Minimum air temperatures going to extremes in Brașov city (Romania)

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Abstract: Brașov is the largest city in the Romanian Carpathians, being located inside the largest low-lying area in the country and exposed to western climatic influences, with well-defined local features, especially in the cold season, when many thermal extremes may occur. The main objective of this study was to analyze the minimum air temperatures and highlight their extreme values over the 1980-2015 period. The climatic data were collected from the Brașov-Ghimbav meteorological station and a set of specific indices, generically called as indices of extremes and climate change by the WMO’s Expert Team on Climate Change Detection and Indices (ETCCDI), were subsequently calculated. The resulting quantitative assessments of minimum air-temperature variations in the above mentioned area has also proved that they can be useful tools in calculating other derived technical parameters which may be relevant for the design and onset of heating or cooling installations, in order to maintain a comfortable indoor climate in residential buildings.

1. Introduction

The municipality of Brașov is known as the largest city in the central part of Romania, being located in the Brașov Depression, at an average altitude of 625 m (Figure 1) (Ielenicz, 2005).

Figure 1. The geographical position of Brașov city in the central part of Romania
The Brašov Depression is a major tectonic low-lying area (3900 km²) on the inner border of the great Carpathian Curvature. It evolved from the marine and stream erosion of sedimentary rocks to an extensive floodplain (550-650 m-high), bordered by a wide belt of pediments (800-1200 m-high). Located in the central part of Romania, the Brašov Depression is characterized by a mid-latitude climate of transition between the humid western or north-western and the frequent continental eastern or south-eastern air-masses (Ciulache, Ionac, 1995).

The surrounding mountains act as important climatic barriers, greatly influencing local climates in this area (Ciulache, 1997). In the southern part of the depression there are the Piatra Craiului, Bucegi and Ciucas Mts., greatly restricting the advancement of southern air-masses. In winter, the cold air invading from N or NE often settles over the basin, causing persistent temperature inversions and low air-temperature values. On the western side, there lie the Perșani Mts., which allow humid western air-masses to extend over the area, attenuating air-temperature ranges (Ionac, Ciulache, 2005).

In the western compartment of the Brašov Depression, there is the Brašov city (Figure 2), exposed to western mid-latitude climatic influences, with well-defined local features. The main climatic aspects highlighted by the existing literature, as well as the climatic parameters recorded at the Brašov-Ghimbav weather station show that the western type of general atmosphere circulation is dominant. However, some excessive features of continentalism may become evident, especially during the cold season, when strong and persistent air temperature inversions may occur (Ciulache, 2006).

The minimum air temperatures often go to extremes (Busuioc et al., 2015), having a great variability in time all over the area of reference, thus reflecting the importance of their analysis (Bartholy, Pongrácz, 2007). Thermal extremes are also frequently recorded during the cold season in other parts of the country (Croitoru, Piticar, 2013) or the world (Founda et al., 2004; Miętus, Filipiak, 2004; Marengo, Camargo, 2008; Roushdi et al., 2016; Sui et al., 2020). Besides, there are some minimum air temperature – related indices which may be calculated in order to estimate the impact of cumulative extremely low air-temperature values on the energy demands for heating or cooling devices in indoor spaces.

All these things being taken into consideration, the practical importance of this study relates to the fact that specific minimum air-temperature parameters and associated indices may be used to assess the bioclimatic comfort of the population living in Brašov city and the energy needs for either heating buildings during the cold season or

Figure 2. The location of Brašov city in the western compartment of the Brašov Depression
air-cooling their inner spaces during summertime. It is well-known that the largest population in the Romanian Carpathians is concentrated in this area and this is important especially during the winter season, when more heat is needed. The respective air-temperature related indices can be used as guidelines for sufficient amounts of heat being provided to the population, but also to ensure that no energy is wasted in the process of production. It is also important to mention that this study can be applied not only to Brașov city, but also to other big cities in Romania, which are mainly based on the public heat energy supply systems.

2. Materials and Methods

The most representative weather station for the Brașov city area is located at Ghimbav (4.5 km west from Brașov), at 45°41’N latitude and 25°31’E longitude, at an altitude of 534 m and is included in the national network of meteorological stations, operated by the National Meteorological Administration (NMA).

In order to relevantly outline the most extreme climatic features of this important intra-mountainous area, the authors have opted for some of the WMO’s Expert Team on Climate Change Detection and Indices (ETCCDI) indices which, unlike the “commonly-used” weather and climatic indices that describe extreme events and phenomena, they mainly refer only to the most rare cases occurring “within the reference statistical distribution of some specific weather elements in a certain area” (Houghton et al., 2001), that is mostly to those specific climatic elements on which systematic and accurate daily measurements and observations are being made, namely: air temperature and rainfall amounts (Vincent et al., 2005; Tang et al., 2013; Piccarreta et al., 2015).

Out of all the 27 existing ETCCDI indices best describing the main characteristics of some extreme weather and climatic events, such as their frequency, amplitude and duration (Zhang et al., 2011), the following have been selected and calculated according to RClimDex or FClimDex methods (CLIMDEX – Datasets for Indices of Climate Extremes - http://www.climdex.org/index.html), over the 1980-2015 period: mean of daily minimum temperature (TN), monthly minimum value of daily minimum temperatures (TNn), monthly maximum value of daily minimum temperatures (TNx), frost days (FD), maximum number of consecutive frost days (CFD), cold spell duration index (CSDI) and heating degree-days (HDDs).

As the period of reference (1980-2015) included homogenous data series, the respective ETCCDI indices were then processed in Excel table and graphical forms, mainly based on the corresponding daily minimum air temperature values (TN) available for all months during the previously-mentioned period. A prospective time evolution trend could also be indicated and the statistical significance of the trend was sustained by simply calculating the R-squared index in Excel.

3. Results

The most favorable synoptic context which is responsible for the lowest minimum air temperatures in Brașov city area is the presence of an extensive anticyclone. This produces the intense radiative cooling of the ground and also strong temperature inversions, especially during the cold season nights (Sfîcă et al., 2019). Over the 1980-2015 period, the lowest minimum air temperature that has ever been recorded (absolute minimum temperature) in Brașov was -33.3°C (on 8th January 2015). The average of the corresponding lowest annual values was -24.9°C (Table 1).

The most extreme values ranged between -33.3°C in 2015 (on 8th January) as the absolute lowest minimum value, and -17.6°C in 1994 (on 16th February and on 20th December), as the highest minimum value recorded. An interesting fact is that 13 absolute yearly minimum air temperatures were registered in January, 12 in December and February respectively and a single one in March (-27.3°C, on 5th March 1987), out of all the 36 years taken into consideration. Even though it is not scientifically customary, if calculating the average mean value of all these 36 yearly minimum air temperatures, the
result would be: -24.9°C (colored in yellow below). This value shows that there are extreme cold conditions, which can easily occur in this area, especially due to persistent thermal inversions during the cold season associated mostly with anticyclonic conditions (Mihai, Teodoreanu, 1969; Mihai, 1971). It is well-known that there are differences between the air-temperatures recorded in Brașov city and those in Ghimbav (4.5 km far west from the city), where the weather station is located (Ciulache, 2006). Due to the development of Brașov town area (located at a higher altitude than Ghimbav), there is an increasing role of the urban heat island, which complicates the understanding of temperature inversions in this area, especially in the cold season.

Table 1. The lowest minimum air temperature (°C) of each year and the date of their occurrence at the Brașov-Ghimbav meteorological station over the period 1980-2015.

The highest monthly mean of daily minimum air temperature (TN) is recorded in July (with a value of 12.8°C), and the lowest in January (with a value of -7.9°C). The annual average is 2.5°C, as showed in Figure 3-A.

For the 1980-2015 period, the highest monthly mean of daily minimum air-temperatures reached as high as 3.9°C (in 2015) and the lowest value is 0.7°C (just above the freezing level, in 1985). The trend of this index is statistically significant (Figure 3-B), increasing with an average value of 1.5°C all through the 1980-2015 period.

The monthly minimum value of daily minimum air temperature (TNn) for this period is recorded on 8th January 2015 (-33.3°C). This index has positive values only in summer, reaching as high as 3.3°C, in July (Figure 4-A). The annual average is calculated as -13.6°C, highlighting an extreme value for Romania, on condition that, out of all the minimum air-temperatures of the 30/31 days of each month, the lowest value of each month was taken into consideration.

The inter-annual variability of the TNn index is pretty large and the trend is slowly decreasing over time but not statistically significant, as showed in Figure 4-B. The highest TNn value is recorded on 16th of February 1994 (-17.6°C) and the lowest value on 8th January 2015 (-33.3°C). The last value mentioned is not far away from the lowest
minimum air temperature ever recorded in Romania (-38.5°C, on 24th January 1942, in Bod, Brașov County).

Data source: NMA archive for temperature values

**Figure 4.** The annual (A) and inter-annual variation (B) of the TNn index at the Brașov-Ghimbaş meteorological station for the period 1980-2015.

The monthly maximum value of daily minimum air temperature (TNx) for the analyzed period took place on 30th August 2003 (23.4°C), as represented in Figure 5-A. The lowest TNx value is calculated in January (6.1°C) and the annual average for this index is 14.4°C. In this case, among all the minimum air-temperatures of the 30/31 days of one month, the highest value of each month was taken into consideration.

The inter-annual variability of the TNx index is moderate and the trend of this index is slowly increasing (Figure 5-B), but not statistically significant, exactly as in the case of the TNn index. The highest value has obviously been recorded on 30th August 2003 (23.4°C), turning it into a typical value for a tropical night (when TNx>20°C). The lowest value has occurred twice, on 10th June 1981 and 29th July 1997 (15.2°C).

Data source: NMA archive for temperature values

**Figure 5.** The annual (A) and inter-annual variation (B) of the TNx index at the Brașov-Ghimbaş meteorological station for the period 1980-2015.

The highest number of frost days (FD) has been recorded in January (28 days for the 1980-2015 period). A frost day is a day in which the minimum air-temperature keeps below 0°C (TN<0°C). An interesting fact is that from May to September, the average FD value is zero, which means that all minimum air temperatures occurring these months are positive (Figure 6-A). This case is similar for May too, but there are years with some negative air-temperature values occurring during this month, especially in cases of late frosts with potential damaging effects on crop plants.

The highest FD value was calculated for 2011 (158 days) and the lowest for 2014 (104 days), as showed in Figure 6-B. The most relevant aspect is that the FD index decreases from around 140 days to 125 days, showing a statistically significant decrease over time, possibly due to latest warming trends.
The highest number of **consecutive frost days (CFD)** was reached in 1982, with 82 consecutive daily minimum air-temperature values below 0°C (from 4th of January to 26th of March). The lowest CFD index value was recorded in 1994, with only 16 consecutive days (Figure 7-A). The trend of this index shows a slight decrease over time, from a value close to 40 consecutive frost days to almost 35 days over the whole analyzed period; yet this decreasing trend is not very statistically significant.

Another interesting fact for this meteorological station is that the maximum values of **the cold-spell duration index (CSDI)** were highest in 1986 and 2002, when four cold waves occurred (Figure 7-B). This index represents the number of intervals per each year where, for at least six consecutive days, the daily minimum air-temperature is lower than the calendar 10th percentile calculated for a 5-day window centered on each calendar day over the 1980-2015 period, as specified in Ionac, Ciulache, 2005. In this case, there is no observed change in tendency over time.

The following degree-days (DDs) indices (Figure 8) are also very important regarding the amount of energy required to heat or to cool homes. Generically, they represent the sum of all daily minimum air-temperature values less than 0°C (HDDn0) and/or than 10°C (HDDn10) from each year analyzed. Obviously, the highest **heating degree-days (HDDs)** values were summed up especially during the cold season and the lowest values are usual for summer (for example, in July, the HDDn10 index had a value of 0°C, which means that all the minimum air-temperature values were greater than 10°C).

The inter-annual variation of heating degree days (HDDs) shows that 1985 was the coldest year from the entire analyzed period (1,318.9°C for the HDDn0 index, respectively 3,504.4°C for the HDDn10 index), and the warmest years were both 2014 and 2015 (with 521°C for HDDn0 index, respectively 2,478.4°C for HDDn10 index), as represented in Figure 8-A. Thus, in 1985, more energy from power plants was needed...
than in the other years taken into consideration, which is demonstrated by the high values of this index. On the other hand, in the last two analyzed years (2014 and 2015), a lower energy consumption was needed, given the higher values of minimum air-temperatures and lower values of HDDn0 index recorded.

In each case, these indices showed a significant decrease over time, especially for the HDDn10 index, pointing to a gradual increasing of the minimum air-temperatures over the analyzed period. The trend for HDDn0 index is decreasing from a value around 1,000°C to only an average value of 700°C, as showed in Figure 8-B. The trend for HDDn10 index is decreasing even more pronouncedly, from a value closer to 3,200°C to almost 2,700°C (Figure 8-C). The main cause of both these trends is most probably the general ongoing climate warming process, which attenuates the normal climatic cooling effects, especially in the cold season of the year.

Data source: NMA archive for temperature values

**Figure 8.** The annual (A), and the inter-annual variation of the HDDn0 index (B) and HDDn10 index (C) at the Brașov-Ghimbav meteorological station for the period 1980-2015.

The monthly and annual frequency of negative air-temperature values (when TN<0°C) is calculated in Table 2, and the frequency of air-temperatures below 10°C is presented in Table 3.

**Table 2.** The frequency of negative air-temperature values (TN<0°C) for the Brașov-Ghimbav meteorological station for the period 1980-2015.

<table>
<thead>
<tr>
<th>Year/Month</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>XII</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>TN&lt;0 (%)</td>
<td>91.8</td>
<td>89.4</td>
<td>65.0</td>
<td>22.7</td>
<td>1.4</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.7</td>
<td>22.9</td>
<td>61.6</td>
<td>84.1</td>
<td>36.6</td>
</tr>
</tbody>
</table>

Data source: NMA archive for temperature values

**Table 3.** The frequency of air temperature values below 10°C for the Brașov-Ghimbav meteorological station for the period 1980-2015.

<table>
<thead>
<tr>
<th>Year/Month</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>XI</th>
<th>XII</th>
<th>Annual</th>
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</thead>
<tbody>
<tr>
<td>TN&lt;10 (%)</td>
<td>100</td>
<td>100</td>
<td>99.9</td>
<td>98.7</td>
<td>79.2</td>
<td>35.9</td>
<td>17.5</td>
<td>25.9</td>
<td>73.5</td>
<td>95.6</td>
<td>99.4</td>
<td>100</td>
<td>77.1</td>
</tr>
</tbody>
</table>

Data source: NMA archive for temperature values
In the first case, in January, 91.8% of all registered values were below 0°C, followed by February with 89.4% and December with 84.1%. Obviously, there are no negative values in summer (from June to August), but in winter (from December to February), all the values keep below 10°C. In March, the percentage of negative air-temperatures reached 99.9%, followed by November (99.4%), April (98.7%) and October (95.6%).

4. Conclusions

The high variations of all the extreme values that were recorded in the Brașov Depression, from 1980 to 2015 reveal not only that the general climatic conditions may often depreciate, but that there is also a high thermal variability from one month to another or from one year to another. Our results are in agreement with the previous knowledge on this topic and they are relevant not only for Brașov city, but also for other big cities in Romania.

This variability has been confirmed by all the indices that were calculated. The monthly mean of daily minimum temperatures (TN index) increased with an average value of 1.5°C in the 1980-2015 period. The monthly minimum value of daily minimum temperature (TNn index) reached the lowest value on 8th January 2015 (-33.3°C), while its corresponding annual average is calculated as -13.6°C, a value that’s pretty low even for Romania. The monthly maximum value of daily minimum temperature (TNx index) reached its highest value ever recorded on 30th August 2003 (23.4°C), while its annual average is 14.4°C. For both TNn and TNx indices, there are no statistically significant changes over time, which is in agreement with the results obtained for other regions in Romania.

The frost days (FD index) evolution trend decreases all over the analyzed period (17 day in average), but there are also some recent exceptions (in 2011, there were 158 frost days). The maximum number of consecutive frost days (CFD index) shows about the same evolution in time.

The cold spell duration index (CSDI index) ranged from one to four cold waves (at least one cold wave occurring each year). The coldest year for the analyzed period was, obviously, 1985, when the sum of all daily minimum air temperatures lower than 0°C (HDDn0 index) and 10°C (HDDn10 index) reached almost record-high values (1,318.9°C, respectively 3,504.4°C), resulting in high energy and fuel consumption. In contrast, the lowest values of these indices were calculated for 2014 and 2015 (HDDn0 value less than 600°C and HDDn10 value less than 2,500°C), requiring low energy and fuel demands. All these results prove the extreme character of the minimum air temperatures and their great variability in time, but also reflect their importance.

The practical importance of all these quantitative assessments is given by the fact that they can be useful tools in calculating some important technical parameters, which may be relevant for the design of heating or cooling installations, in order to ensure bioclimatic comfort of the population, without energy loss.

The most important fact is that both the average value of these extreme indices and their duration in time must be taken into consideration and not only the values produced on a given day, on a specific month or year. By simply identifying the particularities of minimum air-temperatures in Brașov city may prove useful in the management of heat energy being produced and provided for domestic purposes.

All in all, the higher the values obtained for these indices, the more energy must be provided by the power plants to the population of the city. This is very important because Brașov city is one of the largest cities in the country and definitely the greatest town in the Romanian Carpathians.

The present study could be applied to other large cities in Romania too, in order to find out the relationship between the amount of energy provided by power plants and the actual need for heating homes and for indoor human comfort, depending on the building characteristics as well.
References


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