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DEGREE DAYS IN ATHENS AND THESSALONIKI

by

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Abstract: *Study of degree-days in the two major cities of Greece, Athens and Thessaloniki, proves that the latter has much higher values than the former.*

Mean values, as well as mean remaining and mean accumulated degree days are tabulated.

Finally an equation for calculating fuel consumption estimates, as a function of degree-days and certain other factors, is given.

Introduction

The need for estimation of fuel consumption, for small or long intervals, arises quite often in our time. On the other hand the demand for heating fuels is closely related to the prevailing weather conditions, and air temperature in particular.

The unit of measurement that is widely employed by heating engineers in the U.S., the U.K. and other countries, for the estimation of fuel consumption is the «d e g r e e d a y», that is the accumulated temperature deficit below the temperature of 65°F or 18.3°C[1].

The «degree-days» (D_i) of each day are defined by the following relation:

$$D_i = 18.3^0 - T_m ,$$

where T_m the daily mean temperature of a certain place.

When $T_m \geqslant 18.3^0$C we consider the degree-days of that particular day as zero.

We should also mention that when degree days are to be used for the estimation of fuel consumption in spaces where manual work is conducted (factories, workshops etc.) their calculation basis is 45°F-55°F, that is lower than the one used in the present work; in that case we have the so-called «i n d u s t r i a l d e g r e e - d a y s».

In this work we shall examine the «degree-days» of the two major cities in Greece, Athens and Thessaloniki, in which, according to the census of 14 March 1971, are gathered 35,3% of the whole population of Greece.

Data of degree-days, for these two cities are given analytically (per month and heating season) at the end of this paper (Appendix I and II).

Material

The period examined herein extends from 1 October 1945 to 30 September 1973, since the cold season (when artificial heating is needed) in Greece, begins in October and ends in April of the next calendar year. We assume the above two months as the beginning and the end of the heating season, because October as well as April have quite small temperatures *Livadas*[7], *Flocas - Arseni*[6].

The material used has been taken from the following two sources:

— «Climatological Bulletin» of the National Observatory of Athens[9,10] for the city of Athens.

— «Observations Météorologiques de Thessaloniki»[11,12] for the city of Thessaloniki.

Mean and extreme Values of Degree-Days

The mean and extreme annual values (that is the sum total of d.d. of each heating season) of degree days in the cities of Athens and Thessaloniki for the 28-years period (1946-1973) and their differences are given in the following *Table I.*

Table I

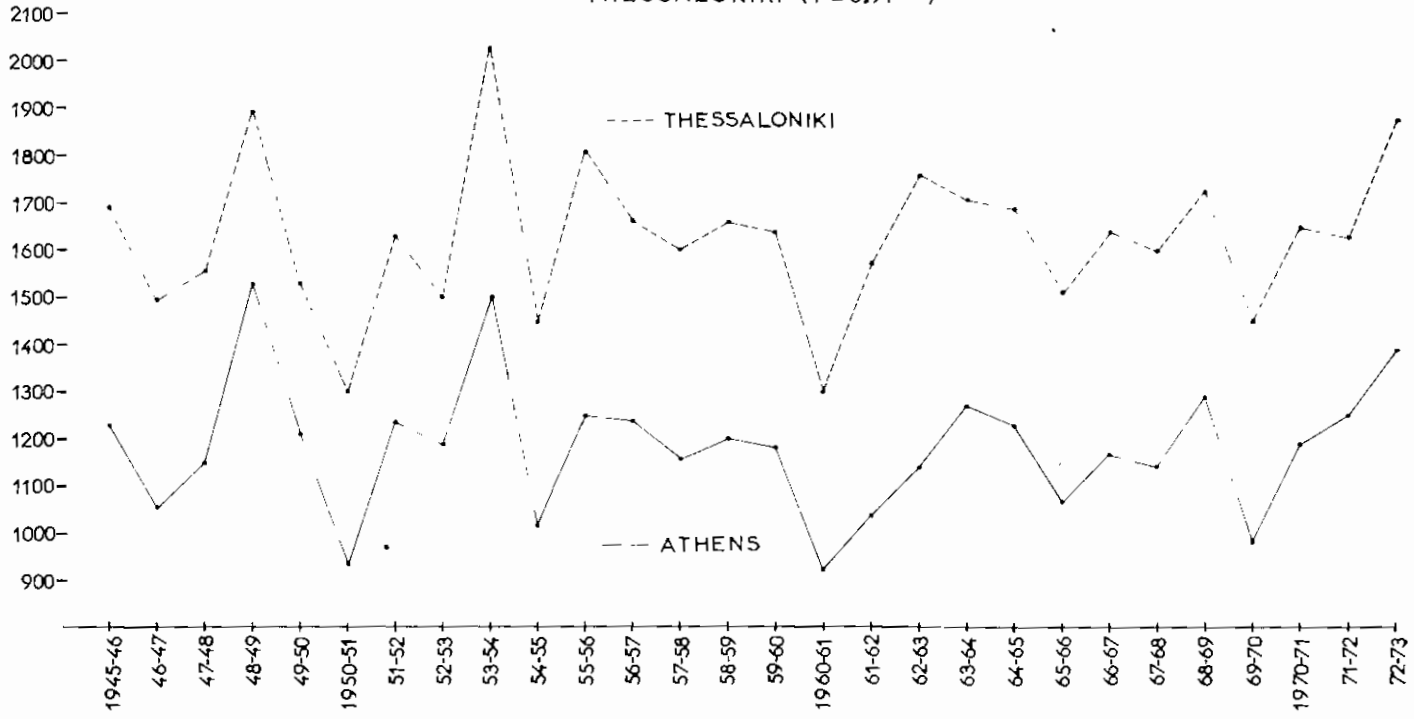
	Athens	Thessaloniki	Δ (A-T)
Max.	1533.0 (1948-1949)	2026.9 (1953-1954)	493.9
Mean	1185.4±140.51	1628.9±159.91	443.5
Min.	924.9 (1960-1961)	1300.0 (1960-1961)	375.1

The warmest winter season (with the minimum of degree-days) coincides in both cities in the 1960-1961 winter; while the coldest has been for Athens the winter of 1948-1949, and for Thessaloniki that of 1953-1954.

The annual numbers of degree-days in both cities have a strong correlation, equal to 0.91 (GRAPH I).

GRAPH I

VARIATION OF DEGREE-DAYS PER YEAR IN ATHENS AND THESSALONIKI (r=0.91)



The winter seasons of 1963-1964 and 1971-1972 had a reversion of conditions in the two districts: that is the value of d.d. rose in Athens while it fell in Thessaloniki; in both cases Thessaloniki had a rather ordinary winter while Athens had an unusually severe winter.

Mean, Accumulated, and Remaining Degree-Days.

In *Table II,* under the heading of «mean degree-days» we give the mean per month values of this parameter. The warmest month of the heating season is October for both areas, and January the coldest. Values are as a rule, higher in Thessaloniki than those of Athens. In Athens a percentage of 88,4% of the days included in the winter season (1/10-30/4) have $T_m < 18.3^{o}C$, while in Thessaloniki the percentage of such days is 93.3%. This fact again explains the superiority of Thessaloniki's values over those of Athens.

In the first part of this same *Table II,* we give under the heading «mean remaining degree-days» their sum-total from the first day of each month till the end of the heating season; while under the heading of «mean accumulated degree-days» the sum total of d.d. from the beginning of the heating season till the end of each month. Each figure in this Table is followed by its standard deviation and probable error. It is noteworthy that all values stand in the interval of mean $\pm 3\sigma$.

Studies conducted in various Institutes of the U.S. (i.e. Univ. of Illinois[4]) proved that when data of degree-days of a certain station cover a long enough period, the estimate of fuel consumption of a future heating season is satisfactorily expressed by mean values of the afore mentioned period. However deviations from such mean values would be recorded in belated or early winters. Still best results are to be obtained in regions with small standard deviation values ($\pm\sigma$). Yet, in spite of such drawbacks, the prediction of future degree-days is meant to play an important role in economy and the petroleum industry.

The Degree-Day Method

The accurate calculation of the estimated fuel consumption of a certain period is extremely difficult, since many factors enter into this calculation, such as the heat loss or the required system capacity whose final result has a different effect on the fuel consumption of every given

moment of the estimate period. Besides, the amount of fuel required also depends on the material used, since each has a different efficiency of utilization.

TABLE II

Degree-days (1.10.1945 - 30.4.1973)

ATHENS

	O	N	D	J	F	M	A	Heating Season
Mean degree days remaining	1185.4	1150.5	1043.9	821.7	543.7	309.0	92.4	
Standard deviation (σ)	140.5	140.2	122.1	95.2	85.9	60.2	31.8	
Probable error	94.8	94.6	82.3	64.2	57.9	40.6	21.5	
Mean degree-days	34.9	106.6	222.2	278.0	233.1	216.6	92.4	1185.4
Srandard deviation (σ)	23.5	31.6	47.7	43.2	45.8	43.9	31.8	140.5
Mean accumulated degree-days	34.9	141.5	364.8	641.3	876.4	1093.0	1185.4	
Standard deviation (σ)	23.5	42.1	74.2	94.0	106.5	125.6	140.5	
Probable error	15.8	28.4	50.0	63.4	71.8	84.7	94.8	

THESSALONIKI

	O	N	D	J	F	M	A	Heating Season
Mean degree days remaining	1628.9	1563.6	1388.5	1066.8	678.7	371.4	106.2	
Standard deviation (σ)	159.9	155.6	144.1	105.2	96.6	62.2	33.6	
Probable error	107.9	105.0	97.2	71.0	65.2	42.0	22.7	
Mean degree-days	65.3	175.1	321.8	388.1	307.3	261.1	106.2	1628.9
Standard deviation (σ)	35.4	33.7	55.1	56.6	57.9	44.4	33.6	159.9
Mean accumulated degree-days	65.3	240.4	562.1	950.2	1257.5	1518.6	1628.9	
Standard deviation (σ)	35.4	55.3	84.6	108.1	127.4	145.0	159.9	
Probable error	23.9	37.3	57.1	72.9	85.9	97.8	107.9	

We shall not go into any further details on the methods for calculating such factors as heat loss, capacity of the building, and feficiency of utilization of fuel, which are beyond our field of study; we shall only give the equation used for calculating fuel consumption estimates, which has as follows:

$$F = U \times N_b \times D \times C_f$$

where: F = fuel consumption for the estimate period.

V = quantity of fuel used per degree-day (building load unit).
N_b= Number of building load unit.
D = Number of degree-days for the estimate period.
C_f= Temperature correction factor.

The values of N_b depend on the building for which the estimate must be found by surveying plans, by observation, or by measuring of the building.

The C_f, that is the temperature correction factor, is a multiplier depending from air temperatures in °F. We should mention that in the U.S. and Brittain, calculation of degree-days is effected by the Fahrenheit temperature scale; since air temperature is measured in Greece by the centigrade scale (°C) our study is based on the scale used in this country.

In countries where such estimates of fuel consumption are employed, the resulting amounts approach very much the actual quantities.

Appendix I

Degree-days in Athens. (1.10.1945 - 30.4.1973)

Year	O	N	D	J	F	M	A	Total
1945-46	6.5	111.5	261.4	297.2	253.1	220.1	81.3	1231.1
1946-47	51.5	67.7	254.8	356.1	186.5	98.1	39.5	1054.2
1947-48	45.0	101.2	170.3	189.5	281.7	259.7	100.1	1147.5
1948-49	18.3	142.9	352.8	299.2	292.7	299.4	127.7	1533.0
1949-50	46.1	97.4	205.0	353.1	218.6	218.9	74.6	1213.7
1950-51	33.9	109.8	152.5	233.8	186.9	158.8	59.7	935.4
1951-52	88.5	113.3	252.2	256.0	250.7	226.8	49.8	1237.3
1952-53	10.2	132.8	166.1	283.7	218.4	296.7	78.9	1186.8
1953-54	38.8	201.8	313.0	316.7	273.6	204.1	159.3	1507.3
1954-55	15.2	120.0	226.0	188.1	140.4	181.4	152.5	1023.6
1955-56	9.7	132.1	188.9	248.3	273.1	316.1	84.2	1252.4
1956-57	33.7	110.9	267.9	312.5	192.0	225.8	105.4	1248.2
1957-58	9.2	119.9	261.2	285.0	173.4	202.0	108.3	1159.0
1958-59	36.0	121.5	183.8	274.4	302.3	180.7	98.6	1197.3
1959-60	86.6	136.4	172.0	244.5	216.0	230.1	97.7	1183.3
1960-61	3.6	41.5	128.8	270.3	276.3	169.1	35.3	924.9
1961-62	32.0	65.8	208.8	242.9	256.9	165.3	70.6	1042.3
1962-63	21.3	59.6	250.9	274.1	198.3	233.2	96.5	1133.9
1963-64	40.3	66.3	207.9	360.5	287.6	210.9	101.3	1274.8
1964-65	12.6	118.6	200.6	266.6	293.0	210.0	126.9	1228.3
1965-66	63.2	88.7	217.0	277.4	149.4	210.4	59.0	1065.1
1966-67	0	70.6	210.4	285.5	281.1	215.0	107.6	1170.2
1967-68	12.1	118.3	188.9	313.5	221.7	226.2	62.6	1143.3
1968-69	39.3	119.1	243.3	319.5	190.2	232.8	144.0	1288.2
1969-70	36.3	74.0	198.5	231.9	187.5	187.8	62.7	978.7
1970-71	41.4	108.5	228.6	224.0	252.9	216.9	116.5	1188.8
1971-72	68.3	118.0	240.7	283.1	256.9	212.1	74.2	1253.3
1972-73	76.9	117.4	269.4	295.1	261.1	257.3	112.1	1389.3
Total	976.5	2985.6	6221.7	7782.5	6572.3	6065.7	2586.9	33191.2
Mean	34.88	106.63	222.20	277.95	233.12	216.63	92.39	1185.40

Appendix II

Degree days in Thessaloniki. (1.10.1945-30.4.1973).

Year	O	N	D	J	F	M	A	Total
1945-46	93.6	176.2	348.0	432.9	314.2	231.0	96.4	1692.3
1946-47	112.1	130.0	313.2	471.3	281.5	143.1	44.8	1496.0
1947-48	75.4	175.1	319.9	275.5	355.2	251.8	105.0	1557.9
1948-49	30.3	211.7	475.5	381.5	326.7	337.1	134.8	1897.6
1949-50	55.5	148.6	294.5	460.1	271.3	228.8	69.1	1527.9
1950-51	43.3	192.1	219.2	322.1	242.2	200.4	81.7	1301.0
1951-52	127.7	157.6	340.3	346.8	326.0	272.9	56.5	1627.8
1952-53	53.0	173.2	239.6	372.7	275.8	302.9	88.1	1505.3
1953-54	77.8	265.1	405.8	472.3	416.1	233.6	156.2	2026.9
1954-55	49.0	194.8	299.3	279.8	195.3	243.3	185.5	1447.9
1955-56	36.9	216.1	293.0	364.4	414.8	373.0	113.0	1811.2
1956-57	68.4	217.2	364.0	412.8	231.0	259.0	113.4	1665.8
1957-58	39.7	173.0	367.7	368.9	245.4	279.4	130.6	1604.7
1958-59	76.7	170.0	293.7	417.8	350.1	231.9	124.3	1664.5
1959-60	125.8	206.4	243.5	355.6	304.1	278.0	130.7	1644.1
1960-61	17.0	114.2	210.9	391.2	317.7	192.5	56.5	1300.0
1961-62	32.8	135.4	345.8	348.2	356.4	254.0	102.0	1574.6
1962-63	43.4	117.5	397.1	454.6	311.5	302.8	129.0	1755.9
1963-64	61.4	137.5	329.4	459.8	348.1	257.4	118.6	1712.2
1964-65	32.2	165.1	295.7	358.2	426.4	261.6	150.9	1690.1
1965-66	75.0	189.8	303.7	417.6	196.0	252.0	80.3	1514.4
1966-67	6.1	153.8	326.3	425.0	351.6	248.5	130.9	1642.2
1967-68	29.3	164.3	329.1	441.7	279.8	272.3	87.1	1603.6
1968-69	65.9	156.1	348.8	437.4	276.7	293.9	151.9	1730.7
1969-70	55.9	153.7	298.7	330.8	276.2	251.0	86.6	1452.9
1970-71	77.1	193.7	330.4	289.6	317.7	295.3	143,6	1647.4
1971-72	108.0	210.7	310.4	360.3	312.9	245.3	87.0	1634.6
1972-73	157.8	203.0	366.0	416.5	284.5	318.1	133.3	1879.2
Total	1288.0	4901.9	9009.5	10865.4	8605.2	7310.9	3087.8	45608.7
Mean	65.29	175.07	321.77	388.05	307.33	261.10	106.21	1628.88

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ΠΕΡΙΛΗΨΙΣ

DEGREE-DAYS ΑΘΗΝΩΝ ΚΑΙ ΘΕΣΣΑΛΟΝΙΚΗΣ

Ὑπὸ
ΑΓΓ. ΑΡΣΕΝΗ - ΠΑΠΑΔΗΜΗΤΡΙΟΥ

Μελετῶμεν εἰς τὴν παροῦσαν ἐργασίαν τὰ degree-days τῶν Ἀθηνῶν καὶ Θεσσαλονίκης.

Ὁρίζεται δὲ ὡς degree-days (Dj) ἑκάστης ἡμέρας τὸ θερμοκρασιακὸν ἔλλειμα αὐτῆς κάτω τῆς θερμοκρασίας τῶν 18.3°C δηλ.

$$D_j = 18.3° - T_M, \text{ ἔνθα}$$

T_M ἡ μέση ἡμερησία τιμὴ τῆς θερμοκρασίας καὶ διὰ $T_M < 18.3°C$.

Ἡ 28ετὴς περίοδος τῆς μελέτης μας εἶναι ἡ περιλαμβανομένη ἀπὸ 1ης Ὀκτωβρίου 1945 ἕως 30 Σεπτεμβρίου 1973 καὶ ἀναφερόμεθα εἰδικώτερα εἰς τὰς χειμερινὰς περιόδους αὐτῆς.

Εἶναι σαφὴς ἡ ὑπεροχὴ τῶν τιμῶν τῶν degree-days τῆς Θεσσαλονίκης ἔναντι τῶν ἀντιστοίχων τῶν Ἀθηνῶν (GRAPH I, APPENDIX I καὶ II). Τοῦτο δικαιολογεῖται καὶ ἀπὸ τὸ μεγαλύτερον ποσοστὸν ἡμερῶν μὲ $T_M < 18.3°C$ ποὺ παρουσιάζει ἡ Θεσσαλονίκη κατὰ τὴν ψυχρὰ περίοδο ἐν σχέσει πρὸς τὰς τῶν Ἀθηνῶν (93.3% ἔναντι τῶν 88.4% τῶν Ἀθηνῶν).

Ὁ θερμότερος ἐξ ὅλων τῶν μηνῶν τῆς θερμαινομένης ἐποχῆς ἀπὸ Ὀκτωβρίου - Ἀπριλίου εἶναι ὁ Ὀκτώβριος, ἐνῶ ὁ ψυχρότερος ὁ Ἰανουάριος. Ἡ χειμερινὴ περίοδος τοῦ 1960-1961 ὑπῆρξεν ἡ θερμοτέρα καὶ διὰ τὰς δύο πόλεις, ἐνῶ ἡ ψυχροτέρα διὰ μὲν τὰς Ἀθήνας ἦτο τὸ 1948-1949 καὶ διὰ δὲ τὴν Θεσσαλονίκην τὸ 1953-1954.

Ἕνας ἀπὸ τοὺς χρησιμοποιουμένους εἰς Ἀμερικὴν καὶ Ἀγγλίαν τύπους, ὑπολογισμῶν τῶν καυσίμων ποὺ ἀπαιτοῦνται εἰς μίαν χρονικὴν περίοδον εἶναι ὁ:

$$F = U \times N_b \times D \times C_f \text{ ἔνθα}$$

F = Ἡ κατανάλωσις καυσίμων τῆς ζητουμένης περιόδου,

U = Ἡ ἀνὰ degree-day ποσότης τοῦ χρησιμοποιουμένου καυσίμου (building load units)
N_b = Ὁ ἀριθμὸς τῶν building load units.
D = Ὁ ἀριθμὸς τῶν degree-days
C_{rj} = Συντελεστὴς διορθώσεως θερμοκρασίας.

Τὸ N_b ἐξαρτᾶται ἀπὸ τὸ κτίριον εἰς τὸ ὁποῖον ἀναφερόμεθα καὶ ὑπολογίζεται διὰ διαφόρων μετρήσεων εἰς αὐτό. Τὸ C_r εἶναι ἕνας συντελεστὴς ὁ ὁποῖος ἐξαρτᾶται ἀπὸ τὴν εἰς °F ἐκφραζομένην θερμοκρασίαν.

Ἡ μελέτη τῶν degree-days παίζει σπουδαῖο ρόλο εἰς τὴν οἰκονομίαν καὶ τὴν βιομηχανίαν πετρελαιοειδῶν, ὅταν βασίζεται εἰς μεγάλας χρονικὰς περιόδους.