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Evaluating the Effect of Different Base Temperatures to Calculate Degree-Days

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Abstract **– Degree-days are used as a forecasting tool to predict energy demand and for normalizing energy consumption to be able to compare between different properties across different years. The base temperature is the main aspect to accurately calculate degree-days. The aim of this study was to evaluate the effect of different base temperatures and their impact on the correlation between energy consumption and degree-days. The base temperature was selected as the standard 15 °C for the region, the balance temperature calculated with dynamic building simulations and the thermostat temperature setting as collected by questionnaires. The methodology followed is based on the analysis of 20 properties located in the cities of Bilbao, San Sebastian and Vitoria in northern Spain. The properties are a combination of flats and houses, from different construction periods, tenancies, occupancy and sizes. This study had highlighted the effect and impact of selecting different base temperatures for the calculation of degree-days and the correlation between energy consumption and degree-days. While the use of the balance temperature as base temperature could generate very good correlation, they were not so dissimilar from using the standard 15 °C base temperature to justify the amount of extra work required to generate the balance temperature. The use of the thermostat setting as an indication of the base temperature was not as reliable as the other base temperature methods in generating a good correlation to explain the energy consumption on the 20 properties investigated in this study.**

Keywords **– Balance temperature; base temperature; degree-day; energy consumption; thermostat**

1. INTRODUCTION

Degree-days were created originally in the agricultural field but it is currently used as a forecasting tool to predict energy demand [1], and for normalizing energy consumption for easy comparison between different years for the assessment of retrofitting interventions [2]. The concept and calculation of degree-days has been well documented in the literature [3], [4]. The use of degree-days can provide a straightforward way to assess the impact of a warm or hard winter on the energy consumption to allow comparisons over different years. According to Mitchells [5], degree-days can be used as well to predict the energy demand for communities. The influence of weather variability on the demand of domestic energy can be assess by the use of degree days [6].

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As highlighted by Bhatnagar et al. [7], degree days are highly used as indicators for heating and cooling loads and further more for ASHRAE climate zone classifications. While De Rosa *et al.* [8] referred to the use of degree days as a versatile indicator to assess energy performance.

One of the main aspects on the calculation of degree-days is the base temperature [9]. If the base temperature has been calculated correctly, then the correlation between energy consumption and degree-days will be a straight line [10]. Several methodologies have been developed across the year to calculate the base temperature, giving the impact on the degree-days calculations [11]. The base temperature can be used based on the heat balance point of the building at which no heating will be required, in the case of the northern region of Spain as 15 °C [12]. Furthermore, it can be calculated by the energy signature methodology presented in the literature [13] with the main limitation of the need of high-resolution data to perform an accurate calculation. As presented by Jimenez-Bescos [14], degree-days can be calculated based on the monitor internal temperature of the property using Internet of Things sensors to provide a more accurate assessment.

Regardless of the taken standard value for the base temperature, the reality is that this can oscillate from the standard value [15]. As a consequence, selecting the wrong value for the base temperature will generate an error in the calculation of the degree-days [16]. The relationship between the degree day and simulation energy use was explore by D'Amico [17], showing the importance of the climate set used in the simulation.

As presented in this introduction, degree days is highly used to assess building energy performance and the precision of the assessment is influenced by the degree day base temperature. The gap in knowledge of this study is the assessment of the impact of degree-day base temperatures and its effect on energy use by means of correlation between energy consumption and degree-days. The correlation between energy consumption and degree-days is very important to be used as energy use indicators.

The aim of this study was to evaluate the effect of different base temperatures and their impact on the correlation between energy consumption and degree-days. The base temperature was selected as the standard 15 degree centigrade for the region [12], the balance temperature calculated with dynamic building simulations and the thermostat temperature setting as collected by questionnaires [18].

2. METHODOLOGY

The methodology followed in this paper is based on the analysis of 20 properties located in the cities of Bilbao, San Sebastian and Vitoria in northern Spain. The properties are a combination of flats and houses, from different construction periods, tenancies, occupancy and sizes. Details of the properties were presented by the authors in [18] containing all the specific parameters regarding the properties.

For each property, bills were collected at bimonthly intervals for a whole year, form July 2012 to June 2013. The bills relate to gas natural for the use of space heating and domestic hot water. Furthermore, the thermostat setting for each property was collected by a questionnaire, as presented in Jimenez-Bescos & Oregi [18], and this setting will be used as the thermostat temperature.

According to the Institute for the Diversification and Saving of Energy [12] the base temperature for the calculation of degree-days in the region of the study should be 15 degrees centigrade.

The balance temperature was calculated individually for each property and for each month of the study. The balance temperature is the temperature at which no heating is required and it is calculated based on the intersection of total heat loss, fabric and ventilation, and total gains, plotted on a graph showing heat losses and gains versus external energy for each month and each property as presented in Fig. 1.

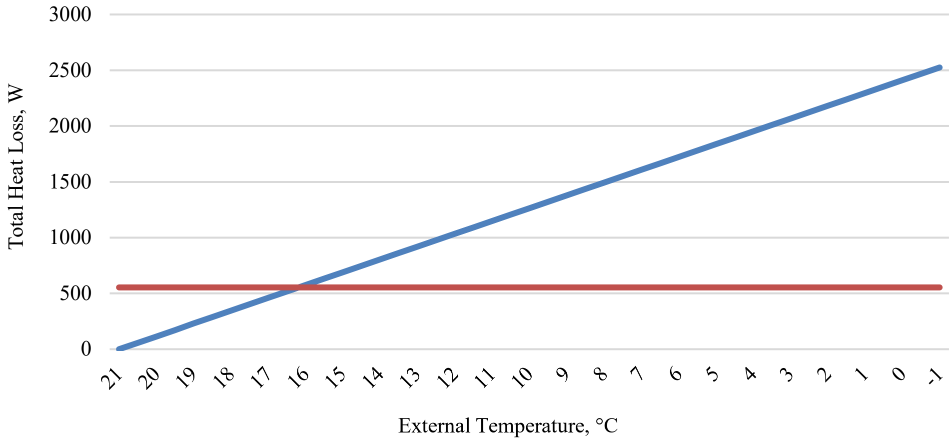

Fig. 1. Calculation of balance temperature for building 7 in January 2013.

The total heat loss contained the fabric and ventilation losses in accordance to the external temperature, being greater at lower external temperatures. While the total heat gains were calculated from the internal gains and solar gains calculated through dynamic building simulation in Design Builder [19] and they were accounting for the monthly variability of gains. The balance temperature was monthly collected for each property as shown in Fig. 1 for the calculation of degree-days.

Weather data was collected form Weather Underground [20] for the three locations in this study and daily average were employed for the calculation of degree-days.

Degree-days were generated on a daily basis from July 2012 to June 2013, as the base temperature minus the average external daily temperature, considering only positive values.

Three base temperatures were tested in this research:

– Thermostat temperature as collected form questionnaire [18];
– 15 degree centigrade in accordance to IDAE [12];
– The balance temperature collected monthly for each property.

As explained in the introduction, degree-days are used to normalized energy consumption and in an ideal scenario a correlation between energy consumption and degree-days should have a coefficient of determination, R^2, of value 1, meaning how much the energy consumption of the property can be explained by the degree-days [21]. The coefficient of determination, R^2, will be changing between the values of 0 and 1, representing a strong correlation the closer to one and on the opposite, no significant between variable the closer to zero. According to Collis and Hussey [22], a cause effect implication cannot be implied just by a strong correlation value of the coefficient of determination.

In this paper, as the degree-days are calculated based on three different base temperatures, the coefficient of determination, R^2, is to compare the correlation according to the three different approaches to calculate degree-days and its fitness to explain the energy consumption.

3. Results

Table 1 shows an example of the process followed for each building, in which the biannual energy consumption is matched with the degree-days for that same period in accordance to the three different base temperatures used in this research.

TABLE 1. ENERGY CONSUMPTION AND DEGREE-DAYS FOR BUILDING 6

Months	**Energy, kWh**	**Temp. 15 °C, Degree-Day**	**Temp. Balance, Degree-Day**	**Temp. Thermostat, Degree-Day**
July/Aug	149.44	0	0	26
Sept/Oct	233.61	37	69.5	171
Nov/Dec	2138.91	246.5	410.5	532
Jan/Feb	1660	390.5	552	684
Mar/April	849.02	230	322	507.5
May/June	648.88	81.5	118	324

Following Table 1, energy consumption is plotted against the degree-days for each base temperature case and the coefficient of determination, R^2, is calculated by fitting a straight line to the data points, as shown in Fig. 2. For each property, the coefficient of determination was calculated following this approach for each of the three base temperature cases.

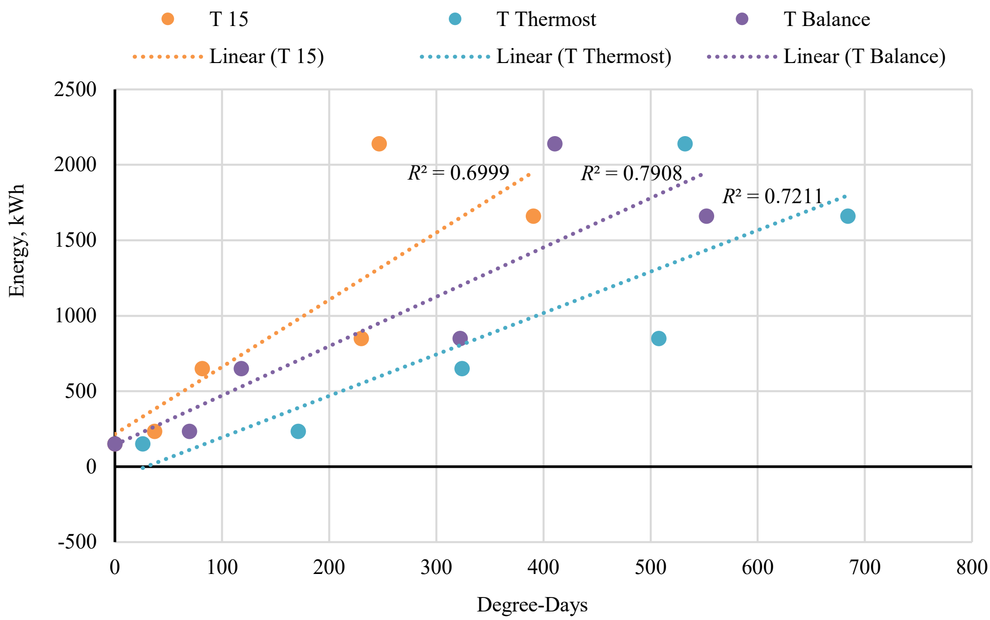

Fig. 2. Energy consumption versus degree-days for building 6.

The results presented in Table 2 and Fig. 3 show that all three base temperatures are able to correlate energy consumption versus degree-day to a good level of fitness, ranging from 0.5175 to 0.9921. In nine of the properties, the higher coefficient of determination is reach by using the base temperature of 15 °C, while using the balance temperature as base temperature, provides the best correlation in eight of the properties. Using the thermostat setting as base temperature, only reach the best correlation in three of the properties.

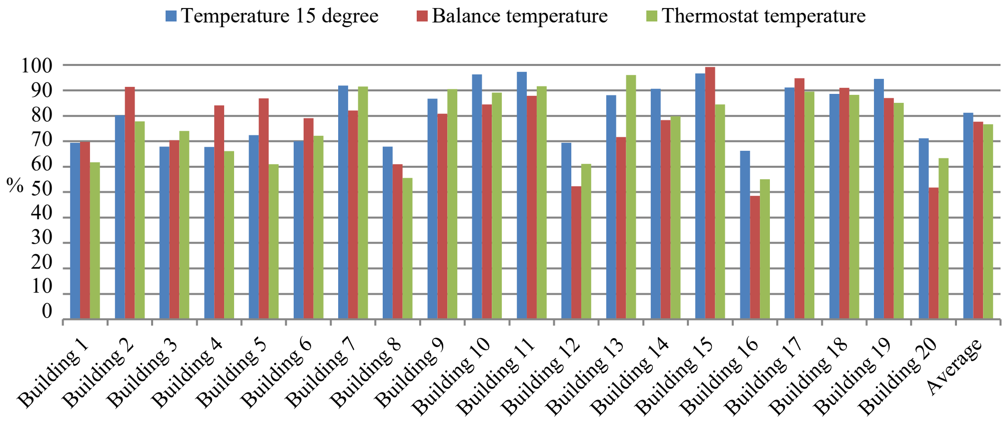

Fig. 3. Coefficient of determination for all buildings and each base temperature.

Most of the calculation for the coefficient of determination for each property, presents a small difference between the degree-day's calculation methods with mostly standard deviation below 0.05 in the comparison of base temperature methods. The standard deviation can provide a good estimation of the agreement between degree-days calculations to explain the energy consumption of the properties.

In general terms and compiling all the properties together as an average, using the base temperature of 15 degrees centigrade generates an average coefficient of determination of 0.8122 with a standard deviation of 0.1189. In the case of using the balance temperature of the properties as base temperature, the average coefficient of determination of 0.7763 with a standard deviation of 0.1472. Finally, the use of the thermostat setting as base temperature generates an average coefficient of determination of 0.7669 with a standard deviation of 0.1366.

Table 3 shows the coefficient of determination, R^2, as an average and standard deviation for all the properties together and then subdivided by construction date and by size of the properties. It must be noted that in the case of properties prior to 1981, in the case of construction date, only one property was available. In a similar way, in the case of properties of less than 70 m^2, for property size, only one property was available. Most of the properties in this research were constructed between 1981 and 2007 and with a size between 70 m^2 and 120 m^2. This group contained 16 properties and 15 properties respectively of the total cohort of 20 properties.

Taking into consideration the breakdown of properties according to construction date, the bigger cohort with 16 properties, between 1981 and 2007, provides a better correlation for all three based temperatures than when all the properties are considered together. On the opposite, the other two groups, prior 1981 and post 2007, have the coefficient of performance reduce in comparison to all properties together.

When considering the size of properties, the bigger group with 15 properties, accounting for between 70 m^2 and 120 m^2, generate higher correlation for the base temperature of 15 degree centigrade and the balance temperature, while the thermostat temperature correlation is slightly reduced. In the case of properties bigger than 120 m^2, the correlation is stronger for the base temperature of 15 °C and the balance temperature, while the thermostat temperature correlation is again reduced. For the property of less than 70 m^2, all correlations are weaker although it must be considered that this group is formed of only one property.

TABLE 2. DETAILS AND COEFFICIENT OF DETERMINATION R^2 FOR EACH BUILDING ACCORDING TO DEGREE-DAY CALCULATION

Building	**Type of Building**	**Construction Date**	**Treated Floor Area, m^2**	**Temp. 15 °C, R^2**	**Temp. Balance, R^2**	**Temp. Thermostat, R^2**
Building 1	Owner	1981–2007	84	0.6943	0.6976	0.6175
Building 2	Owner	1981–2007	74	0.8019	0.9143	0.7784
Building 3	Owner	1981–2007	135	0.6791	0.7036	0.7398
Building 4	Owner	After 2007	80	0.6776	0.8412	0.6609
Building 5	Owner	1981–2007	90	0.7236	0.8683	0.6096
Building 6	Rented	Prior 1981	142	0.6999	0.7908	0.7211
Building 7	Owner	1981–2007	85	0.9195	0.8210	0.9145
Building 8	Owner	1981–2007	70	0.6791	0.6099	0.5560
Building 9	Owner	1981–2007	85	0.8673	0.8088	0.9046
Building 10	Rented	1981–2007	80	0.9629	0.8447	0.8915
Building 11	Owner	1981–2007	105	0.9735	0.8790	0.9167
Building 12	Owner	1981–2007	77	0.6938	0.5228	0.6107
Building 13	Rented	1981–2007	160	0.8813	0.7162	0.9598
Building 14	Social	1981–2007	97	0.9063	0.7836	0.7986
Building 15	Owner	1981–2007	73	0.9671	0.9921	0.8441
Building 16	Owner	After 2007	83	0.6630	0.4858	0.5506
Building 17	Owner	1981–2007	120	0.9117	0.9476	0.8947
Building 18	Owner	1981–2007	92	0.8856	0.9107	0.8830
Building 19	Owner	1981–2007	90	0.9455	0.8700	0.8509
Building 20	Owner	After 2007	67	0.7109	0.5175	0.6342
Average				0.8122	0.7763	0.7669
SD				0.1189	0.1472	0.1366

TABLE 3. COMBINED CORRELATION R^2 ACCORDING TO CONSTRUCTION DATE AND SIZE

		Temp. 15 °C, R^2	Temp. Balance, R^2	Temp. Thermostat, R^2
All Buildings	Average	0.8122	0.7763	0.7669
	SD	0.1189	0.1472	0.1366
By Construction Date				
Between 1981–2007	Average	0.8433	0.8056	0.7982
	SD	0.1125	0.1270	0.1319
After 2007	Average	0.6838	0.6148	0.6152
	SD	0.0246	0.1967	0.0575
Prior 1981		0.6999	0.7908	0.7211
By Size				
Between 70 m² and 120 m²	Average	0.8241	0.7900	0.7592
	SD	0.1228	0.1472	0.1413
More than 120 m²	Average	0.7930	0.7896	0.8289
	SD	0.1205	0.1122	0.1169
Less than 70m²		0.7109	0.5175	0.6342

4. DISCUSSION

The aim of this study was to evaluate the effect of different base temperatures and their impact on the correlation between energy consumption and degree-days. The base temperature was selected as the standard 15 °C for the region [12], the balance temperature calculated with dynamic building simulations and the thermostat temperature as collected by questionnaires [18].

Layberry [9] highlighted the importance of the selection of base temperature in the calculation of degree-days for the normalization of energy consumption, in this study, the results presented in Table 2 and Fig. 3 agreed with this statement, showing that in almost half of the properties the stronger correlations happened with a base temperature of 15 degree centigrade, while the other half occurred with a base temperature equal to the balance temperature, which was calculated according to the total heat losses and total heat gain for each property on a monthly basis. The coefficient of determination, R^2, is smaller, showing a weaker correlation for the case of base temperature taken from the thermostat setting. This disagrees with previous research [14], which showed that using the internal temperature as base temperature can provide more accurately correlations. The main different in this study is that the thermostat setting is fixed across the whole period of study, while in the case of internal temperature [14] the temperature was monitored every 20 minutes and the data was daily average, meaning that each day could potentially have different daily temperature to the previous day and still it will be accounted for. This is one of the main limitations on the use of the thermostat setting as base temperature.

Day *et al*. [11] argue that the base temperature should be calculated separately for each property under analysis. This has been the process followed by this research when using the balance temperature for each property to calculate degree-days. The balance temperature approach used in this research share similar limitations as the study run by Krese *et al*. [13], while a far longer data capture and data processing must be in place, for the case of using the balance temperature as base temperature, the improvements of correlation are very small, in comparison to using the standard 15 °C base temperature, which does not require any data capture and processing at all.

Looking into the impact of base temperature on the correlation of properties, according to construction date and size, this study showed in Table 3 that the higher correlation will occur when using the standard 15 °C base temperature for the main cohorts of properties built between 1981 and 2007 and with a size between 70 m^2 and 120 m^2. The research could not clearly identify the best base temperature for the other groups as they were very small to draw any conclusions.

While the selection of the correct base temperature remains a paramount to avoid mistakes [16], this research shows that using a longer approach by the implementation of a balance temperature as base temperature does not provide an increase on the accuracy of the correlation between energy consumption and degree-days. On the case of using the thermostat setting as base temperature, the results provide a much weaker correlation, suggesting that this approach should be avoid regardless of the easy data collection opportunities.

5. Conclusion

This study had highlighted the effect and impact of selecting different base temperatures for the calculation of degree-days and the correlation between energy consumption and degree-days. While the use of the balance temperature as base temperature could generate very good correlation, they were not so dissimilar from using the standard 15 °C base temperature to justify the amount of extra work required to generate the balance temperature. The use of the thermostat setting as an indication of the base temperature was not as reliable as the other base temperature methods in generating a good correlation to explain the energy consumption on the 20 properties investigated in this study.

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