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Item Type	Book chapter;Postprint
Authors	Mokhtar, Ahmed
Citation	Mokhtar, A. (2022). Examining the Deviation in Energy Saving Estimations Due to the Use of the Degree Days Method. In: Littlewood, J.R., Howlett, R.J., Jain, L.C. (eds) Sustainability in Energy and Buildings 2021 . Smart Innovation, Systems and Technologies, vol 263. Springer, Singapore. https://doi.org/10.1007/978-981-16-6269-0_1
DOI	10.1007/978-981-16-6269-0_1
Publisher	Springer
Download date	2024-08-13 08:10:17
Link to Item	http://hdl.handle.net/11073/25519

Accepted manuscript of:
Mokhtar, A. (2022). Examining the Deviation in Energy Saving Estimations Due to the Use of the Degree Days Method. In: Littlewood, J.R., Howlett, R.J., Jain, L.C. (Eds) *Sustainability in Energy and Buildings 2021* . Smart Innovation, Systems and Technologies, vol 263. Springer, Singapore. https://doi.org/10.1007/978-981-16-6269-0_1

Examining the Deviation in Energy Saving Estimations Due to the Use of the Degree Days Method

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Abstract. Energy performance contracts are commonly used to retrofit buildings and reduce their energy consumption. The financial agreement in the contracts typically depends on calculating the amount of energy saved every year. This is difficult to calculate as many aspects that impact a building's energy consumption continuously change, including the weather. The Degree Days method is commonly used to help estimate the energy saving while the weather is changing. The Degree Days can be calculated with a variety of base temperatures resulting in different values. This paper is a first step in examining the significance of the deviation in energy saving calculations when using this method. It also investigates if there is a more appropriate base temperature to use for that purpose. Energy simulation with actual annual weather data is used to make the investigation. Two different building types and three different energy conservation measures are used. The results of this preliminary investigation show that the deviation can be significant in some cases. They also show the possibility that a particular base temperature for calculating the degree days can give more accurate savings estimations. These can be very important results for users of energy performance contracts.

Keywords: Degree Days, Building Retrofitting, Energy Savings.

1 Introduction

With the signing of the Paris Agreement on climate change, several countries initiated programs to retrofit old buildings to reduce their energy consumption. In addition, many owners see a financial benefit in improving the energy performance of their buildings by reducing their energy bill. As a result, energy service companies (ESCO) are offering various services to accommodate this market demand. An important part of these services is the energy performance contract [1]. These are contracts that aim to finance the retrofitting cost by using the savings in the energy consumption cost. There are basically two common types of energy performance contracts between an owner and an ESCO. These are the Guaranteed Savings contract and the Shared Savings contract. In a simplified way, the main difference between these two types of contracts is in the financing of the retrofitting cost and in the calculations of the savings. In a Guaranteed Savings contract, the owner finances the retrofitting cost and pays the ESCO for their technical service. However, the payment is due only when a certain level of energy consumption saving is achieved from the retrofitting. In a Shared Savings contract, the ESCO finances the retrofitting costs in return for a percentage of the saving in the consumption cost. In both types of contracts, the saving in energy needs to be determined to process the payments according to the contract.

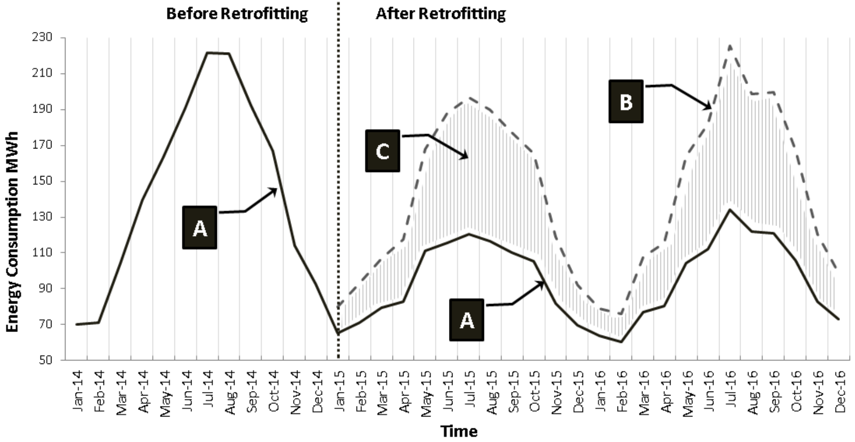

Fig. 1. Building energy consumption before and after retrofitting. (A) is actual consumption. (B) is estimated consumption if there was no retrofitting. (C) is the estimated saving in enegy consumption.

The problem is that energy savings is not a measurable quantity. Rather, it is an estimated one. Fig. 1 illustrates this problem. What can be measured is the energy consumption because it is metered. We can measure it before retrofitting and after retrofitting. Line (A) shows this metered energy consumption. It is certainly easy to assume that - if the retrofitting is not done - the building would have consumed the same energy that we measured before its retrofitting. Hence, the difference between what we measure before retrofitting (the part of line A before retrofitting) and what we measure after retrofitting (the part of line A after retrofitting) is what is being saved. Yet, this is not correct. Several factors affect the building which results in a variation in energy consumption every year. These include changes in the schedule of the building use or in the number of its occupants among many other factors. Therefore, we need to establish an estimation of what would have been the building's energy consumption if it was not retrofitted. Line (B) in Fig. 1 shows an example of this estimation. Using estimated energy consumption (B), and the metered energy consumption (A), we can establish a more accurate estimation of the energy saving due to the retrofitting. This will be the difference between (B) and (A) as represented by the area (C) in Fig. 1. As mentioned above, the estimation in savings has contractual and financial implications for both parties involved in the energy performance contracts. The more accurate the actual saving calculation is, the clearer are the contractual obligations and the fairer is the distribution of saved money.

The challenge now is in estimating line (B) for a particular building reasonably accurately. Several methods exist to make such estimation as defined by the International Performance Measurement and Verification Protocol (IPMVP) [2]. The amount of data needed and the effort and money put in collecting different data varies between these methods. Depending on the nature of the building and the extent of the retrofit, a simple or more complex method is selected to help estimate the saving in energy consumption (C) in Fig. 1.

One of the most important factors that affect the variation in a building's energy consumption is the annual change in the weather conditions. In most buildings, this change has a direct impact on the energy consumption by the HVAC systems. Depending on the building type and its surrounding climate, these systems can be by far the biggest consumer of energy in a building. Hence, fluctuation in weather conditions means fluctuations in the building's annual energy consumption. To estimate the impact of weather in creating line (B) in Fig. 1, the "Degree Days" method is commonly used [3]. The method uses numbers that can be generated from weather data. These numbers change as the weather changes. A simple equation can be used then to estimate line (B) in Fig. 1 from the section of line (A) that is before retrofitting. For example, and following the timeline in Fig. 1, to estimate the energy that the building would have consumed if it were not retrofitted in the year 2015 (E_{Est}), get the energy actually used by the building before retrofitting in year 2014 (E_{Base}) which is considered the base (or reference) year, get the cooling degree days for 2015 (CDD_{Est}) and the cooling degree days for 2014 (CDD_{Base}) and use these in equation (1).

$$(E_{Est}) = (E_{Base}) * \frac{CDD_{Est}}{CDD_{Base}} \qquad (1)$$

The question now is how to calculate the values for the CDD in the needed years. According to Bromley [4], "*Degree days are a measure of how much (in degrees), and for how long (in days), the outside air temperature was below [above] a certain level*". In case of Heating Degree Days (HDD), we measure "below" a certain base temperature while in the case of Cooling Degree Days (CDD), we measure "above" a certain base temperature. HDD are used when we want to estimate the energy needed to heat a building while CDD are used when we want to estimate the energy needed to cool a building. The bigger the number, the more energy is expected to be used by the HVAC system to achieve human thermal comfort. In this article, we focus on using the CDD.

Calculating the CDD requires a base temperature. This is the temperature above which we assume the building requires cooling. The standard base temperature used in ASHRAE is 18.3°C (65°F). However, others use different base temperatures. Azevedo et al. [5] provides a list of base temperatures used in different countries as they appear in the literature. The list shows a variation from 18°C to 28°C and it reflects the assumptions made by the different researchers on the temperature beyond which a building needs to be cooled mechanically. This certainly depends on the type of building and its climatic region.

Once the base temperature is determined, calculating the CDD for a particular period (e.g. month or year) is simple. Using the hourly weather data, a value "X_i" is calculated for each day using equation (2). All the positive values for "X_i" - for the number of hours "h" that are in the calculated period - are summed to be the CDD for the needed period as shown in equation (3).

$$X_i = \frac{\left(T_{Daily\ Max} - T_{Daily\ Min}\right)}{2} - T_{Base\ Temperature} \qquad (2)$$

$$CDD = \sum_{i=1}^{h} \mathrm{X}_i \quad (\text{where } \mathrm{X}_i > 0) \qquad (3)$$

Clearly, the selection of the base temperature impacts the calculated CDD. Hence, the ratio CDD_{Est} / CDD_{Base} that is used in equation (1) will vary accordingly. Consequently, the estimated energy consumption E_{Est} that represents line (B) in Fig. 1 will also vary. Therefore, the estimated saving due to the retrofitting, (C) in Fig. 1, will be different each time we change the base temperature for calculating the CDD. This may affect the amount of money to be paid to the ESCO in the case of a shared savings contract. It may also result in non-payment in the case of a guaranteed savings contract.

This paper is a step towards answering two questions. The first is how big the deviation is in estimating the saving in energy consumption when the CDD method is used. The second is whether there is an optimal base temperature that minimizes the deviation. The paper starts by explaining the methodology used to answer the two questions and it then shows the results and the conclusion of the study.

2 Methodology

Energy saving can never be measured in reality. Therefore, the researcher approach to answering the two questions is to use energy simulation software. With simulation, it is possible to keep all the parameters that impact a building's energy consumption constant, with the exception of the parameters being tested. This allows us to isolate some parameters and hence evaluate the impact of their changes on the building's energy consumption. In our case, we need to do so to create lines (A) and (B) of Fig. 1.

A building is modeled in the energy modeling software IESVE [6]. The following series of simulations are run using the weather data for the city of Sharjah in the United Arab Emirates (ASHRAE Climate Zone 1B Very Hot - Dry):

1. A simulation is done using actual hourly weather data for a base year (e.g. 2014). This creates the part of line (A) that exists before retrofitting as shown in Fig. 1. The sum of the calculated monthly energy consumption represents the base consumption value E_{Base} of equation (1). No particular reason for selecting 2014 as the base year. The author just wants to have four years of performance after retrofitting as a reasonable time for testing the possible deviation in results. Further studies should test different base years and more years after retrofitting.

2. A simulation is done using actual hourly weather data for the consecutive years. (e.g. 2015, 2016, 2017, 2018). This creates line (B) as shown in Fig. 1 based on simulation results.
3. Some Energy Conservation Measures (ECMs) are applied to the simulated building to represent a retrofit work done on the building. The simulation is run using the actual hourly weather data for the consecutive years. (e.g. 2015, 2016, 2017, 2018). This creates the part of line (A) that exists after retrofitting as shown in Fig. 1.

Using equations (2) and (3), several CDD calculations are done using a spreadsheet macro developed by the researcher. The macro uses actual hourly weather data and a base temperature - defined by the user - to make the CDD calculations. The following CDD calculations are done using the weather data for the city of Sharjah in the United Arab Emirates:

1. CDD for the base year (e.g. 2014) and for a range of base temperatures from 15°C to 25°C. For each base temperature, this is the value needed for CDD_{Base} in equation (1). Table 1 shows the results.
2. CDD for the consecutive years (e.g. 2015, 2016, 2017, 2018) and for a range of base temperatures from 15°C to 25°C. For each base temperature, this is the value needed for CDD_{Est} in equation (1). Table 1 shows the results.

Table 1. Calculated CDD for different base temperatures.

Base Temp. °C	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
2014	*4792*	*4439*	*4087*	*3743*	*3413*	*3100*	*2804*	*2528*	*2271*	*2023*	*1791*
2015	4825	4473	4123	3777	3443	3123	2824	2540	2265	2002	1754
2016	4720	4367	4015	3667	3330	3012	2711	2423	2147	1892	1657
2017	4859	4509	4160	3814	3472	3148	2841	2551	2279	2026	1789
2018	4824	4471	4119	3776	3446	3130	2830	2544	2272	2017	1774

For each base temperature, and for each of the consecutive years, we calculate the ratio CDD_{Est} / CDD_{Base} of equation (1). We then use equation (1) to estimate the energy consumption if the building is not retrofitted. This will be line (B) in Fig. 1 based on the CDD method.

To compare the difference between generating line (B) of Fig. 1 by using the two methods, Fig. 2 shows line (B) as (Bs) in case it is generated by the simulation and as (Bc) in case it is generated by the CDD method. The line (Bc) will be different for each base temperature.

Using Fig. 2, the estimated saving based on the simulation result will be the difference between the values in line (Bs) and the values in line (A) for each of the studied years (e.g. 2015, 2016, 2017, 2018). We will refer to this simulation-based saving value as ($S_{Simulation}$). Similarly, the estimated saving based on the CDD method will be the difference between the values in the line (Bc) and the values in line (A) for each of the studied years. We will refer to this CDD-based saving value as (S_{CDD}). The deviation in using the CDD method in estimating the energy saving is calculated using equation (4) for each year and for each of the used base temperatures from 15°C to 25°C as shown in Table 2.

$$Deviation = \frac{(S_{CDD} - S_{Simulation})}{S_{Simulation}} \qquad (4)$$

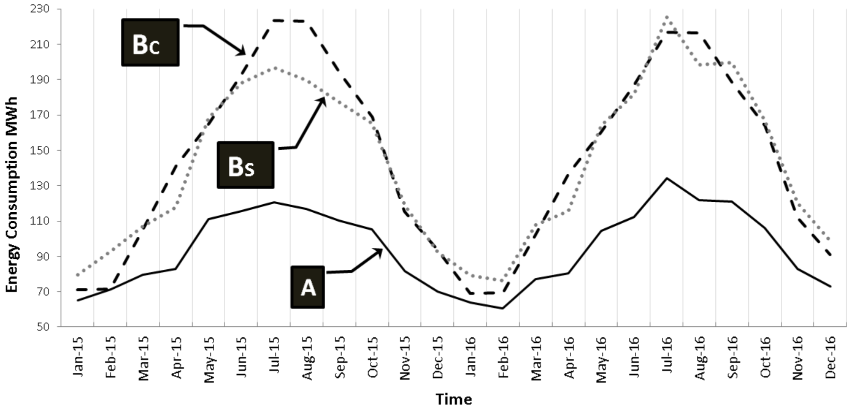

Fig. 2. Estimated energy consumption if no retrofitting is done. Bs is calculated using the computer simulation. Bc is calculated using the CDD method (shown here for base temperature = 18°C).

Table 2. Percentage of deviation in estimating energy saving when using the CDD method.

Base Temp. °C	15	16	17	18	19	20	21	22	23	24	25
2015	2.0%	2.2%	2.5%	2.6%	2.5%	2.1%	2.1%	1.4%	-0.6%	-2.9%	-5.8%
2016	-4.3%	-4.6%	-5.0%	-5.8%	-7.0%	-8.1%	-9.5%	-11.8%	-15.5%	-18.5%	-21.5%
2017	4.2%	4.7%	5.3%	5.7%	5.1%	4.6%	3.9%	2.8%	1.1%	0.5%	-0.3%
2018	1.9%	2.1%	2.2%	2.5%	2.8%	2.8%	2.7%	1.9%	0.2%	-0.8%	-2.8%
Ave. Deviation	**1.0%**	**1.1%**	**1.2%**	**1.3%**	**0.9%**	**0.3%**	**-0.2%**	**-1.4%**	**-3.7%**	**-5.4%**	**-7.6%**

The same process is repeated but for two types of buildings and for three types of ECMs. The objective is to check if the nature of the building and the used ECMs will make a meaningful difference. The buildings types are:

1. A primary school with a single floor and finger plan as shown in Fig. 3. Because of the form and the function of the building, it is considered to have an externally dominated cooling load and its energy performance is greatly impacted by the weather.

2. A hospital with a multi-story and deep plan as shown in Fig. 4. Because of the form and the function of the building, it is considered to have an internally dominated cooling load and its energy performance is less impacted by the weather.

Both modeled buildings are provided as templates by the software IES VE. The weather data for Sharjah is used for the years 2014 until 2018 and the cooling set point temperature is 24°C. The three types of ECMs are:

1. ECMs directly related to the weather. The used ECMs are i) double the efficiency of the HVAC system used (from COP = 3.1 to COP = 6.2) and ii) double the R value of the roof (from $R = 3.5\ m^2\cdot°K/W$ to $R = 7.0\ m^2\cdot°K/W$). This is referred to as ECM (A).
2. ECMs not-directly related to the weather. The ECM used is replacing the florescent lighting with much more efficient LED light (The value for w/m^2 for each space is halved). This is referred to as ECM (C).
3. Both of the above ECMs are used. This is referred to as ECM (B).

The resulting consumption from the simulation in each case is the total building energy consumption and similarly is the estimated saving.

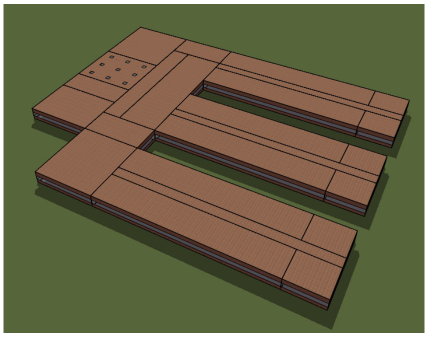

Fig. 3. The model for the primary school used.

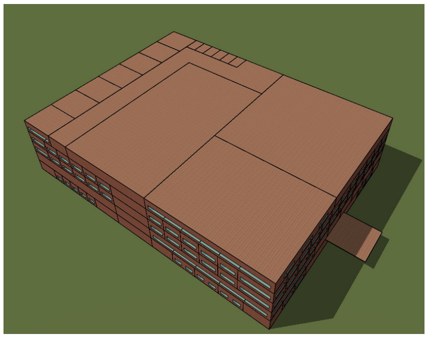

Fig. 4. The model for the hospital used.

3 Results

Fig. 5 shows the results of running the process for the school using the above mentioned three types of ECMs and for a range of base temperatures from 15°C to 25°C. The deviations have very different values for the same base temperature in each year. However, ECM (C) which is not-directly related to the weather, always shows much bigger deviation values. This confirms the need to have sub-metering for these types of ECMs and to not depend on the total consumption of energy to estimate the resulting savings.

The % deviations for the other two types of ECMs barely exceed 5% except for the year 2016.

The % deviations tends to converge to zero near a particular base temperature. However, this temperature changes every year. This is with the exception of the year 2016 which had less CDD than that of 2014 regardless of the base temperature as it was in general a cooler year than the others. Its % deviations are getting bigger as the base temperature increases.

Fig. 6 shows the % deviations when averaged over the four years. There is a trend that is appearing for both the school and the hospital. The % deviations are converging towards zero for the three types of ECMs around the temperature 21/21.5°C even though one building is internally dominated and the other is externally dominated. This is an interesting observation and can lead to a guideline for selecting an appropriate base temperature for calculating the CDD for a particular city.

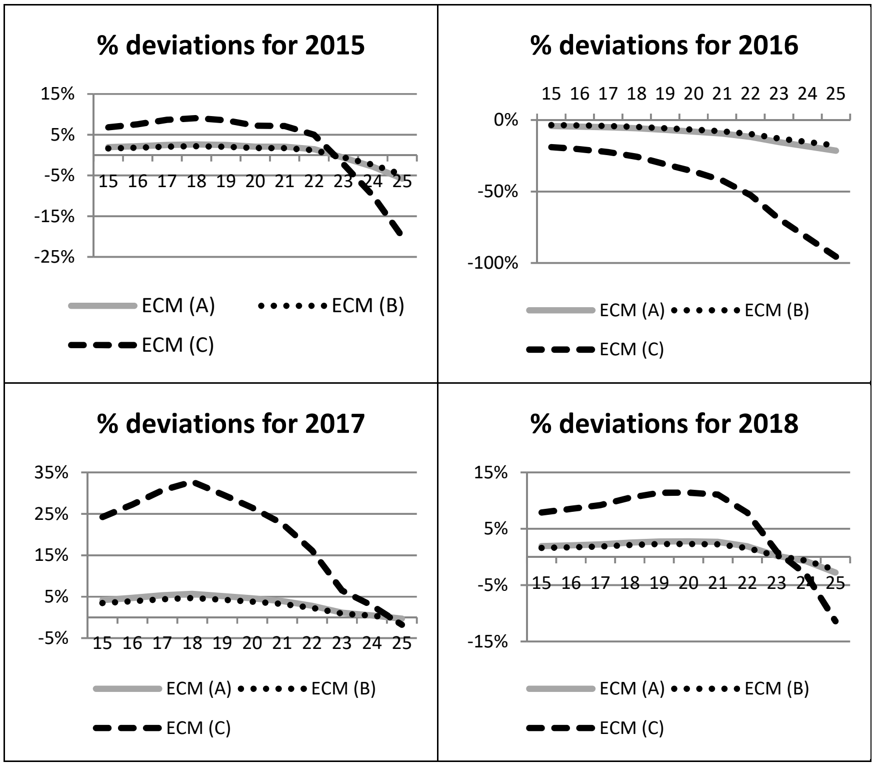

Fig. 5. Change in the % deviation in energy savings due to the change in CDD base temperature for the different types of ECMs and for the different years under study. Note the different scales for the % deviation.

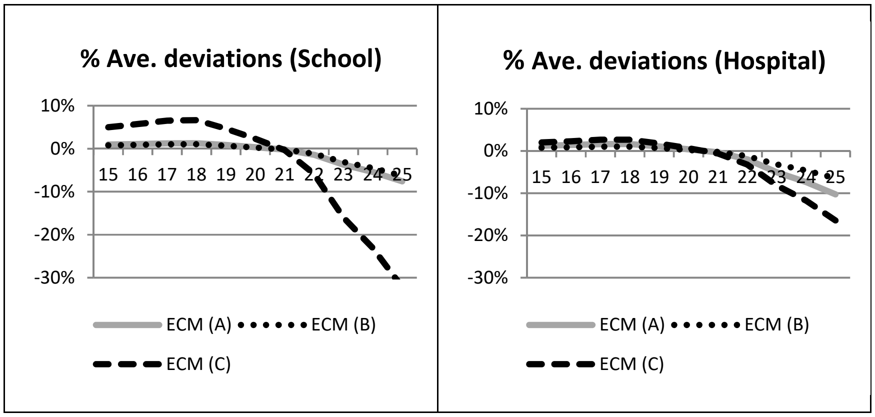

Fig. 6. Average of the % deviations for the four years under study, for the different types of ECMs, and for the two building types.

4 Conclusion

This preliminary examination of the deviation in energy saving estimations due to the use of the Degree Days method should encourage both owners and ESCO to identify a better base temperature to use. More studies need to be done for longer periods of time, for different cities, and for more building types to provide better guidance. It is also important to note that the % deviation in using the CDD method is generally low except for the type of ECMs that are not-directly related to the weather.

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