Modified Degree-Hour Calculation Method

C. Coskun1,*, D. Demiral2, M. Ertürk3 and Z. Oktay3

1Turgut Kıran Maritime College, 
Department of Marine Engineering, Rize University, Rize, 
2Mechanical Engineering Department, 
Faculty of Engineering, Aksaray University, Aksaray, 
3Mechanical Engineering Department, 
Faculty of Engineering, Balikesir University, Balikesir, Turkey

1. Introduction

A wide variety of building energy analysis methods are currently available to HVAC engineers and range from simple to sophisticated. The simplest methods involve the largest number of simplifying assumptions and therefore tend to be the least accurate. The most sophisticated methods involve the fewest assumptions and thus can provide the most accurate results. Generally, methods for building energy analysis can be given at three categories as follows:

- Single Measure Methods (example: Equivalent Full Load Hours)
- Simplified Multiple Measure Methods (example: Bin Method)
- Detailed Multiple Measure Methods (example: Hour by Hour)

Detailed Multiple Measure Method provides the most accurate results. In detailed Multiple Measure Method, energy calculations are on hour-by-hour basis. Within the detailed multiple measure categories are two major sub-categories worth discussing: The Reduced Hour-By-Hour Method and 8760 Hour-By-Hour Method. When consider the detailed methods, it is very difficult to find actual hourly weather data for each place. Also, detailed methods take much time for calculation [1]. The most detailed methods simulate the hourly dynamic heat transfer process inside the building envelope as well as the dynamic behavior of the heating system and the equipment. They are based on thermodynamic principles and solved numerically by using the initial and boundary conditions in addition to the geometry of the building. These procedures account for the influence of many factors such as weather, internal heat gains, building thermal inertia, solar gains, control system, etc., which may significantly vary with time. These methods are defined to be dynamic and they require hourly weather temperature data [2]. Dynamic methods are more detailed and usually require hourly calculations over the whole year for an accurate analysis of the annual load and the energy consumption [2-5].

* Corresponding Author
Forecasting the total or monthly energy requirement for cooling or heating purposes requires the determination of cooling or heating load profiles, for which identification of the two main external factors are necessary namely; the mean outdoor temperature probability distribution and the heat gain from sunlight. Monthly outdoor temperature probability distribution is very important input data for determining monthly heating and cooling degree-hour. It is known that degree-hour values are calculated simply by summing up the differences between the hourly dry-bulb temperatures and a standard reference temperature (base temperature). Outdoor temperature distribution and reference (base) temperature directly affect the heating or cooling load. Reference temperatures for heating in building applications vary from country to country. For instance, in the UK, heating degree-hour values are based on an outside dry bulb temperature of 15.5 °C, while Australia uses 18°C and the United States uses 18.3°C. After estimating the probable outdoor temperature distribution, the total cooling or heating degree-hours values are calculated.

Probability density functions are successfully applied in wind, solar, and hydrogen energy production as well as the outdoor temperature analyses and as such, they are commonly preferred by many researchers [6-13] for energy analyses in the literature. Coskun [13] applied this technique to outdoor temperature and proposed a new approach for degree-hours calculation. He used the sinusoidal function to specify the outdoor temperature probability distribution. Many scientists [14-20] focused on the total cooling/heating degree hours and degree-days values for different countries. In some studies, a constant base temperature method is employed to predict the cooling/heating degree-hours. In the literature, only a few studies are available that focus on both constant and variable base temperatures. More recently, hourly building energy simulations increasingly replaced the simplified load calculation methods such as the degree-days and degree-hours approaches. These simulations provide several advantages over such kinds of simplified methods during the design stage, including the ability to explore the equilibrium state of applying a large number of different combinations (or packages) of energy conservation measures and to account for any dynamic behavior such as the thermal energy storage in the structure itself. However, simplified models and methods are still preferred in practice over these sophisticated building energy simulation programs. In Turkey, people are generally in favor of using less complicated methods [21].

In this study, a modified degree-hours calculation method is developed to obtain more accurate results and then applied to four cities in Turkey.

2. Calculation method and new function

Coskun [13] proposed a sinusoidal function to estimate the probability density distribution of the outdoor temperatures. The proposed sinusoidal function is given by the equation below:

\[ H_{T_{\text{out}}} = a + b \cdot \cos(c \cdot T_{\text{out}} + d) \]  

(1)

where, a, b, c and d are the model parameters, \( T_{\text{out}} \) denotes the outdoor temperature in °C and \( H_{T_{\text{out}}} \) gives the hours lapsed in a month at a temperature of \( T_{\text{out}} \) degrees. After estimation of the temperature probability density distribution, heating and cooling degree-hours were calculated using the equations below;
Modified Degree-Hour Calculation Method

\[ HDH_{Total} = \sum_{n=s}^{k} H_n \cdot (T_{\text{Base}} - T_n) \]  (2)

\[ CDH_{Total} = \sum_{n=s}^{k} H_n \cdot (T_n - T_{\text{Base}}) \]  (3)

Temperature ‘k’ and ‘s’ denotes the temperature limits of the function. \( HDH_{Total} \) and \( CDH_{Total} \) indicate the total heating and cooling degree-hour values for a chosen month, respectively. \( T_{\text{Base}} \) is a reference indoor temperature for both heating or cooling.

2.1 New modeling functions

In this study, two new functions are proposed. The proposed new functions are given by the equations below:

\[ H_{T_{\text{out}}} = f \cdot e^{\frac{-(T_{\text{out}} - g)^2}{2h^2}} \]  (4)

\[ H_{T_{\text{out}}} = e^{k + \frac{m}{T_{\text{out}}} + n \cdot \ln(T_{\text{out}})} \]  (5)

where, \( f, h, g, k, m \) and \( n \) are the new model parameters, which are determined according to mean outdoor temperature probability density distribution, whose determination is explained in detail in Section 3 below.

3. Determination of mean outdoor temperature probability density distribution

We calculated both temperature probability distribution and time elapsed in a month for any temperature interval of 1 °C. In the calculation, hourly dry-bulb outdoor temperature data, based on the last 32 years and recorded by the Turkish State Meteorological Station, were used. In this study, the general trend was tried to be obtained in one formulation. The outdoor temperature distribution frequency exhibits different characteristics in each year and month. Nevertheless, the mean outdoor temperature probability density distribution for each month can be determined by using the long term actual data for the past temperatures, which can be utilized as a reference distribution for degree-hour calculations. It was observed that outdoor temperature has a random fluctuation on general trend. In this study, the mean outdoor temperature probability density distribution was taken as a reference distribution for the modified degree-hours calculation method. Fig. 1 is given to illustrate the fluctuation of actual outdoor temperature frequency distributions for 32 years.

4. Results and discussion

The modified degree-hours calculation method was applied to four cities in Turkey. The model parameters are determined and given in Table 1. Analysis results show that the two new functions result in higher accuracy for the summer season. Therefore, the three functions are incorporated into a modified degree-hours calculation method in this study.
The two functions proposed in this study were also applied to a case study to demonstrate its accuracy. The province of Adana was chosen for this purpose. The actual outdoor temperature probability density distribution and the two functions are shown in Fig. 2 for the month of May. As it can be seen from Fig. 2, the new functions displayed better performance for cooling degree-hours calculations for the summer season. Also, actual and model outdoor temperature probability density distributions for six months were given in Fig. 3 for Adana.

| Adana | Months | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
|-------|--------|---|---|---|---|---|---|---|---|---|----|----|----|
| Model parameters | a | 32.80 | 25.36 | 25.75 | - | - | - | - | - | - | - | - | - |
| | b | 36.37 | 28.30 | 29.35 | - | - | - | - | - | - | - | - | - |
| | c | 0.28 | 0.24 | 0.22 | - | - | - | - | - | - | - | - | - |
| | d | -2.79 | -2.61 | -3.13 | - | - | - | - | - | - | - | - | - |
| | f | - | - | 64.87 | - | - | - | - | - | - | - | - | - |
| | g | - | - | 17.36 | - | - | - | - | - | - | - | - | - |
| | h | - | - | 4.44 | - | - | - | - | - | - | - | - | - |
| | k | - | - | - | - | - | - | - | - | - | - | - | - |
| | m | - | - | - | - | - | - | - | - | - | - | - | - |
| | n | - | - | - | - | - | - | - | - | - | - | - | - |
| Temperature limits | 0.5 | 0.5 | 2.5 | 5.5 | 11.5 | 15.5 | 17.5 | 17.5 | 13.5 | 9.5 | 1.5 | -1.5 | - |
| Balikesir | 19.5 | 21.5 | 25.5 | 33.5 | 39.5 | 40.5 | 43.5 | 43.5 | 41.5 | 38.5 | 30.5 | 24.5 | - |
Modified Degree-Hour Calculation Method

59

Antalya

| Months   | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
|----------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| Model parameters | f | 71.70 | 61.35 | 66.30 | 66.10 | 63.15 | 58.40 | -   | -   | -   | -   | 61.79 |
|           | g | 10.24 | 10.77 | 12.90 | 16.20 | 20.51 | 25.38 | -   | -   | -   | -   | 14.72 |
|           | h | 4.16  | 4.39  | 4.49  | 4.36  | 4.72  | 4.94  | -   | -   | -   | -   | 4.68  |
|           | k | -     | -     | -     | -     | -     | -     | -   | -   | 165.897 | 157.934 | 101.845 |
|           | m | -     | -     | -     | -     | -     | -     | -   | -   | -1034.5 | -975.4 | -557.6 |
|           | n | -     | -     | -     | -     | -     | -     | -   | -   | -37.45 | -35.7 | -23.46 |
| Temperature limits | -1.5 | -1.5 | 0.5 | 4.5 | 8.5 | 12.5 | 17.5 | 17.5 | 14.5 | 9.5 | 3.5 | 0.5 |

| Months | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
|--------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| Model parameters | f | 60.96 | 51.50 | 51.90 | 54.17 | 52.80 | 50.98 | 50.18 | 50.45 | 48.08 | 55.00 | 53.65 | 64.80 |
|           | g | 1.04  | 2.14  | 6.00  | 10.95 | 15.56 | 19.52 | 23.09 | 22.98 | 18.56 | 12.66 | 6.65 | 2.15 |
|           | h | 4.89  | 5.23  | 5.75  | 5.33  | 5.65  | 5.83  | 5.99  | 6.00  | 6.09  | 5.44  | 5.40  | 4.60 |
| Temperature limits | -12.5 | -12.5 | -9.5 | -3.5 | 0.5 | 6.5 | 8.5 | 10.5 | 5.5 | -0.5 | -6.5 | -10.5 |

| Months | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
|--------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| Model parameters | f | 14.5 | 16.5 | 21.5 | 25.5 | 31.5 | 34.5 | 37.5 | 38.5 | 33.5 | 39.5 | 30.5 |
|           | g | -     | -     | -     | -     | -     | -     | -     | -     | -     | -     | -     |
|           | h | -     | -     | -     | -     | -     | -     | -     | -     | -     | -     | -     |
| Temperature limits | -12.5 | -12.5 | -9.5 | -3.5 | 0.5 | 6.5 | 8.5 | 10.5 | 5.5 | -0.5 | -6.5 | -10.5 |

Table 1. Monthly model parameters for the four cities.

Fig. 1. Actual and mean outdoor temperature frequency distributions for Balikesir during the month of January
5. Conclusions

Results of the analysis show that one function is not sufficient for determining the accurate outdoor temperature distribution during the year. In this regard, two new functions were proposed and added to the existing calculation procedure. As a result, the modified degree-
Modified Degree-Hour Calculation Method

hours calculation method obtains more accurate results for each month by using all three outdoor temperature distribution functions. The main advantages of the approach can be listed as follows:

- Outdoor temperature distribution for each month can be determined precisely by using the modified degree-hours calculation method. Probable heating and cooling degree-hours value can be calculated by using probable outdoor temperature distribution for each month.
- Heating and cooling degree-hour values can be calculated for each month with respect to any chosen base temperature.
- The user can easily calculate the time elapsed in a month for temperatures below or above any chosen level of outdoor reference temperature.

6. References

[1] Pegues J. The benefits of 8760 hour-by-hour building energy analysis. Carrier Software Systems. New York, USA: HVAC Systems Engineer. 2002.
[2] Papakostas K, Kyriakis N. Heating and cooling degree-hours for Athens and Thessaloniki, Greece. Renewable Energy. 2005;30(12):1873–1880
[3] Hui SCM, Cheung KP. Application of building energy simulation to air conditioning design. In: Proceedings of the Mainland-Hong Kong HVAC seminar’98, Beijing. 1998. pp 12–20.
[4] ASHRAE Handbook – fundamentals (SI). Energy estimating methods. 1993. Chapter 28.
[5] Said SAM, Habib MA, Iqbal MO. Database for building energy prediction in Saudi Arabia. Energy Conversion and Management 2003;44(1):191–201
[6] Celik AN. On the distributional parameters used in assessment of the suitability of wind speed probability density functions. Energy Conversion and Management 2004; 45: 1735–1747
[7] Carta JA, Ramírez P., Velázquez S. Influence of the level of fit of a density probability function to wind-speed data on the WECS mean power output estimation. Energy Conversion and Management 2008; 49: 2647–2655
[8] Ibanez M, Rosell JJ., Beckman WA. A bi-variable probability density function for the daily clearness index. Solar Energy 2003; 75: 73–80
[9] Ettoumi FY, Mefti A., Adane A., Bouroubi MY. Statistical analysis of solar measurements in Algeria using beta distributions. Renewable Energy 2002; 26: 47–67
[10] Tovar J, Olmo FJ., Batlles FJ., Alados-Arboledas L. Dependence of one-minute global irradiance probability density distributions on hourly irradiation. Energy 2001; 26: 659–668
[11] Coskun C, Oktay Z, Dincer I. Estimation of Monthly Solar Radiation Intensity Distribution for Solar Energy System Analysis. Energy 2011;36(2): 1319-1323
[12] Akyuz E, Coskun C, Oktay Z, Dincer I. Hydrogen Production Probability Distribution for a PV-Electrolyser System. International Journal of Hydrogen Energy 2011;36(17):11292-11299
[13] Coskun C. A novel approach to degree-hour calculation: Indoor and outdoor reference temperature based degree-hour calculation. Energy 2010;35: 2455-2460
[14] Sarak H, Satman A. The degree-day method to estimate the residential heating natural gas consumption in Turkey: a case study. Energy 2001; 28:929-39

www.intechopen.com
[15] Dombaycı OA. Degree-days maps of Turkey for various base temperatures. Degree-days maps of Turkey for various base temperatures, Energy 2009;34:1807-12
[16] Sen Z, Kadioglu M. Heating degree-days for arid regions. Energy 1997;23:1089-94
[17] El-Shaarawi MAI, Al-Masri N. Weather data and heating-degree days for Saudi Arabia. Energy 1996;21: 39-44
[18] Satman A, Yalcinkaya N. Heating and cooling degree-hours for Turkey. Energy 1999;24(10):833–40
[19] Duryamaz A, Kadioglu M, Sen Z. An application of the degree-hours method to estimate the residential heating energy requirement and fuel consumption in Istanbul. Energy 2000;25:1245–56
[20] Büyükalaca O, Bulut H, Yılmaz T. Analysis of variable-base heating and cooling degree-days for Turkey. Applied Energy 2001;69(4):269-283
[21] Oktay Z, Coskun C, Dincer I. A new approach for predicting cooling degree-hours and energy requirements in buildings. Energy 2011; 36:4855-4863
A wide variety of detail regarding genuine and proprietary research from distinguished authors is presented, ranging from new means of evaluation of the local solar irradiance to the manufacturing technology of photovoltaic cells. Also included is the topic of biotechnology based on solar energy and electricity generation onboard space vehicles in an optimized manner with possible transfer to the Earth. The graphical material supports the presentation, transforming the reading into a pleasant and instructive labor for any interested specialist or student.

How to reference
In order to correctly reference this scholarly work, feel free to copy and paste the following:

C. Coskun, D. Demiral, M. Ertürk, Z. Oktay (2012). Modified Degree-Hour Calculation Method, Solar Power, Prof. Radu Rugescu (Ed.), ISBN: 978-953-51-0014-0, InTech, Available from: http://www.intechopen.com/books/solar-power/modified-degree-hour-calculation-method-