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TRANSPORTABLE SOLAR
LABORATORY PROGRAM TEST
RESULTS AND UTILIZATION STUDY
FOR ALBUQUERQUE, N.M.

Honeywell

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TRANSPORTABLE SOLAR LABORATORY
TEST RESULTS AND UTILIZATION
STUDY FOR ALBUQUERQUE, N. M.

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SECTION I

INTRODUCTION

This report is the first in a series of reports on the Transportable Solar Laboratory (TSL), co-sponsored by the National Science Foundation and Honeywell, Inc. These reports will present findings and results of data taken while the TSL was located in several cities around the country. The purpose of the test facility is to provide information on solar energy collection which can be used for the evaluation of heating and cooling of domestic buildings in various climates.

The first location for the TSL was Albuquerque, New Mexico, from August 10, 1974 to August 24, 1974. During this time the TSL was stationed at the Albuquerque Convention Center and at Sandia Laboratories. This report for Albuquerque will present collected solar energy data and total daily efficiency based on instantaneous collection values. A heating and cooling load analysis for a typical 1500 square foot Albuquerque house is given along with the portion of this load that can be provided by solar energy. The final part of this report will provide collector area and storage recommendations for the domestic use of solar collector systems in the Albuquerque area.

SECTION II

TEST DATA RESULTS

WEATHER

Albuquerque has an arid continental climate with a large percentage of clear days (75%). The average annual relative humidity is 42%. Table 1 lists the design weather data used in the analysis.

Table 1. Albuquerque Design Weather Data

Number of heating degree days	4348
Number of cooling degree days	1153
Winter extreme design temperature	14°F
Summer extreme dry bulb design temperature	96°F
Summer extreme wet bulb design temperature	66°F
Summer outdoor daily temperature range	27°F
Latitude	35°0'
Altitude	53°0'

ALBUQUERQUE TEST RESULTS

While the TSL was stationed in Albuquerque, seven days of data were taken. The data gathering system was still in a debugging stage at this time so the results are not continuous throughout several of the testing days. Table 2 presents the insolation data for the seven test days and Table 3 gives the solar collection results for a clear day using the TSL performance curve from previous testing. This performance curve is shown in Figure 1.

The insolation summary in Table 2 lists daily peak insolation, test duration, total insolation during the test period, average insolation over the test period, and calculated peak clearness numbers. The clearness number is the ratio between actual clear day direct radiation intensity at a certain location and the calculated intensity level for the standard atmosphere for the same location and date. The typical number given by Threlkeld-Jordan¹ for summer insolation in Albuquerque is 1.15.

The peak clearness numbers were determined using a calculated insolation curve for the standard atmosphere with Albuquerque's latitude (35°N), an incident angle of 45°, and a southern exposure in August. These calculated clearness numbers are lower than the value determined by Threlkeld-Jordan but greater than 1.00.

Table 3 summarizes the energy collected on a typical clear day, and gives insolation, collected heat, efficiency, and clearness numbers for peak, collection period, and projected full-day insolation data. It should be noted that the efficiencies refer to a space cooling application with operating temperatures above 200°F. It is also evident that the

¹ ASHRAE 1972 Handbook of Fundamentals, Chapter 22, Figure 4, Page 394.

Table 2. Albuquerque Insolation Summary

Test Date	MDT Time on	MDT Time off	Test Duration (Hours)	Daily Total (Btu/ft ²)	Average Insolation Over Time Period (Btu/hr-ft ²)	MDT Time At Peak	Daily Peak Btu/ft ² (hr-ft ²)	Weather Type	Percent of Possible Sunshine ¹	Sky Cover Tenths Sunrise to Sunset ¹	Calculated Clearness Number Peak ²
8/13	9:00	5:00	8.0	1433	179	2:45	334	Cldy	59	6	
8/14	9:00	5:30	8.5	2061	242	1:30	294	Clr	91	2	1.01
8/23	9:30	2:00	4.5	1159	258	1:00	314	Clr/Thunderstorm	61	8	1.08
8/24	8:42	11:42	3.0	425	141	11:42	208	Cldy	22	10	
8/28	12:20	5:20	5.0	830	166	1:10	272	Clr/Thunderstorm	84	8	
8/29	9:00	5:24	8.4	2134	254	1:30	304	Clr	93	1	1.04
8/30	10:00	3:30	5.5	1446	262	1:00	307	Clr	92	1	1.05

NOTES: 1. National Weather Service FCST OFC, INTL. Airport, Albuquerque, N. M. - Local Climatological Data Summary for August, 1974.

2. ASHRAE 1972 Handbook of Fundamentals, P. 394. Threlkeld-Jordan Clearness Number for ALBU Summer = 1.15.

Calculated for Standard Atmosphere at Albuquerque Location in August for Same Orientation:

Aug.	7:00	7:15	12:25	2103	172	1:11	291	Clr	87
------	------	------	-------	------	-----	------	-----	-----	----

Table 3. Albuquerque Collection Summary for Typical Clear Day

INLET TEMPERATURE: 200°F

AMBIENT TEMPERATURE: 80°F

COOLING MODE

ITEM	PEAK	OVER COLLECTION PERIOD	OVER FULL DAY (EXTRAPOLATED)
Insolation	294 Btu/hr-ft ²	2061 Btu/ft ²	2221 Btu/ft ²
Collected Heat	144 Btu/hr-ft ²	808 Btu/ft ²	813 Btu/ft ²
Efficiency	49%	39%	37%
Clearness Number	1.01	1.06	1.06

Figure 1. TSL Performance Curve

peak midday collector efficiency is higher than the overall daily efficiency by 12%. This occurs because solar energy collection efficiency decreases with radiation intensity and the intensity is lower in the early morning and late afternoon. Figure 2 shows the insolation and collection curves for this typical day.

Figure 2. Typical Clear Day Insolation and Collection Curves

LOAD ANALYSIS FOR AN AVERAGE HOUSE IN ALBUQUERQUE

Typical House

The house load used in this analysis is based on an area of 1500 ft² and a volume of 12,000 ft³. It is assumed that a typical house for the area is constructed of concrete blocks with a stucco exterior and a plastered interior. This gives a coefficient of transmission (U) of 0.166 Btu/hr-ft²-°F. The roof is slate with a U value of 0.041 Btu/hr-ft²-°F. It is assumed that the indoor temperature is 70°F in the winter and 75°F in the summer with a 40% relative humidity comfort level in the summer.

Maximum House Loads

The analysis for maximum summer and winter house loads includes calculations of latent and sensible infiltration, sensible transmission, sensible internal heat, and domestic hot water heat. These values are described and calculated in the appendix.

The summary of the design heating and cooling levels for Albuquerque is given in Table 4. The design loads are shown in Figure 3 which graphs house load versus outside dry bulb temperature. The water heating load and the internal sensible load are included in the figure. Note that the actual building load line for cooling would fall somewhere between the two cooling design load lines because there may be some water to remove from the infiltrating air but very seldom would the maximum design amount of humidity be present. (Recall that the average annual relative humidity of Albuquerque is 42%.) From this curve the building space heating or cooling load level for any outside dry bulb temperature can be determined.

Table 4. Design Heating and Cooling Levels for Albuquerque

Load	Heating (Btu/hr)	Cooling (Btu/hr)
Infiltration (sensible)	18144	6804
Infiltration (latent)	---	6480
Transmission	16081	6030
Hot Water	3125	3125
Internal (sensible)	-3555	3555
Total	33795	25994

Figure 3. Building Load for Albuquerque

Average Monthly House Loads

Table 5 shows a monthly breakdown of the heating and cooling loads for Albuquerque. The loads in Btu's were found by determining a factor to convert degree days to Btu's. If degree days per year are divided by 365, an approximate average yearly temperature difference is determined. Using this difference in the house heating load equations results in an average yearly Btu per hour load level required to heat the house. Multiplying by the hours in a year gives the total Btu's required for the heating degree days. Monthly heating load levels are then determined from the yearly Btu per degree day ratio. The same analysis can be used for cooling, but there is an additional cooling load which results from drying out any infiltrating humid air. By using the average monthly humidity and temperature levels, the average monthly enthalpy of the infiltrating air can be found on a psychrometric chart. If the value is above the enthalpy at an assumed comfort design level of 75°F and 40% relative humidity, then an additional load is added to the total monthly cooling load.

Insolation and Collected Solar Energy

The available energy which can be collected in a region for a selective coated collector at two tilt angles has been calculated. This has been done using a subroutine prepared for the ASHRAE task group on energy requirements, percent of possible sunshine data from the U.S. Weather Service, clearness numbers, and a semi-empirical expression for collector performance. The ASHRAE subroutine is called SUN which is an algorithm to find solar position and intensity of direct normal and diffuse radiation without cloud cover. The hourly insolation levels from this program are summed for each month. The available sunshine is given by the product of the monthly insolation, the percent of possible sunshine due to cloud cover, and the clearness number. The best selective coated, 2-cover collector tested to date has a performance equation of

$$\eta = \frac{Q}{Q_{inc}} = 0.712 - 0.051 \frac{T_{in} - T_{amb}}{Q_{incident}}$$

where

Q = heat delivered, Btu/hr-ft²

Q_{inc} = incident solar flux, Btu/hr-ft²

T_{in} = fluid inlet temperature, °F

T_{amb} = ambient temperature, °F

To use this performance equation, the available insolation is reduced to an average hourly flux level and the ambient temperature is taken to be the average monthly ambient temperature. The fluid inlet temperature is 140°F for a winter heating application and 200°F for a summer cooling application. The collected solar energy can then be approximated using available sunshine and the collector efficiency as given by the performance equation. This calculation is summarized in Tables 6a and 6b for 45° and 25° tilt angles, respectively.

The effect of varying tilt angles can readily be seen in Figure 4. By decreasing the tilt angle from the latitude of Albuquerque (35°N), more energy can be collected during the summer cooling months. By increasing the tilt angle, more energy can be collected during the winter months.

Table 5. Total Load for a 1500 Ft² House in Albuquerque

Month	T _{ave} °F	Hum _{ave} %	Degree Heating	Days Cooling	Hot Water 10 ⁶ Btu	Heating 10 ⁶ Btu	- Internal Sensible Heat When Heating 10 ⁶ Btu	Cooling Dry Air 10 ⁶ Btu	+ Internal Sensible Heat When Cooling 10 ⁶ Btu	Cooling Humid Air 10 ⁶ Btu	Total 10 ⁶ Btu
1	35.0	51.2	930	0	2.3	13.6	-2.6	0	0	0	13.3
2	39.9	46.8	703	0	2.1	10.3	-2.4	0	0	0	10.0
3	45.8	37.5	595	5	2.3	8.7	-2.6	0.1	0	0	8.5
4	55.7	30.2	288	0	2.2	4.2	-2.6	0	0	0	3.8
5	65.1	27.8	81	26	2.3	1.2	-1.8	0.4	0.8	0	4.1
6	74.9	29.0	0	277	2.2	0	0	4.1	2.6	0	8.9
7	78.5	43.2	0	414	2.3	0	0	6.1	2.6	2.6	13.6
8	76.2	47.2	0	282	2.3	0	0	4.1	2.6	2.2	11.2
9	70.0	45.2	12	149	2.2	0.2	-0.1	2.2	2.5	0	7.0
10	58.0	41.8	229	0	2.3	3.4	-2.6	0	0	0	3.1
11	43.6	48.5	642	0	2.2	9.4	-2.6	0	0	0	9.0
12	37.0	56.2	868	0	2.3	12.7	-2.6	0	0	0	12.4
Total	56.6	42.0	4348	1153	27.0	63.7	-19.9	17.0	11.1	4.8	104.9

Table 6a. Monthly Solar Radiation for 45° Tilt Angle

Month	Total ¹ Monthly Insolation (10 ³ Btu/ ft ²)	Percent ² of Possible Sunshine	Clearness ³ Number	Available Sunshine (10 ³ Btu/ ft ²)	Avg ² Daily Amb. Temp. (°F)	Available Avg Daily Insolation ₂ (Btu/day ft ²)	Length of Day Hrs.	$\frac{T_{in} - T_{amb}}{Q_{inc}}$ ⁴ Avg (Btu/hr-ft ²)	$\frac{T_{in} - T_{amb}}{Q_{inc}}$ (Btu/hr-ft ²) ⁻¹	Solar Collected (10 ³ Btu/ft ²)	
1	49.4	73	1.05	37.9	35.0	1630	10	163	.64	.36	13.6
2	47.8	74	1.05	37.1	39.9	1767	11	161	.62	.37	13.7
3	54.9	74	1.05	42.6	45.8	1832	12	153	.62	.37	15.8
4	50.9	77	1.15	45.1	55.7	2004	12	167	.50	.44	19.8
5	48.9	80	1.15	45.0	65.1	1935	12	161	.46	.46	20.7
6	45.1	83	1.15	43.0	74.9	1911	12	159	.78	.29	12.4
7	47.2	73	1.15	41.3	78.5	1776	12	148	.82	.26	10.7
8	50.0	76	1.15	43.7	76.2	1880	12	157	.79	.27	11.8
9	51.0	81	1.15	47.5	70.0	2111	12	176	.74	.30	14.2
10	52.5	80	1.05	44.1	58.0	1896	11	172	.48	.45	19.8
11	47.2	78	1.05	38.7	43.6	1720	10	172	.56	.43	16.6
12	45.9	71	1.05	34.2	37.0	1471	10	147	.70	.32	10.9
Total/ Averages	590.8	77		505.6	56.0	1828	11.3	161		.36	180.0

1. For 750 ft² of collectors, no clouds, calculated from ASHRAE program (SUN) 45° tilt angle.

2. Local climatological data USDOC for Albuquerque, N.M. (Average for 1932-1971).

3. From ASHRAE Handbook of Fundamentals 1971.

4. T_{in} = 140°F winter Oct - May
200°F summer June - Sept.

$$\eta = .712 - .551 \frac{T_{in} - T_{amb}}{Q_{inc}} \quad (\text{Selective coated absorber 2-cover collector})$$

average winter $\eta = 40\%$

average summer $\eta = 28\%$

Table 6b. Monthly Solar Radiation for 25° Tilt Angle

Month	Total ¹ Monthly Insolation (10 ³ Btu/ ft ²)	Percent ² of Possible Sunshine	Clearness ³ Number	Available Sunshine (10 ³ Btu/ ft ²)	Avg ² Daily Amb. Temp (°F)	Available Avg Daily Insolation ² (Btu/day ft ²)	Length of Day Hrs.	Q _{inc} Avg (Btu/hr-ft ²)	$\frac{T_{in} - T_{amb}}{Q_{inc}}$ (°F) ⁻¹	η	Solar Collected (10 ³ Btu/ft ²)
1	44.7	73	1.05	34.3	35.0	1475	10	148	.71	.32	11.0
2	44.9	74	1.05	34.9	39.9	1662	11	151	.66	.35	12.2
3	55.0	74	1.05	42.7	45.8	1837	12	153	.62	.37	15.8
4	55.2	77	1.15	48.9	55.7	2173	12	181	.47	.45	22.0
5	56.7	80	1.15	52.2	65.1	2245	12	187	.40	.49	25.6
6	54.3	83	1.15	51.8	74.9	2302	12	192	.65	.35	18.1
7	56.0	76	1.15	48.9	78.5	2103	12	175	.69	.33	16.1
8	55.9	76	1.15	48.9	76.2	2103	12	175	.71	.32	15.6
9	52.7	81	1.15	49.1	70.0	2182	12	182	.71	.32	15.7
10	50.6	80	1.05	42.5	58.0	1828	11	166	.49	.44	18.7
11	43.4	78	1.05	35.5	43.6	1578	10	158	.61	.37	13.1
12	41.0	71	1.05	30.6	37.0	1316	10	132	.78	.28	8.6
Total/ Averages	610.4	77		520.3	56.0	1883	11.3	167		.37	192.5

1. For 750 ft² of collectors, no clouds, calculated from ASHRAE program (SUN) 25° tilt angle.

2. Local climatological data USDOC for Albuquerque, N.M. (Average for 1932-1971).

3. From ASHRAE Handbook of Fundamentals 1971.

4. T_{in} = -140°F winter Oct - May
200°F summer June - Sept.

$$\eta = .712 - .551 \frac{T_{in} - T_{amb}}{Q_{inc}}$$

(Selective coated absorber 2-cover collector)

average winter η = 38%

average summer η = 33%

40054

Figure 4. Required and Supplied Solar Energy for Albuquerque

The third curve of Figure 4 is the solar energy required to supply the total load. This is not the absolute load in Btu's because summer cooling requires a higher level of solar collected energy than the load energy level due to the absorption air conditioner Coefficient of Performance of 0.6. The efficiency of the heat exchangers for hot water heating and space heating directly from solar energy is assumed to be 1.0.

Table 7 gives the summary of conventional energy (Btu's) required, conventional energy cost, solar energy required and supplied, auxiliary energy needed for gas heating and mechanical cooling, and total fuel dollars saved using a 750 square foot solar collector array tilted at 45°. Table 8 gives the November 1974 fuel rates for Albuquerque. The fuel energy required is the amount of Btu's needed to supply the house load. The internal sensible load modifies the house load by decreasing the heating load and increasing the cooling load. The actual amount of Btu's required for conventional heating and cooling is, therefore, this modified house load divided by the boiler efficiency or the air conditioner coefficient of performance. For months when there is both a heating and a cooling load, the internal sensible load is divided in the same proportion as heating to cooling degree days. If the internal sensible load is larger than the heating load, then the difference is added to the cooling load. The energy required and the solar energy supplied by 750 ft² of collectors are graphed in Figure 4.

It is assumed that supplied solar energy can only be utilized during the month it is collected. If there is a surplus of energy during a particular month, it will not be used. This excess is evident in Figure 4 for spring and fall months where loads are low and supplied solar energy is high. For this analysis a more detailed handling of storage capabilities is not possible.

To determine a reasonable quantity of collectors for a location, a graph of collector area versus percent of required solar energy supplied can be generated from Figure 4. Two such curves for Albuquerque are given in Figure 5 for tilt angles of 25° and 45°. It can be seen from such curves that areas above 800 square feet for this particular type of collector would be less cost effective than smaller collector areas. This is due to the lack of match between the load and supply curves of Figure 4. Increasing collector area is helpful in only a few select months (i. e., December, January and June through August). Therefore, an increase in collector area gives only a slight increase in the total solar supplied portion of the yearly load. For this reason, solar heating and cooling systems which could provide all of the average required yearly load may be difficult to justify economically. However, if the system was sized for total average load requirements, then 1080 square feet of collectors mounted at a 25° tilt angle would be needed.

This assumes a sufficient storage capability for complete utilization of energy collected in any particular month. The large majority of clear days in Albuquerque (75%) may imply that a storage capacity for only two or three days could provide nearly the same solar utilization as a larger storage system.

The collector areas required for different applications in Albuquerque are given in Table 9. A corresponding storage volume is given which will allow the system to run for 48 hours for heating if the tank is fully charged to 190°F and 12 hours for cooling if the tank is charged to 230°F. The space heating and cooling loads are again based on a typical 1500 ft² house and are only intended to give a rough estimate of the collector square footage and storage volume required for these applications. The most cost effective quantity of collectors can only be determined after the collector system price is known. As fuel costs rise, collector areas approaching 750 ft² for Albuquerque will probably become more economically viable and financially desirable.

Table 7. Summary of Conventional Energy

Month	Required Conventional			Conventional Fuel Cost ³		Required if Solar				Conventional Supplemental Energy Required		Conventional Supplemental Fuel Savings ³		Total Saving
	Hot ¹ Water 10 ⁶ Btu	Heating ¹ 10 ⁶ Btu	Cooling ² 10 ⁶ Btu	Gas for Hot Water & Heating \$	Elect for Mechanical Cooling \$	Hot ⁴ Water 10 ⁶ Btu	Heating ⁴ 10 ⁶ Btu	Cooling ⁵ 10 ⁶ Btu	Solar ⁶ Supplied 10 ⁶ Btu	Hot Water & Heating ⁷ 10 ⁶ Btu	Cooling ³ 10 ⁶ Btu	Hot Water & Heating \$	Cooling \$	
1	2.9	13.8	0	19.30	0	2.3	11.0	0	13.6	0	0	19.30	0	19.30
2	2.6	9.9	0	15.04	0	2.1	7.9	0	13.7	0	0	15.04	0	15.04
3	2.9	7.6	0.1	13.01	0.88	2.3	6.1	0.2	15.8	0	0	13.01	0.88	13.89
4	2.8	2.0	0	6.68	0	2.2	1.6	0	19.8	0	0	6.68	0	6.68
5	2.9	0	0.9	4.96	7.66	2.3	0	3.0	20.7	0	0	4.96	7.66	12.62
6	2.8	0	3.4	4.72	24.32	2.2	0	11.2	12.4	0	0.3	4.72	21.68	26.40
7	2.9	0	5.6	4.96	37.22	2.3	0	18.8	10.7	0	3.1	4.96	17.60	22.56
8	2.9	0	4.4	4.96	30.18	2.3	0	14.8	11.8	0	1.6	4.96	28.77	33.73
9	2.8	0.1	2.4	4.84	18.46	2.2	0.1	7.8	14.2	0	0	4.84	18.46	23.30
10	2.9	1.0	0	5.68	0	2.3	0.8	0	19.8	0	0	5.68	0	5.68
11	2.8	8.5	0	13.82	0	2.2	6.8	0	16.6	0	0	13.82	0	13.82
12	2.9	12.6	0	18.09	0	2.3	10.1	0	10.9	1.9	0	14.34	0	14.84
Total	34.1	55.5	16.8	116.06	118.72	27.0	44.4	55.8	180.0	0	0	112.81	95.05 (83%)	207.86

NOTES:

1. Load ÷ Boiler efficiency (.8).
2. Load ÷ COP of mechanical air conditioner (2.0).
3. Costs based on local fuel rates as given in Table VI.
4. Load ÷ heat exchanger efficiency (1.0).
5. Load ÷ COP of absorption air conditioner (.6).
6. 750 square feet of collectors at 45° tilt angle.
7. (required if solar - solar supplied) × $\eta_{\text{solar}} \div \eta_{\text{conventional}}$ where $\eta_{\text{solar}} = 1.0$ $\eta_{\text{conventional}} = .8$
8. (required if solar - solar supplied) × $\text{COP}_{\text{solar}} \div \text{COP}_{\text{conventional}}$ where $\text{COP}_{\text{solar}} = .6$
 $\text{COP}_{\text{conventional}} = 2.0$

Table 8. Albuquerque Fuel Rates (November 1974)

Electricity (Overhead Residential Power Line)

<u>Kwh/Month</u>		
<u>From</u>	<u>To</u>	<u>\$/kwh</u>
0	200	.03
200	600	.026
600	up	.018 (Nov-May)
600	up	.020 (June-Oct)

Natural Gas (Residential Heating)

<u>Ft³ x 10³</u>	<u>\$</u>	<u>Ft³ x 10³</u>	<u>\$</u>
1	2.17	16	18.60
2	3.38	17	19.61
3	4.60	18	20.62
4	5.80	19	21.65
5	6.93	20	22.66
6	8.04	21	23.68
7	9.15	22	24.70
8	10.26	23	25.71
9	11.39	24	26.73
10	12.50	25	27.75
11	13.52	26	28.77
12	14.53	27	29.79
13	15.55	28	31.81
14	16.57	29	32.83
15	17.58	30	33.85

Figure 5. Percent of Required Solar Energy Supplied versus Collector Area

Table 9. Collector Area Required for Different Applications in Albuquerque

<u>Use</u>	<u>Square Footage</u> ¹	<u>Storage Capacity</u> ²	<u>Approximate Sizing Factor (gal/ft² day)</u>
Domestic Hot Water ³	160	360	1.1
Heating Only ⁴	690	850	0.6
Heating and Cooling or Cooling Only ⁵	880	1200	2.7
Domestic Hot Water, Heating, and Cooling ⁶	1080	1350	2.5

Notes

1. Square footage for supplying 100% of average load assuming total utilization of monthly supplied solar.
2. 48 hours for hot water and heating, 12 hours for cooling. Fully charged at 190°F for heating, 230°F for cooling.
3. Provides 100 gal/day at 100°F temp rise. December is worst case (45° tilt).
4. December is worst case for heating. Assume 80°F water for heating, 45° tilt.
5. July is worst case for cooling. Assume 200°F water for A/C, 25° tilt.
6. Collector tilt angle of 25°.

APPENDIX

MAXIMUM HOUSE LOADS

The design heating load for a typical Albuquerque house is based on an extreme winter design of 14°F. The design load is a combination of heat losses due to infiltrating outside air, transmission losses through the walls and roof, and internal heat generated by electrical appliances.

The domestic hot water heating load is also included in this analysis. An average hot water usage level for a typical home is 100 gallons per day. For an assumed temperature rise of 100°F, the water heating load would be 75,000 Btu/day or 3125 Btu/hr.

The internal sensible load is the amount of energy added to the house by electrical power consumption. It is assumed that all of the electrical power consumed is converted to radiated heat. The average electricity usage level for a typical home is approximately 25 kwh/day. At 3413 Btu/kwh, the average amount of heat added to the house is 3555 Btu/hour. This load is added to the cooling load but subtracted from the heating load because it supplies a portion of the required heat. Both the hot water load and the internal sensible load are assumed to remain constant throughout the year.

The design heating load is given by the following equation:

$$\begin{aligned}
 H_{\text{required}} &= H_{\text{infiltration}} + H_{\text{transmission}} + H_{\text{hot water}} - H_{\text{internal}} \\
 &\quad \text{(sensible)} \qquad \qquad \qquad \text{(sensible)} \\
 &= CpVN \rho(t_i - t_o) + \sum_{i=1}^n A_i U_i (t_i - t_o) + H_{\text{hot water}} - H_{\text{internal}} \\
 &\qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \text{(sensible)}
 \end{aligned}$$

where

- C_p = .240 Btu/lbm °F
- V = house volume ft³
- N = number of volume exchanges per hour¹ = 1.5
- ρ = .075 lbm/ft³
- $t_i - t_o$ = inside/outside temperature difference (°F)
- A_i = surface area of wall or roof i (ft²)
- U_i = coefficient of transmission of wall or roof i

The design cooling load is based on summer design temperatures of 96°F dry bulb and 66°F wet bulb. Again, the energy required for space cooling is based on infiltration and transmission losses. From the wet bulb temperature, the energy needed to remove the excess water from the infiltrating air can be determined. This is the latent portion of the transmission losses. The dry bulb temperature is used to calculate the energy needed to lower the temperature of infiltrating dry air to 75°F. This is the sensible portion of the transmission losses. The following equation gives the design cooling load.

¹ ASHRAE Handbook of Fundamentals, 1972, pp. 337-370.

$$\begin{aligned}
H_{\text{required}} &= H_{\text{infiltration}} + H_{\text{transmission}} + H_{\text{hot water}} + H_{\text{internal}} \\
&\quad \text{(sensible \& latent)} \qquad \qquad \qquad \text{(sensible)} \\
&= VN\rho C_p(t_o - t_i) + VN\rho(h_o - h_i) + \sum_{i=1}^n A_i U_i(t_o - t_i) + H_{\text{hot water}} \\
&\quad + H_{\text{internal}} \\
&\quad \text{(sensible)}
\end{aligned}$$

where

h_o = outside enthalpy of air determined from wet bulb temperature on psychrometric chart = 31.0 Btu/lb

h_i = inside enthalpy of 75° dry bulb temperature and 40% relative humidity = 26.2 Btu/lb