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Heating and Cooling Energy Consumption Estimation in a Typical House in the Greater Thessaloniki Area, Applying Cooling and Heating Degree Days Method †

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Abstract: In this work, data from ten (10) meteorological stations in various areas of Thessaloniki, Greece were used in order the cooling and heating degree days for each station to be calculated. The specific data were applied to a detached house for each of the ten areas considered. Furthermore, an analysis of the thermal insulation adequacy of the single family house that has been selected with the necessary methodology and the necessary sketches was conducted in order to have the illustration of the building. The study was divided into two cases, where the first refers to a typical thermal insulation that characterizes a building of the territory of Greece, and the second case where the residence has undergone a radical renovation of its thermal insulation. Results show that three different climatic zones appear in the same region instead of one.

Keywords: degree days; energy; buildings; thermal insulation; urban heat island

1. Introduction

Degree days are an important factor in this study. Heating degree days (HDD) are usually calculated using the annual sum of the daily average outdoor air temperature losses from some reference or base temperature [1]. Accordingly, the cooling degree days (CDD) are usually calculated using the annual sum of the losses of the daily average outdoor air temperature from some base temperature that could vary.

As can be seen from the energy requirements, it is important to determine the thermal comfort factor as well. The thermal environment and thermal adaptation are two dominant factors affecting the thermal comfort of occupants and are inextricably linked [2–4]. It is important to mention that the Greek territory is divided into four (4) climatic zones which arise based on the heating degree days.

Insulation is a very important category and finds multiple applications in buildings and building shells. It can be applied to opaque and transparent elements.

According to Verichev et al. [5], an attempt was made to find better thermal insulation for a given area in Chile. Additionally, Amani and Kiaee [6], used a group of thermal insulation materials and they tried, applying engineering software and the Pareto principle, to arrive at the optimal selection of insulation materials that can be placed in a building. Li et al. [7], conducted extensive research on thermal insulation from organic materials and types of polystyrene and polyurethane foams. Gulotta et al. [8] focused on thermal insulation laws in Europe and provided graphs for many countries.

In this paper, a single family house within the greater Thessaloniki area (GTA) was examined divided into two cases where the first refers to the typical thermal insulation of a Greek house and the second to a renovated house (shell thermal upgrade). For this house, depending on the specific location, the HDD and CDD were used in order to estimate the energy consumption for cooling and heating purposes.

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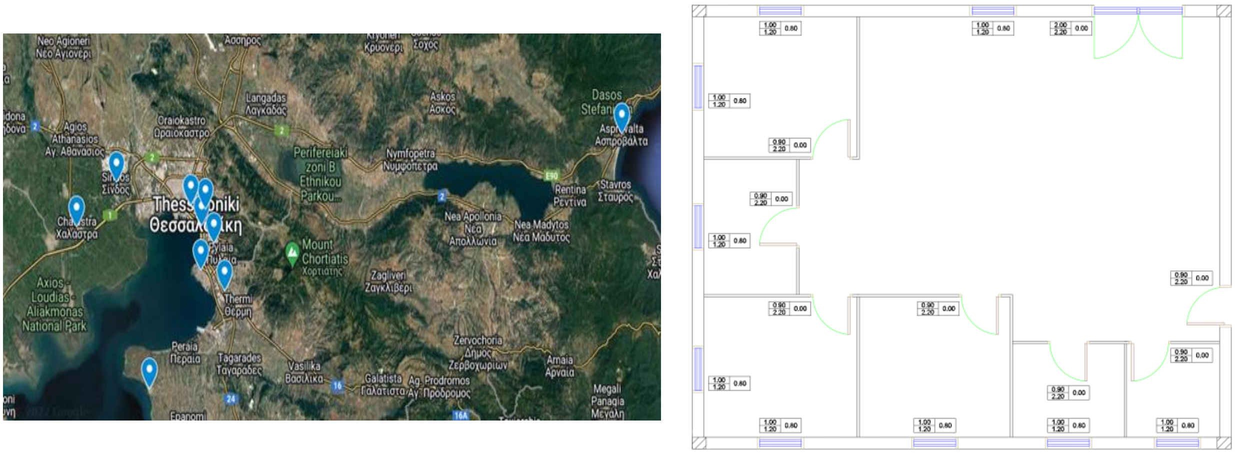
2. Data and Methodology

Figure 1a presents a map of the GTA with the location of the 10 meteorological stations. Those stations are Chalastra (Chal), Sindos (Sin), Nea Michaniona (Nea Mi), Lagkadas (Lagk), Thessaloniki Iternational Trade Fair (TITF), Kalamaria (Kal), Heptapyrgion (Hept), Kordelio (Kord), Noesis (Noe) and Asprovalta (Aspro).



(a) (b)

Figure 1. Map with the location of the 10 examined meteorological stations in the GTA (**a**) and the floor plan of the specific detached house (**b**).

In order to have a better understanding of the building that was examined, Figure 1b shows the floor plan of the specific detached house.

At this point is important to be mentioned that according to the Technical Chamber of Greece, (TEE-TCG) Greece is divided into four (4) different climatic zones taking into account the HDD and CDD [9]. The GTA belongs to the climatic zone C (Figure 2).

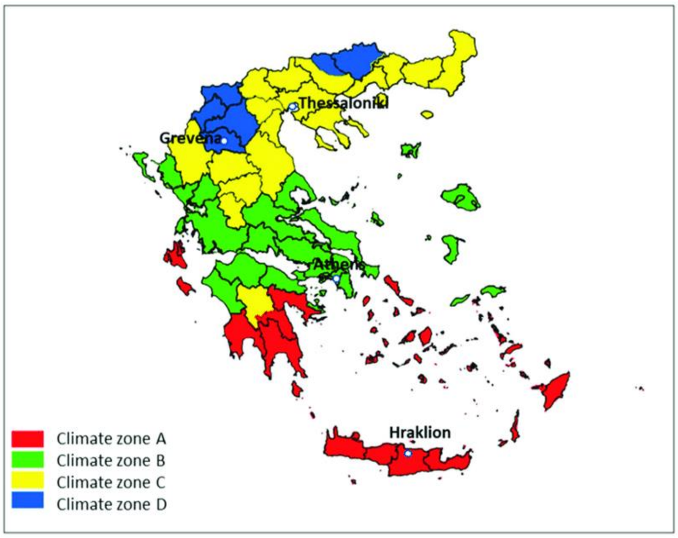


Figure 2. The four climatic zones of Greece.

Air temperature data were collected by the meteorological stations network belonging to the National Observatory of Athens [10] and were applied in order to calculate the HDD and CDD for each of the 10 examined locations. The calculation of daily HDD and daily CDD was conducted using mean daily air temperature, applying Equation (1)) respectively.

$$\mathrm{HDD} = \sum (T_b - T_m) \ \forall \ T_b > T_m \quad [^\circ\mathrm{C}] \qquad \mathrm{CDD} = \sum (T_m - T_b) \ \forall \ T_m > T_b \quad [^\circ\mathrm{C}] \tag{1}$$

where, T_b is the base temperature (°C), and T_m is the mean daily temperature (°C). For HDD the base temperature was taken as T_b = 18 °C and for CDD the base temperature was assumed to be 28 °C.

Then, the annual energy consumption for heating and cooling is denoted by Q_h and Q_c respectively, is calculated by applying Equation (2).

$$Q_h = \frac{U' \cdot \mathrm{AHDD} \cdot 24}{n} \qquad Q_c = \frac{\dot{m} \cdot C_p \cdot \mathrm{ACDD} \cdot 24}{\mathrm{COP}} \tag{2}$$

where, U' denotes the total heat loss coefficient of the building, AHDD and ACDD are the annual sum of heating and cooling degree days respectively, n denotes the degree of efficiency of the boiler of the detached house (0 < n < 1), m denotes the mass flow rate of kg of air cooled every second, C_p is the specific heat of the air (J·kg^{-1}·K^{-1}) and COP indicates the degree of efficiency of the air conditioner of the detached house.

The building heat loss coefficient is calculated using Equation (3).

$$U' = \frac{A \cdot U + \frac{1}{3} \cdot N \cdot V}{1000} \tag{3}$$

where, U denotes the thermal permeability coefficient of the respective material, whether we are talking about external masonry or an opening, A is the area of each measured area (m^2), N is the air infiltration rate per hour and V is the volume of the space under study (m^3).

The thermal insulation will be examined based on the value of the thermal conductivity U. The thermal conductivity directly depends on the thermal resistance R_{tot} which is calculated from the thermal resistance values of internal R_i and external air R_a and the total sum from the quotient of the thickness in terms of the thermal conductivity of the respective material d_i/λ_i. Then, the coefficient of thermal conductivity is the inverse of the thermal resistance and is calculated from the following formula.

$$R_{o\lambda} = R_i + \sum \frac{d_i}{\lambda_i} + R_a \ in \left(\frac{m^2 K}{W} \right) \qquad U = \frac{1}{R_{o\lambda}} in \left(\frac{W}{m^2 K} \right) \tag{4}$$

The mathematical formula that follows concerns the coefficient of thermal conductivity U_w for the openings.

$$U_w = \frac{\sum A_g U_g + \sum A_f U_f + \sum L_g \Psi_g}{\sum A_g + \sum A_f} \tag{5}$$

Finally, the primary energy consumption is calculated using the following formula.

$$\mathrm{PEC_h} = Q_h \cdot \alpha \qquad \mathrm{PEC_c} = Q_c \cdot \alpha \tag{6}$$

The reason this specific method was used is because it is scientifically proven, and the most appropriate method based on the data given.

3. Results and Discussion

According to the above, mentioned methodology the following results of tables and figures occur. These results concern heating and cooling degree days, thermal analysis about all the structural materials of the building, energy consumption and primary energy for heating and cooling purposes.

Table 1 depicts the annual number of HDD and CDD for each one of the ten examined locations within the GTA.

Table 1. Heating and cooling degree days for each station.

Station	HDD (°C)	CDD (°C)
TITF	1071.29	47.72
Nea Mixaniona	1192.04	6.33
Kordelio	1203.58	66.90
Sindos	1212.71	17.73
Chalastra	1253.43	0.53
Noesis	1272.58	32.80
Kalamaria	1336.75	26.65
Asprovalta	1482.47	13.49
Heptapyrgion	1757.88	24.55
Lagkadas	1896.19	7.50

Since this paper is divided into two cases following Equations (4) and (5) in Table 2 the results of the thermal conductivity for both cases and all structural materials are shown. Also, regarding the climate zone of the GTA, there is an extra column which depicts the upper threshold value regarding the coefficient of thermal conductivity.

Table 2. Comparison of the thermal result for both examined cases.

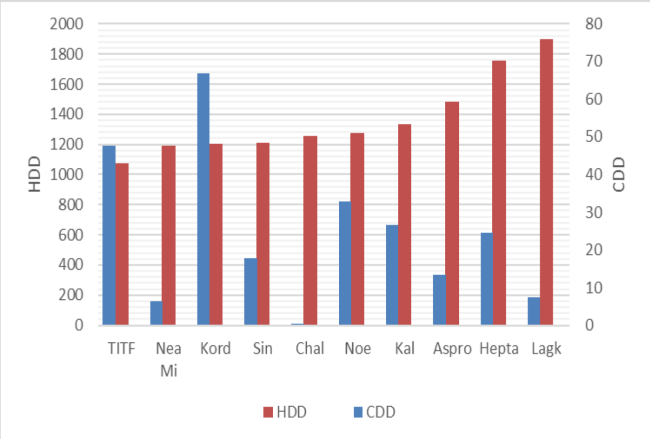
Structural Material	First Case U (W/m^{2}K)	Second Case U (W/m^{2}K)	Upper Threshold U (W/m^{2}K)
External masonry	0.838	0.396	0.45
Floor	0.738	0.738	0.75
Roof	0.497	0.381	0.40
Windows	3.011	2.103	2.80
Balcony door	3.149	2.151	2.80
Door	2.000	2.000	2.80

Lastly, in Table 3, the results of energy consumption and primary energy for heating and cooling purposes are shown (Equations (3) and (6)).

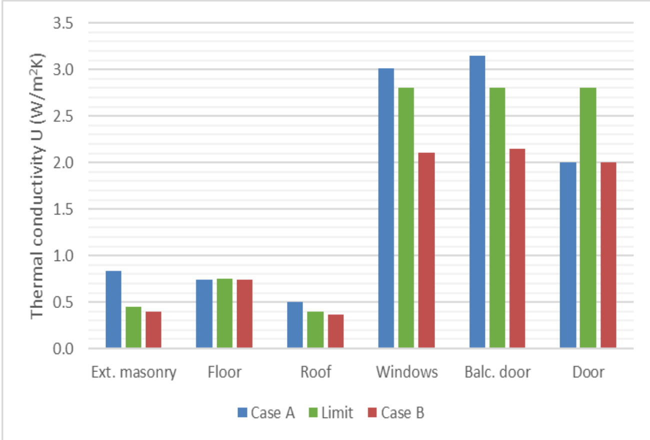
Table 3. Energy consumption and primal energy results for both examined cases.

Station	First Case		Second Case		Same in Both Cases	
	Q_h (kWh)	PEC_h (kWh)	Q_h (kWh)	PEC_h (kWh)	Q_c (kWh)	PEC_c (kWh)
TITF	8870.35	25,724.00	6788.07	19,685.41	317.98	922.13
Nea Mixaniona	9870.14	28,623.41	7553.17	21,904.19	42.20	122.39
Kordelio	9965.69	28,900.50	7626.29	22,116.24	445.80	1292.83
Sindos	10,041.29	29,119.73	7684.14	22,284.00	118.17	342.69
Chalastra	10,378.48	30,097.59	7942.18	23,032.31	3.55	10.31
Noesis	10,536.99	30,557.28	8063.48	23,384.09	218.57	633.85
Kalamaria	11,068.36	32,098.25	8470.11	24,563.33	177.58	514.97
Asprovalta	12,274.90	35,597.22	9393.43	27,240.93	89.88	260.65
Heptapyrgion	14,555.30	42,210.38	11,138.51	32,301.68	163.59	474.42
Lagkadas	15,700.59	45,531.71	12,014.94	34,843.34	49.97	144.92

Furthermore, below are corresponding diagrams in the same order as the tables above. Firstly, Figure 3 shows the HDD and CDD results and the thermal conductivity results for both cases in comparison to the TOTEE limits of the climate zone of Thessaloniki.



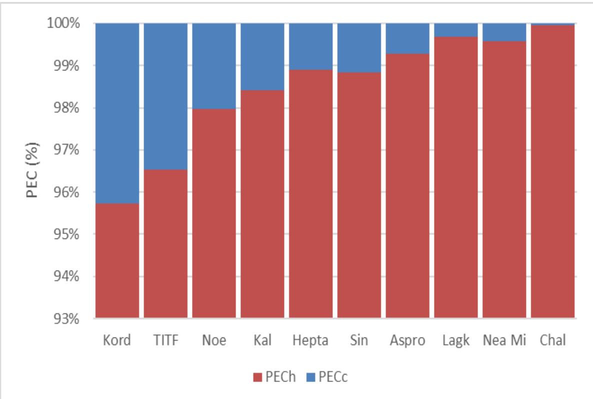
(**a**)



(**b**)

Figure 3. Heating and cooling degree days (**a**) and thermal conductivity for both cases compared to the TOTEE limits (**b**).

Important to note here is that the stations have been sorted in ascending order based on the HDD values. Also, the CDD values correspond to the secondary column (on the right). It is worth mentioning that as shown in Table 2 all the values in the second case (case B) the renovation has helped reduce the thermal conductivity of all the structural materials under the TOTEE limits. Figure 4 shows the values of primary energy consumption for heating (PEC_h) and cooling (PEC_c) for all meteorological stations in both cases.



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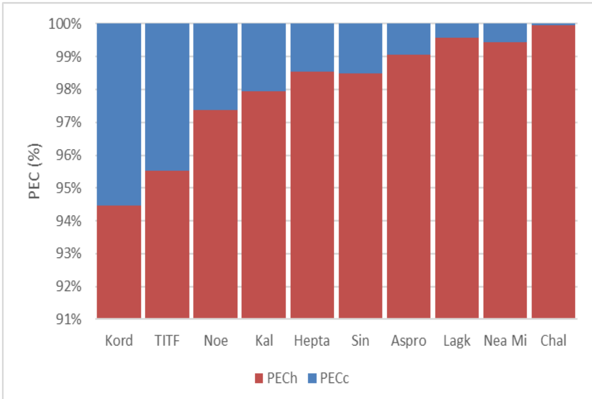

(**b**)

Figure 4. Primary energy consumption (%) for heating (PEC_h) and cooling (PEC_c) purposes for all examined sites for the first (**a**) and second case (**b**).

4. Conclusions

A final conclusion about the heating and cooling degree days, which is very important, is that while based on Figures 3 and 4 all the studied areas are in climate zone C, Figure 1a shows the climate change that has emerged by comparing it with the results of the heating and cooling degree days.

Climate change combined with the urban heat island results in the appearance of three (3) different climate zones in the area under consideration. This explains to a large extent the results of the CDD, as the urban heat island is essentially the phenomenon in which the temperature in the center of the city is higher than that of its suburbs.

Lastly, with the same hypothetical building as in the first case, it was observed that the thermal conductivity coefficient of every structural element except the floor and the external door of the house (external masonry, roof, windows, balcony door) was above the TOTEE limit (Table 2, Figure 1b). This shows that the results of primary energy consumption to cover heating and cooling needs may be inflated.

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