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TITLE: A SIMPLE TECHNIQUE OF ESTIMATING THE PERFORMANCE OF PASSIVE SOLAR HEATING SYSTEMS

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A SIMPLE TECHNIQUE OF ESTIMATING THE PERFORMANCE OF PASSIVE SOLAR HEATING SYSTEMS

by

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ABSTRACT

A method is presented for estimating the annual solar performance of a building using a passive thermal storage wall of the Trombe wall or water wall type with or without night insulation. Tables of performance parameters are given for 84 cities. The method is accurate to ± 3% as compared with hour-by-hour computer simulations.

PROCEDURE

A simple procedure has been devised for predicting the performance of solar heated structures of the thermal storage wall type. The method was originally developed for estimating performance of active systems[1] but proves to be even more accurate for the analysis of passive systems.

The correlation procedure used, called the monthly solar load ratio method, is based on the premise that the monthly solar heating fraction can be correlated with the ratio of monthly solar energy absorbed by the solar wall to the total building monthly thermal load. The correlation procedure is described in detail in Ref. [2].

Data have been obtained for 84 cities for the monthly solar radiation on a horizontal surface and for the monthly heating degree-days. Based on these data and on the correlations of the monthly solar load ratio method, tables of solar heating performance have been prepared for the 84 cities. The tables have been prepared for a specific set of reference passive solar systems as follows:

Vertical, south-facing glass
Wall absorptance = 1.0
Ground reflectance = 0.3
No shading
Thermal Storage = 45 BTU/°F ft^2 of glazing
Trombe wall has vents with back draft dampers
Double Glazing (normal transmittance = 0.747)
Temperature range in building = 65 to 75°F
Other building mass is negligible
Night insulation (when used) is R9;
  5:00 p.m. to 8:00 a.m.
Wall to room conductance = 1.0 BTU/hr °F ft^2
Trombe wall properties: K = 1.0 BTU/ft hr °F
  ρC = 30 BTU/ft^3 °F

Step 1

Estimate the Building Loss Coefficient (BLC) in BTU/degree-day. This is the sum of the building skin conductance plus infiltration. It is the extra energy required (BTU) per day for each additional 1°F increase in temperature difference between the building interior and outside. It can be calculated from the sum of the UxA values for the exterior areas of the building plus infiltration. IMPORTANT--in calculating the Building Loss Coefficient, the passive thermal storage wall should not be included in the load.

Step 2

Calculate the building Load Collector Ratio (LCR) defined as follows:

$$\text{Load Collector Ratio} = \frac{\text{Building Loss Coefficient (BTU/DD)}}{\text{Solar Collection Area (ft}^2\text{)}}$$

In calculating the Load Collector Ratio the solar collection area used should be the net glazed area (the actual solar collection aperture) and not the gross area of the solar wall.

Step 3

Go to Table 1 and locate the city of interest and the wall type of interest. If the Load Collector Ratio determined in Step 2 corresponds exactly to one of the values of Solar Heating Fraction (SHF) listed in the table, then this is the desired answer. If not, one needs to interpolate in the table. The meaning of a Solar Heating Fraction is ambiguous when applied to a passive solar building. What is the building being compared with? As used herein, the SHF is the fraction of the degree-days times the Building Loss Coefficient) which is supplied by the solar wall. The wall is not credited with the heat used to supply its own steady-state load since a "normal" south wall would presumably have a much lower loss coefficient and would inevitably benefit from solar gains, even if they are unintentional.

The auxiliary used is a less ambiguous peg point, leaving the basis of comparison up to the user.

Step 4

The annual auxiliary energy required to maintain the building at a minimum temperature of 65°F can be estimated from the following equation:

$$\text{Auxiliary Energy, BTU/yr} = (1-\text{SHF}) \times \begin{pmatrix}\text{Annual}\\ \text{Heating}\\ \text{Degree-}\\ \text{Days}\end{pmatrix} \times \begin{pmatrix}\text{Building Loss}\\ \text{Coefficient,}\\ \text{BTU/Degree-}\\ \text{Day}\end{pmatrix}$$

EXAMPLE

A 72' x 24' building in Dodge City, Kansas is to be constructed with a 309 sq ft water wall on the south side. The water wall will contain 45 lbs of water per sq ft of south glazing for a total of 13,500 lbs of water or 1618 gallons. The wall is double glazed with normal sealed glass units which have a net transmittance of 0.74 for sunlight striking the glass perpendicularly. Other than the thermal storage wall, the building is of light frame construction with little additional mass. It is desired to estimate the annual solar heating contribution.

(Step 1) The Building Loss Coefficient is estimated as follows:

Skin Conduction:

Surface Type	Area ft^2	U-Value BTU/ft^2 °F hr	UxA BTU/°F hr
Water Wall	309	(not included in BLC)	
Opaque Walls	1107	0.07	77.5
Windows (E,W,N)	120	0.55	66.0
Roof	1728	0.05	86.4
Floor	1728	0.05	86.4
	Building Skin Conductance	=	316.3

Infiltration:
($12320\ ft^3$)(1/2 ACH)(0.018) = 110.9

Total: Building Loss Coefficient = 427.2 BTU/hr°F
= 10250 BTU/DD

The building is tightly sealed and equipped with an air-lock entry and thus the infiltration can probably be held to the minimum recommended level of 1/2 air change per hour.

(Step 2) The building south wall is glazed with 18 standard patio door size sealed double glass units each with a net effective exposed area of 75 x 33 in. for a total of 309 sq ft of collection area. Thus the Load Collector Ratio is 10250/309 = 33.2 BTU/degree-day-sq ft.

(Step 3) In the table for Dodge City, Kansas we find the following entries for the case of a water wall without night insulation:

SHF	0.30	0.40	0.50	0.60
LCR	61	43	31	23

Our Load Collector Ratio of 33.2 lies between the two values of 0.40 and 0.50 Solar Heating Fraction.

SHF = 0.48

The energy saved by the installation of the solar wall is estimated as (0.48)(10250)(4986) = 24.5 MBTU/yr. The energy actually supplied by the solar wall will be greater than this since the room temperature will frequently be above 65°F.

(Step 4) The auxiliary energy can be estimated as:

Auxiliary Energy = (1-0.48)(10250)(4986) = 26.6 MBTU/yr.

VARIATIONS FROM THE ASSUMED REFERENCE SYSTEMS

The monthly solar load ratio curves which have been determined are for the specific reference systems as defined. If it is desired to estimate the performance of a system which is different than one of these reference systems, then it is necessary to make a correction. The most reliable way of doing this is to refer to results of hour-by-hour calculations which are made for a specific system varying only the parameter of interest. Quite a few such calculations have been made by LASL and have been published.[3,4] These describe the effect of water mass in a water wall, the effect of using or not using the vents in the Trombe wall, the effect of thickness of a Trombe wall, and the effect of different thermal conductivities of the material.

The recommended procedure is to make a calculation for the reference case and then to adjust that value up or down.

REFERENCES

1. J. D. Balcomb and J. C. Hedstrom, "A Simplified Method for Calculating Required Solar Collector Array Size for Space Heating," Proceedings, 1976 ISES Annual Meeting, Vol. 4, Winnipeg, Canada, Aug. 15-20, 1976. See also: ERDA's Pacific Regional Solar Heating Handbook, Nov. 1976.

2. J. D. Balcomb and R. D. McFarland, "A Simple Empirical Method for Estimating the Performance of a Passive Solar Heated Building of the Thermal Storage Wall Type, "Proceedings of the 2nd National Passive Solar Conference, Philadelphia, PA, March 16-18, 1978.

3. J. D. Balcomb, et al., "Simulation Analysis of Passive Solar Heated Buildings--Preliminary Results," Solar Energy, Vol. 19, pp 277-282 (1977).

4. J. D. Balcomb, J. C. Hedstrom and R. D. McFarland, "Passive Solar Heating of Buildings." Printed in SAND-77-1204 and also Solar Architecture, Ann Arbor Science (1977).

TABLE I: PERFORMANCE PARAMETERS FOR PASSIVE SOLAR HEATING SYSTEMS USING THERMAL STORAGE WALLS
Load Collector Ratio (BTU/DD-ft^2) for particular values of Solar Heating Fraction (SHF)

Location	DD / Latitude	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Page, Arizona		WW	196	88	54	37	27	19	13	7	
	6632 DD	WWNI	312	145	91	65	43	38	29	22	15
		TW	135	94	56	37	25	17	11	6	
	37°N	TWNI	304	141	89	63	46	35	26	18	12
Phoenix, Arizona		WW	626	294	189	135	102	78	60	44	29
	1765 DD	WWNI	863	407	261	189	145	114	90	69	49
		TW	577	287	179	123	88	64	47	33	21
	33°N	TWNI	819	386	247	176	132	101	76	56	38
Tucson, Arizona		WW	631	291	184	132	100	77	59	43	29
	1800 DD	WWNI	871	403	256	185	142	112	89	63	49
		TW	578	284	176	121	87	63	46	33	21
	32°N	TWNI	825	383	243	173	130	99	75	56	38
Little Rock, Arkansas		WW	239	108	66	46	33	24	17	11	
	3219 DD	WWNI	365	172	107	76	57	44	35	26	18
		TW	232	112	67	44	30	21	14	9	
	35°N	TWNI	356	165	103	73	54	40	30	22	14
Davis, California		WW	409	187	115	79	57	42	30	21	11
	2502 DD	WWNI	585	272	170	120	89	68	52	39	26
		TW	376	183	111	74	51	35	25	16	9
	39°N	TWNI	556	259	161	112	82	61	45	32	21
El Centro, California		WW	1029	482	301	214	161	125	97	72	50
	1458 DD	WWNI	1375	649	407	290	221	175	139	107	77
		TW	916	458	284	194	140	103	75	54	36
	33°N	TWNI	1294	608	382	270	202	154	117	87	60
Fresno, California		WW	405	186	113	77	55	40	29	19	10
	2492 DD	WWNI	577	271	168	117	87	66	50	37	25
		TW	370	181	109	72	49	34	24	15	8
	37°N	TWNI	550	257	159	110	79	59	43	31	20
Inyokern, California		WW	453	209	129	90	66	50	37	26	16
	3528 DD	WWNI	641	300	198	132	100	77	60	46	32
		TW	419	204	124	84	59	42	33	20	12
	35°N	TWNI	613	284	177	124	92	69	52	38	25
Los Angeles, California		WW	763	362	225	158	118	91	70	52	35
	2061 DD	WWNI	1032	498	310	219	165	131	103	80	57
		TW	687	344	213	145	103	75	55	39	26
	34°N	TWNI	979	464	291	205	153	116	88	65	45
Riverside, California		WW	767	356	224	160	121	94	72	53	36
	1803 DD	WWNI	1039	488	308	221	167	134	106	82	59
		TW	692	344	214	146	105	77	56	40	25
	34°N	TWNI	984	459	290	207	155	118	90	67	46
Santa Maria, California		WW	544	272	176	126	95	74	55	41	27
	2967 DD	WWNI	752	376	247	179	137	109	86	66	46
		TW	514	264	167	115	83	61	44	31	20
	35°N	TWNI	720	358	231	166	126	96	73	54	36
Granby, Colorado		WW	196	90	56	39	28	20	14	8	
	6524 DD	WWNI	313	146	94	67	51	40	31	23	15
		TW	197	96	59	38	25	11	12	7	
	40°N	TWNI	303	143	91	65	48	36	27	19	13
Grand Junction, Colorado		WW	199	92	56	39	28	20	13	8	
	6641 DD	WWNI	317	150	95	67	51	39	30	22	15
		TW	201	97	58	39	26	17	11	6	
	39°N	TWNI	310	145	91	64	48	36	26	19	12
Washington, D. C.		WW	179	79	47	32	22	15	9		
	4224 DD	WWNI	292	135	83	58	44	33	25	18	12
		TW	180	85	50	32	21	13	5		
	39°N	TWNI	285	131	81	57	41	31	22	16	10
Apalachicola, Florida		WW	700	322	204	145	110	85	65	48	32
	1308 DD	WWNI	956	444	281	203	155	123	97	75	53
		TW	635	313	194	133	95	77	51	35	24
	30°N	TWNI	906	420	266	189	142	108	82	61	42
Gainesville, Florida		WW	731	333	212	152	115	90	69	51	35
	1239 DD	WWNI	1000	457	292	211	162	129	102	79	56
		TW	662	326	202	139	100	73	54	33	25
	30°N	TWNI	943	435	276	197	148	113	86	64	44
Tallahassee, Florida		WW	621	285	179	128	97	75	57	42	23
	1485 DD	WWNI	857	397	249	180	133	109	87	67	48
		TW	563	279	172	117	84	51	45	32	21
	30°N	TWNI	809	376	237	169	127	97	73	54	37
Tampa, Florida		WW	1147	573	374	272	210	166	129	99	69
	683 DD	WWNI	1520	760	500	365	283	227	182	141	102
		TW	1059	548	351	245	179	134	100	73	49
	28°N	TWNI	1443	717	467	339	258	199	152	114	80
Atlanta, Georgia		WW	301	136	83	58	43	31	23	15	8
	2961 DD	WWNI	448	207	129	91	69	54	42	32	22
		TW	286	133	83	55	38	27	18	12	7
	34°N	TWNI	431	198	123	87	64	48	36	26	17
Boise, Idaho		WW	185	83	49	31	20	12	6		
	5809 DD	WWNI	299	139	[illegible]	59	43	31	23	16	10
		TW	182	86	50	31	20	12	6		
	44°N	TWNI	290	135	83	56	40	29	21	14	8
Lemont (ANL) Illinois		WW	120	51	29	18	11				
	6155 DD	WWNI	219	100	61	42	31	24	18	13	9
		TW	129	59	33	20	12	7			
	42°N	TWNI	216	99	61	42	30	22	16	11	7
Indianapolis, Indiana		WW	136	58	33	21	14	7			
	5699 DD	WWNI	239	109	67	46	34	[illegible]	19	14	9
		TW	142	65	37	23	14	8			
	40°N	TWNI	235	107	[illegible]	45	33	24	17	12	7
Ames, Iowa		WW	117	50	29	18	11				
	6588 DD	WWNI	215	99	61	42	31	23	18	12	8
		TW	127	58	33	20	12	6			
	42°N	TWNI	213	95	60	41	30	22	16	11	7
Dodge City, Kansas		WW	214	99	61	43	31	23	16	10	
	4985 DD	WWNI	335	160	101	72	54	42	33	25	17
		TW	214	104	63	41	28	20	13	8	
	38°N	TWNI	327	154	97	69	51	38	29	21	14
Manhattan, Kansas		WW	165	74	44	30	21	14	8		
	5182 DD	WWNI	274	120	80	56	42	32	25	18	12
		TW	159	80	47	30	20	13	8		
	39°N	TWNI	269	175	78	54	40	30	22	15	10
Lexington, Kentucky		WW	143	61	36	24	18	[illegible]			
	4683 DD	WWNI	246	114	70	49	35	28	21	15	10
		TW	148	70	40	25	16	10	5		
	38°N	TWNI	242	112	69	49	35	25	19	13	8
Lake Charles, Louisiana		WW	522	239	152	109	82	63	48	35	23
	1459 DD	WWNI	730	338	214	155	119	94	74	57	47
		TW	481	237	146	100	71	52	38	25	17
	30°N	TWNI	695	322	204	146	109	83	63	45	32
Shreveport, Louisiana		WW	361	165	104	74	55	42	31	22	14
	2184 DD	WWNI	524	245	155	111	[illegible]	67	51	40	23
		TW	340	167	103	69	49	35	25	17	10
	32°N	TWNI	500	234	148	105	79	60	45	[illegible]	22

TABLE I: PERFORMANCE PARAMETERS FOR PASSIVE SOLAR HEATING SYSTEMS USING THERMAL STORAGE WALLS (CONT.)
Load Collector Ratio (BTU/DD-ft²) for particular values of Solar Heating Fraction (SHF)

Location	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Caribou, Maine	WW	83	34	17	8					
9769 DD	WWNI	172	78	48	33	24	17	13	8	
	TW	97	43	23	12	5				
47°N	TWNI	172	79	48	33	23	17	12	8	4
Portland, Maine	WW	125	54	31	20	13	7			
7511 DD	WWNI	223	103	64	45	33	25	19	14	8
	TW	133	62	35	22	14	8			
44°N	TWNI	221	102	63	44	32	23	17	12	7
Boston, Massachusetts	WW	137	60	35	23	15	9			
5634 DD	WWNI	241	110	68	48	36	27	21	15	9
	TW	145	67	33	24	15	9	5		
42°N	TWNI	238	108	67	47	34	25	18	13	8
East Lansing, Michigan	WW	111	46	25	15	8				
6909 DD	WWNI	208	94	57	39	29	22	16	11	7
	TW	120	54	30	18	10	4			
43°N	TWNI	206	93	57	39	28	20	15	10	6
Sault St. Marie, Michigan	WW	100	40	21	11					
9048 DD	WWNI	193	87	53	36	26	19	13	9	5
	TW	110	49	26	15	7				
46°N	TWNI	192	87	53	36	25	18	13	8	4
St. Cloud, Minnesota	WW	96	39	21	11					
8879 DD	WWNI	189	85	52	36	26	19	14	9	5
	TW	108	48	26	15	7				
46°N	TWNI	189	86	52	36	25	18	13	8	5
Columbia, Missouri	WW	175	77	46	31	21	14	8		
6046 DD	WWNI	287	133	82	57	43	33	25	18	12
	TW	177	83	49	31	20	13	8		
39°N	TWNI	281	129	80	55	41	30	22	15	10
Glasgow, Montana	WW	168	75	44	29	19	12	6		
8996 DD	WWNI	277	130	81	56	41	31	23	17	10
	TW	171	80	47	30	19	12	7		
48°N	TWNI	272	126	78	54	39	29	21	14	9
Great Falls, Montana	WW	143	63	37	23	14	8			
7750 DD	WWNI	246	115	71	49	36	27	20	14	8
	TW	149	69	40	25	15	9			
47°N	TWNI	243	112	69	48	34	25	18	12	7
Lincoln, Nebraska	WW	175	77	45	30	21	14	8		
5864 DD	WWNI	288	133	82	57	42	33	25	18	12
	TW	176	83	48	31	20	13	9		
41°N	TWNI	280	129	79	55	40	30	22	16	10
Ely, Nevada	WW	172	80	50	35	25	18	12	6	
7733 DD	WWNI	282	134	85	61	47	36	28	21	14
	TW	178	86	52	34	23	16	10	6	
39°N	TWNI	277	131	[illegible]	[illegible]	44	33	25	18	11
Las Vegas, Nevada	WW	448	209	130	92	68	52	39	28	17
2709 DD	WWNI	632	300	188	134	102	80	63	48	33
	TW	414	205	126	85	60	43	31	21	13
36°N	TWNI	603	284	179	126	94	71	53	39	26
Reno, Nevada	WW	192	88	54	37	26	18	12	6	
6332 DD	WWNI	307	145	91	65	49	37	28	21	13
	TW	192	93	55	36	24	16	10	5	
39°N	TWNI	298	141	89	62	46	34	25	18	11
Seabrook, New Jersey	WW	163	72	43	29	20	13	8		
4812 DD	WWNI	271	126	78	55	41	31	24	17	11
	TW	167	78	46	29	19	12	7		
39°N	TWNI	267	123	76	53	39	29	21	15	9
Albuquerque, New Mexico	WW	278	133	83	59	44	33	24	16	9
4348 DD	WWNI	414	201	128	92	70	55	43	33	23
	TW	271	135	83	56	39	28	19	13	7
35°N	TWNI	402	193	123	87	65	49	37	27	18
Los Alamos, New Mexico	WW	179	84	52	36	26	18	12	7	
6604 DD	WWNI	288	139	89	64	49	37	29	21	14
	TW	183	89	54	36	24	16	11	6	
36°N	TWNI	283	136	86	61	45	34	25	18	12
Ithaca, New York	WW	93	36	18	9					
6914 DD	WWNI	189	83	50	34	24	18	13	9	5
	TW	105	46	24	13	6				
42°N	TWNI	188	83	50	34	24	17	12	8	4
New York City, New York	WW	147	64	38	25	17	11	5		
4871 DD	WWNI	250	117	72	51	38	29	22	16	10
	TW	152	71	42	26	17	11	6		
41°N	TWNI	247	114	71	49	36	27	20	14	9
Sayville, L.I. New York	WW	165	74	45	30	21	14	9		
4811 DD	WWNI	272	129	80	57	43	33	25	18	12
	TW	169	81	48	31	20	13	8	4	
41°N	TWNI	268	125	78	55	40	30	22	16	10
Schenectady, New York	WW	84	34	18	9					
6650 DD	WWNI	174	79	48	33	24	18	13	9	5
	TW	98	43	23	13	6				
43°N	TWNI	175	79	49	33	24	17	12	8	5
Greensboro, North Carolina	WW	237	107	66	46	33	24	17	11	
3805 DD	WWNI	367	170	107	75	57	44	35	26	18
	TW	231	112	67	44	30	21	14	9	
36°N	TWNI	354	165	103	72	54	40	30	22	14
Hatteras, North Carolina	WW	412	189	110	82	61	46	34	24	15
2612 DD	WWNI	588	274	173	123	93	73	57	43	30
	TW	381	107	115	77	54	37	28	17	11
35°N	TWNI	560	261	164	115	86	65	49	36	24
Raleigh, North Carolina	WW	255	117	71	50	37	27	19	12	7
3393 DD	WWNI	391	182	114	80	61	49	37	28	19
	TW	249	120	72	43	33	23	16	10	5
36°N	TWNI	378	175	109	77	57	43	32	23	15
Bismarck, North Dakota	WW	111	46	25	14	6				
8851 DD	WWNI	209	94	57	33	28	21	15	10	6
	TW	120	54	30	17	9				
47°N	TWNI	207	94	57	39	27	20	14	9	5
Cleveland, Ohio	WW	103	41	22	12					
6351 DD	WWNI	202	89	53	36	26	20	14	10	6
	TW	114	50	27	15	8				
41°N	TWNI	200	89	53	35	26	19	13	9	5
Columbus, Ohio	WW	120	51	29	18	11				
5211 DD	WWNI	218	100	61	42	31	23	17	12	7
	TW	128	59	33	20	12	6			
40°N	TWNI	216	99	61	42	30	22	16	11	6
Put-in-Bay, Ohio	WW	102	39	20	9					
5798 DD	WWNI	199	88	53	35	25	18	13	8	
	TW	112	48	26	14	6				
42°N	TWNI	199	87	52	35	25	18	12	8	4
Oklahoma City, Oklahoma	WW	250	115	70	49	36	26	19	12	6
3725 DD	WWNI	382	179	112	80	60	47	37	28	19
	TW	243	118	71	47	32	23	15	10	5
35°N	TWNI	370	172	103	76	57	43	32	23	15

TABLE I: PERFORMANCE PARAMETERS FOR PASSIVE SOLAR HEATING SYSTEMS USING THERMAL STORAGE WALLS (CONT.)
Load Collector Ratio (BTU/DD-ft^2) for particular values of Solar Heating Fraction (SHF)

Astoria, Oregon	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	207	9[illegible]	59	39	26	17	9		
5186 DD	WWNI	322	158	99	69	50	37	27	19	11
	TW	205	99	59	38	25	16	9		
45°N	TWNI	315	152	95	65	47	34	24	16	9
Corvallis, Oregon	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	224	96	57	37	24	16	9		
4726 DD	WWNI	352	158	97	67	48	36	26	18	11
	TW	217	100	58	36	24	15	9		
45°N	TWNI	341	153	93	63	45	33	23	16	9
Medford, Oregon	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	188	83	49	31	20	12			
5008 DD	WWNI	306	139	86	[illegible]	43	3[illegible]	23	16	9
	TW	186	87	50	[illegible]	20	12	6		
42°N	TWNI	296	136	83	57	40	29	21	14	8
State College, Pennsylvania	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	117	50	28	18	11				
5934 DD	WWNI	214	98	61	42	31	23	17	12	7
	TW	126	58	33	20	12	6			
41°N	TWNI	213	97	60	41	30	22	16	11	6
Newport, Rhode Island	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	150	66	40	27	19	12	7		
5804 DD	WWNI	256	118	74	52	39	30	23	17	11
	TW	156	74	43	27	18	11	7		
41°N	TWNI	251	116	72	51	37	28	20	14	9
Charleston, South Carolina	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	442	204	127	9[illegible]	67	52	39	28	16
2033 DD	WWNI	624	295	184	132	100	79	63	48	34
	TW	407	202	124	84	59	43	31	21	13
33°N	TWNI	594	279	176	124	93	71	53	39	27
Rapid City, South Dakota	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	149	67	40	26	18	11	6		
7345 DD	WWNI	253	118	74	52	39	30	22	16	10
	TW	155	73	43	27	17	11	6		
Nashville, Tennessee	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	227	99	59	40	28	20	[illegible]3	8	
3578 DD	WWNI	355	161	98	68	51	39	30	23	15
	TW	219	103	61	39	26	19	11	7	
36°N	TWNI	343	155	95	65	48	36	27	19	12
Oak Ridge, Tennessee	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	204	90	54	36	26	18	12	6	
3817 DD	WWNI	325	149	92	64	48	37	29	21	14
	TW	201	95	56	36	24	16	10	6	
36°N	TWNI	315	145	89	62	[illegible]	34	25	18	11
Brownsville, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	1052	526	348	254	194	151	117	88	60
600 DD	WWNI	1399	700	465	342	265	209	165	127	90
	TW	976	506	324	226	165	123	91	66	44
26°N	TWNI	1330	664	435	315	239	183	140	104	71
El Paso, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	431	205	129	92	69	52	39	28	18
2700 DD	WWNI	600	295	187	134	103	80	63	48	34
	TW	402	202	125	85	60	[illegible]	31	22	13
32°N	TWNI	582	279	178	126	94	72	54	40	27
Fort Worth, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	364	171	108	76	57	43	32	23	14
2405 DD	WWNI	526	251	159	115	87	69	54	41	27
	TW	344	171	106	71	50	36	26	1[illegible]	10
33°N	TWNI	503	239	152	108	81	61	46	34	23
Midland, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	385	184	115	82	61	47	35	25	16
2591 DD	WWNI	548	267	169	121	93	73	57	44	31
	TW	362	182	113	76	54	39	28	19	12
32°N	TWNI	527	253	161	115	86	65	49	36	24
San Antonio, Texas	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	547	253	159	114	86	65	50	37	24
1546 DD	WWNI	762	355	224	162	124	98	78	60	42
	TW	501	248	154	104	75	54	40	20	19
30°N	TWNI	722	337	213	152	114	87	66	49	33
Flaming Gorge, Utah	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	170	79	49	33	23	16	10	5	
6929 DD	WWNI	277	132	84	60	45	35	27	20	13
	TW	173	84	50	33	22	15	9	5	
41°N	TWNI	272	129	82	58	43	32	24	17	11
Salt Lake City, Utah	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	192	86	52	35	24	16	10		
6052 DD	WWNI	308	143	90	63	46	35	27	19	12
	TW	190	91	54	34	23	15	9	4	
41°N	TWNI	299	140	87	60	44	32	24	17	10
Burlington, Vermont	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	80	30	15						
8269 DD	WWNI	171	75	46	31	23	17	12	8	4
	TW	94	41	21	11					
44°N	TWNI	172	77	46	31	22	16	11	7	4
Pullman, Washington	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	178	78	44	27	17	9			
5542 DD	WWNI	291	134	82	56	40	29	21	14	8
	TW	175	81	46	28	18	10			
47°N	TWNI	282	130	79	53	37	27	19	13	7
Richland, Washington	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	179	77	43	25	15	7			
5941 DD	WWNI	293	133	81	54	38	27	19	13	7
	TW	176	80	45	27	16	9			
47°N	TWNI	285	130	78	52	36	25	18	12	7
Seattle, Washington	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	219	93	52	32	20	11			
4424 DD	WWNI	346	154	93	62	44	31	22	15	9
	TW	211	95	54	33	20	12	6		
48°N	TWNI	333	149	89	59	41	29	20	13	8
Spokane, Washington	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	149	63	34	20	10				
6655 DD	WWNI	255	116	70	47	33	23	17	11	6
	TW	151	68	38	22	13	6			
48°N	TWNI	251	114	68	45	32	22	16	10	5
Madison, Wisconsin	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	108	44	24	14	7				
7853 DD	WWNI	206	92	56	39	28	21	16	11	6
	TW	119	53	29	17	10				
43°N	TWNI	204	92	56	35	27	20	14	10	6
Lander, Wyoming	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	163	76	47	32	22	15	9		
7870 DD	WWNI	267	129	82	53	44	34	25	19	12
	TW	168	81	49	32	21	14	9	4	
43°N	TWNI	264	126	80	56	41	31	23	16	10
Laramie, Wyoming	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	157	72	44	31	22	15	10		
7381 DD	WWNI	263	124	79	56	43	33	26	19	13
	TW	164	79	47	31	21	14	9	4	
41°N	TWNI	259	122	77	55	41	30	23	16	10
Edmonton, Alberta	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	93	34							
10268 DD	WWNI	184	83	48	31	20	13	8	4	
	TW	102	42	20						
54°N	TWNI	184	83	48	31	20	14	9	5	
Ottawa, Ontario	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	91	35	17	7					
8735 DD	WWNI	185	81	49	31	24	17	12	8	4
	TW	103	45	23	13					
45°N	TWNI	184	[illegible]	49	3[illegible]	24	17	12	8	4
Toronto, Ontario	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	103	42	23	14	6				
6827 DD	WWNI	194	89	55	39	27	21	15	10	6
	TW	114	51	28	16	9				
44°N	TWNI	197	89	55	37	27	19	14	9	5
Winnipeg, Manatoba	SHF	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	WW	74	27							
10679 DD	WWNI	162	73	44	29	20	14	9	5	
	TW	88	37	18	7					
50°N	TWNI	164	74	44	29	20	14	9	5	