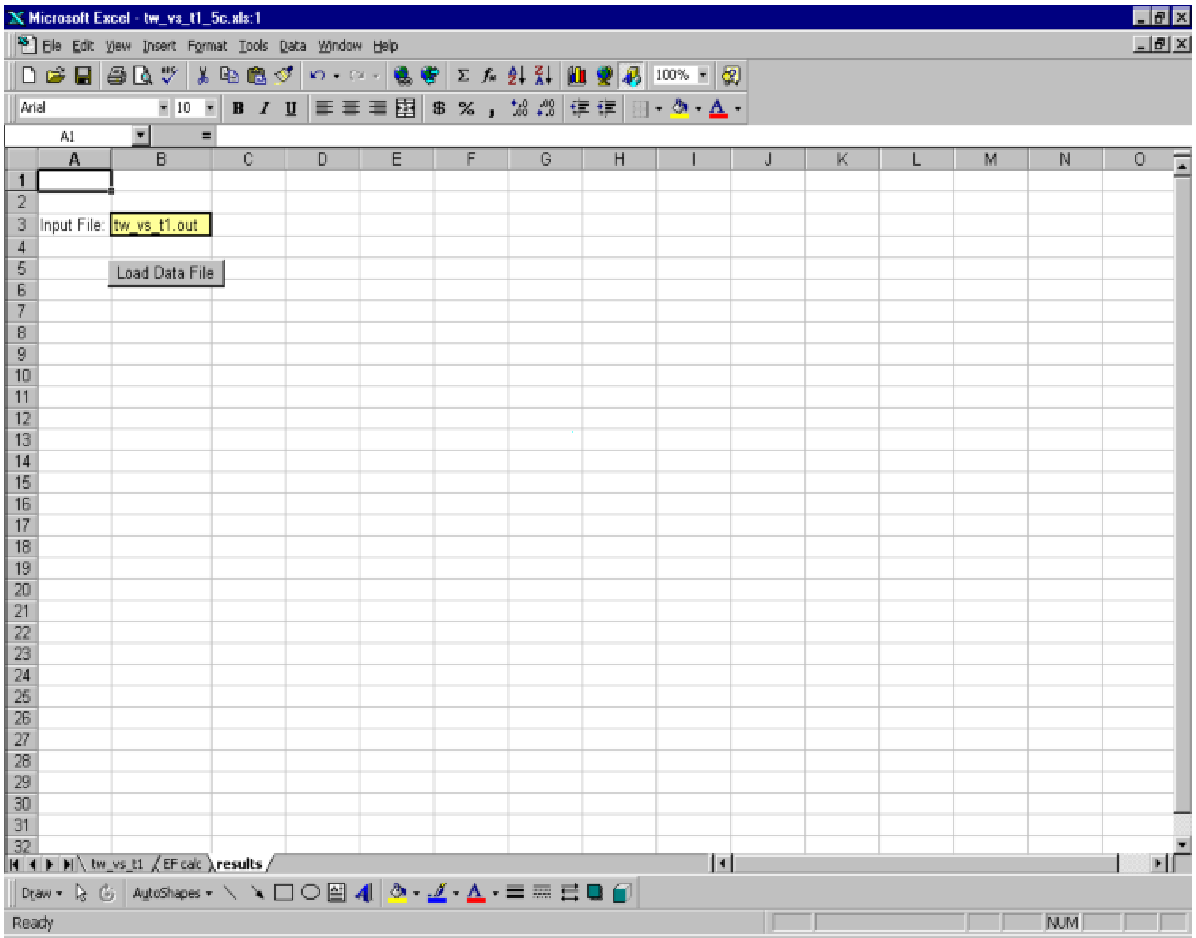


Figure D-1.1 Excel Screen View of *Results* Worksheet

D-1.2.3 *"tw_vs_t1"* Worksheet

After the *tw_vs_t1.out* file is loaded into the spreadsheet tool, the user is automatically transferred over to the *tw_vs_t1* worksheet. The *tw_vs_t1* worksheet is where the *tw_vs_t1.out* file is actually loaded. Because the *tw_vs_t1* worksheet will contain a previously loaded *tw_vs_t1.out* file, the user will need to edit the worksheet after the current *tw_vs_t1.out* file is loaded. Editing consists of clearing out the data from the previous file. Figure D-1.2 shows a partial Excel screen view of the spreadsheet tool's *tw_vs_t1* worksheet. It shows the data that are provided in WATSIM's *tw_vs_t1.out* file.

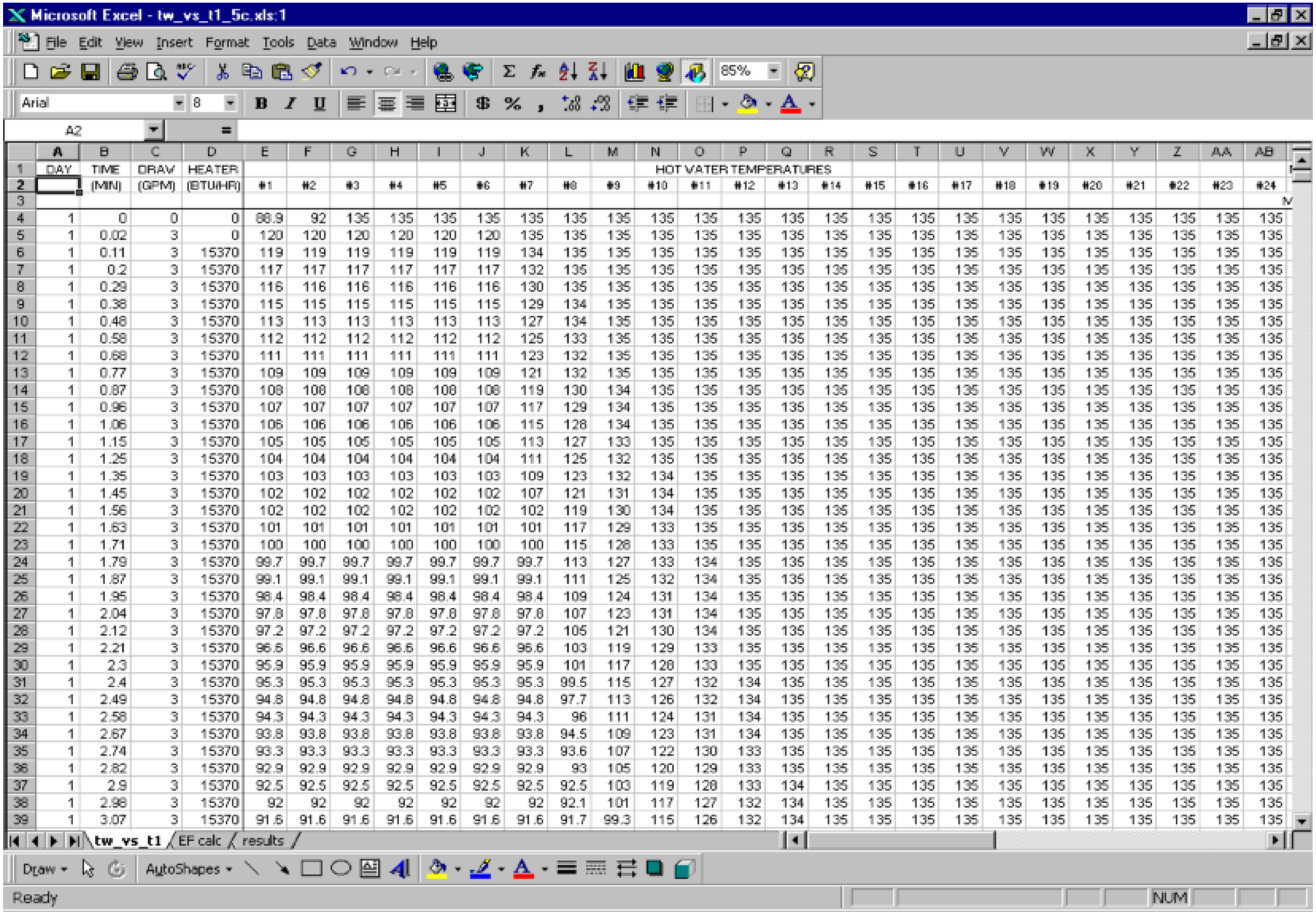
- Column A provides the DAY on which data are being recorded. Since the DOE simulated use test lasts 24 hours, a value of 1 is always recorded.

- Column B provides the TIME (in minutes) when data are being recorded. Since the DOE simulated use test lasts 24 hours, the last value in which data will be recorded is at the 1440^{th} minute. Obviously, all the data up the 1440^{th} minute cannot be shown in Figure D-1.2 as hundreds of data records are contained in any single *tw_vs_t1.out* file.

- Column C provides the water DRAW (in gallons per minute) at the time the data are being recorded. Since the draw pattern is conducted per the requirements of the DOE simulated use test, the value recorded will either be 3 gpm or 0 gpm. It should be noted that during the water draw period, WATSIM records data into the *tw_vs_t1.out* file approximately every 5 seconds. Thus, during the six draw periods lasting approximately 3½ minutes as prescribed by the DOE simulated use test, a wealth of data will be recorded.

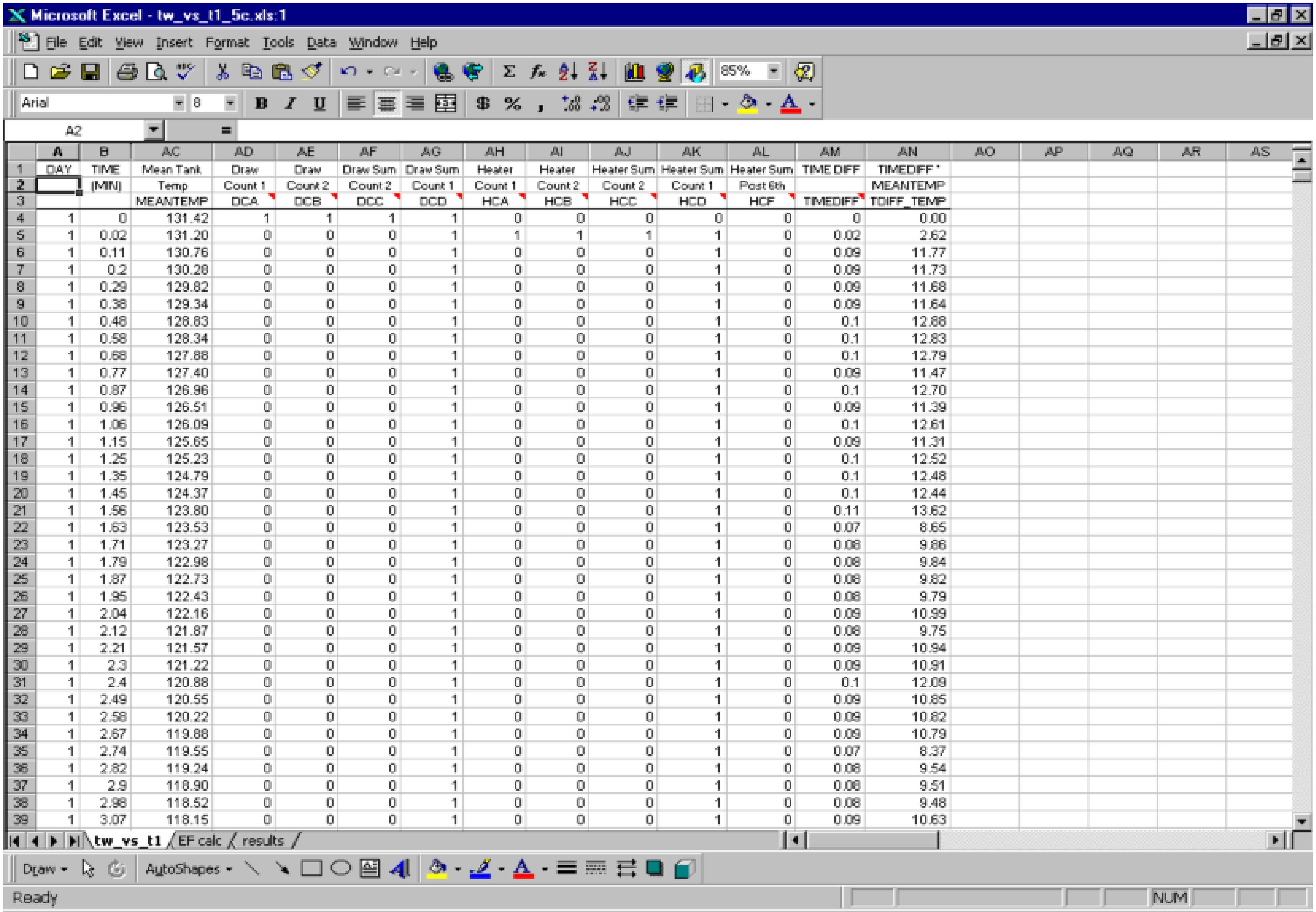
- Column D provides the rate of electrical HEATER consumption (in Btu/hr) at the time in which data are being recorded. In Figure D-1.2, results are provided for a 50-gal (190-liter) electric storage water heater with two 4.5 kW electrical heater elements. Thus, in the case shown in Figure D-1.2, the rate of electrical heater consumption will always be 15,370 Btu/hr (4.5 kW) when the heater element is required to come on to maintain the temperature setpoint. It should be noted that during a non-water draw period while the heater element is on, WATSIM records data into the *tw_vs_t1.out file* approximately every 33 seconds. At conditions where there is no water draw and the heater element is off, WATSIM records data into the *tw_vs_t1.out* file approximately every 5 minutes.

- Columns E through AB contain the HOT WATER TEMPERATURE profile data. For example, Temperature #1 corresponds to the temperature measurement taken closest to the bottom of the tank while Temperature #24 corresponds to the measurement taken closest to the top of the tank. Temperature #24 is assumed to equal the temperature of the hot water drawn from the water heater. Temperature #24 is also referred to as the DRAWTEMP. The 24 temperatures are measured at evenly spaced intervals throughout the tank.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB
1	DAY	TIME	DRAW	HEATER										HOT VATER TEMPERATURES														
2		(MIN)	(GPM)	(BTU/HR)	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17	#18	#19	#20	#21	#22	#23	#24
3																												
4	1	0	0	0	88.9	92	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
5	1	0.02	3	0	120	120	120	120	120	120	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
6	1	0.11	3	15370	119	119	119	119	119	119	134	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
7	1	0.2	3	15370	117	117	117	117	117	117	132	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
8	1	0.29	3	15370	116	116	116	116	116	116	130	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
9	1	0.38	3	15370	115	115	115	115	115	115	129	134	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
10	1	0.48	3	15370	113	113	113	113	113	113	127	134	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
11	1	0.58	3	15370	112	112	112	112	112	112	125	133	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
12	1	0.68	3	15370	111	111	111	111	111	111	123	132	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
13	1	0.77	3	15370	109	109	109	109	109	109	121	132	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
14	1	0.87	3	15370	108	108	108	108	108	108	119	130	134	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
15	1	0.96	3	15370	107	107	107	107	107	107	117	129	134	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
16	1	1.06	3	15370	106	106	106	106	106	106	115	128	134	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
17	1	1.15	3	15370	105	105	105	105	105	105	113	127	133	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
18	1	1.25	3	15370	104	104	104	104	104	104	111	125	132	135	135	135	135	135	135	135	135	135	135	135	135	135	135	135
19	1	1.35	3	15370	103	103	103	103	103	103	109	123	132	134	135	135	135	135	135	135	135	135	135	135	135	135	135	135
20	1	1.45	3	15370	102	102	102	102	102	102	107	121	131	134	135	135	135	135	135	135	135	135	135	135	135	135	135	135
21	1	1.56	3	15370	102	102	102	102	102	102	102	119	130	134	135	135	135	135	135	135	135	135	135	135	135	135	135	135
22	1	1.63	3	15370	101	101	101	101	101	101	101	117	129	133	135	135	135	135	135	135	135	135	135	135	135	135	135	135
23	1	1.71	3	15370	100	100	100	100	100	100	100	115	128	133	135	135	135	135	135	135	135	135	135	135	135	135	135	135
24	1	1.79	3	15370	99.7	99.7	99.7	99.7	99.7	99.7	99.7	113	127	133	134	135	135	135	135	135	135	135	135	135	135	135	135	135
25	1	1.87	3	15370	99.1	99.1	99.1	99.1	99.1	99.1	99.1	111	125	132	134	135	135	135	135	135	135	135	135	135	135	135	135	135
26	1	1.95	3	15370	98.4	98.4	98.4	98.4	98.4	98.4	98.4	109	124	131	134	135	135	135	135	135	135	135	135	135	135	135	135	135
27	1	2.04	3	15370	97.8	97.8	97.8	97.8	97.8	97.8	97.8	107	123	131	134	135	135	135	135	135	135	135	135	135	135	135	135	135
28	1	2.12	3	15370	97.2	97.2	97.2	97.2	97.2	97.2	97.2	105	121	130	134	135	135	135	135	135	135	135	135	135	135	135	135	135
29	1	2.21	3	15370	96.6	96.6	96.6	96.6	96.6	96.6	96.6	103	119	129	133	135	135	135	135	135	135	135	135	135	135	135	135	135
30	1	2.3	3	15370	95.9	95.9	95.9	95.9	95.9	95.9	95.9	101	117	128	133	135	135	135	135	135	135	135	135	135	135	135	135	135
31	1	2.4	3	15370	95.3	95.3	95.3	95.3	95.3	95.3	95.3	99.5	115	127	132	134	135	135	135	135	135	135	135	135	135	135	135	135
32	1	2.49	3	15370	94.8	94.8	94.8	94.8	94.8	94.8	94.8	97.7	113	126	132	134	135	135	135	135	135	135	135	135	135	135	135	135
33	1	2.58	3	15370	94.3	94.3	94.3	94.3	94.3	94.3	94.3	96	111	124	131	134	135	135	135	135	135	135	135	135	135	135	135	135
34	1	2.67	3	15370	93.8	93.8	93.8	93.8	93.8	93.8	93.8	94.5	109	123	131	134	135	135	135	135	135	135	135	135	135	135	135	135
35	1	2.74	3	15370	93.3	93.3	93.3	93.3	93.3	93.3	93.3	93.6	107	122	130	133	135	135	135	135	135	135	135	135	135	135	135	135
36	1	2.82	3	15370	92.9	92.9	92.9	92.9	92.9	92.9	92.9	93	105	120	129	133	135	135	135	135	135	135	135	135	135	135	135	135
37	1	2.9	3	15370	92.5	92.5	92.5	92.5	92.5	92.5	92.5	92.5	103	119	128	133	134	135	135	135	135	135	135	135	135	135	135	135
38	1	2.98	3	15370	92	92	92	92	92	92	92	92.1	101	117	127	132	134	135	135	135	135	135	135	135	135	135	135	135
39	1	3.07	3	15370	91.6	91.6	91.6	91.6	91.6	91.6	91.6	91.7	99.3	115	126	132	134	135	135	135	135	135	135	135	135	135	135	135

Figure D-1.2 Excel Screen View (1 of 2) of *tw_vs_t1* Worksheet: *tw_vs_t1.out* Variables



Microsoft Excel - tw_vs_t1_5c.xls:1

	A	B	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	DAY	TIME	Mean Tank	Draw	Draw	Draw Sum	Draw Sum	Heater	Heater	Heater Sum	Heater Sum	Heater Sum	TIME DIFF	TIMEDIFF *
2		(MIN)	Temp	Count 1	Count 2	Count 2	Count 1	Count 1	Count 2	Count 2	Count 1	Post 6th		MEANTEMP
3			MEANTEMP	DCA	DCB	DCC	DCD	HCA	HCB	HCC	HCD	HCF	TIMEDIFF	TDIFF_TEMP
4	1	0	131.42	1	1	1	1	0	0	0	0	0	0	0.00
5	1	0.02	131.20	0	0	0	1	1	1	1	1	0	0.02	2.62
6	1	0.11	130.76	0	0	0	1	0	0	0	1	0	0.09	11.77
7	1	0.2	130.28	0	0	0	1	0	0	0	1	0	0.09	11.73
8	1	0.29	129.82	0	0	0	1	0	0	0	1	0	0.09	11.68
9	1	0.38	129.34	0	0	0	1	0	0	0	1	0	0.09	11.64
10	1	0.48	128.83	0	0	0	1	0	0	0	1	0	0.1	12.88
11	1	0.58	128.34	0	0	0	1	0	0	0	1	0	0.1	12.83
12	1	0.68	127.88	0	0	0	1	0	0	0	1	0	0.1	12.79
13	1	0.77	127.40	0	0	0	1	0	0	0	1	0	0.09	11.47
14	1	0.87	126.96	0	0	0	1	0	0	0	1	0	0.1	12.70
15	1	0.96	126.51	0	0	0	1	0	0	0	1	0	0.09	11.39
16	1	1.06	126.09	0	0	0	1	0	0	0	1	0	0.1	12.61
17	1	1.15	125.65	0	0	0	1	0	0	0	1	0	0.09	11.31
18	1	1.25	125.23	0	0	0	1	0	0	0	1	0	0.1	12.52
19	1	1.35	124.79	0	0	0	1	0	0	0	1	0	0.1	12.48
20	1	1.45	124.37	0	0	0	1	0	0	0	1	0	0.1	12.44
21	1	1.56	123.80	0	0	0	1	0	0	0	1	0	0.11	13.62
22	1	1.63	123.53	0	0	0	1	0	0	0	1	0	0.07	8.65
23	1	1.71	123.27	0	0	0	1	0	0	0	1	0	0.08	9.86
24	1	1.79	122.98	0	0	0	1	0	0	0	1	0	0.08	9.84
25	1	1.87	122.73	0	0	0	1	0	0	0	1	0	0.08	9.82
26	1	1.95	122.43	0	0	0	1	0	0	0	1	0	0.08	9.79
27	1	2.04	122.16	0	0	0	1	0	0	0	1	0	0.09	10.99
28	1	2.12	121.87	0	0	0	1	0	0	0	1	0	0.08	9.75
29	1	2.21	121.57	0	0	0	1	0	0	0	1	0	0.09	10.94
30	1	2.3	121.22	0	0	0	1	0	0	0	1	0	0.09	10.91
31	1	2.4	120.88	0	0	0	1	0	0	0	1	0	0.1	12.09
32	1	2.49	120.55	0	0	0	1	0	0	0	1	0	0.09	10.85
33	1	2.58	120.22	0	0	0	1	0	0	0	1	0	0.09	10.82
34	1	2.67	119.88	0	0	0	1	0	0	0	1	0	0.09	10.79
35	1	2.74	119.55	0	0	0	1	0	0	0	1	0	0.07	8.37
36	1	2.82	119.24	0	0	0	1	0	0	0	1	0	0.08	9.54
37	1	2.9	118.90	0	0	0	1	0	0	0	1	0	0.08	9.51
38	1	2.98	118.52	0	0	0	1	0	0	0	1	0	0.08	9.48
39	1	3.07	118.15	0	0	0	1	0	0	0	1	0	0.09	10.63

tw_vs_t1 / EF calc / results

Figure D-1.3 Excel Screen View (2 of 2) of *tw_vs_t1* Worksheet: Calculated Variables

Figure D-1.3 shows the remaining variables in the *tw_vs_t1* worksheet. The remaining variables are NOT recorded by WATSIM into the *tw_vs_t1.out* file. Rather, they are variables which are automatically calculated in order to determine quantities necessary for establishing the EF, RE, and UA of the water heater being analyzed according to the DOE test procedure. Figure D-1.3 presents a partial Excel screen view of the spreadsheet tool's *tw_vs_t1* worksheet showing the calculated variables.

- MEANTEMP is located in column AC. It represents the mean hot water tank temperature and is based on 12 of the 24 temperatures recorded in Columns E through AB. The following equation shows how MEANTEMP is calculated.

$$T_{mean} = \frac{\left| \frac{T_2 + T_3}{2} + \frac{T_6 + T_7}{2} + \frac{T_{10} + T_{11}}{2} + \frac{T_{14} + T_{15}}{2} + \frac{T_{18} + T_{19}}{2} + \frac{T_{22} + T_{23}}{2} \right|}{6}$$

  Since the DOE test procedure requires that six temperature readings be used to establish the mean tank temperature, those temperatures recorded in *tw_vs_t1.out* that best represent the six temperatures (the average of the two temperatures representing the six evenly spaced regions of the tank) are used to calculate MEANTEMP.

- DCA is located in column AD. DCA returns a value of 1 only if the row DRAW changes from a value of 0 to 1.

- DCB is located in column AE. DCB is 1 whenever DRAW changes value (going from a value of either 0 to 1 or 1 to 0). Thus, a value of 1 will be calculated for DCB only at the beginning and end of each water draw period.

- DCC is located in column AF. DCC sums up the values in column AE (variable DCB) if and only if DCB equals a value of 1 *and* DRAW changes value. Thus, a value of 1 or greater will be calculated for DCC only at the beginning and end of each water draw period. For example, during the first draw period, DCC will equal a value of 1 at the beginning of the draw and a value of 2 at the end of the draw. During the second draw period, DCC will equal a value of 3 at the beginning of the draw and a value of 4 at the end of the draw. DCC gets increased by a value of 1 for each subsequent draw.

- DCD is located in column AG. DCD changes to an incrementally larger value for the length of each of the six draw periods. For example, DCD is a value of 1 during the length of the first draw period, a value of 2 during the length of the second draw period, a value of 3 during the length of third draw period, and so on for each subsequent draw period.

- HCA is located in column AH. HCA is comparable to variable DCA except that its value is based on the status of HEATER rather than DRAW. HCA changes to a value of 1 only when HEATER changes from a value of 0 to 1.

- HCB is located in column AI. HCB is comparable to variable DCB except that its value is based on the status of HEATER rather than DRAW. HCB switches to a value of 1 whenever HEATER changes value (going from a value of either 0 to 1 or 1 to 0). Thus, a value of 1 will be calculated for HCB only at the beginning and end of each time period in which the heater element is on.

- HCC is located in column AJ. HCC is comparable to variable DCC except that its value is based on the status of HEATER rather than DRAW.

- HCD is located in column AK. HCC is comparable to variable DCC except that its value is based on the status of HEATER rather than DRAW. HCD changes to an incrementally larger value for the length of each time period that the heater element is on. It should be noted that, unlike the water draw periods, there may be more than six time periods in which the heater element comes on. The heater element comes on to maintain temperature setpoint; thus, it cycles during standby operation after all six water draws have been completed. For example, a typical baseline 50-gal (190-liter) electric water heater will have its heater element cycle 9 to 10 times in the course of the 24-hour DOE simulated use test.

- HCF is located in column AL. HCF switches to a value of 1 and remains a value of 1 after the heater element has cycled for sixth time.

- TIMEDIFF is located in column AM. TIMEDIFF tracks the time difference between each set of recorded data.

- TDIFF_TEMP is located in column AN and is used to calculate "time-weighted average" mean tank temperatures. Because the time difference between data records varies depending on the status of the water DRAW and the HEATER elements, the mean tank temperature for a time period spanning multiple water draws cannot be determined directly from the values calculated for MEANTEMP. TDIFF_TEMP allows for the determination of accurate mean tank temperatures. TDIFF_TEMP is calculated by multiplying TIMEDIFF by MEANTEMP. Thus, for any desired time period, the mean tank temperature is determined by summing the values for TDIFF_TEMP and dividing by the elapsed time for the time period.

D-1.2.4 *"EF calc"* Worksheet

This worksheet shows the results of the procedure. After all of the data have been loaded and intermediate values generated in the *tw_vs_t1* worksheet, the user must manually switch to the *EF calc* worksheet to see the results of the energy performance calculations. All the energy performance calculations in the *EF calc* worksheet, including those for EF, RE, and UA, are done automatically. Figure D-1.4 shows the energy performance values as they are presented in the *EF calc* worksheet. All the variables in the *EF calc* worksheet are required by the DOE test procedure equations in order to determine RE, UA, and EF. The *EF calc* worksheet uses the same nomenclature as in the DOE test procedure in order to maintain consistency and to enable the user to easily identify and define all the variables.

All shaded areas in the *EF calc* worksheet represent variables that are determined directly from the data in the *tw_vs_t1* worksheet. All other variables are determined from DOE test procedure equations or are equal to default values provided in the test procedure. A list of variables in the *EF calc* worksheet determined from the data in *tw_vs_t1* worksheet is provided below.

- M_1, mass of water (lb_m) withdrawn during the first draw: Determined by multiplying the DRAW rate (3 gpm) during the first draw by the elapsed time of the first draw. Once the total draw is determined in gallons, it is converted to lb_m using conversion factors. The calculation is based on the use of variable DCC in the *tw_vs_t1* worksheet. The TIME when DCC equals 1 (the beginning of the first draw) is subtracted from the TIME when DCC equals 2 (the end of the first draw) in order to calculate the elapsed time.

- $T_{del,1}$, average delivery temperature ($^\circ$F) for the first draw: Determined by calculating the average draw temperature during the first draw. The calculation is based on the use of variable DCD in the *tw_vs_t1* worksheet. First, all the DRAWTEMPs (hot water temperature #24) for the period when DCD equals 1 (the length of the first draw) are summed. Then, the summed DRAWTEMP value is divided by the number of times in which DCD equals 1 to arrive at the average delivery temperature during the first draw.

- $T_{max,1}$, maximum mean tank temperature ($^\circ$F) recorded after cutout following the first draw: The key to to determining $T_{max,1}$ is selecting the maximum temperature after the HEATER element first cycles off. This determination is based on the use of variable HCC in the *tw_vs_t1* worksheet. Since the maximum temperature occurs immediately after the HEATER element cycles off, the value for the maximum MEANTEMP is when HCC equals 2 (the end of the first HEATER cycle).

- T_o, maximum mean tank temperature ($^\circ$F) recorded prior to the first draw: This is simply the first value for MEANTEMP recorded in the *tw_vs_1* worksheet.

- Q_r, total energy (Btu) used by the water heater between cutout following the first draw, including auxiliary energy such as pilot lights, pumps, fans, etc.: Determined by multiplying the HEATER's rate of consumption (15,370 Btu) during its first cycle by the elapsed time of the HEATER's first cycle. Key to determining Q_r is the calculation of the elapsed time of the first HEATER cycle. The calculation is based on the use of variable HCC in the *tw_vs_t1* worksheet. The TIME when HCC equals 1 (the beginning of the first cycle, i.e., when the HEATER element first turns on) is subtracted from the TIME when HCC equals 2 (the end of the first cycle, i.e., when the HEATER element first turns off) in order to calculate the elapsed time.

- Q_{stby}, total energy (Btu) consumed by the water heater between the time at which the maximum mean tank temperature is observed after the sixth draw and the end of the 24-hour test period: Determined by calculating the total HEATER energy consumption during the standby period of the water heater. The standby period, with respect to calculating Q_{stby} starts immediately after the sixth cycle of the HEATER element. This is because the maximum mean tank temperature occurs immediately after the HEATER element cycles off for the sixth time. Key to determining Q_{stby} is the calculation of the elapsed time of each HEATER cycle after the HEATER element's sixth cycle. The calculation is based on the use of variable HCC in the *tw_vs_t1* worksheet. At the TIME when the HEATER cycles off for the sixth time, HCC equals 12. Thus, the elapsed time of the seventh HEATER cycle is determined by subtracting the TIME when HCC equals 13 (the beginning of the seventh cycle) from the TIME when HCC equals 14 (the end of the seventh cycle). The elapsed times of all subsequent cycles are determined in the same manner with the beginning and ending HCC values for each cycle incremented by 1. Once all the elapsed times are determined, they are summed and then multiplied by the HEATER's rate of consumption to come up the total HEATER energy consumption during the standby period.

- T_{24}, mean tank temperature (°F) at the end of the 24-hour test period: This is simply the value for MEANTEMP corresponding to the last record in the *tw_vs_1* worksheet (i.e., when TIME equals 1440).

- T_{su}, maximum mean tank temperature (°F) observed after the sixth draw: Key to determining T_{su} is selecting the maximum temperature after the HEATER element cycles off for the sixth time. This determination is based on the use of variable HCC in the *tw_vs_t1* worksheet. Since the maximum temperature occurs immediately after the HEATER element cycles off, the value for the maximum MEANTEMP is when HCC equals 12 (the end of the sixth HEATER cycle).

- $t_{stby,1}$, elapsed time (hours) between the time at which the maximum mean tank temperature is observed after the sixth draw and the end of the 24-hour test period: Very similar to determining T_{su}. Key to determining $t_{stby,1}$ is selecting the maximum temperature after the HEATER element cycles off for the sixth time. This determination is based on the use of variable HCC in the *tw_vs_t1* worksheet. Since the maximum temperature occurs immediately after the HEATER element cycles off, the value for the maximum MEANTEMP is when HCC equals 12 (the end of the sixth HEATER cycle). The TIME corresponding to when HCC equals 12 is subtracted from 1440 (the TIME at the end of the test period) to arrive at the elapsed time.

- $T_{t,stby}$, average storage tank temperature (°F) between the time at which the maximum mean tank temperature is observed after the sixth draw and the end of the 24-hour test period: Key to determining $T_{t,stby}$ is selecting the maximum temperature after the HEATER element cycles off for the sixth time. This determination is based on the use of variable HCF in the *tw_vs_t1* worksheet. Since the maximum temperature occurs immediately after the HEATER element cycles off, the value for the maximum MEANTEMP is when HCF equals 1 (the end of the sixth HEATER cycle). HCF remains a value of 1 for the remainder of the 24-hour test period. For time period when HCF equals 1, the sum of the TDIFF_TEMP values and the sum of the TIMEDIFF values are calculated. The average storage tank temperature is determined by dividing the sum of the above TDIFF_TEMP values by the sum of the above TIMEDIFF values.

- M_2, mass of water (lb_m) withdrawn during the second draw: Determined by multiplying the DRAW rate (3 gpm) during the second draw by the elapsed time of the second draw. Once the total draw is determined in gallons, it is converted to lb_m using conversion factors. The calculation is based on the use of variable DCC in the *tw_vs_t1* worksheet. The TIME when DCC equals 3 (the beginning of the second draw) is subtracted from the TIME when DCC equals 4 (the end of the second draw) in order to calculate the elapsed time.

- $T_{del,2}$, average delivery temperature (°F) for the second draw: Determined by calculating the average draw temperature during the second draw. The calculation is based on the use of variable DCD in the *tw_vs_t1* worksheet. First, all the DRAWTEMPs (hot water temperature #24) for the period when DCD equals 2 (the length of the second draw) are summed. Then, the summed DRAWTEMP value is divided by the number of times in which DCD equals 2 to arrive at the average delivery temperature during the second draw.

- M_3, mass of water (lb_m) withdrawn during the third draw: Determined by multiplying the DRAW rate (3 gpm) during the third draw by the elapsed time of the third draw. Once the total draw is determined in gallons, it is converted to lb_m using conversion factors. The calculation is based on the use of variable DCC in the *tw_vs_t1* worksheet. The TIME when DCC equals 5 (the beginning of the third draw) is subtracted from the TIME when DCC equals 6 (the end of the third draw) in order to calculate the elapsed time.

- $T_{del,3}$, average delivery temperature (°F) for the third draw: Determined by calculating the average draw temperature during the third draw. The calculation is based on the use of variable DCD in the *tw_vs_t1* worksheet. First, all the DRAWTEMPs (hot water temperature #24) for the period when DCD equals 3 (the length of the third draw) are summed. Then, the summed DRAWTEMP value is divided by the number of times in which DCD equals 3 to arrive at the average delivery temperature during the third draw.

- M_4, mass of water (lb_m) withdrawn during the fourth draw: Determined by multiplying the DRAW rate (3 gpm) during the fourth draw by the elapsed time of the fourth draw. Once the total draw is determined in gallons, it is converted to lb_m using conversion factors. The calculation is based on the use of variable DCC in the *tw_vs_t1* worksheet. The TIME when DCC equals 7 (the beginning of the fourth draw) is subtracted from the TIME when DCC equals 8 (the end of the fourth draw) in order to calculate the elapsed time.

- $T_{del,4}$, average delivery temperature (°F) for the fourth draw: Determined by calculating the average draw temperature during the fourth draw. The calculation is based on the use of variable DCD in the *tw_vs_t1* worksheet. First, all the DRAWTEMPs (hot water temperature #24) for the period when DCD equals 4 (the length of the fourth draw) are summed. Then, the summed DRAWTEMP value is divided by the number of times in which DCD equals 4 to arrive at the average delivery temperature during the fourth draw.

- M_5, mass of water (lb_m) withdrawn during the fifth draw: Determined by multiplying the DRAW rate (3 gpm) during the fifth draw by the elapsed time of the fifth draw. Once the total draw is determined in gallons, it is converted to lb_m using conversion factors. The calculation is based on the use of variable DCC in the *tw_vs_t1* worksheet. The TIME when DCC equals 9 (the beginning of the fifth draw) is subtracted from the TIME when DCC equals 10 (the end of the fifth draw) in order to calculate the elapsed time.

- $T_{del,5}$, average delivery temperature (°F) for the fifth draw: Determined by calculating the average draw temperature during the fifth draw. The calculation is based on the use of variable DCD in the *tw_vs_t1* worksheet. First, all the DRAWTEMPs (hot water temperature #24) for the period when DCD equals 5 (the length of the fifth draw) are summed. Then, the summed DRAWTEMP value is divided by the number of times in which DCD equals 5 to arrive at the average delivery temperature during the fifth draw.

- M_6, mass of water (lb_m) withdrawn during the sixth draw: Determined by multiplying the DRAW rate (3 gpm) during the sixth draw by the elapsed time of the sixth draw. Once the total draw is determined in gallons, it is converted to lb_m using conversion factors. The calculation is based on the use of variable DCC in the *tw_vs_t1* worksheet. The TIME when DCC equals 11 (the beginning of the sixth draw) is subtracted from the TIME when DCC equals 12 (the end of the sixth draw) in order to calculate the elapsed time.

- $T_{del,6}$, average delivery temperature (°F) for the sixth draw: Determined by calculating the average draw temperature during the sixth draw. The calculation is based on the use of variable DCD in the *tw_vs_t1* worksheet. First, all the DRAWTEMPs (hot water temperature #24) for the period when DCD equals 6 (the length of the sixth draw) are summed. Then, the summed DRAWTEMP value is divided by the number of times in which DCD equals 6 to arrive at the average delivery temperature during the sixth draw.

- Q, total energy (Btu) used by the water heater during the 24-hour simulated use test including auxiliary energy such as pumps, fans, etc.: Determined in a very similar manner to Q_{stby}. Key to determining Q is the calculation of the elapsed time of each HEATER cycle in the 24-hour test period. The calculation is based on the use of variable HCC in the *tw_vs_t1* worksheet. The variable HCC increments by a value of 1 each time the HEATER turns on and off. Thus, for the first HEATER cycle, HCC equals 1 when the HEATER turns on and increases to a value of 2 when the HEATER turns off. For each subsequent HEATER cycle, the value of HCC increases by 1. Thus, the elapsed TIME of any given cycle is determined by subtracting the TIME corresponding to the "beginning" HCC value for that cycle from the TIME corresponding to the "ending" HCC value for the same cycle. The "beginning" HCC value for any cycle will have an odd numerical value while the "ending" HCC value will have an even numerical value. Thus, if the HEATER cycles ten times in a 24-hour period, the "beginning" HCC value will equal 19 and the "ending" HCC value will equal 20. Once the elapsed times of all HEATER cycles are determined, they are summed and then multiplied by the HEATER's rate of consumption to come up the total HEATER energy consumption during the 24-hour test period.

- T_{stby}, mean tank temperature (°F) during the total standby portion of the 24-hour test: Determined by calculating the average mean tank temperature whenever a DRAW is not occurring. This determination is based on the use of variable DCD in the *tw_vs_t1* worksheet. Whenever DCD equals 0 (i.e., when a DRAW is not occurring), the sum of the TDIFF_TEMP values and the sum of the TIMEDIFF values are calculated. The average mean tank temperature is determined by dividing the sum of the above TDIFF_TEMP values by the sum of the above TIMEDIFF values.

- $t_{stby,2}$, the number of hours during the 24-hour simulated test when water was not being withdrawn from the water heater: Determined by calculating the elapsed times between DRAWS and the elapsed time between the end of the last (sixth) DRAW and the 24-hour time period. This determination is based on the use of variable DCC in the *tw_vs_t1* worksheet. The TIME when DCC equals 3 (the beginning of the second draw) is subtracted from the TIME when DCC equals 2 (the end of the first draw) in order to calculate the elapsed time between the first and second draw periods. For each subsequent time period between draws, the elapsed time is calculated in the same manner. The TIME when DCC equals 12 (the end of the sixth draw) is substracted from the TIME at the end of the 24-hour test period in order to calculate the elapsed time between the end of the 24 test period and the last draw. After all the elapsed times when water is not being drawn are determined, they are summed to arrive at the value for $t_{stby,2}$.

RECOVERY EFFICIENCY (n_r) CALCULATIONS

M_1	$T_{del,1}$	$T_{in,1}$	$(T_{del,1}+T_{in,1})/2$	C_{p1}	$T_{max,1}$	T_o	$(T_{max,1}+T_o)/2$	C_{p2}	V_{st}	p	Q_r	n_r
lb m	*F*	***F***	*F*	*Btu/lb m -F*	*F*	*F*	*F*	*Btu/lb m -F*	*gal*	*lb m /gal*	*Btu*	
88.00	135.00	***58.00***	96.50	0.99	131.42	131.42	131.42	1.00	45.00	8.23	6936.99	**0.9669**

UA CALCULATIONS

Q_{stby}	T_{24}	T_{su}	$(T_{24}+T_{su})/2$	$t_{stby,1}$	C_p	p	M	Q_{hr}	$T_{t,stby}$	$T_{s,stby}$	UA
Btu	*F*	*F*	*F*	*hours*	*Btu/lb m -F*	***lb m /gal***	*lb m*	*Btu/hr*	*F*	***F***	*Btu/hr-F*
4598.19	132.28	131.41	131.84	18.54	1.00	8.23	370.13	230.12	130.82	***67.50***	**3.63**

PRELIMINARY CALCULATIONS

M_1	$T_{del,1}$	C_{p1}	M_2	$T_{del,2}$	C_{p2}	M_3	$T_{del,3}$	C_{p3}
lb m	*F*	*Btu/lb m -F*	*lb m*	*F*	*Btu/lb m -F*	*lb m*	*F*	*Btu/lb m -F*
88.00	135.00	1.00	88.00	134.60	0.99	87.50	134.60	0.99

PRELIMINARY CALCULATIONS

M_4	$T_{del,4}$	C_{p4}	M_5	$T_{del,5}$	C_{p5}	M_6	$T_{del,6}$	C_{p6}
lb m	*F*	*Btu/lb m -F*	*lb m*	*F*	*Btu/lb m -F*	*lb m*	*F*	*Btu/lb m -F*
87.50	134.60	0.99	88.00	134.60	0.99	88.24	134.60	0.99

ENERGY USED TO HEAT WATER (Q_{HW}) -- CALCULATIONS

$M_1C_{p1}(T_{del,1}-T_{in})/n_r$	$M_2C_{p2}(T_{del,2}-T_{in})/n_r$	$M_3C_{p3}(T_{del,3}-T_{in})/n_r$	$M_4C_{p4}(T_{del,4}-T_{in})/n_r$	$M_5C_{p5}(T_{del,5}-T_{in})/n_r$	$M_6C_{p6}(T_{del,6}-T_{in})/n_r$	Q_{HW}
7007.06	6901.38	6863.15	6862.72	6901.38	6921.15	**41456.85**

T_{in}
F
58.00

ENERGY USED TO HEAT WATER IF DELIVERED TEMPERATURE EQUALS 135'F ($Q_{HW,77}$) -- CALCULATIONS

$M_1C_{p1}(135-58)/n_r$	$M_2C_{p2}(135-58)/n_r$	$M_3C_{p3}(135-58)/n_r$	$M_4C_{p4}(135-58)/n_r$	$M_5C_{p5}(135-58)/n_r$	$M_6C_{p6}(135-58)/n_r$	$Q_{HW,77}$
7007.50	6937.42	6898.56	6898.56	6937.42	6956.85	**41636.31**

MODIFIED DAILY WATER HEATING ENERGY CONSUMPTION (Q_{dm}) CALCULATIONS

Q	Q_d	T_{stby}	$T_{a,stby}$	$t_{stby,2}$	Q_{da}	Q_{HWD}	Q_{dm}
Btu	*Btu*	*F*	*F*		*Btu*	*Btu*	*Btu*
46640.27	46311.71	130.11	67.50	23.64	46731.63	179.47	**46911.10**

ENERGY FACTOR (E_f) CALCULATIONS

$M_1C_{p1}(135-58)/Q_{dm}$	$M_2C_{p2}(135-58)/Q_{dm}$	$M_3C_{p3}(135-58)/Q_{dm}$	$M_4C_{p4}(135-58)/Q_{dm}$	$M_5C_{p5}(135-58)/Q_{dm}$	$M_6C_{p6}(135-58)/Q_{dm}$	E_f
0.1444	0.1430	0.1422	0.1422	0.1430	0.1434	**0.858**

Figure D-1.4 Energy Performance Values as Presented in the *EF calc* Worksheet

REFERENCE

1. *Title 10, Code of Federal Regulations, Part 430- Energy Conservation Program for Consumer Products, Appendix E to Subpart B- Uniform Test Procedure for Measuring the Energy Consumption of Water Heaters,* January 1, 1998.