IJPAS | INTERNATIONAL JOURNAL PURE AND APPLIED SCIENCES
ISSN: 2149-0910
Vol. 10(2); 352-366 (2024)
DOI: 10.29132/ijpas.1474617

Research Article

Investigation of a Novel Approach in Free Cooling Degree Hour Calculations for Muğla Province

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Received: 27.04.2024
Accepted: 27.11.2024

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Abstract: In order to reduce cooling energy without compromising comfort conditions, insulation applications on external walls, columns, and beams, as well as the use of double glazing in windows, play a significant role. Another effective method in reducing cooling energy is the implementation of free cooling systems. In this system, cooling systems achieve energy savings by bypassing the fresh air taken from outside directly into the indoor space without passing through cooling coils. The implementation of this system requires the examination of reliable outdoor air temperature distributions throughout the cooling season during the project planning phase. In this study, various analyses were conducted using five different computer programs. According to the analysis results, the operation times of free cooling systems and the Free Cooling Degree Hour Value (FCDHV) to meet cooling loads were determined for every hour of each month for the province of Muğla. The estimated highest seasonal FCDHV for Muğla was found to be 11810.7, with the highest hourly FCDHV being 177.5 occurring between 05:30-06:30, and the highest 24-hour FCDHV being 2209 in September. When these data were converted to percentage values, it was determined that a 70.6% energy savings were achieved from free cooling systems.

Keywords: Muğla; outside temperature; free cooling degree hour; free cooling times; cooling degree hour

Muğla İli Serbest Soğutma Derece Saati Hesaplamalarında Yeni Bir Yaklaşımın İncelenmesi

Özet: Binalardaki enerji talebi genellikle kış mevsimi boyunca odaların ısıtılması yaz mevsimi boyunca ise odaların soğutulması için kullanılmaktadır. Konfor koşullarını etkilemeden soğutma enerjisinin azaltılması amacıyla, dış duvarlar, kolonlar ve kirişlerde yalıtım uygulamaları ile pencerelerde çift cam kullanımı önemli bir rol oynamaktadır. Soğutma enerjisinin azaltılmasında etkili bir diğer yöntem de serbest soğutma sistemleridir. Bu sistemde, soğutma sistemleri dışarıdan alınan taze havayı soğutma bataryalarına bypass ederek doğrudan iç mekana ileterek enerji tasarrufu sağlamaktadır. Bu sistem, projenin planlama aşamasında soğutma sezonu boyunca güvenilir dış hava sıcaklık dağılımlarının incelenmesini gerektirmektedir. Bu çalışmada, beş farklı bilgisayar programı kullanılarak çeşitli analizler yapılmıştır. Analiz sonuçlarına göre, Muğla ili için her ayın her saatinde ve belirli saat aralıklarında serbest soğutma sistemlerinin çalışma süreleri ve soğutma yüklerini karşılayacak Serbest Soğutma Derece Saat Değeri (SSDSD) literatüre kazandırılmıştır. Muğla ili için tahmin edilen en yüksek sezonluk SSDSD'nin 11810.7 olduğu, saatlik en yüksek SSDSD'nin 177.5 olduğu ve saat 05.30-06.30 arasında gerçekleştiği, en yüksek 24 saatlik SSDSD'nin eylül ayında ve 2209 olarak belirlenmiştir. Elde edilen bu veriler yüzdelik hesaba vurulunca, serbest soğutma sistemlerinden %70.6 oranında bir enerji tasarrufu sağlandığı tespit edilmiştir.

Anahtar Kelimeler: Muğla; dış hava sıcaklığı; serbest soğutma derece saat; serbest soğutma süreleri; soğutma derece saat

1. Introduction

The free heating or free cooling capacity of a building depends on various factors such as indoor air temperature density, outside air temperature, components of the building's outer skeleton, heat transfer coefficients of the outer skeleton components, and ventilation methods [1]. Within any structure in a residential area, when the internal air exchange rate and heat source density are relatively constant, a similar relationship has been observed between the thermal properties of the wall and the thermal performance of the building [2]. Therefore, studies have been conducted on the wall structure and thermophysical properties that affect the thermal performance of the wall [3]. One of the systems used to reduce energy consumption for heating or cooling purposes in residences is free cooling systems [4]. In free cooling systems, if the indoor space reference temperature or enthalpy is higher than the outside ambient temperature or enthalpy, the outside air is directly brought into the indoor space and used to bring the room temperatures to comfort levels [5]. This situation also indicates how critical the outside air temperature and enthalpy values are in free cooling systems [6]. The prominence of temperature-controlled systems has resulted from various problems in enthalpy-controlled systems [7]. In free cooling systems, since the outside air is directly sent into the indoor space, it can significantly improve indoor air quality [8]. The high-quality indoor air achieved with these systems can increase indoor air quality by 5-10% in many regions of the world [9].

Free cooling systems should be considered to be unable to meet cooling loads alone and therefore cannot completely replace mechanical cooling systems [10]. Free cooling systems can help reduce the capacity of mechanically operated cooling systems in areas with high cooling loads [11], [12]. In applications of free cooling systems, heat energy absorbed during daytime hours is transferred to the outside environment using free cooling after the sun sets [13], [14]. In a building where free cooling is applied in the evening, depending on the thermal capacity of the building components, it has been calculated that the total cooling energy requirement in the structure can be reduced by 27% to 36% [15]. Applications using free cooling systems allow for lower operation, maintenance, and initial investment costs of the mechanical HVAC system due to the lower mechanical cooling load [16], [17].

The contributions of this study to the literature are as follows:

I. In the province of Muğla, throughout the year, at any hour of each month, the outdoor air temperature distributions with a 1°C temperature difference are revealed proportionally and temporally through this study within the monthly dataset (30x24=720 hours).

II. In the cooling season of the Muğla province, at any time of any month, cooling durations with a 1°C temperature difference have been determined proportionally and temporally within the monthly dataset.

III. The concept of FCDHV (Free Cooling Degree Hour Values) has been introduced into the literature for the province of Muğla.

IV. By determining the FCDHV for the province of Muğla, it will be possible to predict the seasonal and hourly cooling energy savings for any time interval during the summer season months.

V. The presentation of this study will encourage research in the field of outdoor air-linked cooling systems and air conditioning systems.

VI. The Cooling Degree Hour Values (CDHV) for Muğla, which are not present in the literature on an hourly basis for any month of the cooling season, any two time periods, and on a seasonal basis, will be introduced to the literature for the first time through this study.

VII. For Muğla, the Free Cooling Degree Hour Values (FCDHV) that are not present in the literature on an hourly basis for any month of the cooling season, any two time periods, and on a seasonal basis, will be introduced to the literature for the first time through this study.

2. Material and Methods

Providing comfort temperature in commonly used enclosed spaces such as schools, residences, shopping malls, government offices, offices, industrial facilities, and most places where people are present is of utmost importance for human health and productivity[18]. The achievement of comfort temperature is accomplished through heating, cooling systems, and air conditioning systems [19], [20].

Cooling or heating loads can be calculated using the temperature and time parameters of these systems [21]. Moreover, determining the winter (heating) and summer (cooling) seasons, determining the amount of fuel used for heating in residences, determining the amount of energy used for cooling, determining the diameter of natural gas pipes, determining the most suitable insulation thicknesses for external walls, determining the timing of planting and harvesting in agriculture, calculating heating and cooling for quail poultry houses, planning the timing of efforts to increase soil fertility in agriculture, and various applications utilize degree-day methods [22], [23]. These degree-day methods are widely used in a broad spectrum of applications, from calculating the optimal insulation thicknesses to the energy needs we expend for heating or cooling [24]. Upon reviewing the current literature, degree-day values have been calculated for both heating and cooling seasons at different indoor reference temperatures for Turkey and many countries worldwide [25]. Considering the methods in the literature, the connections between visual basic based software written in this context and the information on the results to be obtained are provided in the flowchart.

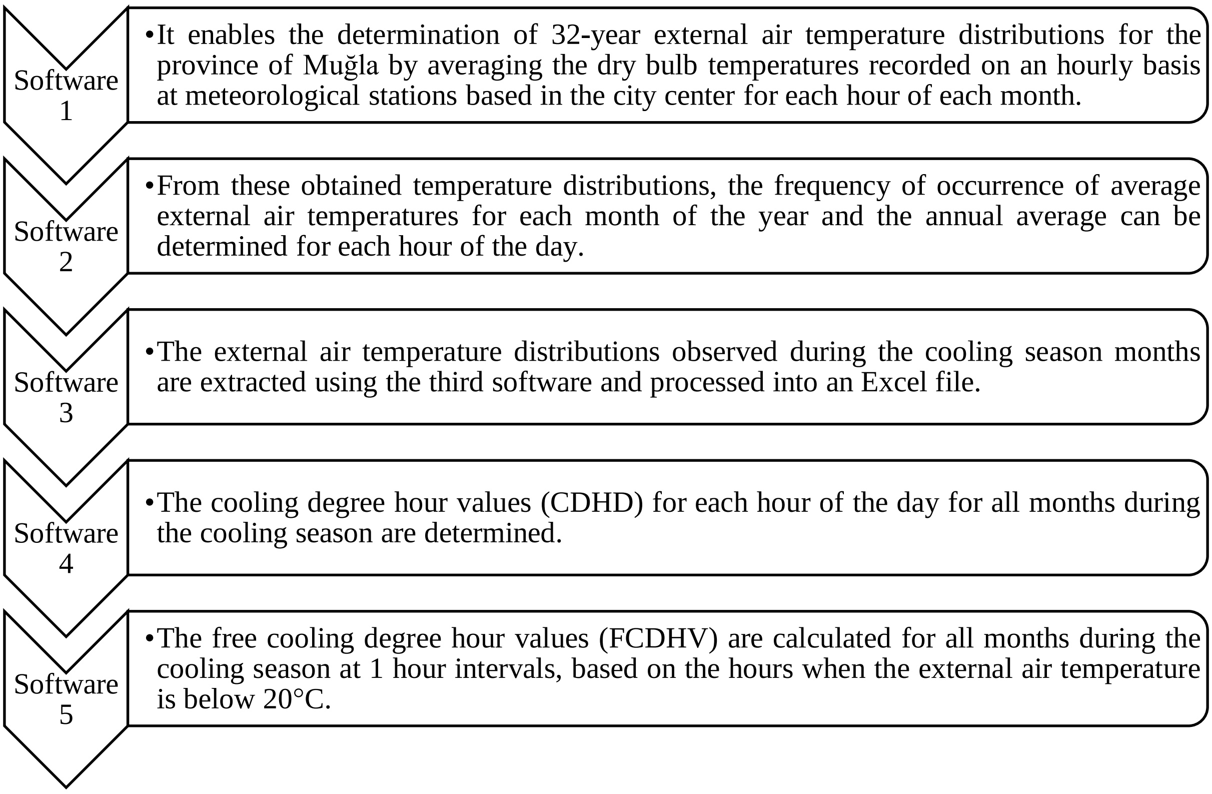

Figure 1. The flowchart of the software

2.1. Degree-Time Methods

In temperature distributions, differences are observed every year, and these differences are increasing due to the impact of global warming. Therefore, the Cooling Degree Hour Value (CDHV) calculated depending on the indoor reference temperature also varies [19], [21]. In these calculations, the most critical parameter is the outdoor dry bulb temperature data obtained for at least 10 years. As the number of years of data we have increases, the estimated CDHV will be more precise [26].

It is known in the literature that there are three different methods for calculating degree-time calculations [27]. These methods are degree-days, degree-hours, and degree-minutes. Since the degree-hour method is used in this article and to keep the article concise, only the degree-hour method has been explained.

2.2. Degree-Hour Methods

Continuous operating air conditioning systems (such as those used in residences and hospitals) and intermittent operating air conditioning systems (such as those in offices, schools, government buildings, shopping malls, etc.) can be calculated for their cooling energy needs [13], [28]. For these systems, the most significant advantage of CDHV calculations compared to other systems is the ability to calculate the Cooling Degree Hour Value (CDHV) for every hour of every month in the summer season, for any two hours, or for any time interval [17].The degree-hour method determines the energy required for cooling and heating in a closed space proportionally to the difference between the outdoor air temperature and the balance point temperature [17]. In this method, the first step is to determine a balance point at which the cooling degree hour values are calculated. For these calculations, measurement values representing the total number of hours throughout the year, which is 8760 (24x360) hours, are needed. The balance point temperature is the outdoor air temperature at which there is no need for cooling or heating in a closed space. Generally, for uninsulated buildings, the degree-hour values are calculated based on a balance temperature of 18°C for heating and 25°C for cooling. HDH and CDH are calculated with the equations given below [13].

$$\mathbf{HDH} = (\mathbf{1\ hour}) \sum_{\mathbf{hours}} (\mathbf{T_{indoor}} - \mathbf{T_{external}})^{+} \qquad (\mathbf{2.1})$$

$$\mathbf{CDH} = (\mathbf{1\ hour}) \sum_{\mathbf{hours}} (\mathbf{T_{external}} - \mathbf{T_{indoor}})^{+} \qquad (\mathbf{2.2})$$

2.3. Statement of Meteorological Data Sets

In degree-day calculations, a data set of hourly dry bulb temperatures recorded for at least a decade in retrospect holds significant importance. This data set, obtained by the Ministry of Environment, Urbanization, and Climate Change, General Directorate of Meteorology, includes hourly recorded dry bulb temperatures for 24 hours of the day. In total, it comprises 720 hours monthly (30x24) and 8760 hours yearly (720x12) recordings. The extent to which past data sets are expanded significantly impacts the precision of degree-hour calculations. Within the scope of his doctoral thesis, Mustafa Ertürk meticulously obtained a 32-year meteorological data set, encompassing 280320 data points (32x8760) for a single province. Ertürk expanded his analysis to cover a total of 22145320 data points (79x280320) for 79 provinces.

2.3.1. External Air Temperature Distributions

The meteorological data set obtained for Muğla province has been utilized to determine the external air temperature distributions. This data set spans 32 years from 1974 to 2018 and includes dry bulb temperatures. The 32-year temperature data set has been compiled into an Excel file. The data for Muğla province in the Excel file were transferred to a computer program, and separate evaluations were conducted for every month and every hour of the day. As a result of these evaluations, the maximum and minimum temperatures within the yearly 8760-hour duration, as well as the percentage of temperatures between these two extremes, have been determined.

Table 1 presents the average temperature distribution with 1°C intervals between 07:00-08:00 for each month, aggregated annually. Although this distribution was calculated for the remaining 23 hours of the day, the other 23-hour details are not provided in the article to avoid unnecessary lengthening. The distribution of the frequency of occurrence of 32-year external air temperature data obtained from the General Directorate of Meteorology in 1°C intervals is provided. Thus, the factors contributing to the zero values in this table are the outdoor air temperatures measured over the 32 years. This indicates that the temperature in the province of Muğla has not dropped to -9.5°C during this 32-year period. In the first column of this table, External Air Temperature (EAT) values are shown at 1°C intervals, and the percentage of total monthly average external air temperatures for each month is displayed in the column opposite each month with a 1°C difference. The last column provides the distributions of annual average external air temperature.

Table 1. *Annual average external temperature distributions in Muğla between 07:00-08:00*

EAT (°C)	ANNUAL AND MONTHLY AVERAGE EXTERNAL AİR TEMPERATURE DİSTRİBUTİONS (% PERİOD)												PAEATD (%PERİOD)
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	
-9.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
-8.5	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.018333
-7.5	0.00	0.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.018333
-6.5	0.60	0.55	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.1125
-5.5	1.00	0.66	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.155
-4.5	1.60	1.44	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	1.50	0.42833
-3.5	2.90	3.09	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.20	0.6325
-2.5	6.01	5.19	0.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.73	4.11	1.39583
-1.5	7.91	5.41	2.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.52	4.71	1.71417
-0.5	9.21	6.63	2.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.87	4.81	2.10333
0.5	8.51	6.85	3.83	0.21	0.00	0.00	0.00	0.00	0.00	0.00	3.01	7.41	2.485
1.5	7.81	7.29	3.73	0.52	0.00	0.00	0.00	0.00	0.00	0.00	3.64	9.12	2.67583
2.5	6.81	10.94	6.75	0.41	0.00	0.00	0.00	0.00	0.00	0.10	6.44	7.52	3.2475
3.5	8.61	9.39	8.37	1.04	0.00	0.00	0.00	0.00	0.00	0.20	7.38	6.71	3.475
4.5	5.91	7.40	9.48	1.97	0.00	0.00	0.00	0.00	0.00	0.60	7.59	7.31	3.355
5.5	6.61	8.18	10.69	2.17	0.00	0.00	0.00	0.00	0.00	1.01	7.38	7.62	3.63833
6.5	7.21	7.18	10.69	5.69	0.20	0.00	0.00	0.00	0.00	1.71	9.25	8.12	4.17083
7.5	5.61	7.73	11.19	8.80	0.30	0.00	0.00	0.00	0.00	2.62	8.94	7.52	4.3925
8.5	6.01	4.53	8.67	11.08	0.40	0.00	0.00	0.00	0.00	3.82	8.11	6.61	4.1025
9.5	4.00	4.31	8.27	10.56	1.91	0.00	0.00	0.00	0.10	7.24	9.36	5.51	4.27167
10.5	2.30	1.77	5.34	11.49	3.62	0.00	0.00	0.00	0.31	8.85	7.48	5.21	3.86417
11.5	0.60	0.33	2.52	11.90	5.43	0.10	0.00	0.00	0.10	12.17	6.86	2.81	3.56833
12.5	0.00	0.44	1.61	10.77	6.64	0.41	0.00	0.00	1.25	10.76	5.20	1.00	3.17333
13.5	0.10	0.11	1.01	5.69	7.14	1.24	0.00	0.00	2.08	9.46	3.22	0.20	2.52083

14.5	0.40	0.00	0.71	6.94	8.65	1.04	0.00	0.00	5.40	13.18	0.83	0.10	3.10417
15.5	0.20	0.11	0.50	3.52	9.66	1.45	0.00	0.20	6.85	8.95	0.94	0.40	2.73167
16.5	0.00	0.00	0.00	3.21	12.88	4.15	0.20	0.10	11.11	6.54	0.52	0.10	3.23417
17.5	0.10	0.00	0.10	1.45	11.27	5.49	0.70	0.80	14.43	3.92	0.42	0.00	3.22333
18.5	0.00	0.00	0.00	0.93	8.85	8.19	1.91	3.21	12.15	3.42	0.10	0.10	3.23833
19.5	0.00	0.00	0.10	0.72	7.24	9.74	2.71	4.02	12.56	2.72	0.00	0.00	3.3175
20.5	0.00	0.00	0.00	0.31	5.84	12.12	6.12	8.73	11.53	0.70	0.10	0.00	3.7875
21.5	0.00	0.00	0.00	0.52	4.53	13.99	8.84	13.45	8.72	0.60	0.00	0.00	4.22083
22.5	0.00	0.00	0.00	0.00	2.11	11.40	12.65	14.86	5.40	0.60	0.00	0.00	3.91833
23.5	0.00	0.00	0.00	0.10	1.41	10.67	15.96	15.06	3.43	0.50	0.00	0.00	3.9275
24.5	0.00	0.00	0.00	0.00	1.21	8.08	16.97	15.16	2.28	0.10	0.00	0.00	3.65
25.5	0.00	0.00	0.00	0.00	0.20	6.32	13.15	10.14	1.35	0.10	0.00	0.00	2.605
26.5	0.00	0.00	0.00	0.00	0.10	3.01	10.24	6.22	0.42	0.00	0.00	0.00	1.66583
27.5	0.00	0.00	0.00	0.00	0.20	1.35	4.62	4.02	0.00	0.10	0.00	0.00	0.8575
28.5	0.00	0.00	0.00	0.00	0.00	0.41	2.41	1.71	0.00	0.00	0.00	0.00	0.3775
29.5	0.00	0.00	0.00	0.00	0.10	0.31	1.71	1.20	0.21	0.00	0.00	0.00	0.294167
30.5	0.00	0.00	0.00	0.00	0.00	0.21	0.70	0.30	0.21	0.00	0.00	0.00	0.118333
31.5	0.00	0.00	0.00	0.00	0.10	0.10	0.40	0.30	0.00	0.00	0.00	0.00	0.075
32.5	0.00	0.00	0.00	0.00	0.00	0.21	0.20	0.00	0.10	0.00	0.00	0.00	0.0425
33.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.008333
34.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.008333
35.5	0.00	0.00	0.00	0.00	0.00	0.00	0.1	0.10	0.00	0.00	0.00	0.00	0.016667
36.5	0.00	0.00	0.00	0.00	0.00	0.00	0.1	0.20	0.00	0.00	0.00	0.00	0.025
37.5	0.00	0.00	0.00	0.00	0.00	0.00	0.2	0.00	0.00	0.00	0.00	0.00	0.016667
38.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39.5	0.00	0.00	0.00	0.00	0.00	0.00	0.1	0.00	0.00	0.00	0.00	0.00	0.008333
40.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

2.3.2. The Determination of External Air Temperature Distributions for The Cooling Season

Through the second computer program, the external air temperature distributions during the cooling season months for Muğla province have been thoroughly examined.

Table 2. *External air temperature distributions for the cooling season months in Muğla province*

EAT (°C)	Average External Air Temperature Distributions for Cooling Season Months (% Period)						Average External Air Temperature Distribution for Cooling Season (%Period)
	May	Jun	July	Aug	Sep	Oct	
2.5	0.00	0.00	0.00	0.00	0.00	0.10	0.016667
3.5	0.00	0.00	0.00	0.00	0.00	0.20	0.033334
4.5	0.00	0.00	0.00	0.00	0.00	0.60	0.10
5.5	0.00	0.00	0.00	0.00	0.00	1.01	0.168333
6.5	0.20	0.00	0.00	0.00	0.00	1.71	0.318333
7.5	0.30	0.00	0.00	0.00	0.00	2.62	0.486667
8.5	0.40	0.00	0.00	0.00	0.00	3.82	0.703333
9.5	1.91	0.00	0.00	0.00	0.10	7.24	1.541667
10.5	3.62	0.00	0.00	0.00	0.31	8.85	2.13
11.5	5.43	0.10	0.00	0.00	0.10	12.17	2.966667
12.5	6.64	0.41	0.00	0.00	1.25	10.76	3.176667
13.5	7.14	1.24	0.00	0.00	2.08	9.46	3.32
14.5	8.65	1.04	0.00	0.00	5.40	13.18	4.711666
15.5	9.66	1.45	0.00	0.20	6.85	8.95	4.518333
16.5	12.88	4.15	0.20	0.10	11.11	6.54	5.83
17.5	11.27	5.49	0.70	0.80	14.43	3.92	6.101666
18.5	8.85	8.19	1.91	3.21	12.15	3.42	6.288333
19.5	7.24	9.74	2.71	4.02	12.56	2.72	6.498333
20.5	5.84	12.12	6.12	8.73	11.53	0.70	7.506667
21.5	4.53	13.99	8.84	13.45	8.72	0.60	8.335
22.5	2.11	11.40	12.65	14.86	5.40	0.60	7.836667
23.5	1.41	10.67	15.96	15.06	3.43	0.50	7.838333
24.5	1.21	8.08	16.97	15.16	2.28	0.10	7.30
25.5	0.20	6.32	13.15	10.14	1.35	0.10	5.21
26.5	0.10	3.01	10.24	6.22	0.42	0.00	3.331666
27.5	0.20	1.35	4.62	4.02	0.00	0.10	1.715
28.5	0.00	0.41	2.41	1.71	0.00	0.00	0.755
29.5	0.10	0.31	1.71	1.20	0.21	0.00	0.588333
30.5	0.00	0.21	0.70	0.30	0.21	0.00	0.236667
31.5	0.00	0.00	0.00	0.00	0.10	0.10	0.033333
32.5	0.00	0.00	0.00	0.00	0.00	0.21	0.035
33.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 2 below presents the values calculated between 07:00-08:00 for Muğla province. Calculations have also been made for the remaining twenty-three hours of the day and the frequencies of external air temperatures for the total twenty-four hours have been transferred to the third software.

3. Results and Discussion

In uninsulated buildings, cooling is required when the outdoor air temperature is 20°C and above. Cooling Degree Hour Value (CDHV) has been calculated for all months of the cooling season for 24 hours using three different software. The results obtained from the software are combined, and the 24-hour combined form table is presented in Table 3. According to TS 825 insulation regulations, the indoor reference temperature for heat loss calculations is taken as 20°C. After entering this reference temperature into the software, the 24-hour SDSD for Muğla province is presented in Table 3.

Table 3. *Cooling degree hour values according to 20°C indoor reference temperature for Muğla*

HOURS	CDHV DURİNG THE COOLİNG SEASON MONTHS OF MUĞLA [Degree Hour]						SEASONAL CDHV [Degree-Hour]
	May	Jun	July	Aug	Sep	Oct	
00:30	2.7	25.4	88.8	77.9	16.6	1.6	213.0
01:30	2.3	21.1	74.4	65.9	13.4	1.6	178.7
02:30	1.4	16.2	62.5	57.4	10.5	1.4	149.3
03:30	1.1	12.7	53.5	49.7	8.3	1.1	126.5
04:30	0.7	10.0	47.9	45.4	6.8	0.9	111.7
05:30	0.9	11.2	47.3	39.6	5.3	0.8	105.1
06:30	2.4	24.2	72.0	55.0	9.1	0.8	163.5
07:30	9.5	61.8	128.2	104.7	21.8	1.9	327.9
08:30	32.9	120.2	203.4	179.5	70.1	8.1	614.2
09:30	64.6	173.7	275.3	250.7	138.9	30.2	933.4
10:30	94.2	217.9	347.1	310.0	199.7	64.9	1233.8
11:30	111.8	243.0	378.8	348.5	238.1	89.4	1409.7
12:30	122.2	265.0	392.0	374.3	268.1	108.7	1530.2
13:30	125.7	272.5	391.7	378.1	270.8	110.7	1549.5
14:30	120.5	267.1	388.3	386.2	263.1	104.4	1529.6
15:30	89.4	255.3	374.9	366.2	242.6	83.5	1411.9
16:30	93.1	231.4	348.7	328.0	202.7	54.1	1258.1
17:30	67.4	195.5	310.8	284.7	151.0	27.8	1037.2
18:30	39.3	147.6	262.1	230.9	106.6	14.2	800.6
19:30	22.4	108.3	213.7	189.3	76.8	8.1	618.5
20:30	13.4	80.0	174.9	155.4	51.9	3.7	479.4
21:30	8.7	61.9	146.3	127.7	34.2	2.4	381.2
22:30	5.7	46.9	126.1	108.8	26.9	2.2	316.5
23:30	2.3	35.6	105.8	90.7	18.9	1.5	254.7
Total CDHV [Degree-Hour]	1034.7	2904.3	5014.7	4604.3	2452.1	724.0	16734.2

Table 3 for Muğla province has been introduced to the literature. In this table, it has been calculated that the highest cooling demand will be in July and the lowest cooling demand will be in October. For every hour of each month in the cooling season in Muğla province, Cooling Degree Hour Values between any two hours are detailed presented in Table 3.

3.1. Calculation of Free Cooling Degree Hour Values for Muğla Province

When the outdoor temperature is below the indoor reference temperature (20°C), free cooling systems operate. In this case, cooling systems (such as full air-conditioning systems) bypass the cooling coils and directly send fresh air from the outside to the interior space, covering a portion of the space's cooling load. For the implementation of this system, it is important during the design phase to know the 24-hour outdoor temperature distribution values for all months of the cooling season.

In this study, frequency values of external air temperature distributions between any two hours for each hour of each month in the cooling season in Muğla province, as well as seasonal free cooling operation times for each month of the cooling season, have been introduced to the literature. Cooling Degree Hour Values (CDHV) have been added to the literature to meet cooling loads before the cooling systems come into operation.

3.1.1. The Calculation Steps for Free Cooling Degree Hour Values

The calculations for free cooling values take into an account the frequency of external temperatures below the indoor reference temperature. These values are of immense importance for free cooling systems**.**

Table 4. *Free cooling external air temperature frequency for Muğla between 07:00-08:00*

EAT (°C)	Average External Air Temperature Distributions for Cooling Season Months (% Period)						Average External Air Temperature Distribution for Cooling Season (% Period)
	May	Jun	July	Aug	Sep	Oct	
2.5	0.00	0.00	0.00	0.00	0.00	0.10	0.016667
3.5	0.00	0.00	0.00	0.00	0.00	0.20	0.033334
4.5	0.00	0.00	0.00	0.00	0.00	0.60	0.1
5.5	0.00	0.00	0.00	0.00	0.00	1.01	0.168333
6.5	0.20	0.00	0.00	0.00	0.00	1.71	0.318333
7.5	0.30	0.00	0.00	0.00	0.00	2.62	0.486667
8.5	0.40	0.00	0.00	0.00	0.00	3.82	0.703333
9.5	1.91	0.00	0.00	0.00	0.10	7.24	1.541667
10.5	3.62	0.00	0.00	0.00	0.31	8.85	2.13
11.5	5.43	0.10	0.00	0.00	0.10	12.17	2.966667
12.5	6.64	0.41	0.00	0.00	1.25	10.76	3.176667
13.5	7.14	1.24	0.00	0.00	2.08	9.46	3.32
14.5	8.65	1.04	0.00	0.00	5.40	13.18	4.711666
15.5	9.66	1.45	0.00	0.20	6.85	8.95	4.518333
16.5	12.88	4.15	0.20	0.10	11.11	6.54	5.83
17.5	11.27	5.49	0.70	0.80	14.43	3.92	6.101666

18.5	8.85	8.19	1.91	3.21	12.15	3.42	6.288333
19.5	7.24	9.74	2.71	4.02	12.56	2.72	6.498333

For Muğla province, Table 4 has been obtained by arranging the external air temperature distribution data for the 07:00-08:00 time interval for free cooling periods. The frequencies of outdoor temperatures below 20°C are presented in Table 4. Table 4 for the 07:00-08:00 time interval has been separately calculated for the remaining 23 hours of the day.

The frequencies of outdoor temperatures during free cooling periods generated in Table 4 have been transferred to software 5 from the table created for the 07:00-08:00 time interval. Using this software, Cooling Degree Hour Values (CDHV) have been calculated for any hour of any month in the cooling season for Muğla. This study has been carried out separately for the remaining 23 hours of the day and included in software 5. The software results have been combined to obtain Table 5

Table 5. *Seasonal and monthly free cooling degree hour values for Muğla province's 24 hours*

HOURS	FCDHV FOR COOLİNG SEASON MONTHS İN MUĞLA PROVİNCE [Degree-Hour]						Free CDHV [Degree-Hour]
	May	Jun	July	Aug	Sep	Oct	Total
00:30	26.9	113.5	170.9	171.7	95.5	17.8	596.3
01:30	22.8	101.8	170.3	164.1	85.1	15.1	559.3
02:30	18.3	91.1	168.1	157.9	75.5	12.8	523.7
03:30	15.3	81.6	161.8	153.2	65.5	10.8	488.3
04:30	12.5	74.7	155.2	145.5	58.0	9.7	455.6
05:30	13.6	80.3	159.0	141.4	52.3	8.7	455.3
06:30	26.0	116.0	177.5	162.8	65.6	9.4	557.3
07:30	67.2	151.1	156.2	165.1	113.7	19.7	673.0
08:30	112.4	127.0	72.5	88.6	161.0	53.7	615.1
09:30	121.8	91.3	25.8	28.8	128.1	98.4	494.2
10:30	123.2	60.3	10.5	8.7	78.1	113.0	393.8
11:30	115.1	46.7	6.1	3.2	46.4	109.2	326.6
12:30	106.5	36.6	6.4	2.5	35.0	101.5	288.6
13:30	102.8	33.7	5.1	2.7	33.6	100.6	278.4
14:30	104.0	35.5	6.5	3.2	39.3	107.2	295.7
15:30	109.2	41.1	8.9	5.1	47.0	112.2	323.6
16:30	109.4	47.7	10.0	7.7	69.9	115.3	360.0
17:30	115.4	72.3	16.4	21.1	115.6	99.3	440.0
18:30	108.3	102.4	34.1	43.0	155.5	77.3	520.6
19:30	94.6	133.8	59.7	83.8	159.9	60.6	592.4
20:30	76.5	144.8	100.1	116.5	157.7	46.3	641.9
21:30	59.4	145.2	134.1	147.3	141.0	33.5	660.5
22:30	46.1	139.5	154.9	163.5	122.3	25.3	651.6
23:30	25.2	129.4	167.8	169.2	107.6	19.8	619.0
Total Free CDHV [Degree-Hour]	1732.4	2197.4	2138.1	2156.5	2209.0	1377.2	11810.7

In Table 5, it can be observed that the maximum seasonal cooling degree hour (CDH) value is 673, occurring between 06:30 and 07:30. The highest CDH throughout the cooling season, especially in July, is observed with a value of 177.5 between 05:30 and 06:30. The total 24-hour CDH value calculated for Muğla province during the cooling season is determined to be 2209, with the highest value occurring in September.

The data from Table 5 is shown in Figure 1. This figure provides a summary, based on the results of 5 different software programs of the total 32-year external air temperature data for a total of 8760 hours in Muğla province.

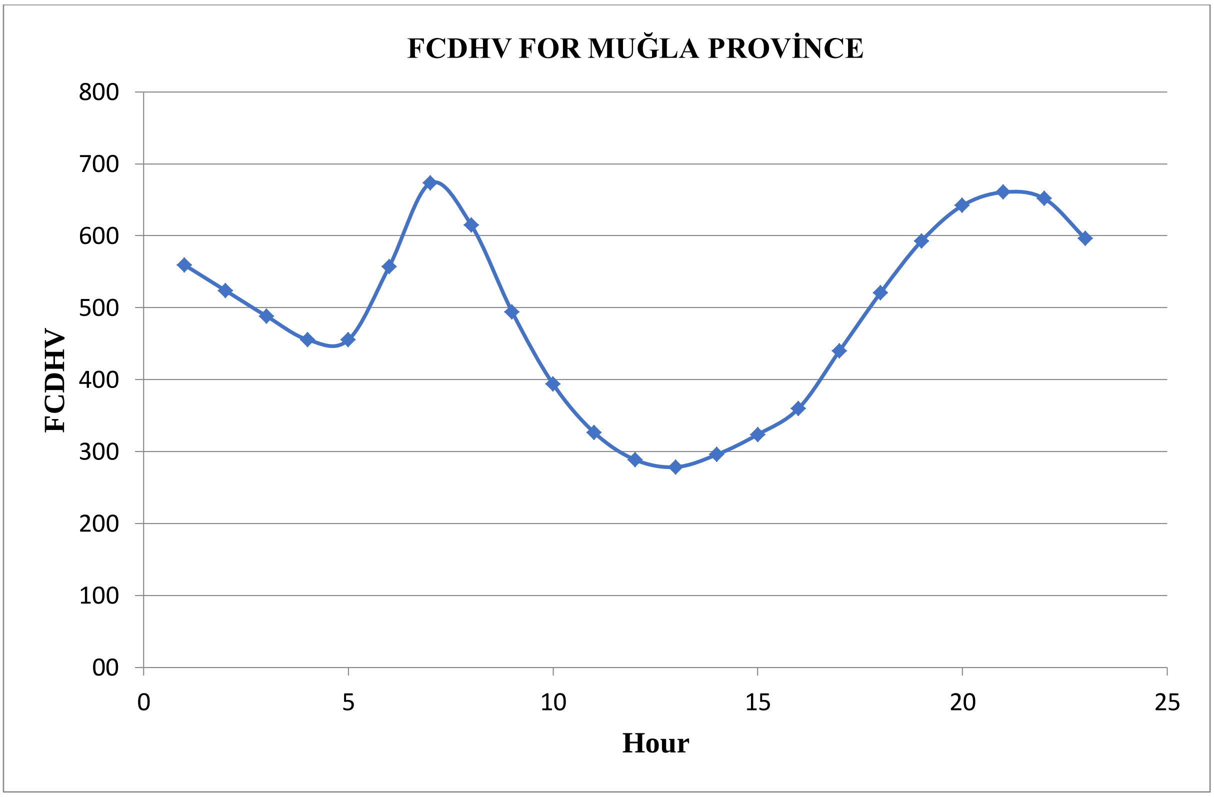

Figure 2. Seasonal free cooling degree hour values for Muğla province

Taking the data from Table 5 into account, the Free Cooling Degree Hour Values for each month throughout the cooling season have been presented monthly in Figure 2.

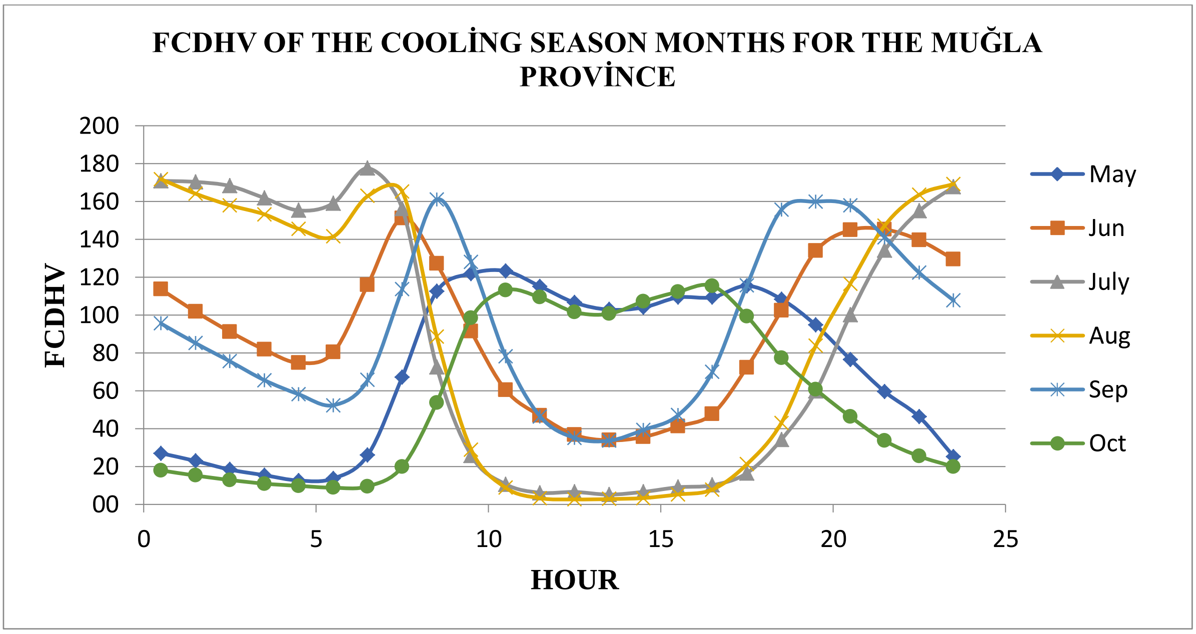

Figure 3. Free cooling degree hour values for months in the cooling season for Muğla province

The total Cooling Degree Hour Values (CDHV) and the total Free Cooling Degree Hour Values (FCDHV) for Muğla are presented comparatively in Table 6.

Table 6. *Comparison of FCDHV and CDHV for Muğla province*

24 HOURS OF THE DAY	FCDHV and CDHV for COOLİNG SEASON MONTHS İN MUĞLA [Degree-Hour]						FCDHV [Degree-Hour]
	May	Jun	July	Aug	Sep	Oct	Total
Total CDHV [Degree-Hour]	1034.7	2904.3	5014.7	4604.3	2452.1	724.0	16734.2
Total FCDHV [Degree-Hour]	1732.4	2197.4	2138.1	2156.5	2209.0	1377.2	11810.7
CDHV and FCDHV with difference [%]	167.43	75.66	42.636	46.836	90.086	190.22	70.578

The percentage difference between the total cooling degree-hour values and the total free cooling degree-hour values is calculated through proportional comparison. This percentage difference theoretically demonstrates the amount of energy saving that can be achieved through free cooling. It has been determined that Muğla's highest SSDSD to SDSD coverage ratio is 190.22% in October, the lowest is 42.636% in July, and the seasonal ratio is 70.578%.

4. Conclusion

In this study, various analyses were conducted using five different software programs developed to contribute to the literature for Muğla province. The first software was used to determine the external air temperature distributions, including the frequencies within 8760 hours and monthly distributions. These distributions were then transferred to the second software. With the second software, the cooling season months and frequencies of external air temperatures for Muğla province were determined for each hour. These distributions were transferred to the third software to determine the cooling loads at any time of any hour during the cooling season. The fourth software was used to determine the frequencies of outdoor air temperatures during the cooling season for each hour of the day. The fifth software was used to determine the Free Cooling Degree Hour Values for all months of the cooling season. These values were added to the literature for Muğla province.

As a result of this study, it was found that Muğla's CDHV is 16734.2 and FCDHV is 11810.7. It was also determined that a 70.578% energy recovery can be achieved throughout the cooling season from the free cooling cycles that will be implemented. This study contributes valuable information to the literature for Muğla province.

Acknowledgements

This study has been supported by Professor Doctor Mustafa Ali Ertürk.

Conflict of İnterest

The Authors report no conflict of interest relevant to this article.

Research and Publication Ethics Statement

The authors declare that this study complies with research and publication ethics.

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