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Climatic zoning and its application to Spanish building energy performance regulations

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ABSTRACT

The main requirements of European Directive 2002/91/EC on the energy performance of buildings (EPBD) are the application of minimum energy performance requirements for new buildings and certification of the energy performance of buildings. Its transposition into the national law of member states of the European Union has signified the appearance of new and more onerous requirements in terms of construction quality from the point of view of energy performance, and in terms of the procedure for certification of the energy performance of buildings. In both cases, the levels required tend to be based on climatic conditions, fundamentally in countries such as Spain, where the climatic variability is very pronounced. This paper presents a methodology developed for the climatic zoning of the localities not included in the above-mentioned regulations in order to facilitate their application. By way of example, the method is shown which was used to generate the climatic files and carry out the subsequent climatic zoning of all the municipalities of the region of Andalusia in southern Spain.

1. Introduction

The transposition of European Directive 2002/91/EC (EPBD) [1] into the national law of member states of the European Union has signified the appearance of new and more onerous requirements in terms of construction quality from the point of view of energy performance and in terms of the procedure for certification of the energy performance of buildings.

In Spain, this transposition was effected by Royal Decree 314/2006 of 17 March [2] approving the Technical Building Code which modifies the previous energy code NBE-CT-79, and Royal Decree 47/2007, of 19 January [3], approving the basic procedure for certification of the energy performance of new buildings.

Both the new energy performance requirements established by Royal Decree 314/2006 in Section HE-1 on Energy Demand Limitation of Buildings and the procedure for certification of the energy performance of buildings are determined according to the climatic variability of 12 different climatic zones.

As is explained in these regulations, climatic zoning in Spain has been carried out in accordance with a variable expressly defined for such purpose which is known as climatic severity [4], calculated as the comparison between the heating/cooling demand of a certain building and that which the same building would have in a reference locality. Where the demand used in the calculation is heating demand, the variable calculated is characterised as winter climatic severity. Meanwhile, where the calculation uses the cooling demand, the variable calculated is characterised as summer climatic severity. In both cases, the reference locality used is Madrid, and it has been shown that the variable is independent to the type of building used in the calculation, although it is necessary to define the type of building.

Following this procedure, the Spanish energy regulations classify the 52 provincial capitals into 12 climatic zones, identified by a letter from A to E and a number from 1 to 4. The letter refers to the winter climatic zoning, while the number refers to the summer climatic zoning.

Where a locality is not included in the above list, different simplified methods are proposed to calculate the corresponding climatic zone, and consequently the energy performance requirements which buildings in the locality should comply with.

The objective of the methodology presented in this paper is to achieve a more precise calculation of the climatic zone of a locality where it is not one of the 52 localities included in the regulations. As is explained below, it is a double methodology, given that it

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distinguishes between localities which have climatic records and those which do not.

2. Methodology

The present article sets out, firstly, the procedure for the generation of climatic files for localities with climatic records, and secondly, the process of obtaining the climatic zone for all of the localities in the Andalusian Autonomous Community.

The following is a summary of the main steps which have been followed.

Step 1: Obtaining climatic records.

For the generation of the climatic files, the climatic records (temperature, radiation and humidity) provided by the Andalusian Regional Government on different web sites [5] was used as the source of the information, which was then subjected to a statistical analysis, detecting anomalies which were filtered. In this way, a new database was generated for a total of 128 localities in Andalusia.

Step 2: Generation of climatic files.

The monthly values thereby obtained for the provincial capitals do not coincide exactly with those corresponding to the reference years used in section HE-1 "Energy Demand Limitation", there being a slight deviation both in terms of degree days and radiation.

Taking into account the latter factor, a hypothesis was developed that the deviation in all the localities of a province is the same as that existing in its provincial capital, and in this way, the modified climatic years were generated for the 128 localities previously mentioned. Accordingly, the modified climatic year for a locality does not correspond to the direct mean of the climatic records for a series of years, but rather on the contrary modifies this mean with the same deviation as that present in the provincial capital.

Using METEONORM software [6] and the modified climatic year of the localities, hourly values were generated (climatic files), adding two variables: absolute humidity and sky temperature, both of which were calculated based on the hourly values generated.

Step 3: Allocation of climatic zones.

The procedure for obtaining the climatic zones in Andalusia is divided into two parts; first the climatic zones were obtained for the localities with climatic records, which we refer to as reference localities, using the procedure specified in the basic document HE-1 of the Technical Code. During this process four localities were disregarded because they presented incoherent results, with only 124 localities being used for the following step.

Following this the climatic zones were obtained for the localities without climatic records (646), by means of an interpolation procedure using their distance from the above-mentioned reference localities. The distance is corrected according to the North–South difference (latitude), the difference in altitude and proximity to the sea, thereby obtaining an "effective distance". For any given locality without a climatic record, the reference localities within a specific radius of action are selected for the interpolation.

Using the values of the degree days and radiation of the reference localities, the respective values are obtained for the localities without climatic records, carrying out a final correction of the winter and summer degree days due to the difference in altitude existing between the locality and the reference localities selected.

The process of obtaining the climatic zones for localities without climatic records is concluded with the procedure established in the Technical Building Code.

3. Obtaining climatic records

3.1. Initial data

Each of the meteorological stations with recorded data available on the different web sites of the Andalusian Regional Government have different means of organising the data, and so a specific data gathering procedure was established which distinguishes three principal sources.

The first two databases used have information from 1990 through 2006 regarding the average temperature, global radiation and relative humidity, while the third database, also known as the advanced database, has data from 1970 to 2006, and also includes the variables of minimum daily temperature and maximum daily temperature.

3.2. Filtering of values

None of the databases contains the totality of information for all the municipalities, and it is also necessary to eliminate the data which is outside the range established in the information source.

Using the filtered values the monthly mean was calculated, which was ordered by month and year for each of the meteorological stations.

The original data used on the basis that it was within the admissible ranges was then filtered on a monthly basis for each of the meteorological stations (this is carried out solely if there is more than one station per locality).

This second filtering of the data considers as admissible data corresponding to stations in the same locality which is in a new range delimited by the mean value minus the typical deviation as the minimum admissible value, and the mean value plus the typical deviation as the maximum admissible value.

Finally, for each locality the mean was calculated for all the stations which are subjected to the data filtering process.

3.2.1. Generation of climatic files

The general option (LIDER Programme) for Energy Demand Limitation under the Technical Building Code (CTE-HE-1) provides reference years for the provincial capitals of Spain and in particular for the eight provincial capitals of Andalusia.

Given that the data available in climatic records for the localities in Andalusia is not sufficient to enable direct generation of their corresponding reference years, a methodology has been developed in this paper which is capable of generating what have been characterised as "*modified climatic years*".

The modified climatic year for any given locality is defined as the series of 8760 hourly records of climatic variables, such as temperature, radiation, etc., which are generated from the reference year of the capital of the province where it is located, and the climatic records for both the locality in question and its provincial capital.

In this way, the modified climatic year for a locality does not correspond to the direct mean of the climatic records for a series of years, but rather on the contrary modifies this mean with the same deviation as that present in the provincial capital.

4. Calculation of increase (temperature) for provincial capitals

We define "*Increase*" in temperature [7] for any given month, as the difference between the value of this variable in any given year and the reference year. The increase thereby defined is expressed in degrees centigrade.

An increase accordingly exists for each

- provincial capital
- month, and
- year for which recorded data exists.

In order to calculate the increase for the provincial capitals, the following values are taken as the initial values:

- Monthly temperatures of the provincial capital for each of the months from 1 January 1996 to December 2005.
- The values of the reference year for the provincial capital, calculated based on the climatic files of the LIDER programme.

5. Calculation of the quotient (global radiation and relative humidity) for provincial capitals

We define the "*Quotient*" of the global radiation [8] and relative humidity for any given month as the value of this variable in any given year divided by the value of the reference year. The quotient is a dimensionless variable.

A quotient accordingly exists for each

- provincial capital
- month, and
- year for which recorded data exists

In order to calculate the quotient for the provincial capitals, the following values are taken as the initial values:

- Mean monthly accumulated global radiation and relative humidity for the provincial capital for each of the months from 1 January 1996 to December 2005.
- The values of the reference year for the provincial capital, calculated based on the climatic files of the LIDER programme.

6. Calculation of the modified climatic year for a locality

6.1. Calculation hypothesis

"*For each locality and each climatic variable (temperature, relative humidity and accumulated global radiation), the same Increases and Quotients are applied as those calculated in accordance with the preceding section for its corresponding provincial capital.*"

Based on the expressions which are set out in Tables 1 and 2 and the above hypothesis, a calculation procedure was established to calculate the modified climatic year for the localities in Andalusia for which measured data exists, in terms of each of the variables studied.

6.2. Procedure

- A value is obtained for each of the variables, determining from the expressions in Tables 1 and 2 the reference year, which is labelled $T_{\text{reference year, month } y}$, $RH_{\text{reference year, month } y}$, $GR_{\text{reference year, month } y}$ in the following expressions.
- Once the 120 values have been obtained for each of the variables, a third filtering of the data is carried out using the mean and the typical deviation on a monthly basis. This filtering is analogous to that explained previously, in that it considers as admissible those values which are within a range delimited by the mean value minus the typical deviation as the minimum admissible value, and the mean value plus the typical deviation as the maximum admissible value.

Table 1
Increase formula

Variable	Increase
Mean daily temperature[a]	$\Delta T_{\text{year } x,\text{ month } y} = T_{\text{year } x,\text{ month } y} - T_{\text{reference year, month } y}$

where $T_{\text{reference year, month } y}$ = mean monthly temperature for month "y" of reference year (12 months); $T_{\text{year } x,\text{ month } y}$ = mean monthly temperature for month "y" of year "x" (120 months).
[a] An increase is recorded for the 120 months of the study period.

Table 2
Quotient formulas

Variable	Quotient
Mean relative humidity[a]	$\Delta RH_{\text{year } x,\text{ month } y} = \frac{RH_{\text{year } x,\text{ month } y}}{RH_{\text{reference year month } y}}$
Monthly accumulated global radiation[a]	$\Delta GR_{\text{year } x \text{ month } y} = \frac{GR_{\text{year } x \text{ month } y}}{GR_{\text{reference year month } y}}$

where $RH_{\text{reference year, month } y}$ = mean monthly relative humidity for month "y" of reference year (12 months); $RH_{\text{year } x,\text{ month } y}$ = mean monthly relative humidity for month "y" of year "x" (120 months); $GR_{\text{reference year, month } y}$ = accumulated global radiation for month "y" of reference year (12 months); $GR_{\text{year } x,\text{ month } y}$ = accumulated global radiation for month "y" of year "x" (120 months).
[a] A differential is recorded for the 120 months of the study period.

7. Generation of hourly data

The hourly data was generated using METEONORM Version 5.1, based on the monthly values calculated in the previous section.

The files thereby generated were modified by the LIDER Program to include other necessary values which are not generated by METEONORM, such as the sky temperature, the absolute humidity and the zenith.

8. Allocation of climatic zones

8.1. General procedure

The process of obtaining a climatic zone for each of the 770 localities in Andalusia varies in accordance with the information on each of the same, with three possible options:

- *Option A*: simplified option, used for localities which only have altitude data (Appendix D.1 "Determination of climatic zones based on tabulated values", in section HE-1 of the Technical Building Code, p. 31).

  This option has not been used in any of the cases of the present paper.
- *Option B*: this option requires some of the climatic variables for the locality (degree days, Radiation or Insolation) (Appendix D.2 "Determination of climatic zones based on climatic records", section HE-1 of the Technical Building Code, p. 31, 32 and 33.).

  This option has been used for localities with climatic records (124 localities, given that 4 localities with climatic records were disregarded due to the incoherence of their results).

- *Option C*: used for localities which do not have meteorological data, and which have geographical data relating to latitude, longitude, altitude and UTM co-ordinates (procedure applied in this paper).

This option has been used for the localities without climatic records, that is, the remainder of the localities up to the total of 770 (646 localities).

Option C alone is detailed below. To follow the procedure of options A and B please refer to Appendix D in section HE-1: ‘‘Energy demand limitation’’ of the Technical Building Code.

9. Option C: obtaining climatic zones (without meteorological data)

This option combines procedures from options A and B and a methodology developed in this paper for the interpolation of Radiation and degree days.

The sequence of this option is as follows:

- Determination of the reference localities (124 localities with climatic records).
- Determination of the latitude, longitude, altitude and UTM co-ordinates for the locality in question (localities without climatic records).
- Interpolation of Radiation and degree days for the locality in question.
- Determination of the climatic zone of the locality in question.

9.1. Reference localities

The reference localities are the 124 Andalusian municipalities for which climatic files have been generated in the previous sections.

9.2. Necessary data

For both the previous reference localities and the localities which do not have climatic records, and those for which the climatic zone is to be calculated, the following data is necessary: name of the municipality, province to which it belongs, latitude, longitude, altitude and UTM co-ordinates.

9.3. Interpolation methodology for radiation and degree days

The methodology is based on the inverse distance weighted interpolation method developed by Shepard.

This method in turn applies the method developed by Zelenka et al. [9], with a correction according to the altitude difference, another correction according to the North–South distance or latitude calculated by Wald and Lefèvre [10], and finally another correction according to the proximity to the sea.

9.3.1. Calculation of the geographical distance

The calculation of the geographical distance (d) between two localities can be carried out using the following expression:

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \quad (1)$$

where x and y are the UTM co-ordinates for the locality (km) and z is the altitude of the locality (km).

9.3.1.1. Correction according to altitude difference. For the purposes of the interpolation calculation of the radiation and temperature, a first modification of the calculation of the distance between two localities is proposed which makes a correction according to the difference in altitude between the two.

The hypothesis developed by Zelenka et al. states that 50 km of horizontal distance is equivalent to 100 m in altitude for the calculation of radiation, while for the calculation of temperature (degree days) it is considered that 10 km of horizontal distance is equivalent to 100 m in altitude.

The expression [1] is simplified in the following manner:

$$d = \sqrt{(d_{\text{hor}})^2 + (z_1 - z_2)^2} \quad (2)$$

where the geodesic distance (or horizontal distance) is

$$d_{\text{hor}} = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

With the formula for the calculation of the distance (d) and the preceding hypothesis, the altitude difference is multiplied by a correction factor (v) with a value of 500 for radiation and 100 for temperature.

The correction factor is introduced in expression [2], to obtain an effective distance (d_{ef}):

$$d_{\text{ef}} = \sqrt{(d_{\text{hor}})^2 + [v(z_1 - z_2)]^2} \quad (3)$$

9.3.1.2. Correction according to the difference in the North–South distance (latitude). A second modification in the calculation of the distance between two localities makes a correction according to the difference in the North–South distance (latitude) namely (F_{NS}), as defined by Wald and Lefèvre:

$$d^*_{\text{ef}} = F_{\text{NS}} d_{\text{ef}} \quad (4)$$

where:

$$F_{\text{NS}} = 1 + 0.3|\phi_2 - \phi_1|\left[1 + \frac{(\sin\phi_2 + \sin\phi_1)}{2}\right] \quad (5)$$

where Φ is the latitude expressed in degrees.

Accordingly, the effective distance (km) is

$$d^*_{\text{ef}} = \sqrt{F^2_{\text{NS}}[d^2_{\text{hor}} + (v(z_1 - z_2)^2)]} \quad (6)$$

9.3.1.3. Correction according to proximity to the sea. With this procedure a correction is made for the influence of the proximity of the sea to the locality in question.

Firstly all the localities are divided into two groups, ‘‘inland localities’’ and ‘‘coastal localities’’.

For the localities in the first group no distinction is made with respect to the reference localities to be used for the interpolation based on their proximity to the sea, that is to say, both inland and coastal reference localities may be used.

On the other hand, for the localities in the second group a pre-selection is made of the reference localities located on the coast and the interpolation is accordingly carried out only using these localities and not inland reference localities.

9.3.1.3.1. Selection of localities for the interpolation. For the purposes of the interpolation, the reference localities used are those which are within a specific distance from the locality to be calculated.

The maximum horizontal distance used is 100 km and the maximum vertical distance used is 1 km (Fig. 1).

In addition, as explained in the preceding section, if the locality to be calculated is located on the coast, only reference localities which are also on the coast are used.

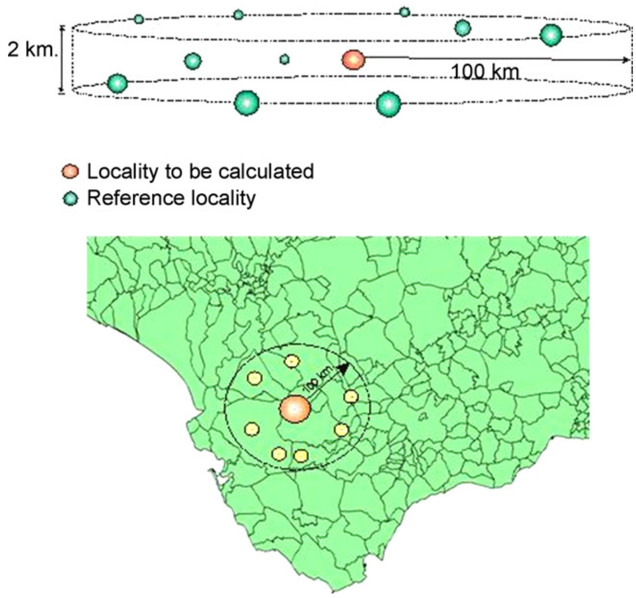

Fig. 1. Selection of localities for interpolation.

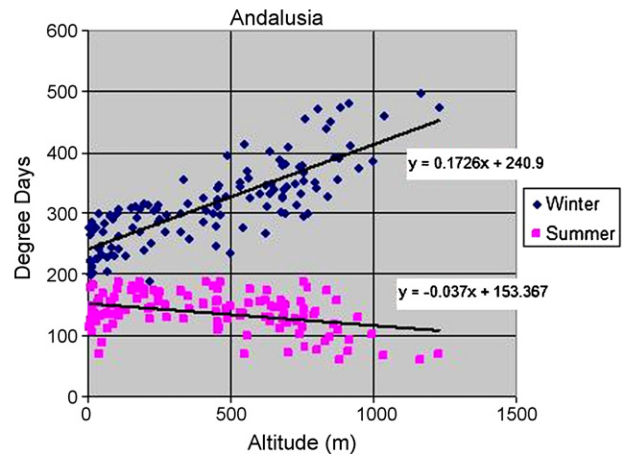

Fig. 2. Dispersion of the degree days (DD) of the 124 localities with climatic records in Andalusia.

9.3.1.3.2. Interpolation procedure. The interpolation procedure is based on the inverse distance weighting method developed by Shepard [11], as was mentioned at the beginning of this section.

The expressions for the calculation of the radiation and degree days for localities without climate records are the following:

- for winter and summer radiation:

$$\begin{aligned} &\text{Winter,}\quad \text{Rad}_{\text{Win}} = \sum_{i=1}^{n} w_i\,\text{Rad}_{\text{Win}_i} \\ &\text{Summer,}\quad \text{Rad}_{\text{Sum}} = \sum_{i=1}^{n} w_i\,\text{Rad}_{\text{Sum}_i} \end{aligned} \tag{7}$$

- for degree days:

$$\begin{aligned} &\text{Winter,}\quad \text{DD}_{\text{Win}} = \sum_{i=1}^{n} w_i\,\text{DD}_{\text{Win}_i} \\ &\text{Summer,}\quad \text{DD}_{\text{Sum}} = \sum_{i=1}^{n} w_i\,\text{DD}_{\text{Sum}_i} \end{aligned} \tag{8}$$

$$\text{For all cases}: \quad \sum_{i=1}^{n} w_i = 1$$

where w_i is the weighting factor of reference locality i; Rad is the accumulated global radiation in winter (inv subscript) or summer (ver subscript); DD is the degree days in winter (inv subscript) or summer (ver subscript); n is the reference localities used to carry out the interpolation.

The weighting factor (w_i) is calculated based on the effective distance according to the following equation:

$$w_i = \frac{1/(d^*_{\text{ef}_i})^2}{\sum_{j=1}^{N}(1/(d^*_{\text{ef}_i})^2)} \tag{9}$$

where $d^*_{\text{ef}_i}$ is the effective distance (see expression [6]); N is the reference localities used to carry out the interpolation.

9.3.1.3.3. Correction due to the altitude difference in degree days. Finally, it is necessary to apply a correction to the degree days thereby calculated, due to the fact that the altitude of the locality in question may not necessarily coincide with the mean altitude of the localities used in the interpolation.

Before applying this correction it is necessary to calculate the relationship between the altitude and both the degree days and the Radiation, and the difference between the real altitude of the locality and the mean altitude of the reference localities used in the interpolation.

To visualise the relationship between the altitude and both the degree days and the Radiation, the following graph shows the degree days and Radiation of the 124 localities with climatic records versus their altitude, to obtain a trend line (Fig. 2).

Also represented in an analogous manner is the accumulated global radiation for winter and summer versus the altitude for the 124 localities in Andalusia (Fig. 3).

9.3.1.3.4. Altitude difference. The difference in altitude between the real altitude of the locality in question and the "mean altitude" of the localities used for the interpolation of the degree days is then calculated.

The mean altitude is calculated following a similar procedure to the mean degree days, using the same weighting factors (Fig. 4).

The preceding diagram represents three reference localities (spheres a, b, c), which have climatic records and a locality without

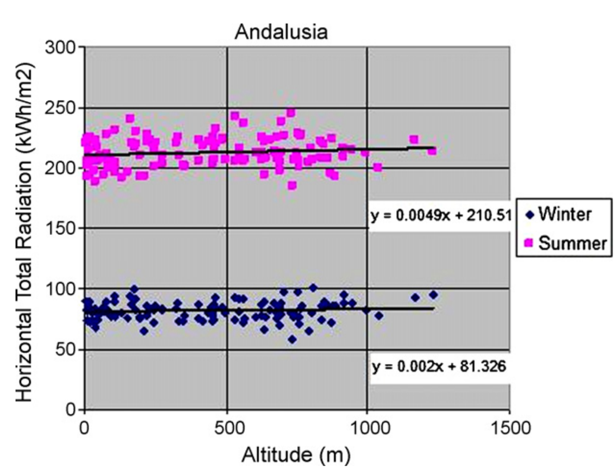

Fig. 3. Dispersion of radiation for the 124 localities with climatic records in Andalusia.

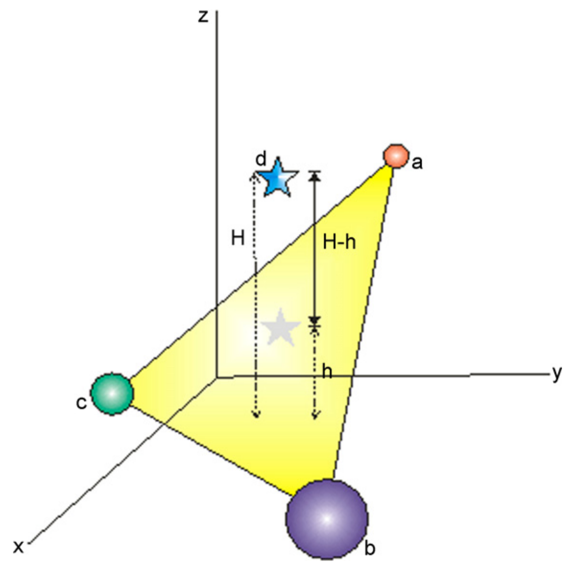

Fig. 4. Altitude difference between the real and mean altitude of a locality calculated in the same manner as the degree days.

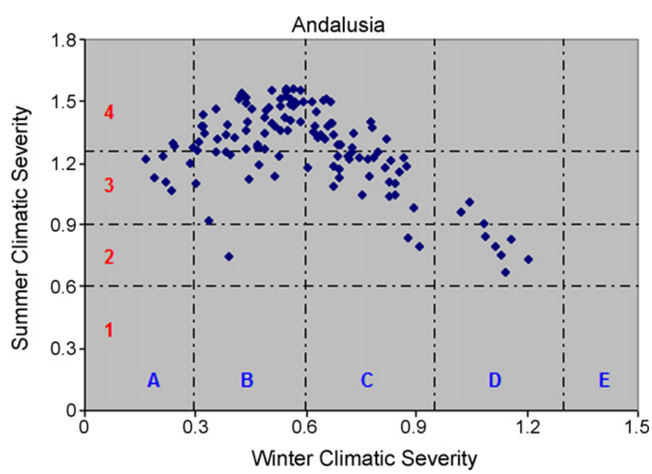

Fig. 5. Dispersion of the climatic zones of the 124 localities with climatic records in Andalusia.

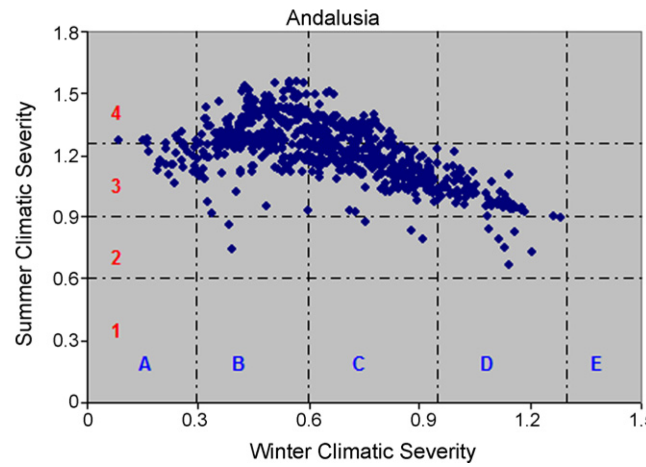

Fig. 6. Dispersion of the climatic zones of the 770 localities of Andalusia.

a climatic record (star d) for which the Radiation and degree days are to be calculated.

$$DD^{*}_{\mathrm{Win}} = DD_{\mathrm{Win}} + (H - h)\frac{17.31}{100} \quad (10)$$

$$DD^{*}_{\mathrm{Sum}} = DD_{\mathrm{Sum}} - (H - h)\frac{3.70}{100} \quad (11)$$

where "H" is the altitude of the locality calculated and "h" is the mean altitude of the three localities used in the interpolation.

9.4. Climatic zones in Andalusia

The climatic zone which corresponds to any given locality for which the Radiation and degree days have been calculated according to the above procedure may be obtained by following option B of Appendix D in section HE-1: "Energy demand limitation" of the Technical Building Code.

Firstly, the climate severities are calculated for the reference localities and following this for the total of the Andalusian localities.

The following graphs show the distribution of these localities in the different climatic zones (Figs. 5 and 6).

It is important to highlight that all the climatic zones with Andalusian localities (namely all except for C1, D1 and E1) are

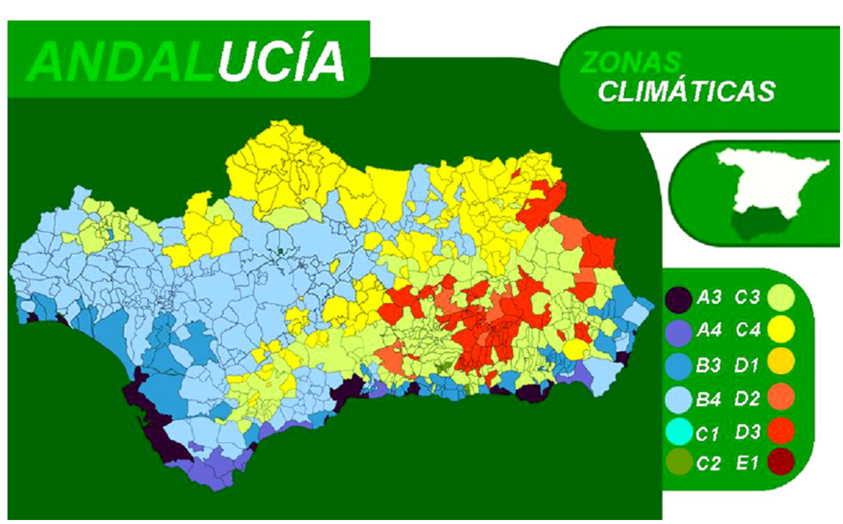

Fig. 7. Climatic zones in Andalusia.

represented by reference localities as can be seen in Fig. 5, which guarantees the correct functioning of the interpolation procedure.

The following map shows the climatic zones of all the municipalities in Andalusia (Fig. 7).

10. Conclusions

This paper presents a complete methodology which enables climatic zoning of any locality to be carried out for its application under the Spanish building energy regulations. More specifically, it presents by way of an example the climatic zoning carried out for the Andalusian region, in which two different situations are posed: localities with climatic records and other localities without such records.

In this way a much more detailed climatic zoning is achieved than that provided by the regulations previously mentioned, and as such, the levels of demand are more in accordance with the climatic reality of each of the localities.

The fact that climatic records have been available for certain localities has enabled verification of the lack of precision or even incoherence of the data, requiring the carrying out of a series of data filters for their correction. For localities with various different records, it has been confirmed that there can be major and unjustified differences between the same.

Apart from the filtering of data mentioned above, it is evident that it is necessary to substitute the data thereby obtained for the data used in the regulations, given that if we compare both series of data for the provincial capitals there is a slight discrepancy which should also be applied to the rest of localities with climatic records. This can be referred to as the conversion of reference climatic data into modified climatic data.

On the other hand, for the localities without climatic records, an interpolation procedure has been proposed based on the effective distance, which takes into account the geodesic distance between the locality in question and the localities with climatic records, the difference in altitude between the same, the different in latitude and finally their proximity to the sea. It has been demonstrated that all these factors influence the results obtained to a greater or lesser extent. For example, it has been observed that the degree days and the radiation are fundamentally dependent on the altitude in winter, when the degree days increase by 17.31 U per 100 m increase in altitude, while the summer degree days diminished by 3.70 U per 100 m increase in altitude. It has also been observed that both the winter and summer radiation in Andalusia is on average independent to the altitude, and so it is unnecessary to make any correction of the radiation on account of the altitude.

Finally, it can be expected that the interpolation procedure developed for localities without climatic records gives sufficiently good results provided that there are sufficient localities with climatic records spread throughout the region in question, and which belong to different climatic zones. Both these circumstances were present in the example which is given in this paper.

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