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ESTIMATING THE ENERGY CONSERVATION POTENTIAL OF VENTILATION CONTROL THROUGH WEATHER DATA ANALYSIS

by

T. Kusuda and J. W. Bean

ABSTRACT

Hourly weather data for six selected cities in the United States covering eleven consecutive years were analyzed to aid in estimating the possible energy saving that could be achieved by closing the outdoor dampers during unoccupied hours. The analysis shows that, depending upon the local weather condition, and with some simplifying assumptions, from 74 to 83 percent of the energy used for heating the make-up air could potentially be saved by closing the outdoor dampers when the building is not occupied. Based upon a premise that the energy required for cooling the outdoor ventilation air is proportional to the average enthalpy difference between the outdoor air and the air leaving the cooling coil, from 53 to 63 percent of the energy for cooling of ventilation air could be saved by closing the outdoor dampers during unoccupied hours.

Hourly temperature and enthalpy values are presented in histogram form for occupied and unoccupied periods (office use), with the suggestion that similar data processing be carried out for other cities as well.

Key Words: Air conditioning requirements; energy conservation; intermittent ventilation; ventilation control; weather data analysis.

1. INTRODUCTION

Recent studies conducted by the National Bureau of Standards indicate that the heating and cooling of outdoor air needed for commercial building ventilation is a major component of heating and cooling energy requirements for a given building [1, 2]*. For example, 75 percent of the average fuel oil consumed by 19 New York City schools was used to heat the ventilation air. The critical evaluation of the real requirements of ventilation air from the standpoint of the occupants' health, thermal comfort, and the quality of indoor air merits attention in order to minimize the excess use of outdoor air and hence conserve energy [3]. On the other hand, it is now possible to reduce the requirements for mechanical cooling by taking advantage of cool outdoor air for cooling where possible.

For the sake of energy conservation, the following should be considered:

1. When the ventilating air is either heated or cooled, the quantity of outdoor air should be minimized to the point really necessary for maintaining indoor air quality and the occupants' comfort and health.

2. The use of outdoor air for "natural" cooling should be maximized during the non-heating season.

3. Energy should be recovered from the exhaust air wherever possible by the use of heat exchangers.

* Numbers in brackets indicate references at end of text.

Although each of these considerations merits separate and detailed analysis depending upon the specific application, the attention of this report will be directed toward one of the simplest steps: closing outdoor air dampers during unoccupied periods.

2. ENERGY SAVING BY CLOSING THE OUTDOOR AIR DAMPERS DURING UNOCCUPIED PERIODS

The energy saving as a result of closing the outdoor ventilation dampers during the unoccupied periods was analyzed as described below. Detailed hourly mechanical system simulation calculations by the use of computer revealed that the heating requirement Q_H for processing the ventilation air can be approximated by a linear function of the difference between the indoor temperature t_i and outdoor temperature t_o.

$$Q_H = a\,(t_i - t_o) \qquad (1)$$

In this equation, a is a proportionality constant which depends on the amount of total ventilation air and the efficiency of the heating system used in a given building.

Let Q_o = the annual energy consumption for heating of ventilation air when the outdoor air damper is open continuously

and Q_p = the annual energy consumption for heating of ventilation air when outdoor ventilation is on only during the occupied periods.

Then

$$Q_o = a \sum_{\text{total}} (t_i - t_o)^{*/} \qquad (2)$$

$$Q_p = a \sum_{\text{occupied hours}} (t_i - t_o)^{*/} \qquad (3)$$

The following energy saving factor η_H can be used as a measure of the energy saving due to shutting down the ventilation system during the unoccupied periods:

$$\eta_H = \frac{Q_o - Q_p}{Q_o} \times 100 \qquad (4)$$

or

$$\eta_H = \frac{\sum\limits_{\text{unoccupied}} (t_i - t_o)}{\sum\limits_{\text{total}} (t_i - t_o)} \times 100 \qquad (5)$$

In the equations (2) through (5), Σ signifies the summation over an entire year for hours when:

$$t_i \geq t_o$$

*/ No distinction is made at this point for the notations between the in and outdoor temperatures during the occupied and unoccupied periods.

Equation (5) may be modified as:

$$\eta_H = \left(\frac{\bar{t}_i{}' - \bar{t}_o{}'}{\bar{t}_i - \bar{t}_o} \right) \frac{N'}{N} \times 100 \qquad (6)$$

where $\bar{t}_i$ = the average indoor temperature during the heating season

$\bar{t}_i{}'$ = the average indoor temperature during the unoccupied period

$\bar{t}_o{}'$ = the average outdoor temperature during the unoccupied hours

$\bar{t}_o$ = The average outdoor temperature during the heating season

N' = the number of hours during the heating season when the building is unoccupied

N = the total numberof hours during the heating season.

In order to evaluate η_H, it is only necessary to know the average indoor and outdoor air temperatures during the heating season during the unoccupied hours of the same time period, since the values of N' and N can be very easily determined. While the average outdoor air temperature ($\bar{t}_o$) during the heating season may be available or estimated from monthly degree-day data, the average outdoor temperature during the unoccupied period of the heating season has not been compiled, to the best of the authors' knowledge.

Figures 1 through 3 */ were prepared to compare the monthly average temperature for three periods in a day: hour 1 through hour 8, hour 9 through hour 16, and hour 17 through hour 24 for Concord, New Hampshire; Washington, D. C.; and Orlando, Florida, respectively. These figures show that the average temperatures during the occupied hours (9-16) are considerably different from those during the non-occupied hours (1-8 and 17-24) in Concord, New Hampshire; however, the differences are smaller in the southern cities. For the sake of interest, similar plots were made for the outdoor dewpoint temperature for the same cities and are shown in Figures 4 through 6. These latter figures show that there is no significant difference in dewpoint temperature between the occupied and unoccupied periods.

In those localities where the daily average outdoor temperature, $\bar{t}_o$, is very nearly the same as the average outdoor temperature during the unoccupied periods, $\bar{t}_o{}'$, the energy-saving factor η_H can be calculated simply by knowing the occupied hours during the season, and by the indoor temperatures during the occupied and unoccupied periods.

If one assumes that the heating season consists of all the non-summer months (September through March) and the working hours are from 8 a.m. to 5 p.m. of 147 working days, the total occupied heating hours will be 1323, whereas the total heating hours will be 5088 (212 days), including Saturdays, Sundays, and holidays. The value for η_H can thus be written as:

$$\eta_H = \left(\frac{5088 - 1323}{5088} \right) \left(\frac{\bar{t}_i{}' - \bar{t}_o{}'}{\bar{t}_i - \bar{t}_o} \right) \times 100 = 74 \left(\frac{\bar{t}_i{}' - \bar{t}_o{}'}{\bar{t}_i - \bar{t}_o} \right) \qquad (7)$$

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* Figures are grouped at end of text.

where $$\bar{t}_i = \frac{(5088 - 1323)\ \bar{t}_i' + 1323\ \bar{t}_i''}{5088}$$

and $\bar{t}_i''$ = average indoor temperature during the occupied hours.

Equation (7) shows that the percent savings for the heating of ventilation air is 74 percent when the average indoor temperature and the average outdoor temperature remain constant throughout the occupied and unoccupied periods. The percentage savings tends to increase when the unoccupied period has a lower average outdoor temperature. The value of η_H is also affected by the level of indoor temperature, since for a given outdoor temperature depression during the unoccupied period, as compared to the average outdoor temperature for the season, the percentage savings becomes higher for the location when the annual average value of $\bar{t}_o$ is closer to the indoor temperature.

Calculation of this type of data can be made easier and more accurate if statistical data for the hourly outdoor temperature are available for the occupied and non-occupied hours separately. It would also be helpful if data were available to analyze the potential of using natural cooling instead of air conditioning during the cooler night hours of the summer months, reserving air conditioning for those periods when the building is occupied, and the outside air is warm.

3. ANALYSIS OF WEATHER DATA

In order to demonstrate a possible energy saving through the proper use and schedule of ventilation air, hourly weather data for six selected cities were analyzed as follows:

(a) Hourly frequency histograms of dry-bulb temperature for the occupied and non-occupied periods as well as for the total year were first constructed for eleven consecutive years for Washington, D. C., covering 1954 through 1964. The results are shown in Figures 7 through 17. The shapes of the histograms vary considerably from year to year. Indicated in the upper righthand corner of these figures are three indices which are developed from the histogram, termed "heating degree hours" (HTGDH); cooling degree hours (CLGDH); and cooling enthalpy hours (CLGEH). The definitions of these quantities are as follows:

$$\text{HTGDH} = \sum (70 - t_o)$$

$$\text{CLGDH} = \sum (t_o - 75)$$

$$\text{CLGEH} = \sum (h_o - 24)$$

The definitions of these degree hours are such that the summation for the above equations was carried out only for the periods when the values in the parentheses were positive. The quantity "24" in CLGEH is the enthalpy value of moist air corresponding to the dewpoint temperature of 56° F (13.3°C), which is the apparatus dewpoint temperature of typical air-cooling systems. This value was used instead of the indoor air enthalpy because the outdoor air is usually cooled down to the apparatus dewpoint temperature first.* Table 1 lists the year-to-year variations of HTGDH, CLGDH and CLGEH, as well as the percent of these values, for the unoccupied period for Washington, D. C., during 1954-1964. When it is assumed that the indoor temperatures for occupied and unoccupied hours are the same during the heating season, these values represent η_H, the ventilation energy saving factor. For the purpose of this analysis, it has been assumed that the energy required for cooling ventilation is proportional to the cooling enthalpy hours (CLGEH). Based on this assumption, the energy saving due to shutting off the outdoor ventilation air during unoccupied hours

*This assumption is also consistent with the other assumption that the cooling system operates under an assumed and constant coefficient of performance representing an average value of the cooling season.

in the summer season would be equal to the fraction of the total cooling enthalpy hours that occurred during the unoccupied hours.

As can be seen from Table 1, the heating degree hours (HTGDH) and the corresponding energy saving factors are very consistent throughout the 11-year period with spreads of 13 and 3 percent, respectively. Cooling degree hours (CLGDH) and cooling enthalpy hours (CLGEH), however, vary widely from year to year, represented by the spread of 41 and 86 percent, respectively. The energy saving factors for ventilation air cooling varied much less during the same period (15 and 14 percent, respectively).

Table 1

Washington, D. C.
Hourly Weather Data Summary

	HTGDH		CLGDH		CLGEH	
Year	Total	η_H*	Total	η_H*	Total	η_H*
1954	134104	75	10999	53	18050	41
1955	138690	74	10264	53	21112	62
1956	141990	75	7662	55	14488	62
1957	133908	74	11271	59	28755	65
1958	149174	74	7216	55	11110	59
1959	129606	73	13313	56	39410	67
1960	144260	74	9048	56	18971	61
1961	142330	74	10189	52	26840	64
1962	147410	73	8611	53	14119	58
1963	148116	74	9436	51	17559	62
1964	137706	74	10640	54	14728	61
Average	140663	74	9877	55	20495	63
Spread	18510	2	4055	8	17645	9
% Spread	13	3	41	15	86	14

* percentage of degree hours during the unoccupied period (5 p.m. - 8 a.m.) which is the "energy saving factor."

Key: ________ minimum

-------- maximum

(b) The hourly weather data analysis for the ten-year period was performed for other cities (Orlando, Florida; Concord, New Hampshire; Phoenix, Arizona; Omaha, Nebraska; and Newark, New Jersey) to examine how the histograms, as well as the ten-year average values for HTGDH, CLGDH and CLGEH, varied from city to city. Figures 18 through 23 depict the ten-year average annual hourly frequency of outdoor temperature, whereas Figures 24 through 29 depict the same for the outdoor air enthalpy. Shown in each of these figures are the histograms for occupied hours, non-occupied hours and total hours. It is interesting to note that except for Phoenix and Orlando, the temperature histograms show two distinct peaks.

Compared with the temperature profiles, enthalpy-frequency profiles are much more irregular, especially in the enthalpy range of 20-35 Btu/lb., which is very surprising if one considers that these figures represent the ten-year averages. It is unclear at the moment why the enthalpy histograms show such fluctuations.

Table 2 shows the ten-year average values of the heating degree hours, cooling degree hours, and cooling enthalpy hours for these six cities. Although these values vary considerably from city to city because of the difference in their climatic conditions, the energy-saving factors are relatively consistent among the cities.

Table 2. Average* of Hourly Weather Data Summary for Six Selected Cities

	HTGDH		CLGDH		CLGEH	
	Total	% Unoccupied	Total	% Unoccupied	Total	% Unoccupied
Washington, D. C.	140663	74	9877	55	20495	63
Orlando, Florida	35551	83	21286	45	51331	61
Concord, New Hampshire	216855	75	4225	45	8402	54
Phoenix, Arizona	65560	80	47902	59	15312	59
Omaha, Nebraska	187778	74	10714	56	12977	61
Newark, New Jersey	157264	75	7111	49	14693	59

* Washington and Concord were calculated from 11-year data.

4. TABULATION OF THE HOURLY FREQUENCIES OF DRY-BULB TEMPERATURE AND ENTHALPY

The histogram of hourly outdoor temperature and enthalpy for the occupied and non-occupied periods is useful in observing the general profile. Tabulated data which are represented in these histograms are also needed, however, especially for the "bin" method of energy consumption analysis when the heating and cooling loads are calculated for each of the temperature bins[4]. Tables 3 through 14 have thus been included in this report to provide this information. These tables are grouped together following Section 6.

5. SUMMARY AND DISCUSSION

It was pointed out in this paper that the energy consumption for the heating and cooling of ventilation air can be a significant part of the overall building energy usage, and it is strongly influenced by the hourly outdoor dry-bulb temperature and enthalpy value. By cutting off all make-up air during unoccupied heating hours, it is possible to decrease the energy used to heat the outdoor air from 74 to 83 percent, depending upon the climatic region.

The corresponding saving for cooling the make-up air could be from 54 to 63 percent, depending upon the weather conditions of the region under consideration. These figures are, however, obtained on the assumption that the indoor conditions were maintained at the same levels during occupied and unoccupied hours. Also, no consideration has been given to the fact that the ventilation rate may be regulated in accordance with the need of specific spaces even during the occupied period. Although more extensive studies are needed to account for these aspects of the hour-by-hour simulation of the ventilation system, the data presented herein provide firsthand estimates for the potential energy saving by shutting off the make-up air supply system during unoccupied periods. The magnitude of the possible energy saving obtained by this sort of ventilation control can be estimated from the histogram data of hourly dry-bulb temperature and enthalpy for occupied and non-occupied periods. This paper presents such data for six selected cities in both tabular and graphical forms. Data of this type should be developed for most of the major cities in the United States, because they are not only useful for estimating possible energy savings by controlling ventilation air, but also for other purposes such as in the "bin" method of annual energy calculations for buildings. The findings of this paper indicate the value of increased research and hardware development activities in the area of ventilation system controls.

6. REFERENCES

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Table 3. Average Hourly Frequencies of Outdoor Temperature for Occupied and Unoccupied Periods for Phoenix, Arizona

Outdoor Temperature, °F	Occupied Hours Per Year	Unoccupied Hours Per Year	Total*
18.	0.	0.	1.
20.	0.	1.	1.
22.	1.	1.	1.
24.	0.	1.	2.
26.	1.	3.	4.
28.	2.	10.	12.
30.	3.	19.	22.
32.	5.	26.	31.
34.	8.	34.	42.
36.	13.	57.	70.
38.	16.	77.	93.
40.	23.	106.	129.
42.	28.	150.	178.
44.	32.	157.	189.
46.	39.	170.	210.
48.	46.	210.	257.
50.	47.	202.	249.
52.	54.	215.	269.
54.	63.	235.	298.
56.	69.	223.	292.
58.	70.	231.	301.
60.	82.	223.	305.
62.	77.	214.	291.
64.	82.	216.	298.
66.	86.	213.	299.
68.	90.	215.	305.
70.	90.	221.	311.
72.	89.	219.	307.
74.	87.	217.	305.
76.	91.	232.	323.
78.	86.	235.	321.
80.	101.	224.	325.
82.	92.	225.	317.
84.	100.	212.	312.
86.	91.	181.	272.
88.	91.	163.	254.
90.	99.	151.	249.
92.	98.	136.	234.
94.	94.	121.	215.
96.	93.	122.	215.
98.	88.	102.	190.
100.	69.	84.	153.
102.	56.	65.	122.
104.	41.	47.	88.
106.	24.	28.	53.
108.	14.	16.	30.
110.	6.	7.	13.
112.	2.	1.	3.
114.	1.	0.	1.
116.	0.	0.	1.
TOTAL	2542.	6222.	8765.**

*Due to rounding-off arithmetics, the total hours may not exactly match the sum of occupied and unoccupied hours.

**The average total number of hours would vary from 8765 to 8767 depending upon the number of leap years included in the calculation period.

Table 4. Average Hourly Frequencies of Outdoor Air Enthalpy for Occupied and Unoccupied Periods for Phoenix, Arizona

Outdoor Air Enthalpy, Btu/lb	Occupied Hours Per Year	Unoccupied Hours Per Year	Total
6.	0.	1.	1.
7.	1.	2.	3.
8.	1.	5.	6.
9.	4.	22.	26.
10.	5.	27.	32.
11.	13.	53.	65.
12.	21.	93.	113.
13.	36.	141.	177.
14.	60.	260.	319.
15.	56.	246.	302.
16.	71.	281.	352.
17.	96.	327.	424.
18.	123.	363.	486.
19.	127.	317.	445.
20.	92.	274.	366.
21.	162.	400.	563.
22.	171.	392.	563.
23.	90.	190.	280.
24.	180.	362.	542.
25.	92.	171.	263.
26.	148.	309.	457.
27.	76.	148.	224.
28.	135.	239.	374.
29.	68.	159.	227.
30.	67.	125.	192.
31.	89.	148.	237.
32.	83.	217.	301.
33.	55.	133.	188.
34.	57.	149.	206.
35.	67.	164.	232.
36.	71.	164.	235.
37.	66.	135.	202.
38.	69.	98.	168.
39.	52.	66.	118.
40.	27.	29.	56.
41.	8.	7.	15.
42.	1.	1.	2.
43.	1.	1.	1.
46.	0.	0.	1.
TOTAL	2542.	6223.	8765.*

*The average total number of hours would vary from 8765 to 8767 depending on the number of leap years included in the calculation period.

Table 5. Average Hourly Frequencies of Outdoor Temperature for Occupied and Unoccupied Periods for Concord, New Hampshire

Outdoor Temperature, °F	Occupied Hours Per Year	Unoccupied Hours Per Year	Total*
-26.	0.	0.	1.
-24.	0.	1.	1.
-22.	0.	1.	1.
-20.	0.	1.	1.
-18.	1.	2.	3.
-16.	0.	2.	3.
-14.	1.	3.	3.
-12.	1.	5.	6.
-10.	1.	4.	4.
- 8.	1.	10.	11.
- 6.	2.	13.	14.
- 4.	3.	14.	17.
- 2.	5.	16.	21.
0.	4.	15.	19.
2.	5.	21.	26.
4.	7.	31.	38.
6.	9.	35.	43.
8.	10.	44.	54.
10.	11.	52.	63.
12.	15.	63.	78.
14.	20.	69.	89.
16.	23.	84.	107.
18.	27.	94.	121.
20.	35.	122.	157.
22.	39.	140.	179.
24.	49.	171.	220.
26.	53.	183.	236.
28.	63.	216.	278.
30.	71.	242.	313.
32.	88.	262.	350.
34.	87.	248.	335.
36.	86.	225.	311.
38.	79.	203.	283.
40.	74.	201.	276.
42.	79.	208.	286.
44.	77.	206.	283.
46.	71.	205.	276.
48.	71.	198.	269.
50.	69.	208.	277.
52.	73.	210.	283.
54.	70.	200.	270.
56.	79.	216.	295.
58.	76.	207.	282.
60.	85.	210.	295.
62.	81.	199.	280.
64.	88.	185.	273.
66.	77.	174.	252.
68.	83.	156.	239.
70.	79.	136.	215.
72.	77.	110.	187.
74.	77.	90.	167.
76.	66.	72.	137.
78.	63.	61.	123.
80.	60.	53.	113.
82.	51.	40.	91.
84.	44.	29.	73.
86.	26.	23.	49.
88.	20.	17.	36.
90.	13.	12.	25.
92.	7.	6.	13.
94.	5.	3.	8.
96.	3.	1.	3.
98.	1.	0.	1.
TOTAL	2542.	6225.	8767.*

* The average total number of hours would vary from 8765 to 8767 depending upon the number of leap years included in the calculation period.

Table 6. Average Hourly Frequencies of Outdoor Air Enthalpy for Occupied and Unoccupied Periods for Concord, New Hampsire

Outdoor Air Enthalpy, Btu/lb	Occupied Hours Per Year	Unoccupied Hours Per Year	Total
- 5.	1.	2.	3.
- 4.	1.	4.	5.
- 3.	1.	8.	9.
- 2.	2.	16.	18.
- 1.	4.	25.	29.
0.	8.	28.	36.
1.	10.	38.	48.
2.	17.	69.	86.
3.	20.	82.	103.
4.	28.	99.	127.
5.	38.	134.	172.
6.	56.	176.	232.
7.	79.	234.	313.
8.	69.	246.	315.
9.	96.	274.	371.
10.	94.	310.	405.
11.	132.	322.	455.
12.	108.	306.	413.
13.	132.	323.	455.
14.	93.	201.	294.
15.	91.	218.	309.
16.	92.	225.	317.
17.	89.	229.	318.
18.	86.	219.	305.
19.	88.	213.	301.
20.	93.	219.	312.
21.	70.	138.	208.
22.	72.	195.	266.
23.	100.	218.	318.
24.	59.	133.	192.
25.	107.	222.	328.
26.	60.	130.	190.
27.	101.	198.	299.
28.	54.	110.	165.
29.	52.	107.	160
30.	81.	161.	242.
31.	54.	97.	150.
32.	41.	72.	113.
33.	41.	58.	99.
34.	44.	63.	106.
35.	30.	46.	76.
36.	20.	24.	44.
37.	13.	14.	27.
38.	7.	9.	15.
39.	5.	5.	10.
40.	2.	1.	3.
41.	1.	0.	1.
TOTAL	2541	6224	8765*

*The average total number of hours would vary from 8765 to 8767, depending upon the number of leap years included in the calculation period.

Table 7. Average Hourly Frequencies of Outdoor Temperature for Occupied and Unoccupied Periods for Newark, New Jersey

Outdoor Temperature, °F	Occupied Hours Per Year	Unoccupied Hours Per Year	Total*
0.	0.	0.	1.
2.	0.	0.	1.
4.	1.	1.	1.
6.	1.	5.	7.
8.	1.	4.	5.
10.	3.	6.	9.
12.	4.	10.	14.
14.	5.	22.	27.
16.	8.	28.	36.
18.	11.	36.	47.
20.	12.	43.	55.
22.	16.	63.	79.
24.	21.	83.	104.
26.	29.	100.	129.
28.	36.	126.	162.
30.	49.	166.	214.
32.	64.	204.	268.
34.	81.	237.	318.
36.	84.	261.	345.
38.	88.	260.	348.
40.	90.	235.	324.
42.	84.	222.	306.
44.	89.	235.	324.
46.	83.	208.	291.
48.	79.	194.	273.
50.	78.	204.	282.
52.	78.	212.	290.
54.	79.	210.	288.
56.	74.	218.	292.
58.	77.	213.	290.
60.	83.	226.	308.
62.	83.	230.	313.
64.	86.	232.	318.
66.	86.	224.	309.
68.	95.	245.	340.
70.	96.	230.	326.
72.	87.	232.	319.
74.	90.	209.	298.
76.	91.	149.	240.
78.	85.	120.	206.
80.	81.	89.	170.
82.	66.	71.	137.
84.	52.	50.	103.
86.	45.	37.	82.
88.	32.	24.	56.
90.	24.	17.	41.
92.	16.	13.	29.
94.	9.	8.	17.
96.	5.	5.	10.
98.	4.	3.	7.
100.	2.	1.	3.
TOTAL	2542	6222	8765*

* Due to rounding-off arithmetics, the total hours may not exactly match the sum of occupied and unoccupied hours.

** The average total number of hours would vary from 8765 to 8767, depending upon the number of leap years included in the calculation period.

Table 8. Average Hourly Frequencies of Outdoor Air Enthalpy for Occupied and Unoccupied Periods for Newark, N. J.

Outdoor Air Enthalpy, Btu/lb.	Occupied Hours Per Year	Unoccupied Hours Per Year	Total
1.	1.	1.	2.
2.	2.	8.	11.
3.	5.	11.	16.
4.	8.	31.	39.
5.	15.	55.	69.
6.	26.	78.	103.
7.	36.	123.	159.
8.	43.	151.	195.
9.	66.	202.	268.
10.	78.	251.	329.
11.	118.	305.	423.
12.	137.	372.	509.
13.	118.	300.	418.
14.	102.	251.	353.
15.	95.	235.	331.
16.	96.	232.	329.
17.	93.	219.	312.
18.	84.	221.	306.
19.	93.	228.	321.
20.	97.	230.	326.
21.	88.	220.	309.
22.	64.	134.	197.
23.	101.	223.	325.
24.	86.	189.	274.
25.	70.	193.	263.
26.	91.	186.	277.
27.	82.	214.	296.
28.	62.	135.	196.
29.	103.	232.	335.
30.	57.	146.	204.
31.	49.	110.	159.
32.	62.	128.	189.
33.	78.	180.	258.
34.	52.	127.	178.
35.	45.	98.	143.
36.	40.	68.	109.
37.	31.	62.	93.
38.	30.	36.	66.
39.	19.	21.	39.
40.	12.	9.	21.
41.	4.	3.	8.
42.	1.	1.	3.
43.	1.	1.	1.
44.	0.	0.	1.
TOTALS	2542	6223	8765

* The average total number of hours would vary from 8765 to 8767 depending upon the number of leap years included in the calculation period.

Table 9. Average Hourly Frequencies of Outdoor Temperature for Occupied and Unoccupied Periods for Washington, D. C.

Outdoor Temperature, °F	Occupied Hours Per Year	Unoccupied Hours Per Year	Total*
6.	1.	1.	1.
8.	1.	1.	2.
10.	2.	6.	7.
12.	4.	10.	14.
14.	5.	14.	19.
16.	6.	18.	24.
18.	10.	31.	40.
20.	13.	47.	60.
22.	18.	52.	70.
24.	21.	67.	87.
26.	31.	91.	122.
28.	32.	106.	137.
30.	46.	145.	191.
32.	58.	194.	251.
34.	62.	199.	262.
36.	77.	215.	293.
38.	82.	227.	309.
40.	78.	217.	295.
42.	83.	223.	306.
44.	77.	211.	287.
46.	73.	199.	272.
48.	76.	181.	257.
50.	67.	197.	264.
52.	76.	186.	263.
54.	71.	181.	253.
56.	73.	190.	263.
58.	71.	179.	250.
60.	78.	198.	276.
62.	88.	226.	314.
64.	79.	211.	290.
66.	83.	231.	314.
68.	84.	235.	318.
70.	98.	269.	367.
72.	102.	287.	389.
74.	108.	274.	382.
76.	99.	214.	313.
78.	84.	165.	249.
80.	91.	148.	238.
82.	81.	117.	198.
84.	74.	94.	168.
86.	61.	65.	127.
88.	54.	42.	96.
90.	35.	31.	66.
92.	20.	19.	39.
94.	6.	7.	12.
96.	3.	3.	6.
98.	2.	1.	3.
TOTAL	2543.	6223.	8767.**

* Due to rounding-off arithmetics, the total hours may not exactly match the sum of occupied and unoccupied hours.

** The average total number of hours would vary from 8765 to 8767 depending upon the number of leap years included in the calculation period.

Table 10. Average Hourly Frequencies of Outdoor Air Enthalpy for Occupied and Unoccupied Periods for Washington, D. C.

Enthalpy, Btu/lb	Occupied Hours Per Year	Unoccupied Hours Per Year	Total
1.	0.	0.	1.
2.	1.	3.	4.
3.	4.	15.	19.
4.	7.	22.	30.
5.	15.	39.	54.
6.	24.	79.	103.
7.	41.	110.	151.
8.	43.	132.	175.
9.	58.	169.	227.
10.	66.	229.	295.
11.	114.	306.	420.
12.	127.	356.	483.
13.	106.	266.	372.
14.	96.	237.	333.
15.	92.	220.	312.
16.	94.	230.	324.
17.	86.	203.	289.
18.	92.	194.	286.
19.	81.	187.	268.
20.	83.	201.	284.
21.	74.	181.	255.
22.	50.	123.	174.
23.	86.	208.	294.
24.	78.	162.	240.
25.	63.	166.	229.
26.	81.	169.	250.
27.	83.	217.	300.
28.	71.	158.	229.
29.	101.	258.	358.
30.	57.	164.	221.
31.	52.	131.	182.
32.	70.	142.	211.
33.	104.	229.	333.
34.	78.	187.	265.
35.	62.	152.	214.
36.	56.	122.	178.
37.	44.	96.	140.
38.	45.	73.	118.
39.	29.	41.	70.
40.	17.	25.	42.
41.	7.	13.	20.
42.	3.	6.	8.
43.	1.	2.	3.
44.	1.	1.	2.
45.	0.	1.	1.
TOTAL	2543.	6224.	8767.*

* The average total number of hours would vary from 8765 to 8767 depending upon the number of leap years included in the calculation period.

Table 11. Average Hourly Frequencies of Outdoor Temperature for Occupied and Unoccupied Periods for Omaha, Nebraska

Outdoor Temperature, °F	Occupied Hours Per Year	Unoccupied Hours Per Year	Total*
-16.	0.	0.	1.
-14.	1.	1.	2.
-12.	0.	2.	2.
-10.	1.	5.	5.
-8.	2.	7.	8.
-6.	2.	10.	12.
-4.	3.	14.	17.
-2.	6.	18.	23.
0.	8.	22.	30.
2.	12.	28.	39.
4.	14.	35.	48.
6.	12.	39.	51.
8.	15.	49.	64.
10.	18.	52.	70.
12.	20.	58.	78.
14.	26.	74.	100.
16.	25.	74.	100.
18.	32.	91.	123.
20.	39.	102.	141.
22.	46.	113.	159.
24.	49.	131.	180.
26.	50.	145.	195.
28.	55.	170.	225.
30.	58.	189.	247.
32.	64.	208.	272.
34.	73.	214.	287.
36.	68.	182.	249.
38.	66.	175.	241.
40.	61.	173.	234.
42.	65.	152.	217.
44.	62.	157.	219.
46.	56.	147.	202.
48.	56.	141.	197.
50.	63.	146.	209.
52.	60.	149.	209.
54.	59.	168.	228.
56.	58.	164.	222.
58.	52.	167.	220.
60.	64.	180.	244.
62.	65.	188.	253.
64.	69.	219.	288.
66.	76.	212.	288.
68.	80.	214.	294.
70.	89.	217.	306.
72.	87.	183.	271.
74.	91.	194.	286.
76.	78.	163.	242.
78.	75.	143.	218.
80.	78.	126.	204.
82.	66.	105.	170.
84.	65.	91.	156.
86.	54.	61.	114.
88.	43.	50.	93.
90.	35.	38.	73.
92.	27.	27.	55.
94.	18.	19.	38.
96.	9.	9.	17.
98.	7.	5.	12.
100.	4.	3.	7.
102.	2.	2.	4.
104.	1.	1.	2.
106.	0.	0.	1.
TOTAL	2542.	6225.	8767.*

*The average total number of hours would vary from 8765 to 8767 depending upon the number of leap years included in the calculation period.

Table 12. Average Hourly Frequencies of Outdoor Air Enthalpy for Occupied and Unoccupied Periods for Omaha, Nebraska

Outdoor Air Enthalpy, Btu/lb	Occupied Hours Per Year	Unoccupied Hours Per Year	Total
-4.	1.	0.	1.
-3.	1.	3.	4.
-2.	3.	12.	15.
-1.	4.	20.	24.
0.	13.	34.	47.
1.	18.	45.	63.
2.	29.	81.	110.
3.	28.	83.	110.
4.	35.	98.	132.
5.	43.	118.	161.
6.	60.	152.	212.
7.	74.	185.	259.
8.	54.	150.	204.
9.	96.	278.	374.
10.	70.	220.	291.
11.	117.	344.	462.
12.	100.	267.	367.
13.	106.	260.	366.
14.	97.	237.	334.
15.	80.	175.	256.
16.	68.	156.	225.
17.	72.	169.	241.
18.	65.	151.	216.
19.	60.	155.	215.
20.	49.	123.	173.
21.	68.	179.	247.
22.	79.	189.	268.
23.	57.	121.	178.
24.	82.	188.	270.
25.	53.	115.	168.
26.	79.	210.	289.
27.	43.	109.	152.
28.	96.	226.	322.
29.	64.	152.	216.
30.	63.	139.	203.
31.	78.	157.	235.
32.	80.	208.	288.
33.	44.	118.	162.
34.	57.	114.	172.
35.	41.	83.	124.
36.	42.	90.	132.
37.	37.	71.	108.
38.	39.	67.	107.
39.	31.	61.	92.
40.	24.	38.	61.
41.	19.	29.	49.
42.	10.	22.	32.
43.	6.	9.	15.
44.	4.	4.	8.
45.	1.	2.	3.
46.	0.	1.	1.
TOTAL	2542	6225	8767*

* The average total number of hours would vary from 8765 to 8767 depending upon the number of leap years included in the calculation period.

Table 13. Average Hourly Frequencies of Outdoor Temperature for Occupied and Unoccupied Periods for Orlando, Florida

Outdoor Temperature, °F	Occupied Hours Per Year	Unoccupied Hours Per Year	Total*
26.	0.	0.	1.
28.	0.	1.	1.
30.	0.	2.	2.
32.	1.	4.	5.
34.	1.	7.	8.
36.	4.	15.	19.
38.	4.	21.	25.
40.	6.	34.	40.
42.	7.	44.	51.
44.	10.	57.	67.
46.	14.	74.	88.
48.	15.	84.	99.
50.	18.	104.	122.
52.	23.	122.	145.
54.	30.	139.	169.
56.	39.	168.	207.
58.	48.	213.	262.
60.	53.	239.	292.
62.	65.	283.	348.
64.	82.	333.	415.
66.	91.	372.	463.
68.	92.	382.	474.
70.	126.	430.	555.
72.	136.	586.	723.
74.	178.	713.	891.
76.	198.	565.	763.
78.	201.	347.	548.
80.	208.	246.	454.
82.	201.	186.	387.
84.	188.	143.	331.
86.	163.	117.	280.
88.	147.	92.	239.
90.	107.	57.	165.
92.	56.	33.	89.
94.	22.	10.	33.
96.	4.	1.	5.
98.	1.	0.	1.
TOTAL	2542	6225	8767**

* Due to rounding-off arithmetics, the total hours may not exactly match the sum of occupied and unoccupied hours.

** The average total number of hours would vary from 8765 to 8767 depending upon number of leap years included in the calculation period.

Table 14. Average Hourly Frequencies of Outdoor Air Enthalpy for Occupied and Unoccupied Periods for Orlando, Florida

Outdoor Air Enthalpy, Btu/lb	Occupied Hours Per Year	Unoccupied Hours Per Year	Total
8.	0.	1.	1.
9.	0.	3.	3.
10.	1.	4.	5.
11.	3.	8.	11.
12.	8.	23.	31.
13.	7.	26.	33.
14.	11.	42.	53.
15.	14.	55.	69.
16.	20.	71.	91.
17.	27.	93.	120.
18.	29.	101.	130.
19.	32.	120.	151.
20.	43.	143.	186.
21.	47.	159.	206.
22.	29.	94.	123.
23.	71.	219.	290.
24.	61.	166.	227.
25.	59.	221.	280.
26.	89.	214.	303.
27.	87.	281.	368.
28.	72.	205.	276.
29.	166.	402.	569.
30.	102.	258.	361.
31.	97.	236.	333.
32.	116.	265.	381.
33.	200.	381.	581.
34.	121.	380.	501.
35.	117.	385.	503.
36.	120.	406.	525.
37.	137.	416.	553.
38.	200.	417.	617.
39.	175.	221.	396.
40.	168.	141.	309.
41.	83.	55.	138.
42.	20.	11.	31.
43.	7.	2.	9.
44.	1.	0.	1.
TOTAL	2542	6225	8767 *

* The average total number of hours would vary from 8765 to 8767 depending upon the number of leap years included in the calculation period.

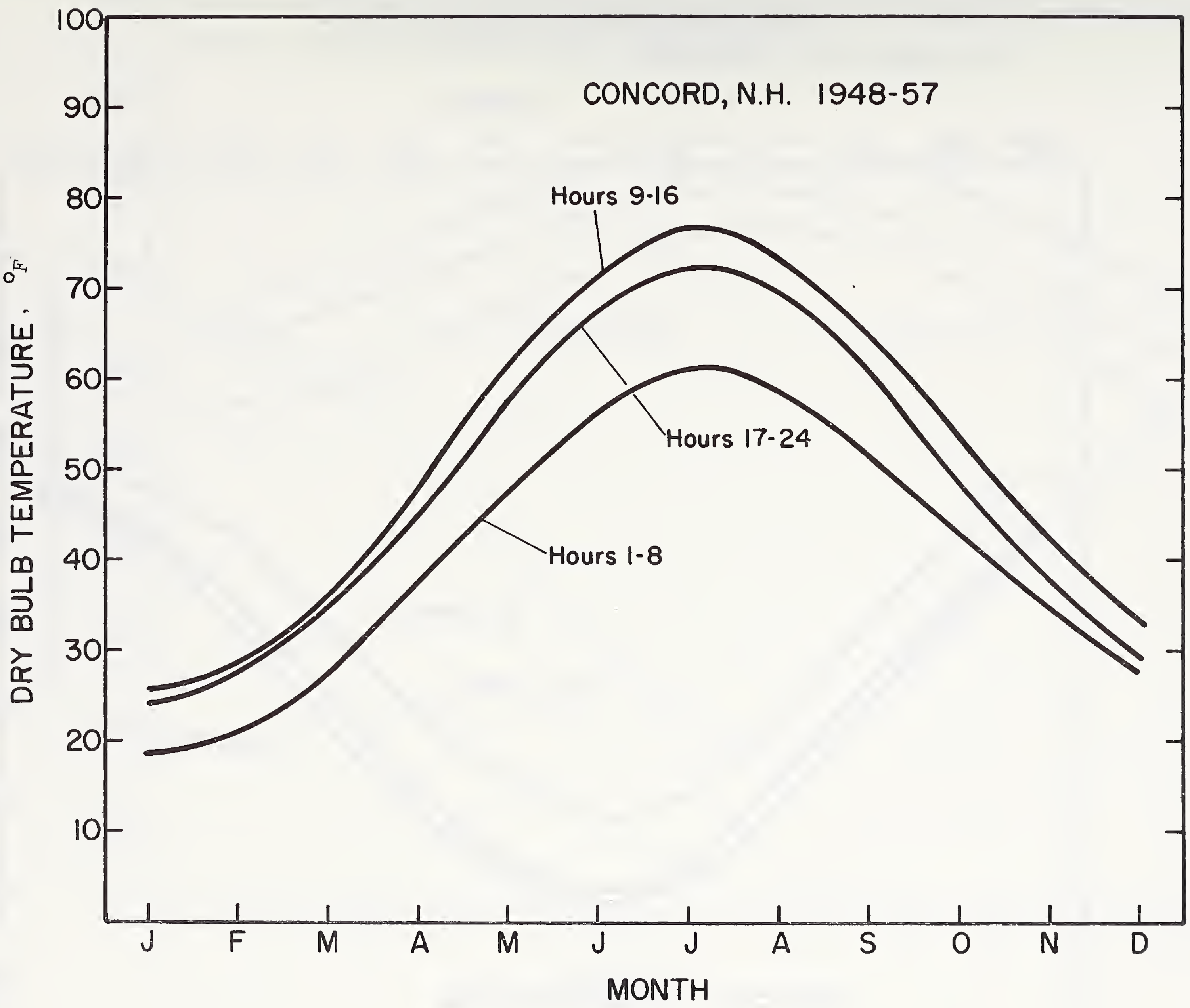


Figure 1. Monthly Average Outdoor Temperature for Three Daily Time Periods in Concord, New Hampshire.

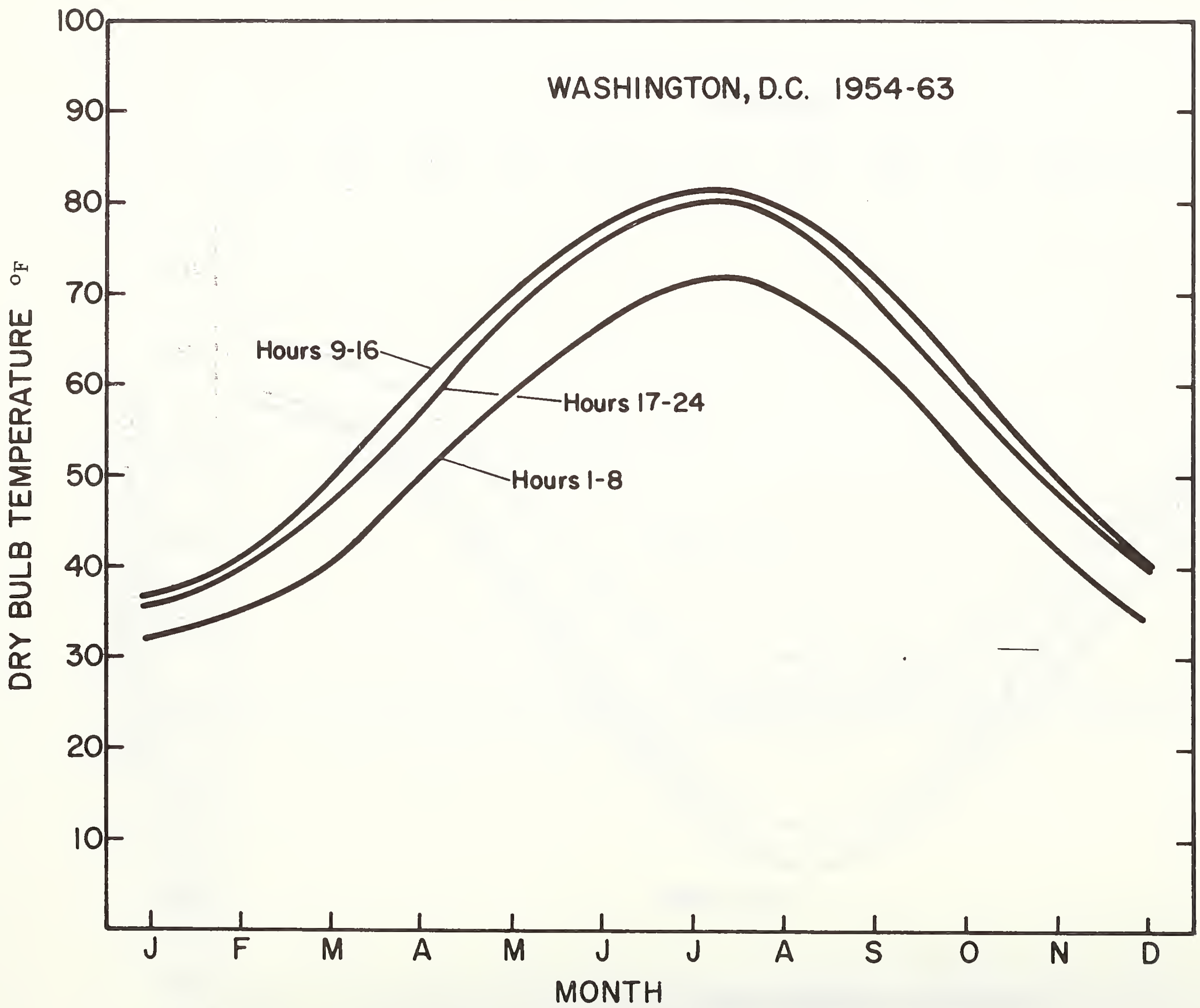


Figure 2. Monthly Average Outdoor Temperature for Three Daily Time Periods in Washington, D.C.

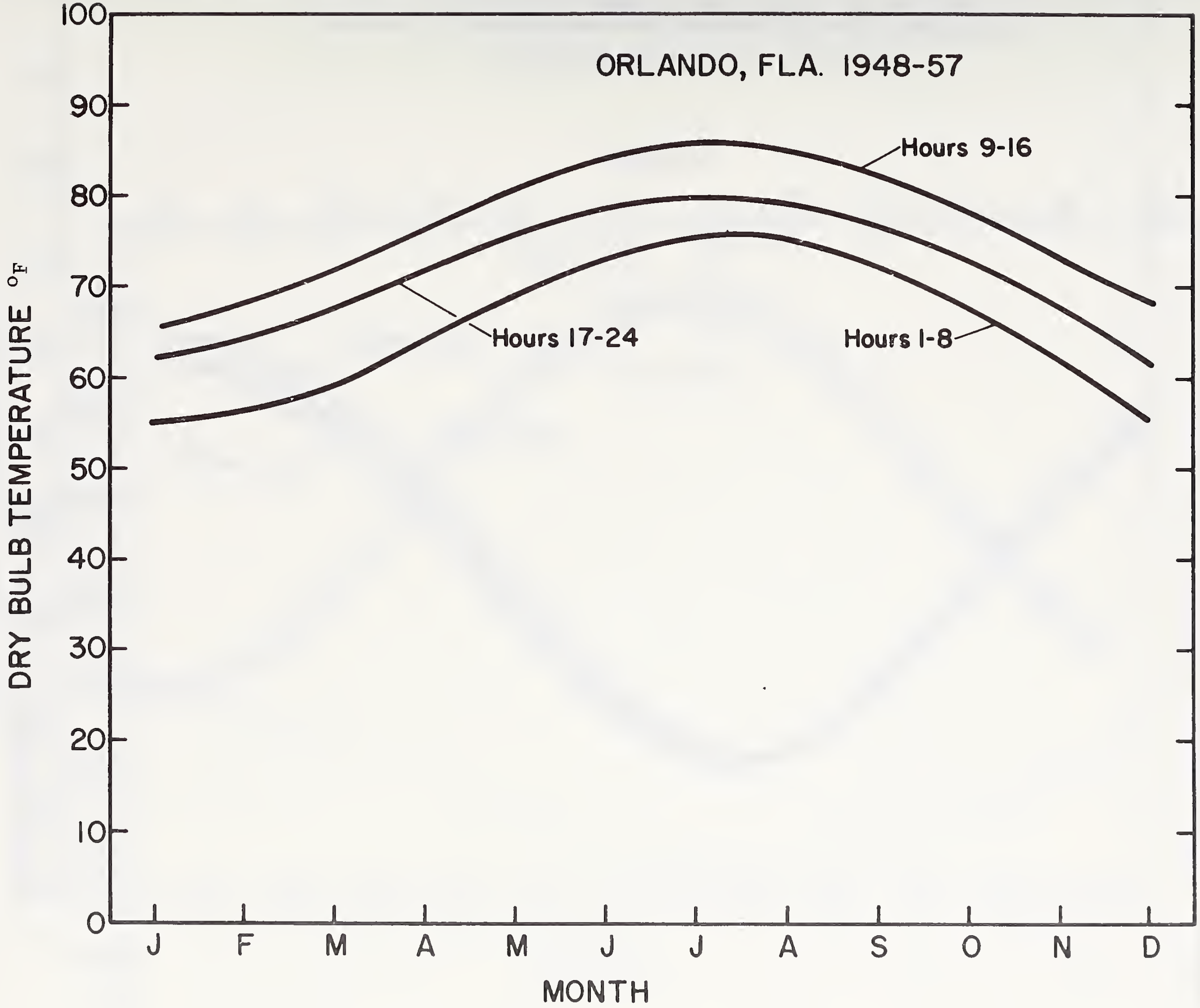


Figure 3. Monthly Average Outdoor Temperature for Three Daily Time Periods in Orlando, Florida.

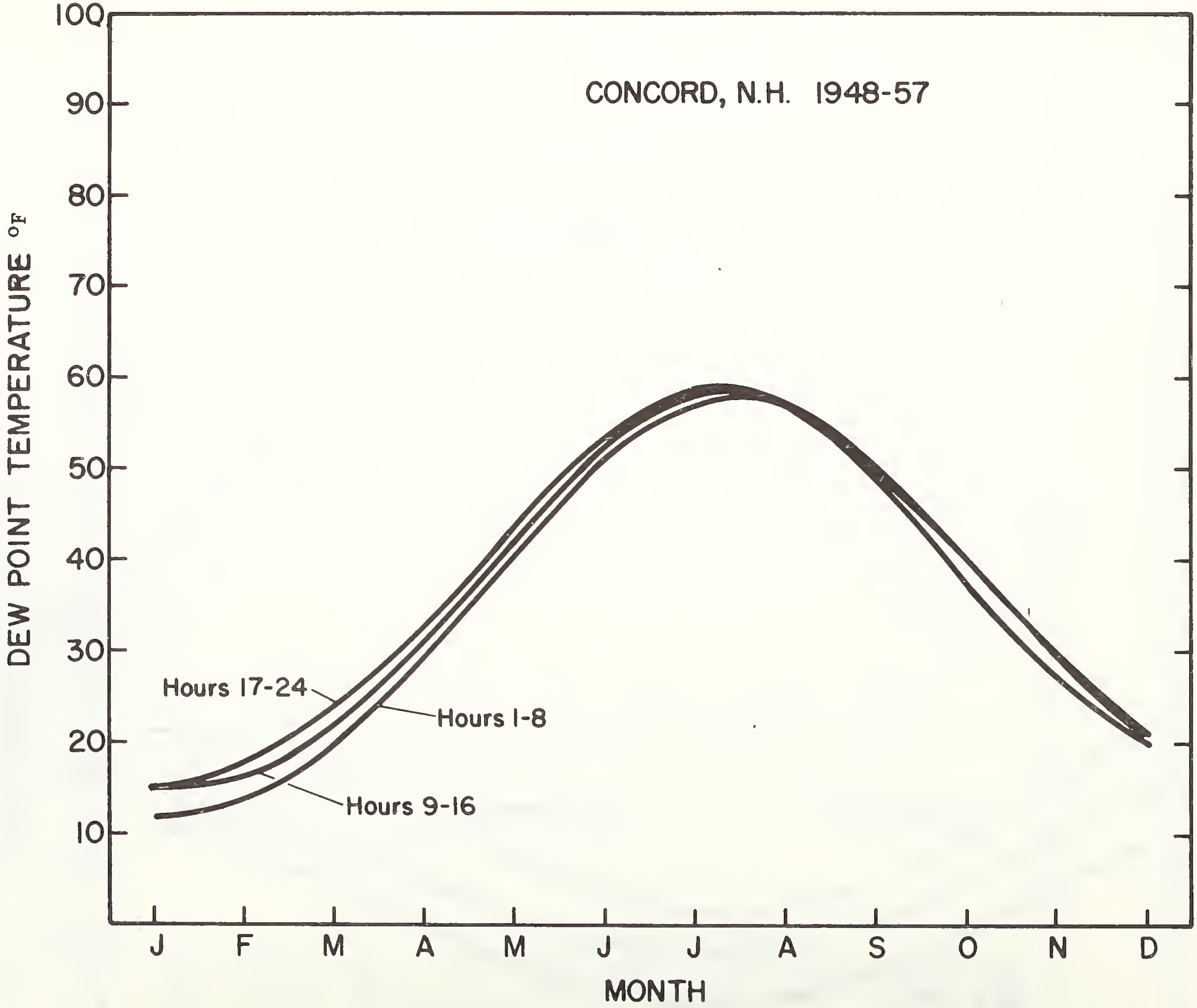


Figure 4. Monthly Average Outdoor Dewpoint Temperature for Three Daily Time Periods in Concord, New Hampshire.

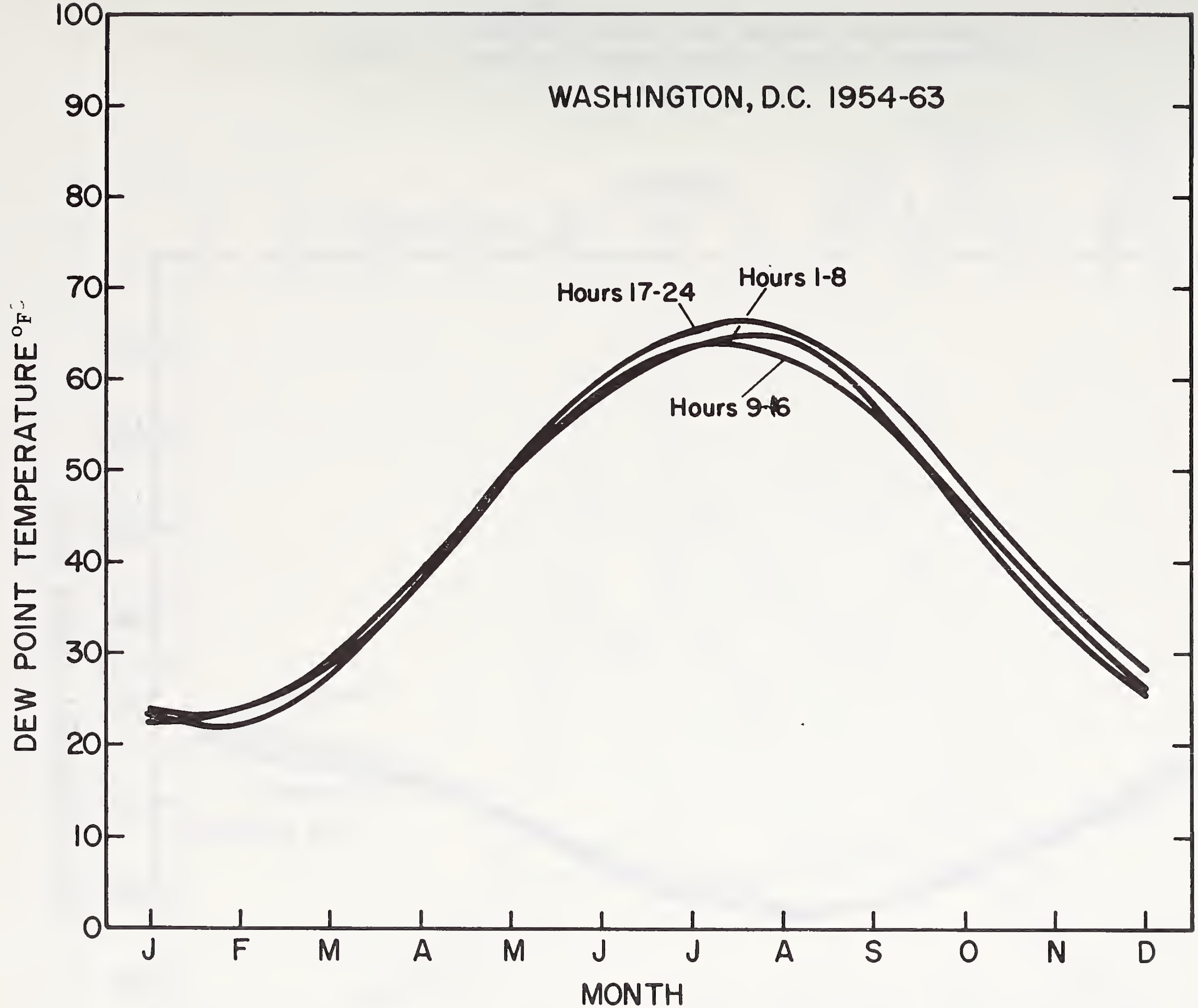


Figure 5. Monthly Average Outdoor Dewpoint Temperature for Three Daily Time Periods in Washington, D. C.

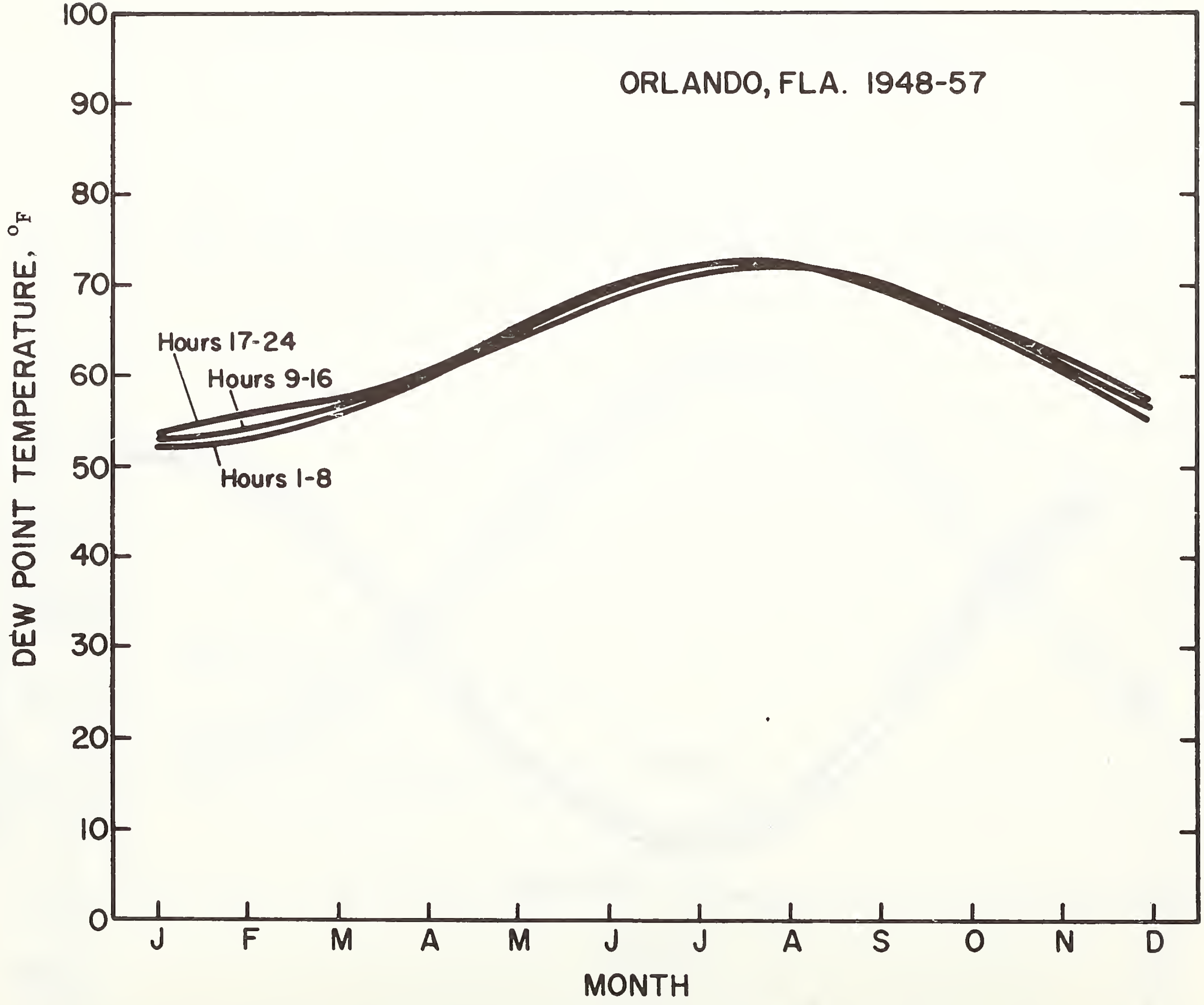
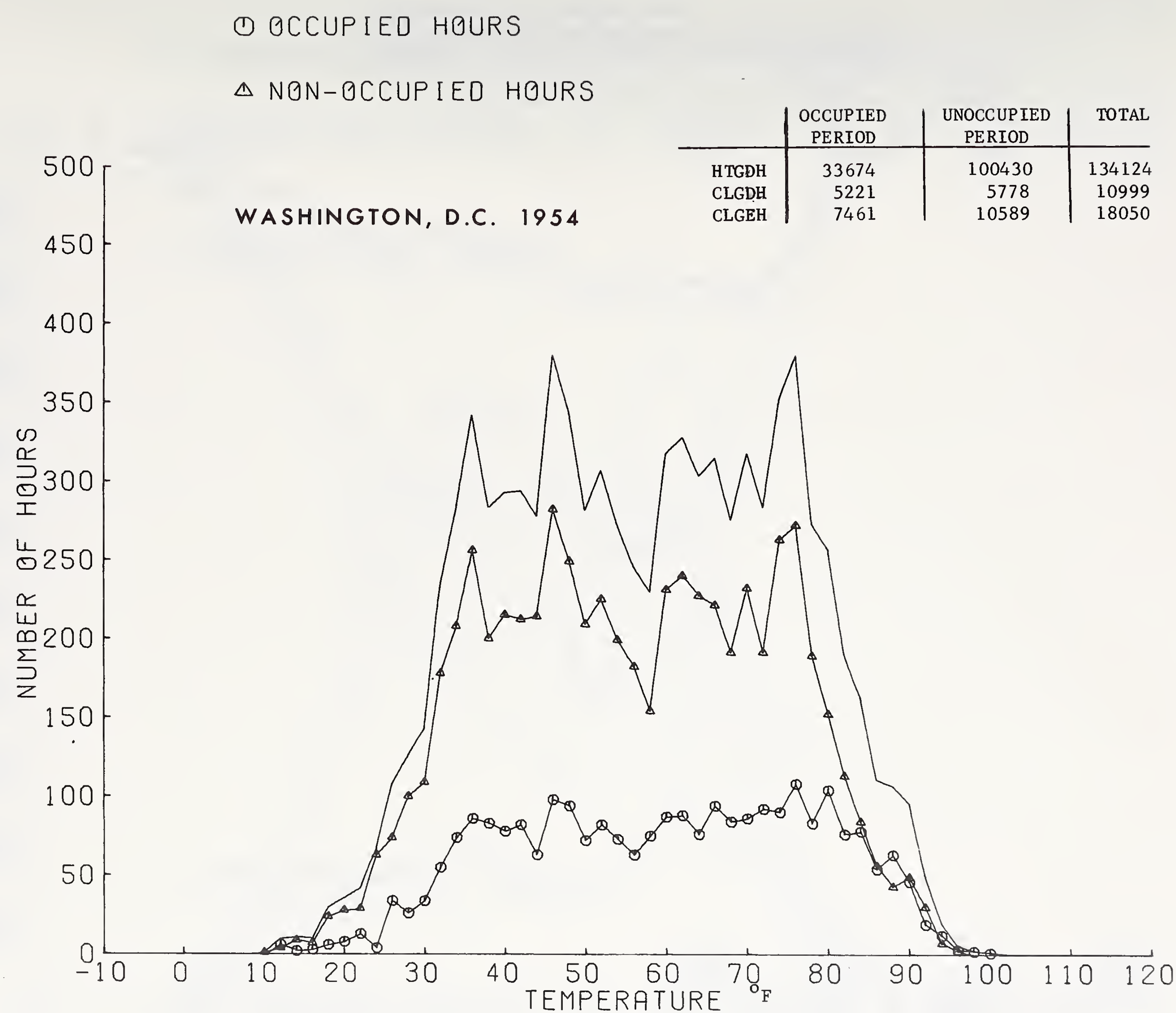


Figure 6. Monthly Average Outdoor Dewpoint Temperature for Three Daily Time Periods for Orlando, Florida.



	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	33674	100430	134124
CLGDH	5221	5778	10999
CLGEH	7461	10589	18050

Figure 7. Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1954 Washington, D.C. Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	36040	102650	138690
CLGDH	4709	5555	10264
CLGEH	8003	13109	21112

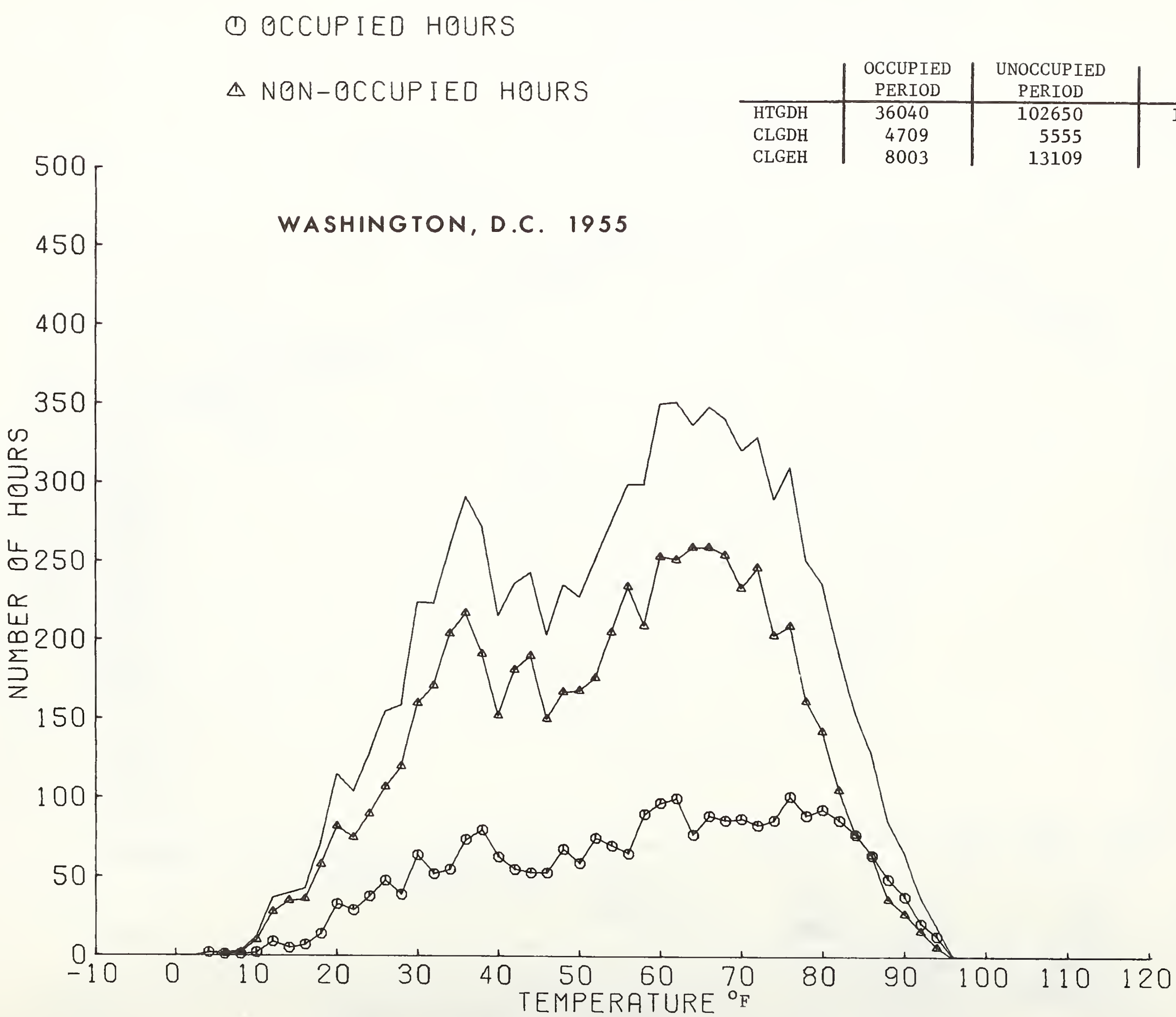


Figure 8. Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1955 Washington, D.C. Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	35504	106486	141990
CLGDH	3450	4212	7662
CLGEH	5530	8958	14488

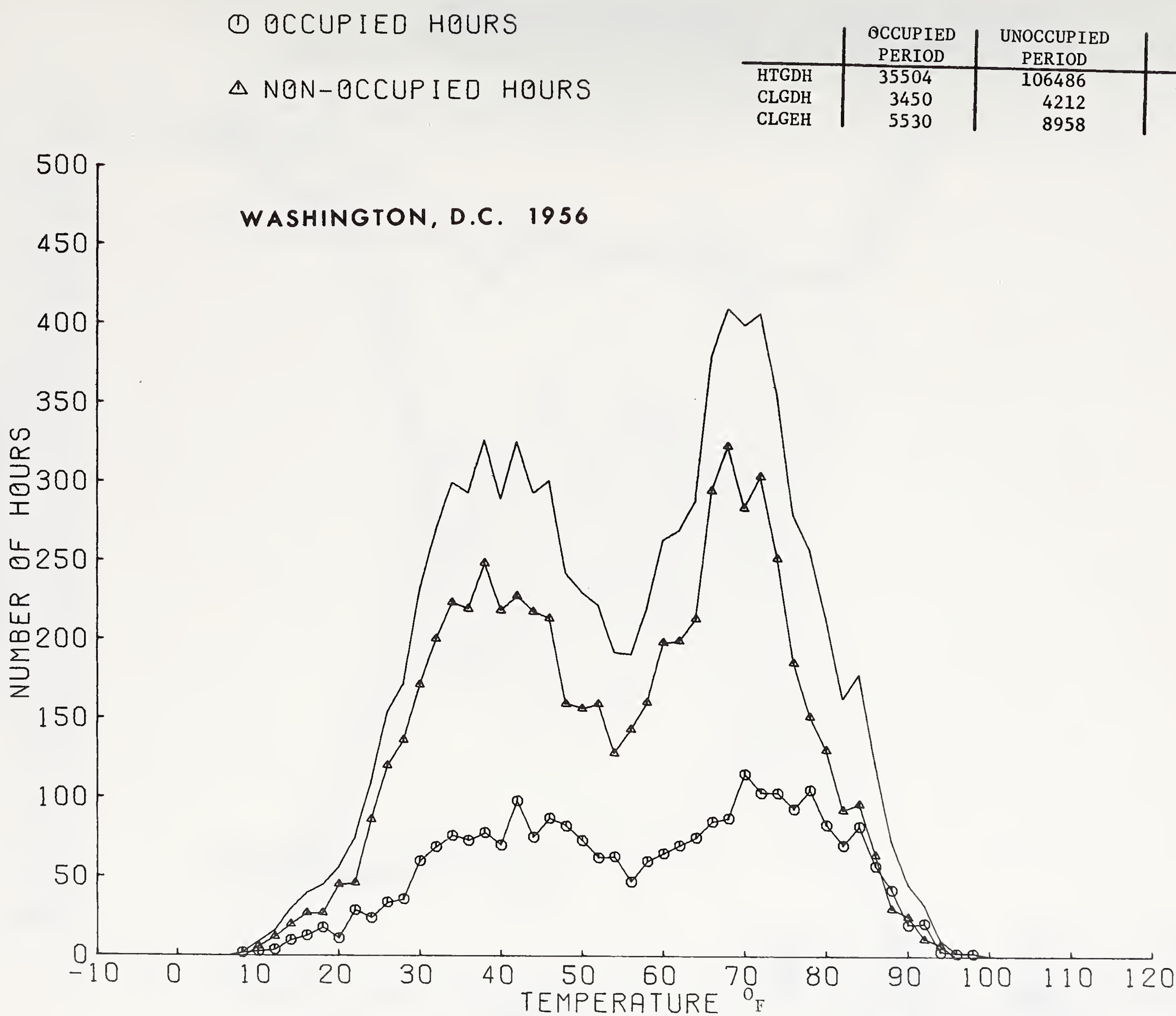
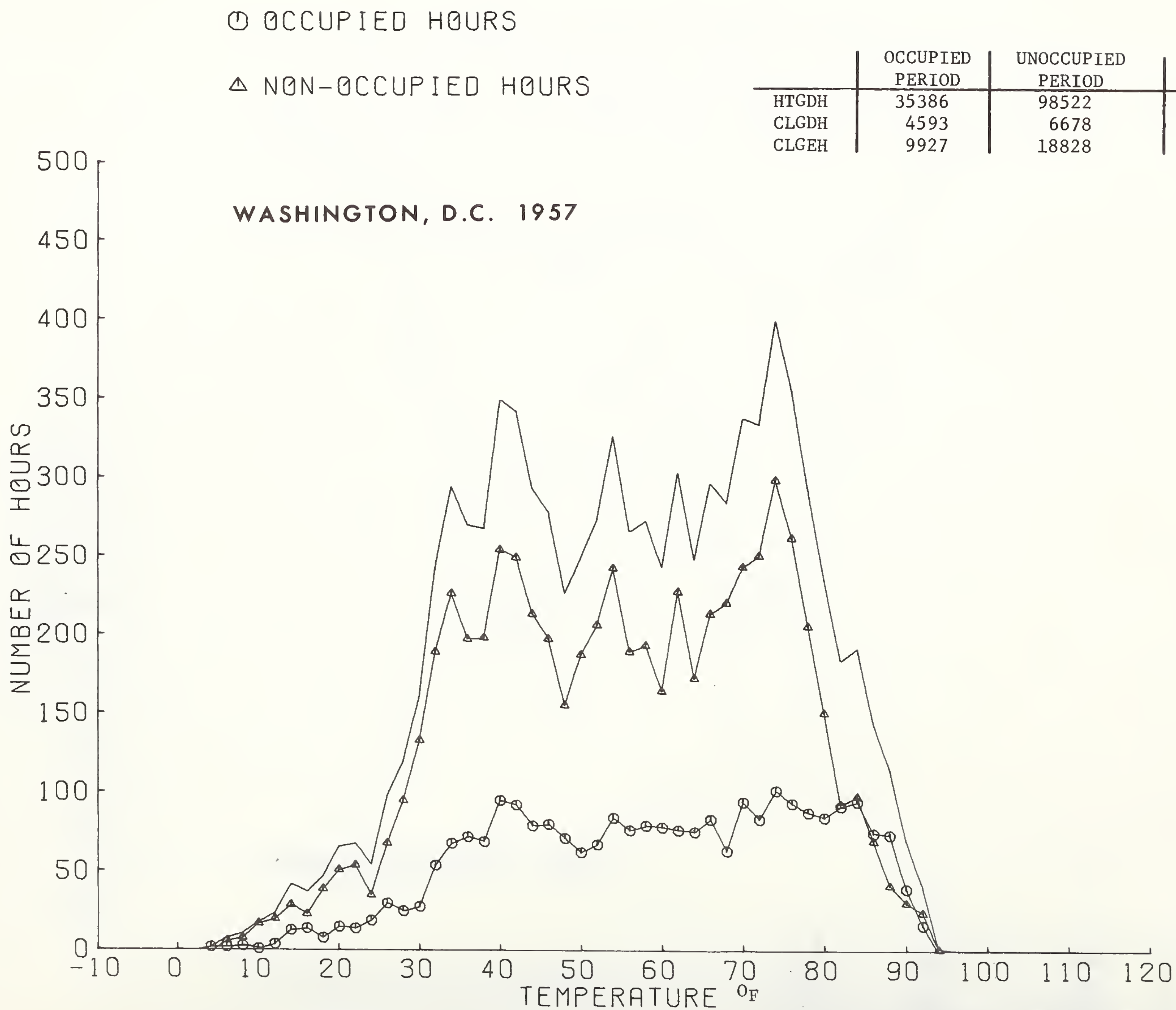


Figure 9. Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1956 Washington, D.C. Weather Data



	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	35386	98522	133908
CLGDH	4593	6678	11271
CLGEH	9927	18828	28755

Figure 10. Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1957 Washington, D.C. Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	39402	109772	149174
CLGDH	3234	3982	7216
CLGEH	4512	6598	11110

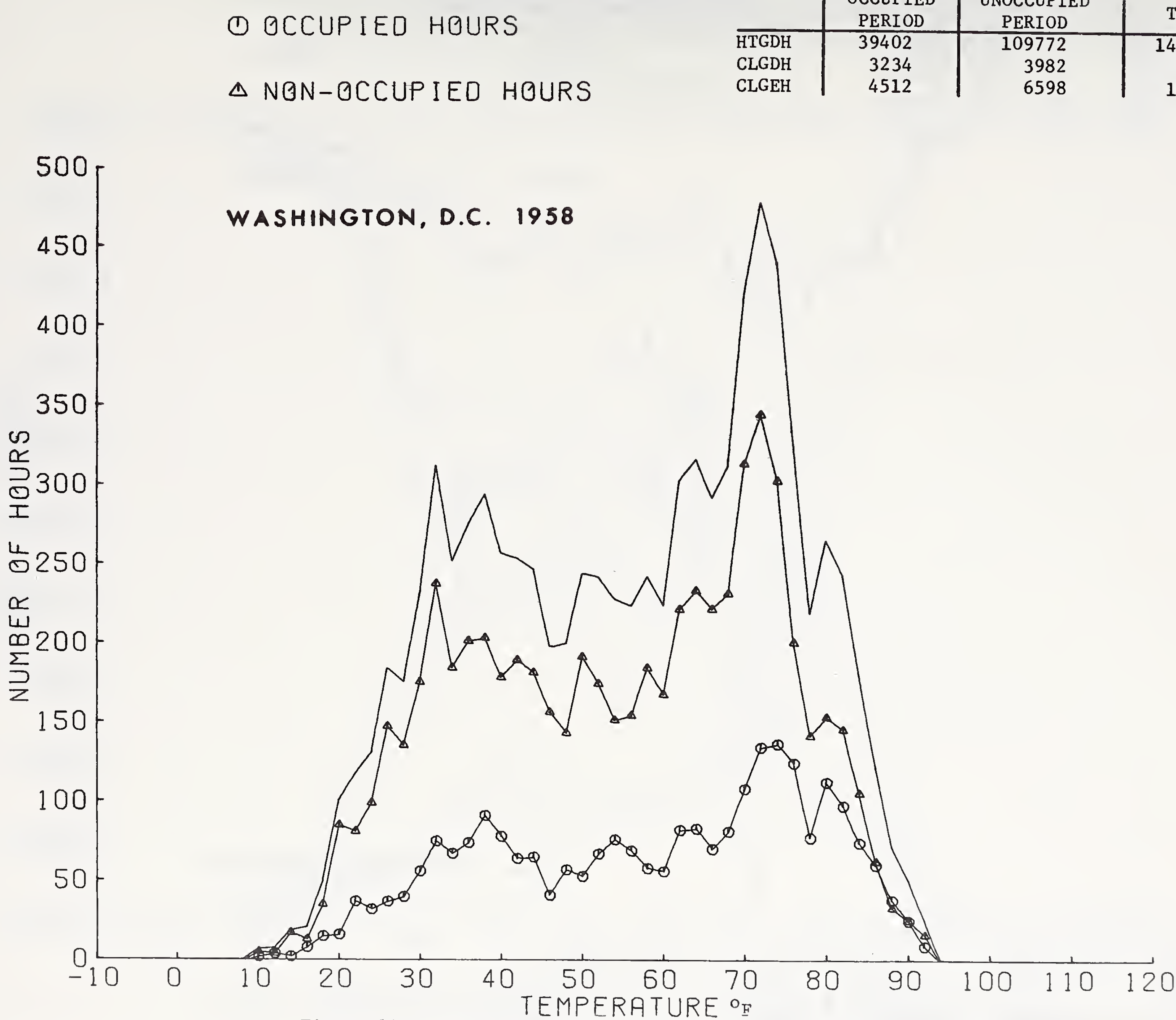


Figure 11. Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1958 Washington, D.C. Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	34450	95156	129606
CLGDH	5844	7469	13313
CLGEH	13053	26358	39410

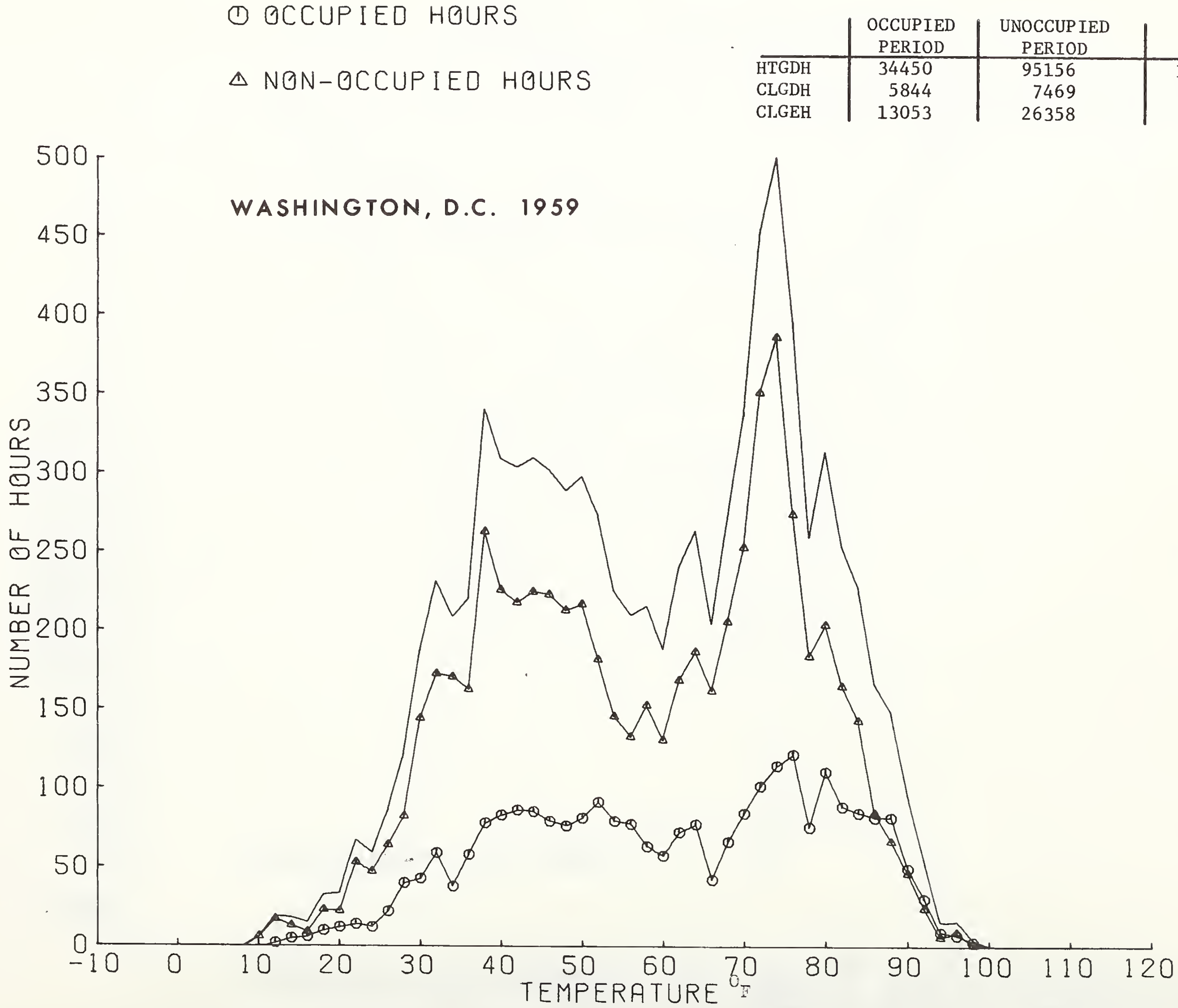
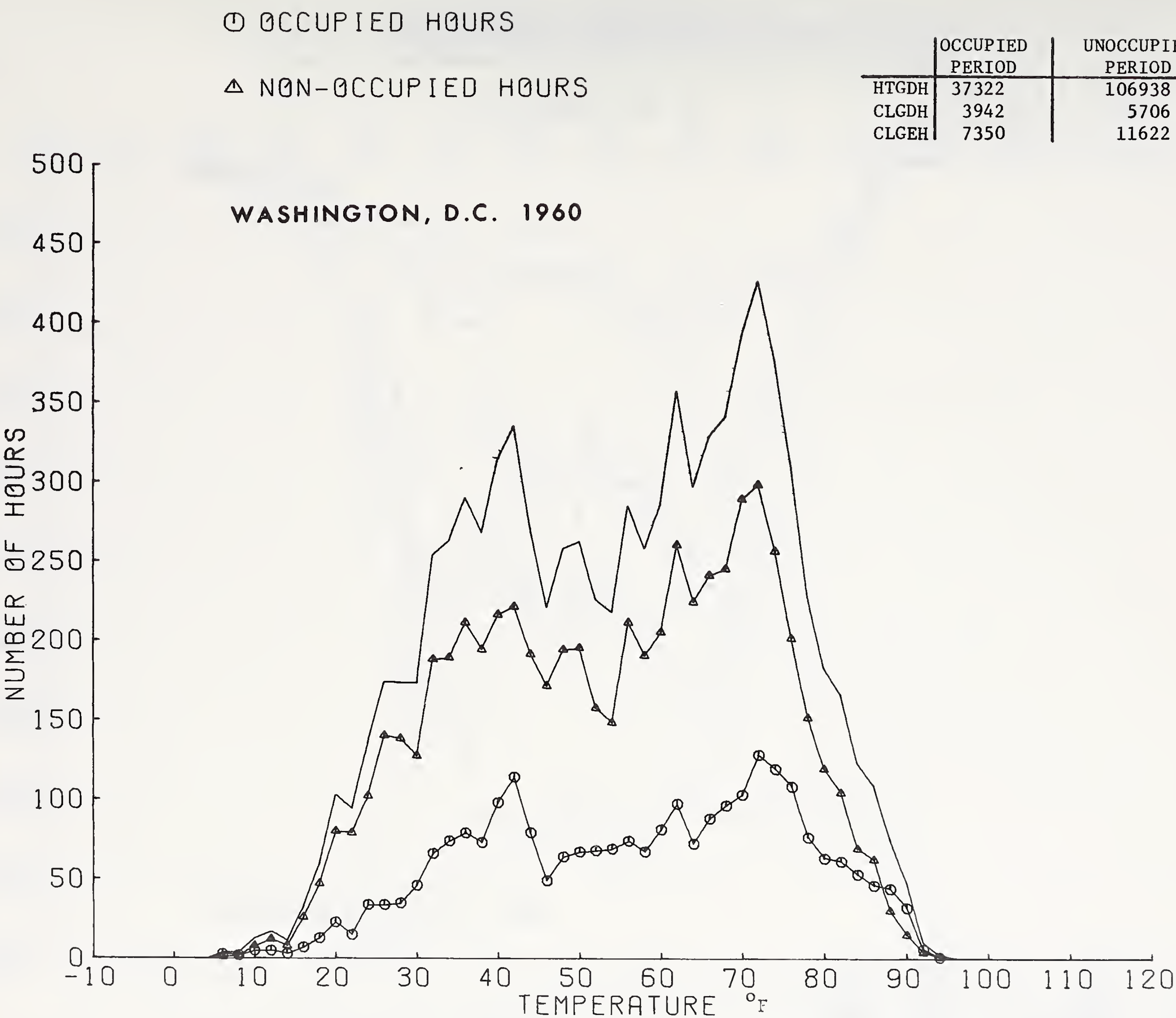


Figure 12. Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1959 Washington, D.C. Weather Data



	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	37322	106938	144260
CLGDH	3942	5706	9048
CLGEH	7350	11622	18971

Figure 13. Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1960 Washington, D.C. Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	36640	105690	142330
CLGDH	4877	5312	10189
CLGEH	9777	17063	26840

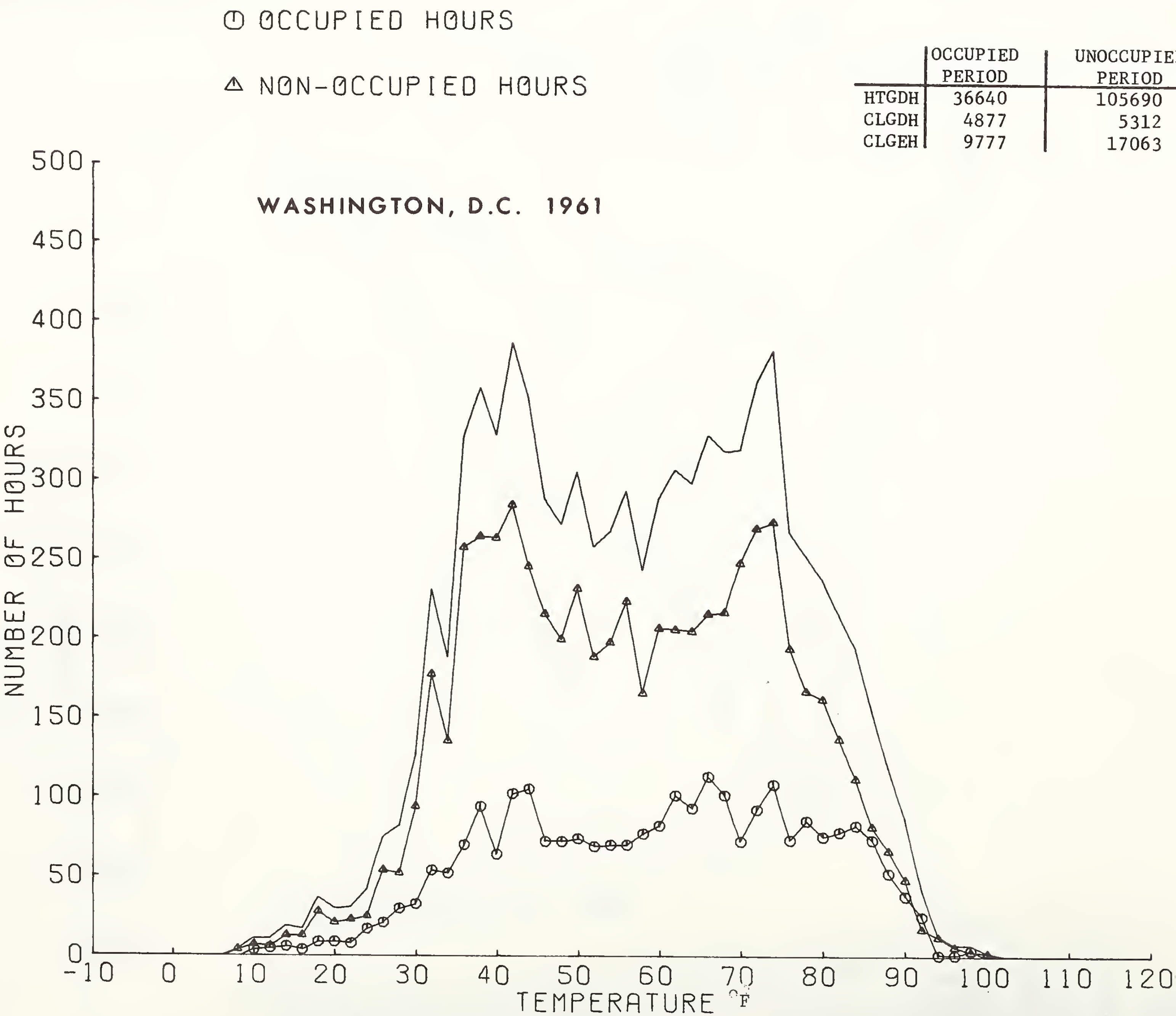
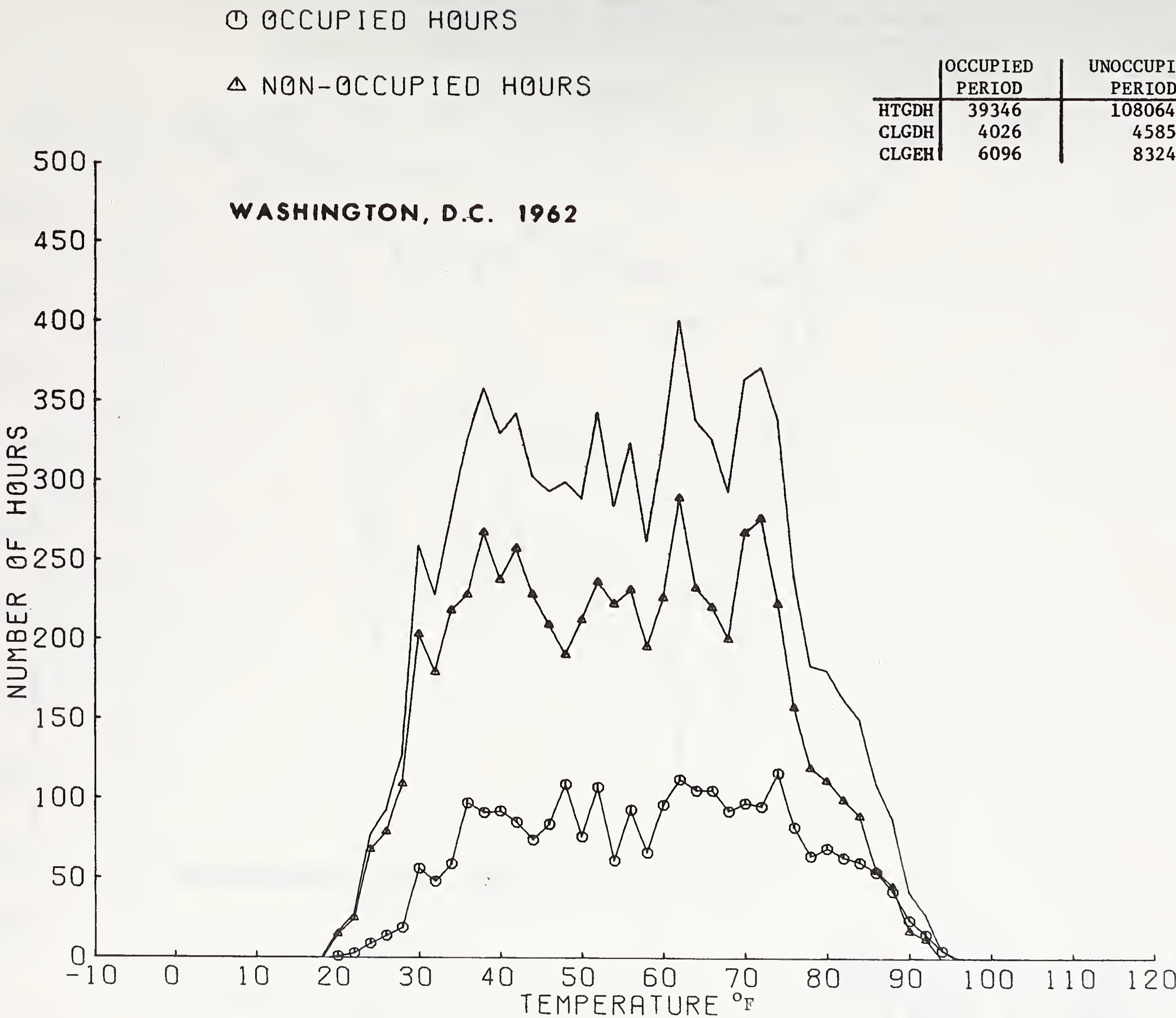
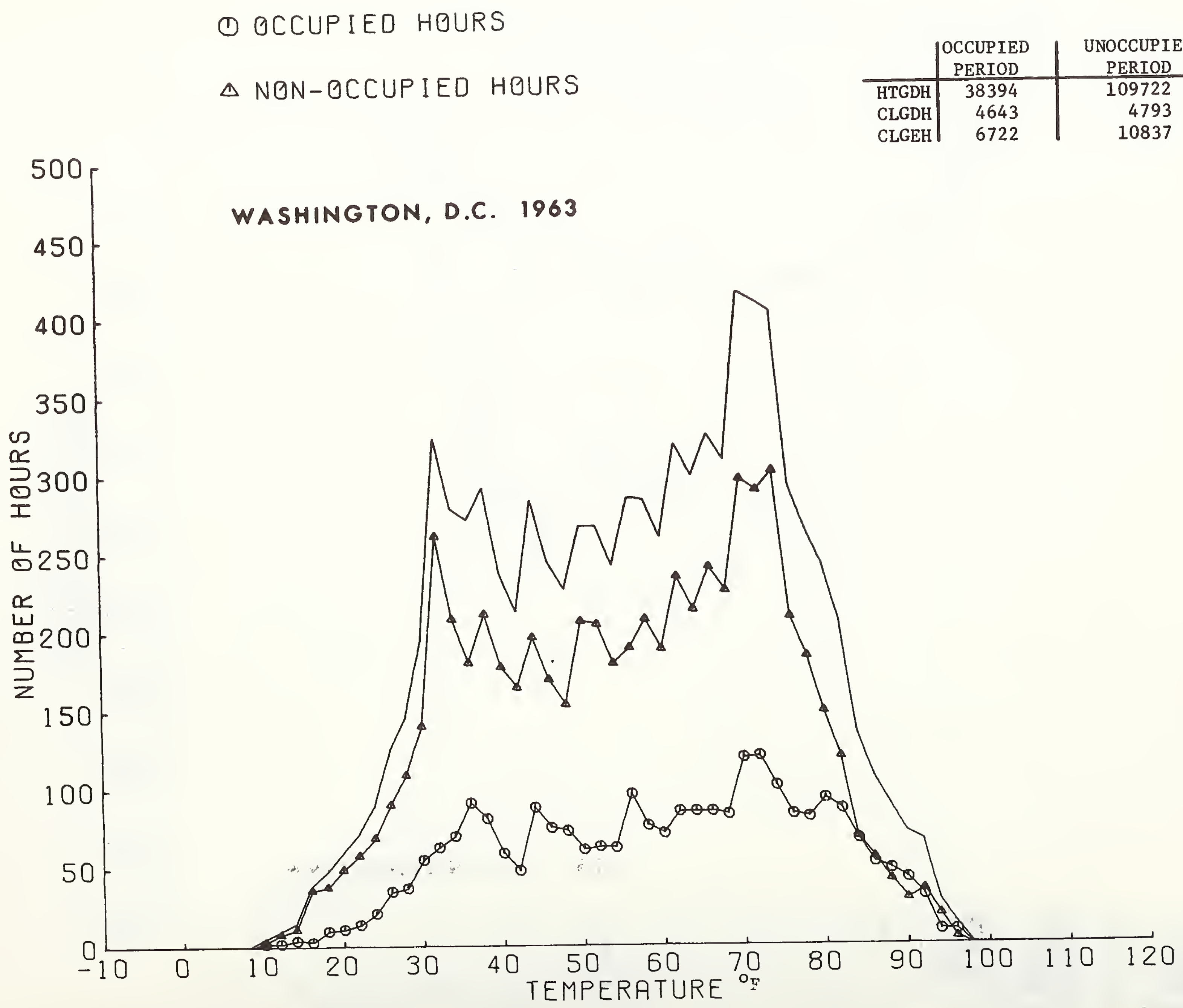


Figure 14. Histogram for Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1961 Washington, D.C. Weather Data



	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	39346	108064	147410
CLGDH	4026	4585	8611
CLGEH	6096	8324	14419

Figure 15. Histogram for Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1962 Washington, D.C. Weather Data



	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	38394	109722	148116
CLGDH	4643	4793	9436
CLGEH	6722	10837	17559

Figure 16. Histogram for Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1963 Washington, D.C. Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	35558	102148	137706
CLGDH	4899	5741	10640
CLGEH	5797	8930	14728

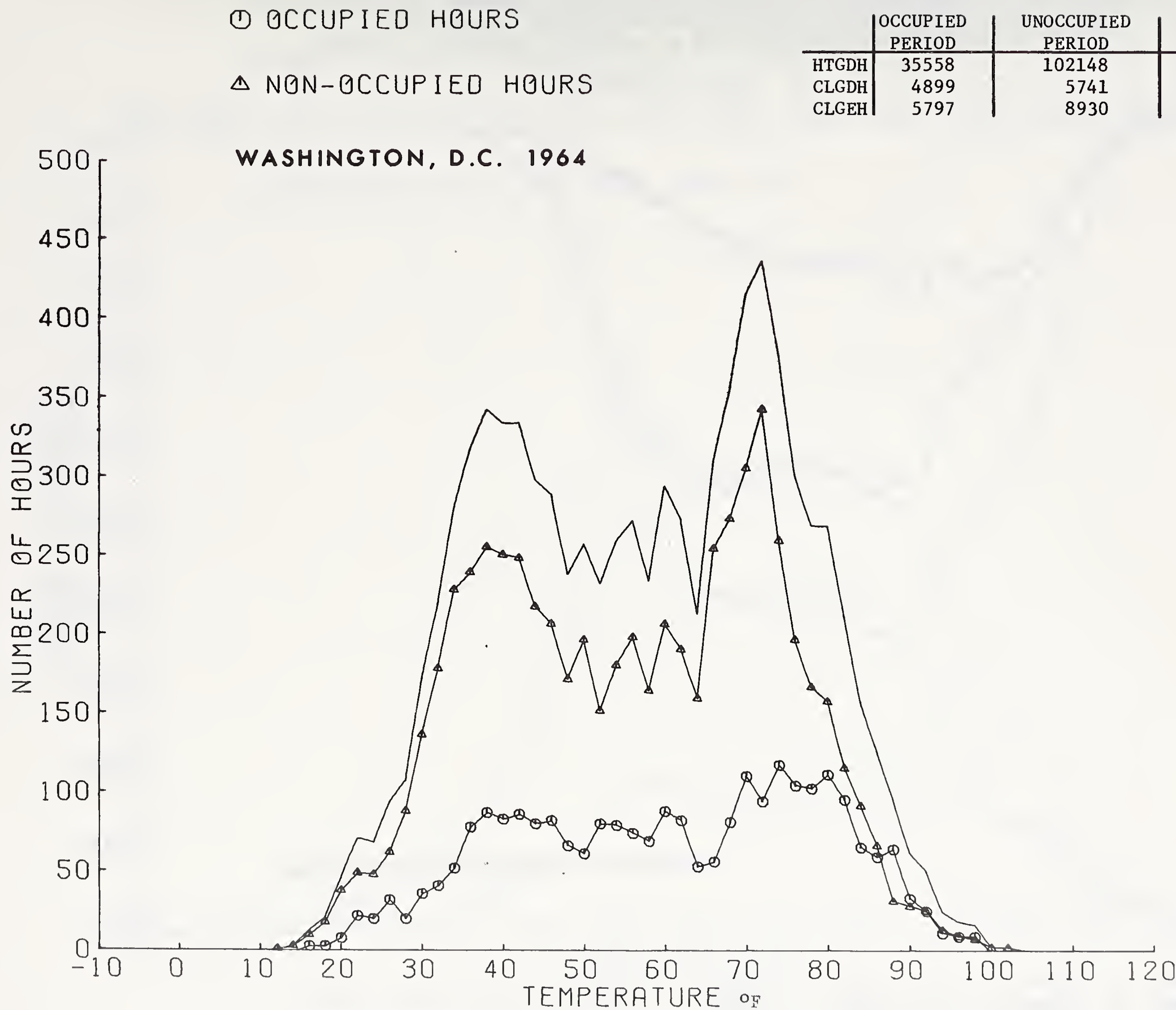
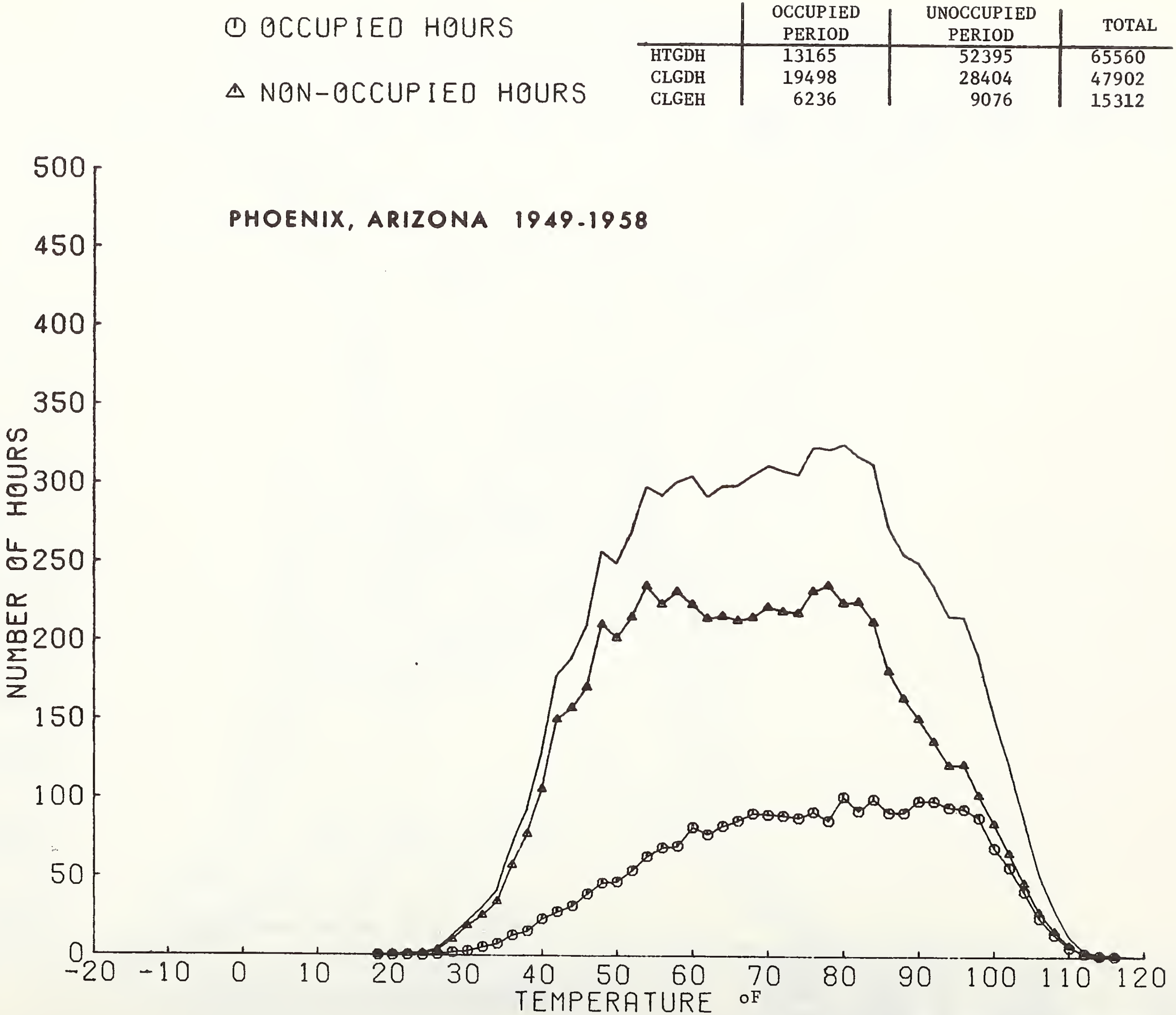


Figure 17. Histogram for Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1964 Washington, D.C. Weather Data



	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	13165	52395	65560
CLGDH	19498	28404	47902
CLGEH	6236	9076	15312

Figure 18. Average Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1949-1958 Phoenix, Arizona Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	53281	164474	216855
CLGDH	2339	1886	4225
CLGEH	3897	4505	8402

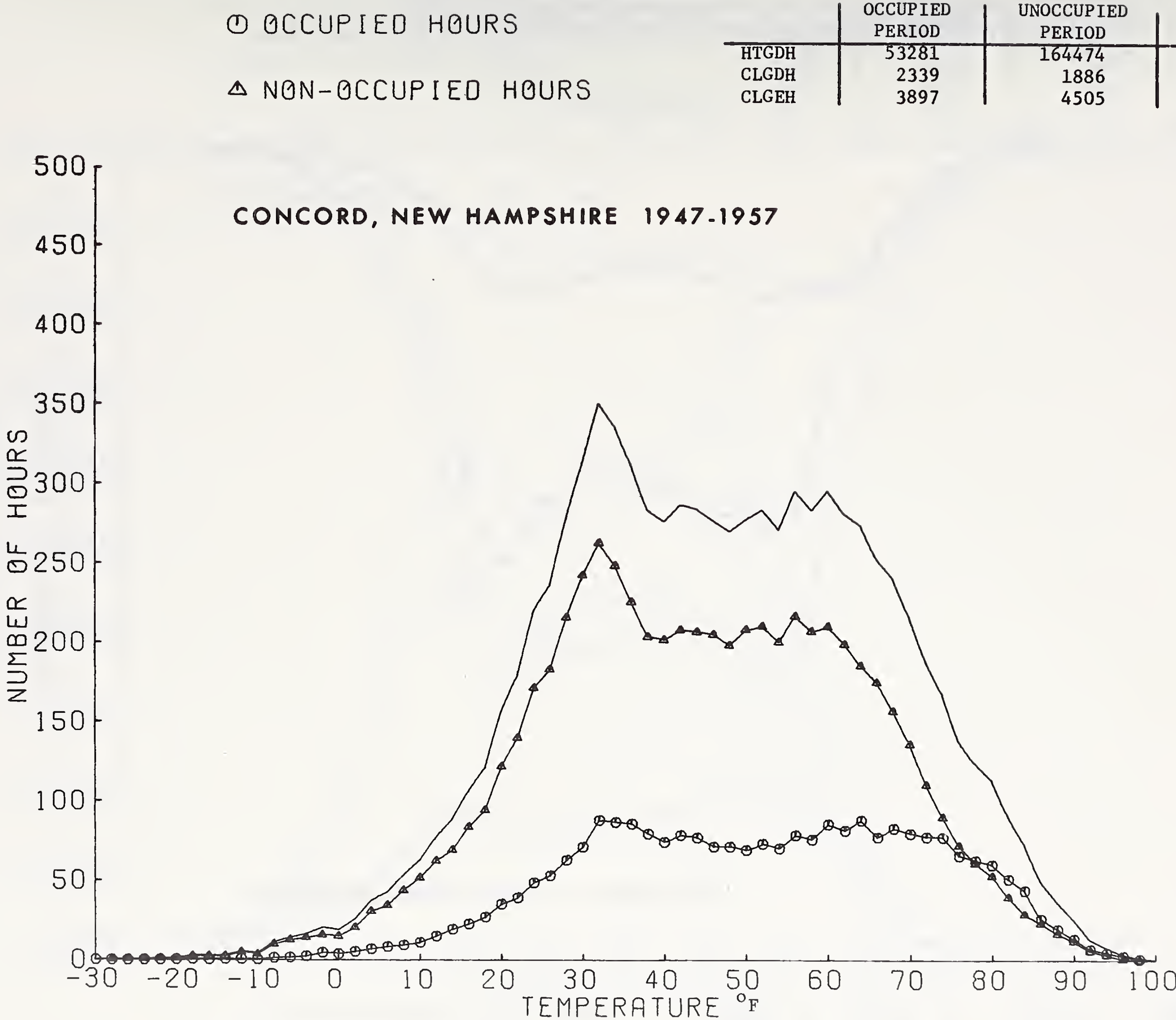


Figure 19. Average Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1947-1956 Concord, New Hampshire Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	39773	117491	157264
CLGDH	3645	3465	7111
CLGEH	6037	8656	14693

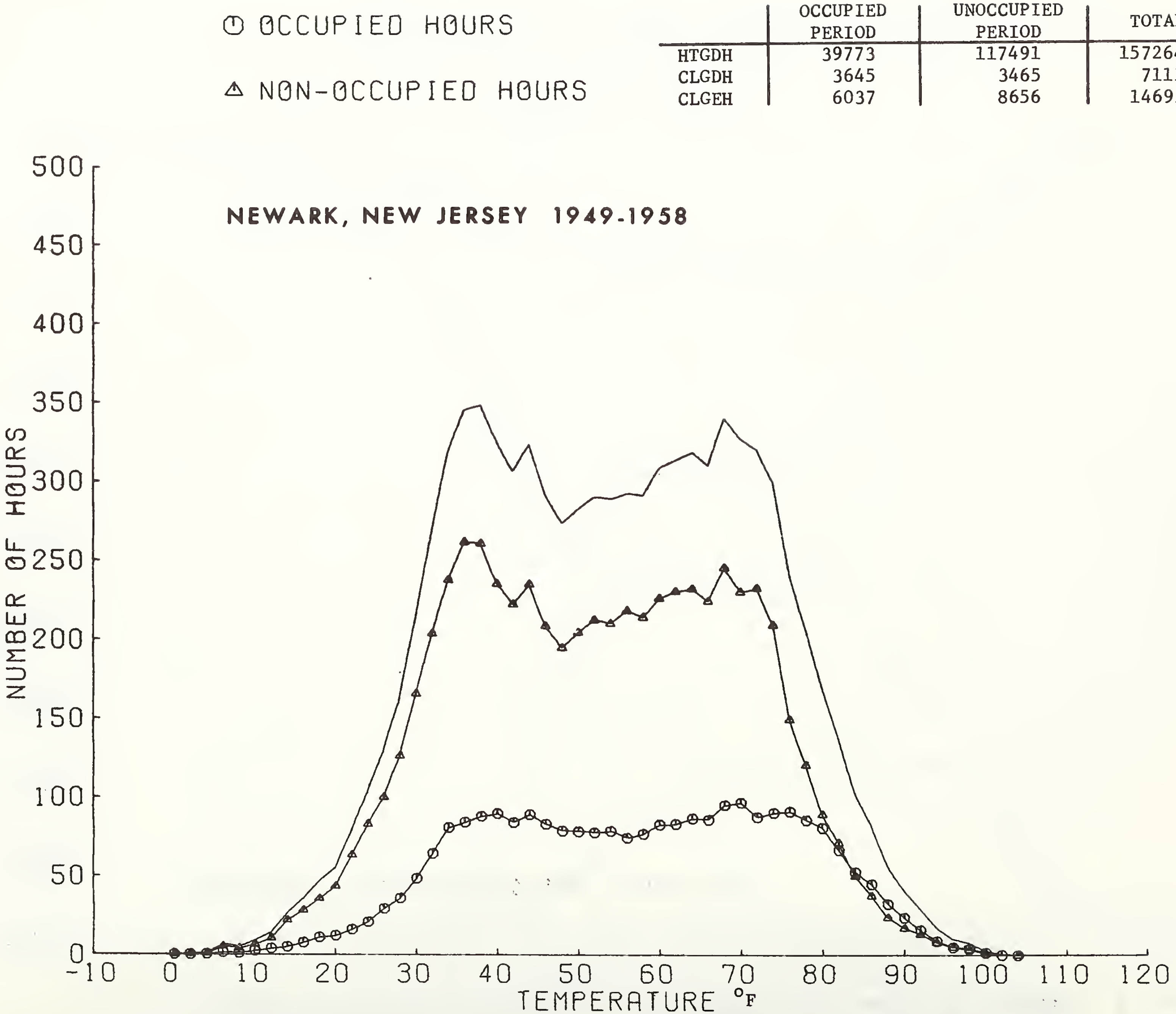


Figure 20. Average Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1949-1958 Newark, New Jersey Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	36520	104143	140663
CLGDH	4494	5383	9877
CLGEH	7657	12838	20495

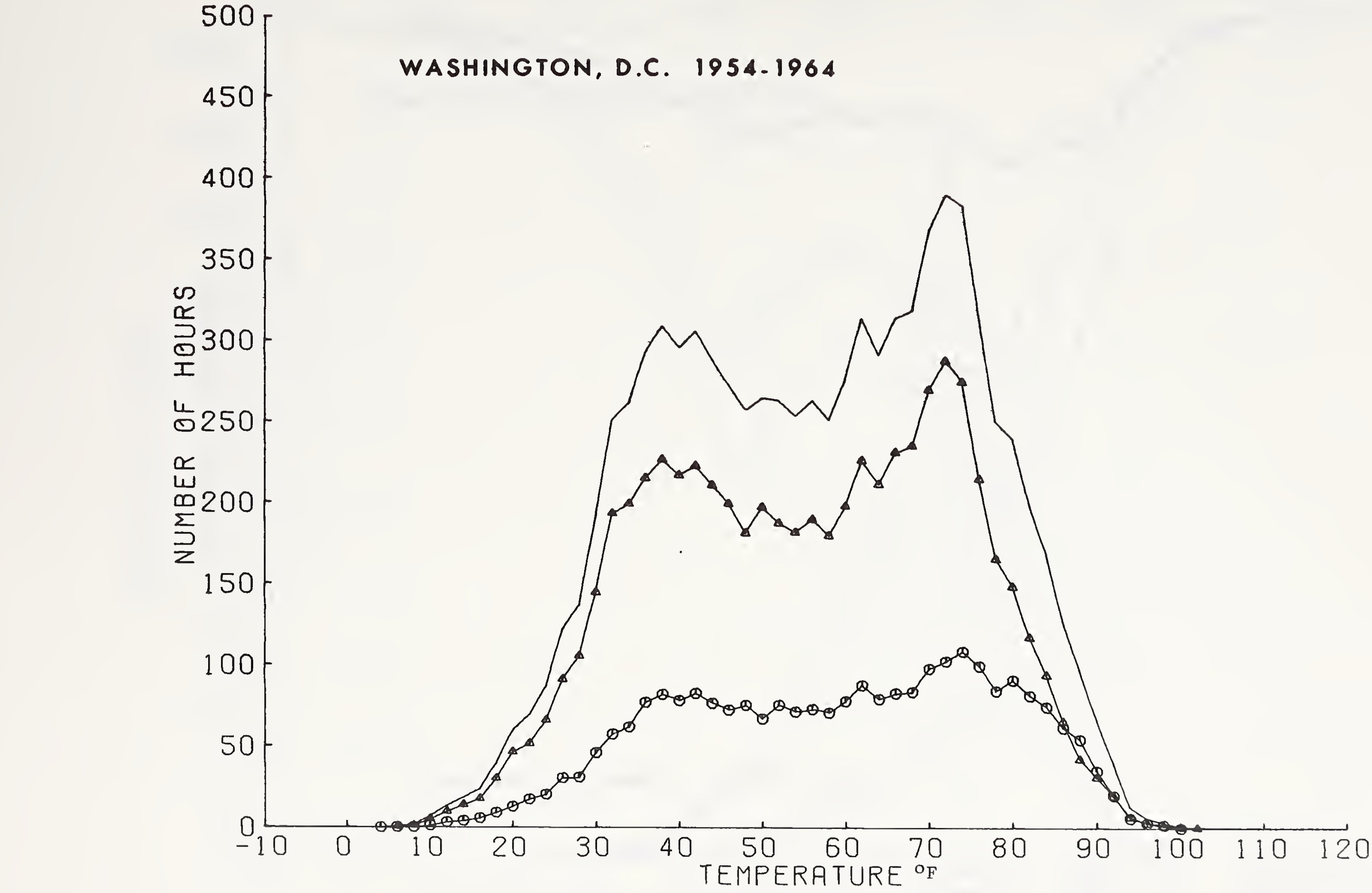


Figure 21. Average Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1954-1964 Washington, D.C. Weather Data

⊕ OCCUPIED HOURS

△ NON-OCCUPIED HOURS

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	49227	138551	187778
CLGDH	4748	5966	10714
CLGEH	5079	7898	12977

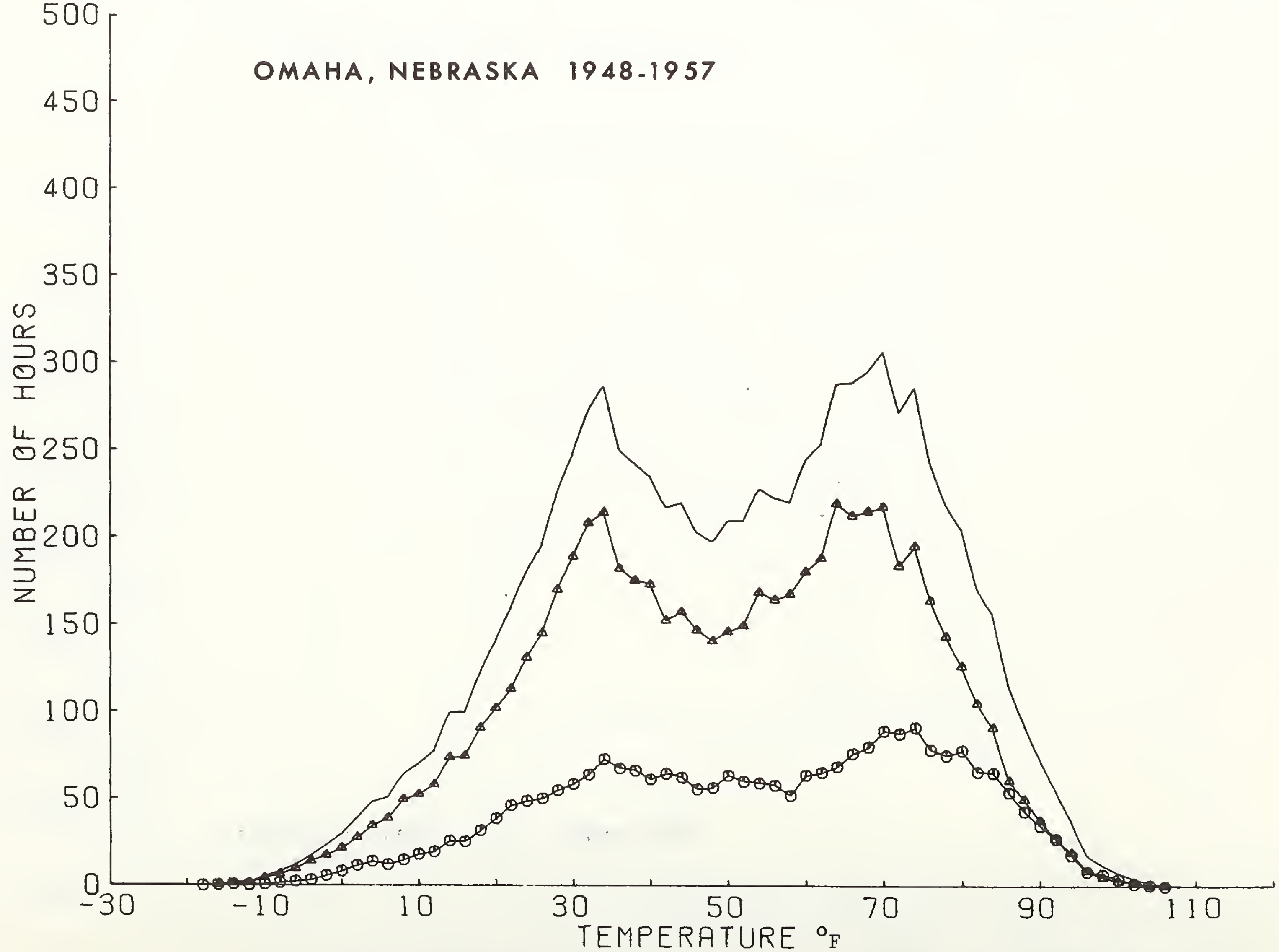


Figure 22. Average Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1948-1957 Omaha, Nebraska Weather Data

	OCCUPIED PERIOD	UNOCCUPIED PERIOD	TOTAL
HTGDH	6163	29388	35551
CLGDH	11730	9577	21286
CLGEH	20045	31287	51331

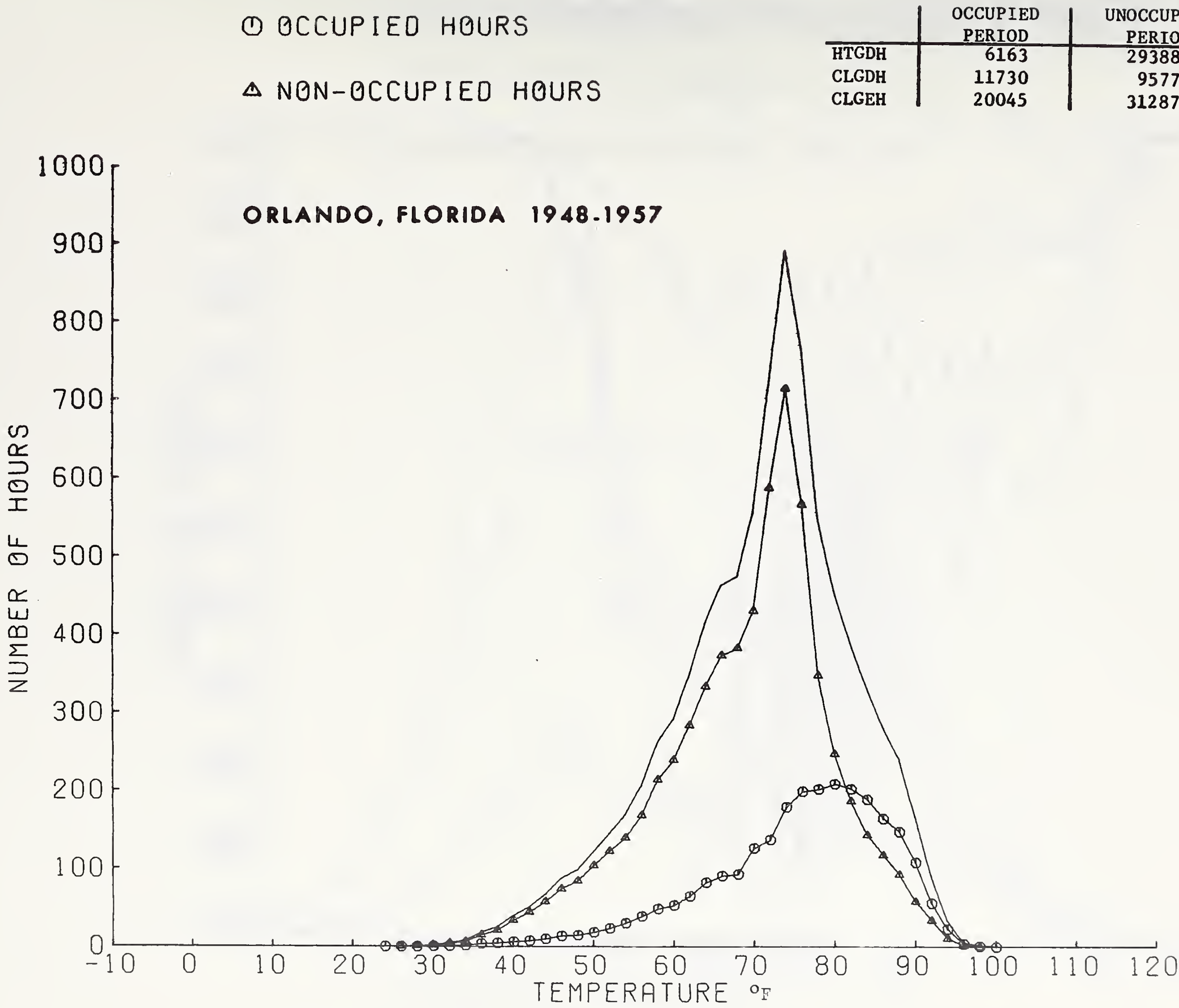


Figure 23. Average Histogram of Hourly Outdoor Dry-Bulb Temperature; Total, Occupied and Non-Occupied Periods for 1948-1957 Orlando, Florida Weather Data

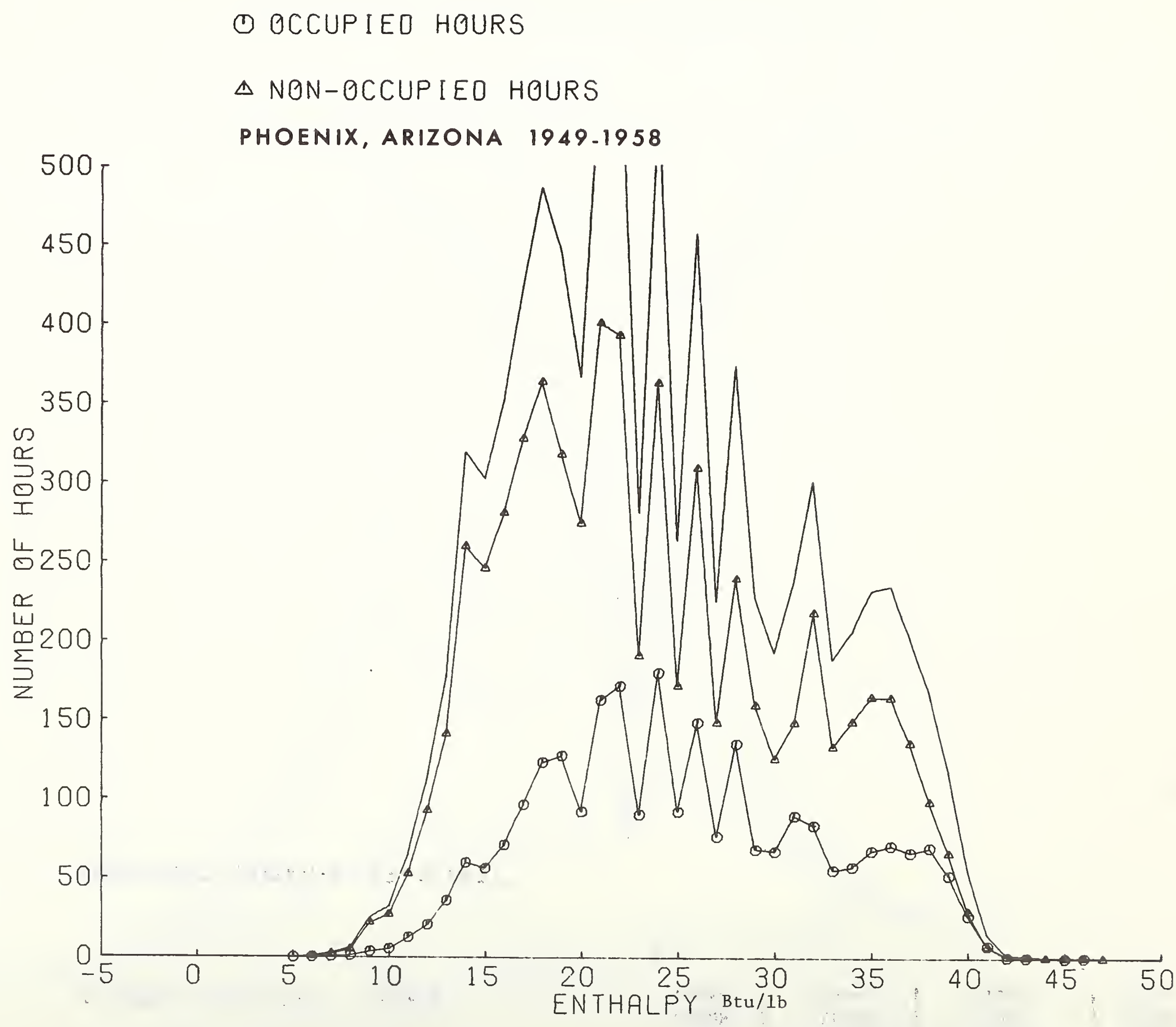


Figure 24. Average Histogram of Hourly Enthalpy; Total, Occupied and Non-Occupied Periods for 1949-1958, Phoenix, Arizona Weather Data

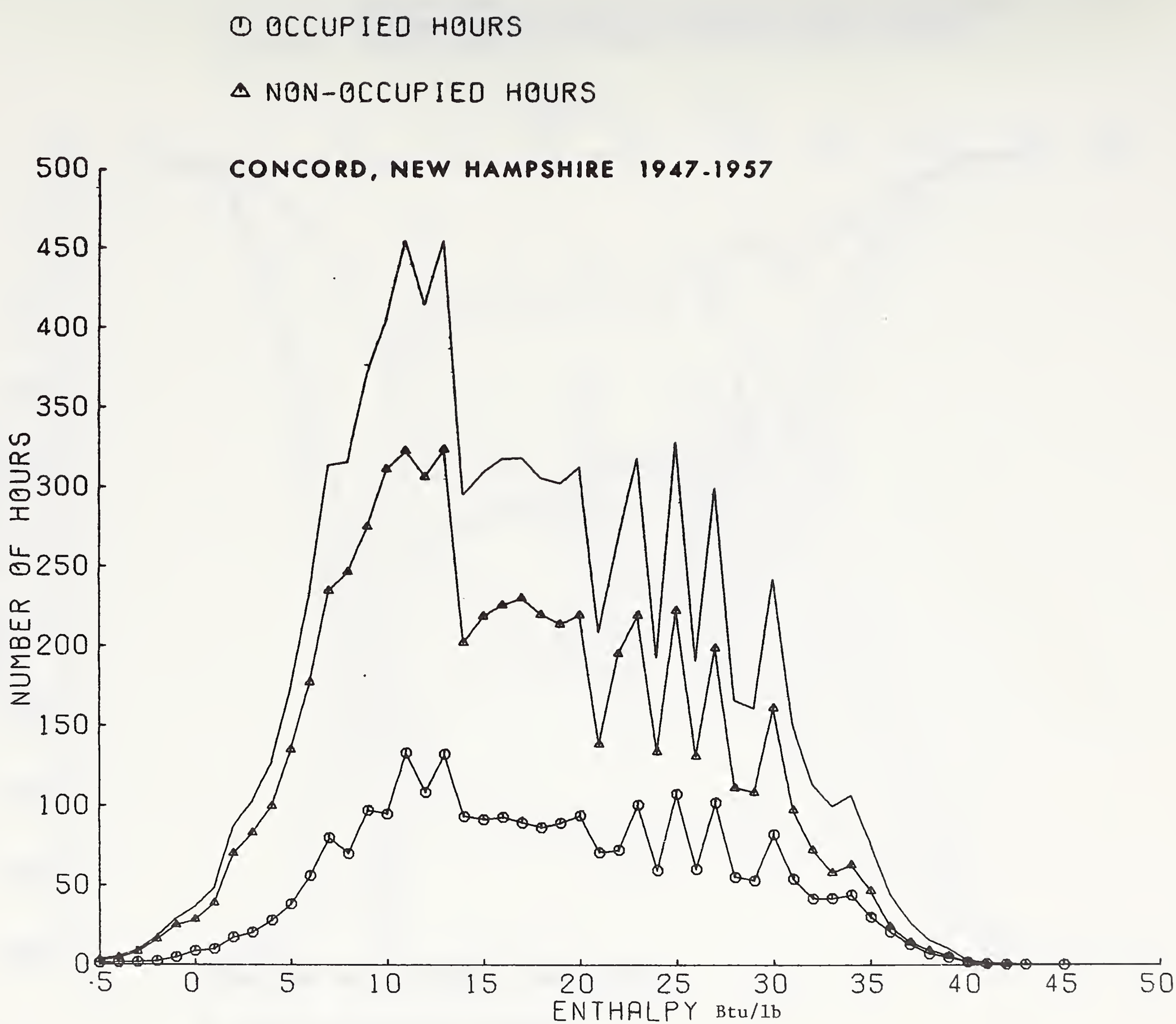


Figure 25. Average Histogram of Hourly Enthalpy; Total, Occupied and Non-Occupied Periods for 1947-1956, Concord, New Hampshire Weather Data

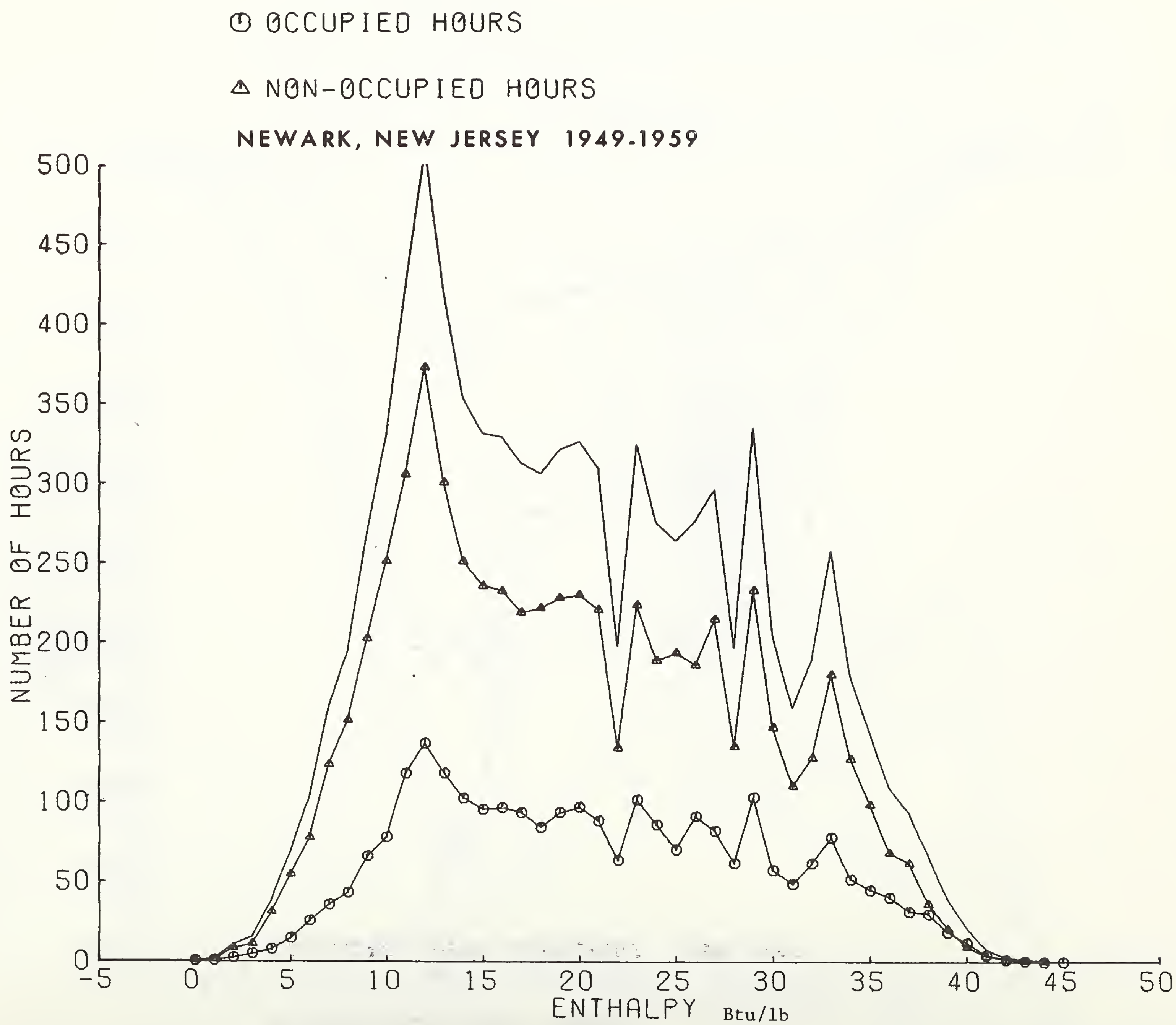


Figure 26. Average Histogram of Hourly Enthalpy; Total , Occupied and Non-Occupied Periods for 1949-1958, Newark, New Jersey Weather Data

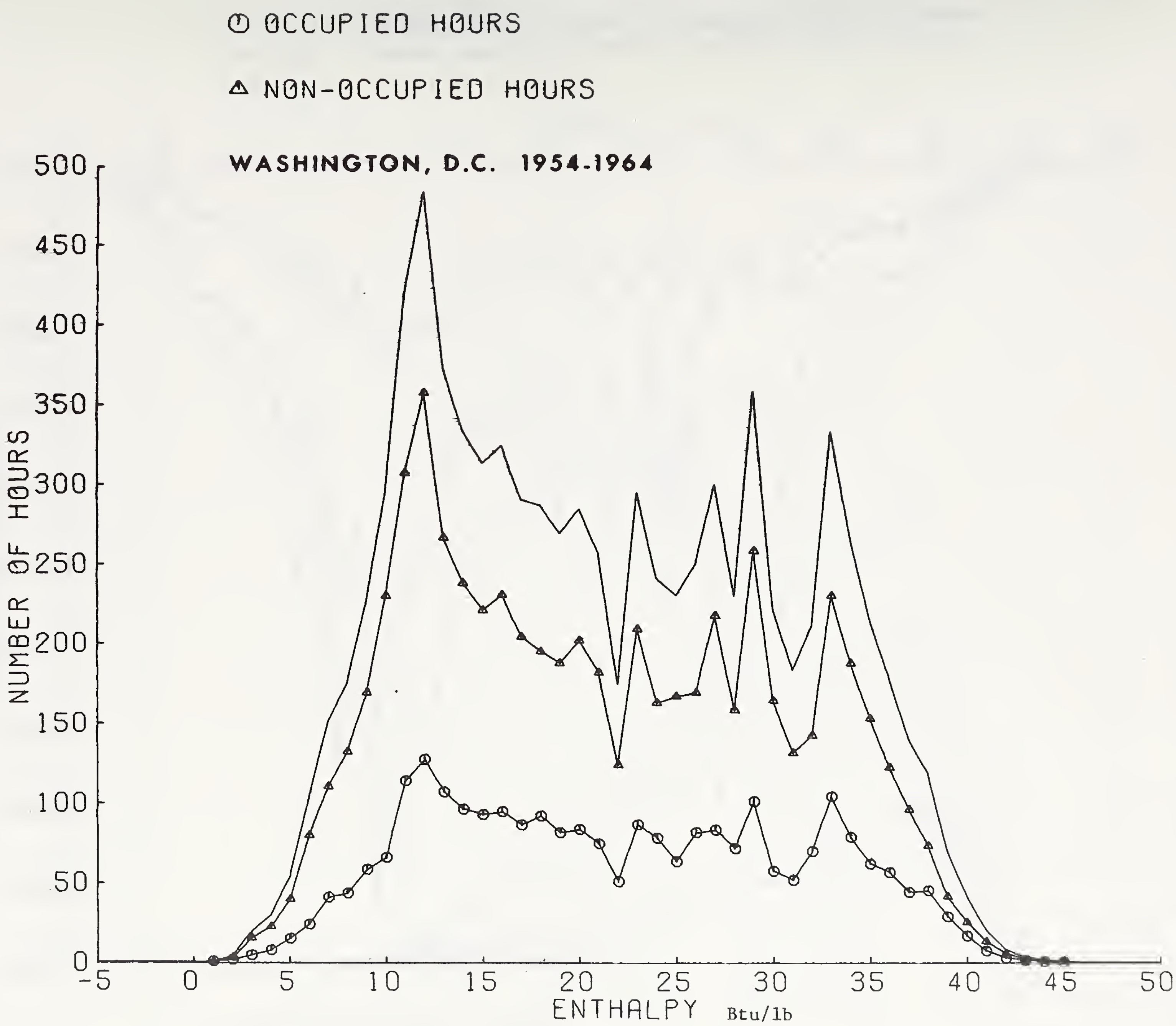


Figure 27. Average Histogram of Hourly Enthalpy; Total, Occupied and Non-Occupied Periods for 1954-1964, Washington, D.C. Weather Data

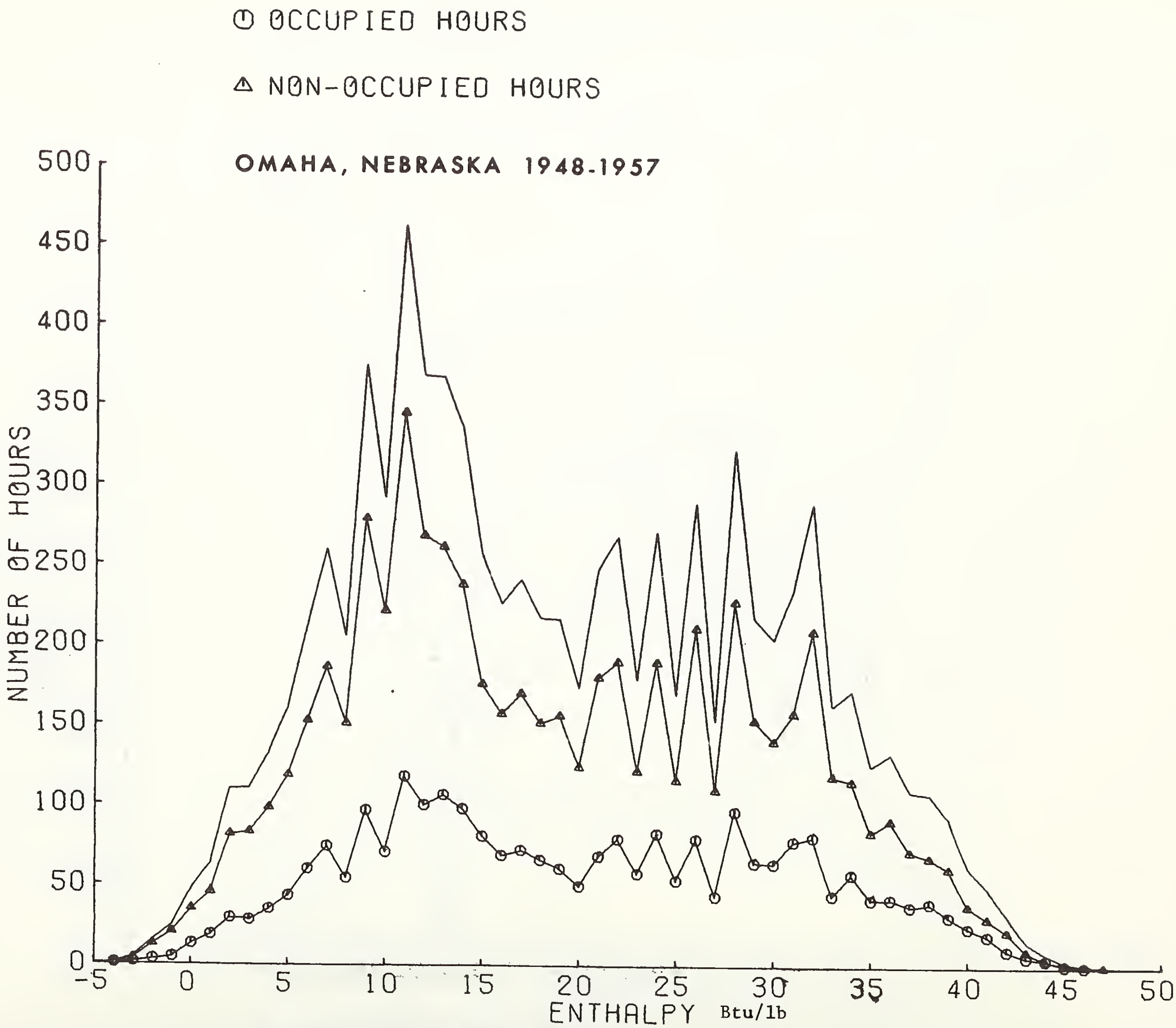


Figure 28. Average Histogram of Hourly Enthalpy; Total, Occupied and Non-Occupied Periods for 1948-1959, Omaha, Nebraska Weather Data

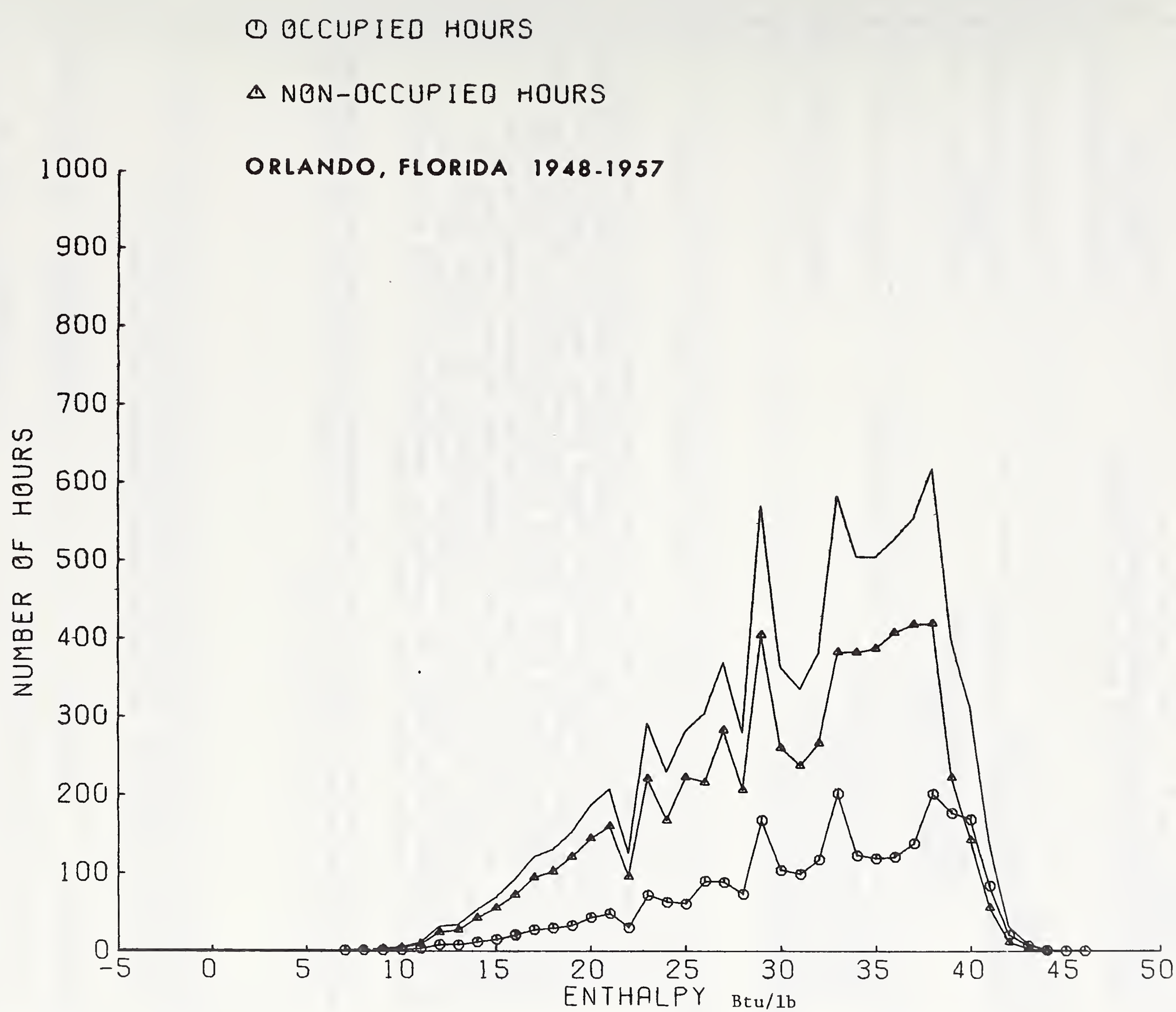


Figure 29. Average Histogram of Hourly Enthalpy; Total, Occupied and Non-Occupied Periods for 1948-1957, Orlando, Florida Weather Data

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Hourly weather data for six selected cities in the United States covering eleven consecutive years were analyzed to aid in estimating the possible energy saving that could be achieved by closing the outdoor dampers during unoccupied hours. The analysis shows that, depending upon the local weather condition, and with some simplifying assumptions, from 74 to 83 percent of the energy used for heating the make-up air could potentially be saved by closing the outdoor dampers when the building is not occupied. Based upon a premise that the energy required for cooling the outdoor ventilation air is proportional to the average enthalpy difference between the outdoor air and the air leaving the cooling coil, from 53 to 63 percent of the energy for cooling of ventilation air could be saved by closing the outdoor dampers during unoccupied hours.

Hourly temperature and enthalpy values are presented in histogram form for occupied and unoccupied periods (office use), with the suggestion that similar data processing be carried out for other cities as well.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Air conditioning requirements; energy conservation; intermittent ventilation; ventilation control; weather data analysis

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