Impact of weather extremes on fresh air ventilation systems

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Abstract. In the last decades, climate changes start to have a significant impact on society and environment. Extreme temperatures affect more often the functioning of fresh air ventilation systems, as they are designed according to specific standards and norms, without considering the extreme weather events. The main object of this study is to analyze the extreme weather events registered in six major cities from Romania, based on daily observation data for outdoor air temperature variations (minimum and maximum). The analysis covers the outdoor air temperature data recorded by the local weather stations from these cities over a period of 9 years, between 2011 and 2019.

1. Introduction

Worldwide, buildings represent one of the biggest energy consumers with up to 40% of the total final energy consumption. Numerous studies conducted around the world demonstrate the impact of global warming on the changes of ambient air temperature and energy consumption in built environment [1]. Climate change has a large impact on the energy consumption in the buildings and influences the ventilation loads, which vary directly with the ambient temperature:

- load needed to cool the air from outdoor temperature $t_{ODA}$ to desired indoor temperature $t_{IDA}$:
  \[ Q_{\text{heating}} = c_p V \rho (t_{ODA} - t_{IDA}) \text{ [J]} \]  

- load needed to heat the air from outdoor temperature $t_{ODA}$ to desired indoor temperature $t_{IDA}$:

  \[ Q_{\text{cooling}} = c_p V \rho (t_{IDA} - t_{ODA}) \text{ [J]} \]  

where $c_p$ is specific heat capacity of air, [kJ/(kg K)], $\rho$ is air density [kg/m$^3$], $V$ is volumetric flow of outdoor ventilation air entering in the building [l/s], $t_{IDA}$ is indoor air temperature [°C] and $t_{ODA}$ is outdoor air temperature [°C].

In Romania, for the design, execution and operation of a ventilation and air conditioning system is used the I5-2010 norm [7] where, in chapter 5.2, are defined the external parameters needed for the calculation of ventilated / air-conditioned buildings.

According to this norm, for summer season the outdoor air calculation temperature is the maximum value of hourly temperature from the average climatic year, for all county capitals the values being indicated in Annex 2 of this technical regulation.

For winter season the outdoor air calculation temperature is provided by a separate standard SR 1907-1 [8] and is chosen according to the climatic zone in which the city is located, the map with the five climatic zones for winter calculation temperatures being defined in Annex A of this standard.
The main objective of present study is to identify and to analyze the extreme weather events based on daily observation of maximum outdoor air temperatures during summer and minimum outdoor air temperatures during winter, and to compare these recorded values with the outdoor air calculation temperatures recommended by I5 – 2010 norm for summer and SR 1907-1 standard for winter.

Temperatures data series represent the daily maximum and daily minimum temperature data sets recorded at six weather stations across Romania over 9 years-period between 2011 and 2019. All data series were freely downloaded from Weather Underground Historical Database [9] for București, Iași, Timișoara, Cluj-Napoca, Constanța and Sibiu, as shown in figure 1.

2. Recorded data
First set of analyzed data includes the maximum air temperatures recorded monthly over the extended summer season April-September and minimum air temperatures recorded monthly over the extended winter season October-March.

For each month where the recorded temperature exceeded the calculation value recommended by the actual technical regulations and norms, the procedure centralized the number of exceedance days as well.

During summer season, the real air temperature inside a city (concrete, asphalt) is usually higher with at least 3 °C than the meteorological recorded value (measured in a closed box, in the shadow, over a grass surface). Thus, the authors estimated a statistic total number of days of exceedance of the summer calculation temperature according to I5 – 2010, by adding 3 °C to the meteorologically recorded air temperatures. This statistic data is more useful to analyze the real magnitude of extreme weather events during summer season.

For winter season, the meteorological recorded values were considered as extreme temperatures, because on one hand, these temperatures were generally recorded during night and on the other hand, the real air temperature inside the city will be higher with few °C then recorded value, depending on the heat radiated by the buildings and heating systems installed in the city.

Although in some of the analyzed cities there were exceedances for every month of the extended summer season, for a better view of extreme weather events, in the last part of the analysis, the authors focused only on the normal summer season between June and August.
2.1. Data recorded during extended winter season

![Graphs showing minimum monthly temperature recorded during extended winter season for various locations.](image)

**Figure 2.** Minimum monthly temperature recorded during extended winter season and calculation temperature according to SR 1907-1 standard (°C).

(Data in Appendix A – Table A1)
2.2. Data recorded during extended summer season

![Graphs showing temperature data for various cities: Bucharest, Iasi, Timisoara, Cluj-Napoca, Constanta, Sibiu.](Image)

**Figure 3.** Maximum monthly temperature recorded during extended summer season and calculation temperature according to I5 – 2010 normative (°C).

(Data in Appendix A – Table A2)
2.3. Statistic data during extended summer season obtained by adding 3 °C to recorded values

Figure 4. Maximum statistic monthly temperature during extended summer season obtained by adding 3 °C to recorded value and calculation temperature according to I5 – 2010 normative (°C).

(Data in Appendix A – Table A3)
2.4. Data recorded during normal summer season

**Figure 5.** Maximum monthly temperature recorded during normal summer season and calculation temperature according to I5 – 2010 normative (°C).
2.5. Statistic data during normal summer season, obtained by adding 3 °C to recorded value

**Figure 6.** Maximum statistic monthly temperature during normal summer season obtained by adding 3 °C to recorded value and calculation temperature according to I5 – 2010 normative (°C).
### 2.6. Days with exceedance recorded during extended winter season

| Table 1. Number of days with exceedance of the calculation temperature according to SR 1907-1 recorded during extended winter season. |
|---|
| **Year** | **2011** | **2012** | **2013** | **2014** | **2015** | **2016** | **2017** | **2018** | **2019** |
| **București** | | | | | | | | | |
| January | 0 | 2 | 0 | 2 | 2 | 3 | 2 | 0 | 0 |
| February | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | 0 | 7 | 0 | 3 | 2 | 3 | 2 | 1 | 0 |
| **Iași** | | | | | | | | | |
| January | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| February | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 2 | 1 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | 0 | 7 | 0 | 1 | 0 | 0 | 2 | 1 | 0 |
| **Timișoara** | | | | | | | | | |
| January | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 0 |
| February | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | 0 | 9 | 0 | 2 | 1 | 0 | 2 | 2 | 0 |
| **Cluj-Napoca** | | | | | | | | | |
| January | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| February | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | 2 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **Constanța** | | | | | | | | | |
| January | 2 | 3 | 0 | 2 | 4 | 5 | 4 | 0 | 1 |
| February | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| March | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| October | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| November | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| December | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **TOTAL** | 2 | 9 | 0 | 2 | 4 | 5 | 4 | 1 | 1 |
Table 2. Number of days with exceedance of the calculation temperature according to I5 – 2010 recorded during extended summer season.

| Year   | April | May | June | July | August | September | TOTAL |
|--------|-------|-----|------|------|--------|-----------|-------|
| Bucuresi | 0     | 0   | 0    | 0    | 0      | 0         | 0     |
| Iași    | 0     | 0   | 0    | 0    | 0      | 0         | 0     |
| Timișoara | 0    | 0   | 0    | 0    | 0      | 0         | 0     |
| Cluj-Napoca | 0  | 0   | 0    | 0    | 0      | 0         | 0     |

2.7. Days with exceedance recorded during extended summer season

| Year   | April | May | June | July | August | September | TOTAL |
|--------|-------|-----|------|------|--------|-----------|-------|
| Sibiu  | 4     | 4   | 0    | 0    | 4      | 3         | 5     |
|        | 0     | 0   | 0    | 0    | 0      | 0         | 0     |

TOTAL: 6 8 0 1 4 3 5 1 1
### Table 3: Statistic number of days with exceedance of the calculation temperature according to I5 – 2010 during extended summer season, considering additional 3 °C to meteorological recorded values.

| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|------|------|------|------|------|------|------|------|------|------|
| **Constanta** |      |      |      |      |      |      |      |      |      |
| April  | 0    | 0    | 0    | 0    | 0    | 1    | 0    | 0    | 0    |
| May    | 0    | 1    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| June   | 4    | 7    | 8    | 2    | 0    | 10   | 9    | 5    | 14   |
| July   | 16   | 23   | 3    | 7    | 15   | 17   | 15   | 3    | 8    |
| August | 8    | 16   | 16   | 14   | 20   | 15   | 18   | 20   | 14   |
| September | 4   | 2    | 0    | 0    | 3    | 8    | 5    | 4    | 1    |
| TOTAL  | 32   | 49   | 27   | 23   | 38   | 51   | 47   | 32   | 37   |
| **Sibiu** |    |      |      |      |      |      |      |      |      |
| April  | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| May    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| June   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| July   | 0    | 2    | 1    | 0    | 0    | 0    | 1    | 0    | 0    |
| August | 0    | 6    | 1    | 0    | 2    | 0    | 1    | 0    | 0    |
| September | 0   | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| TOTAL  | 0    | 8    | 2    | 0    | 2    | 0    | 2    | 0    | 0    |

2.8. **Total statistic number of days with exceedance during extended summer season**

Table 3: Statistic number of days with exceedance of the calculation temperature according to I5 – 2010 during extended summer season, considering additional 3 °C to meteorological recorded values.
3. Calculation of the heating and cooling capacities required for ventilation of a building

Ventilation is the process of introducing outdoor fresh air into a building in order to ensure acceptable levels of Indoor Air Quality. Usually the fresh air is supplied into the building through an air handling unit where is heated and humidified during heating period (winter season) or cooled and dehumidified during cooling period (summer season), thus being achieved the demanded temperature and humidity for the occupied spaces.

To observe the influence of extreme temperatures on fresh air ventilation systems were calculated the heating and the cooling capacities of a standard double deck air-handling unit with a nominal airflow of 30,000 m$^3$/h, equipped with high efficiency heat recovery system with enthalpy heat wheel, meeting the energy efficiency requirements of Ecodesign Directive 1253/2014 [10].

The calculation of heating and cooling capacities considers the temperature and humidity recovery during both winter and summer, as well as the variation of outdoor air parameters within the limits observed in the study from chapter 2 of this paper.

3.1. Indoor air conditions

To calculate the recovery efficiency, following indoor air parameters were defined:
- heating period: 21 °C temperature and 30% relative humidity
- cooling period: 26 °C temperature and 50% relative humidity

To calculate the heating and cooling capacities, following supply air parameters were defined:
- heating coil:
• inlet parameters: parameters after recovery during winter season
• outlet parameters: 25 °C temperature and resulting relative humidity
• cooling coil:
  • inlet parameters: parameters after recovery during summer season
  • outlet parameters: 22 °C temperature and resulting relative humidity

3.2. Heating loads

Table 4. Heating loads depending on outdoor air temperature variations.

| outdoor air | indoor air | air after recovery / before heating coil | air after heating coil | Heating load [kW] |
|-------------|------------|-----------------------------------------|-----------------------|------------------|
| Temp. [°C] | Rel.hum. [%] | Temp. [°C] | Rel.hum. [%] | Temp. [°C] | Rel.hum. [%] | Temp. [°C] | Rel.hum. [%] | |
| -12.0       | 80.0%      | 21.0     | 30.0%      | 13.4     | 27.7%      | 25.0     | 13.5%      | 117.8    |
| -15.0       | 80.0%      | 21.0     | 30.0%      | 12.7     | 31.5%      | 25.0     | 14.5%      | 125.0    |
| -18.0       | 80.0%      | 21.0     | 30.0%      | 12.0     | 33.8%      | 25.0     | 14.9%      | 132.1    |
| -20.0       | 80.0%      | 21.0     | 30.0%      | 11.5     | 34.9%      | 25.0     | 14.9%      | 137.2    |
| -23.0       | 80.0%      | 21.0     | 30.0%      | 10.8     | 36.5%      | 25.0     | 14.9%      | 144.3    |
| -25.0       | 80.0%      | 21.0     | 30.0%      | 10.3     | 37.6%      | 25.0     | 14.8%      | 149.4    |

Figure 7. Heating capacity depending on outdoor air temperature variations.

3.3. Cooling loads

Table 5. Cooling loads depending on outdoor air temperature and relative humidity variations.

| outdoor air | indoor air | air after recovery / before cooling coil | air after cooling coil | Cooling load [kW] |
|-------------|------------|-----------------------------------------|-----------------------|------------------|
| Temp. [°C] | Rel.hum. [%] | Temp. [°C] | Rel.hum. [%] | Temp. [°C] | Rel.hum. [%] | Temp. [°C] | Rel.hum. [%] | |
| 30.0        | 35.0%      | 26.0     | 50.0%      | 27.1     | 42.4%      | 22.0     | 57.6%      | 52.5     |
| 32.0        | 35.0%      | 26.0     | 50.0%      | 27.6     | 45.1%      | 22.0     | 61.4%      | 65.1     |
| 34.0        | 35.0%      | 26.0     | 50.0%      | 28.2     | 48.0%      | 22.0     | 66.0%      | 79.1     |
| 36.0        | 35.0%      | 26.0     | 50.0%      | 28.7     | 51.1%      | 22.0     | 71.1%      | 91.4     |
| 38.0        | 35.0%      | 26.0     | 50.0%      | 29.0     | 55.0%      | 22.0     | 74.3%      | 112.0    |
| City | Total days | Total days | Exceedance | Total days | Total days |
|------|------------|------------|-------------|------------|------------|
|      | with exceedance | with exceedance | days / total | with exceedance | with exceedance |
|      | of SR 1907-1-extended | of SR 1907-1-standard | days extended | of SR 1907-1-standard | of SR 1907-1-standard |
| 30.0 | 40.0% | 26.0 | 50.0% | 29.3 | 59.3% | 22.0 | 78.6% | 131.9 |
| 32.0 | 40.0% | 26.0 | 50.0% | 27.1 | 47.3% | 22.0 | 62.9% | 58.2 |
| 34.0 | 40.0% | 26.0 | 50.0% | 27.6 | 50.4% | 22.0 | 66.7% | 74.0 |
| 36.0 | 40.0% | 26.0 | 50.0% | 28.2 | 53.6% | 22.0 | 72.0% | 88.6 |
| 38.0 | 40.0% | 26.0 | 50.0% | 28.7 | 57.0% | 22.0 | 75.4% | 111.2 |
| 40.0 | 40.0% | 26.0 | 50.0% | 29.3 | 61.2% | 22.0 | 79.6% | 130.5 |
| 30.0 | 45.0% | 26.0 | 50.0% | 27.1 | 52.1% | 22.0 | 67.0% | 68.8 |
| 32.0 | 45.0% | 26.0 | 50.0% | 27.6 | 55.4% | 22.0 | 72.0% | 81.5 |
| 34.0 | 45.0% | 26.0 | 50.0% | 28.2 | 58.9% | 22.0 | 76.7% | 101.8 |
| 36.0 | 45.0% | 26.0 | 50.0% | 28.7 | 62.5% | 22.0 | 80.0% | 127.0 |
| 38.0 | 45.0% | 26.0 | 50.0% | 29.0 | 66.8% | 22.0 | 84.1% | 148.3 |
| 40.0 | 45.0% | 26.0 | 50.0% | 29.3 | 71.6% | 22.0 | 88.3% | 173.6 |

### Figure 8. Cooling capacity depending on outdoor air temperature variations.

### 4. Results and discussions

#### 4.1. Days with exceedance of the calculation temperatures form technical regulations

The data compiled in tables 1, 2 and 3 yielded the total number of days with exceedance of calculation temperature indicated in the technical regulations and norms for the entire analyzed period of 9 years, as shown in tables 6, 7 and 8.

### Table 6. Number of exceedance days during winter related to 9-years period of analysis.

| City | Total days with exceedance of SR 1907-1-extended | Total days extended winter | Exceedance days / total days extended winter | Total days with exceedance of SR 1907-1-standard | Total days standard winter | Exceedance days / total days standard winter |
|------|-----------------------------------------------|--------------------------|------------------------------------------|-----------------------------------------------|----------------------------|------------------------------------------|
Along the entire period of 9 years under analysis, the total number of days with exceedance during the winter is maximum 3.5% related to the standard season December-February. Thus, the authors consider that the calculation temperatures indicated in the SR 1907-1 standard are covering for all the six cities included in this study.

At the opposite side, the analysis regarding the number of days of exceedance during the summer, for the same period of 9 years, for some cities, shows that there were significant differences compared to the calculation temperatures recommended by I5 – 2010 norm, especially in standard summer season June-August.

Analyzing the values given in tables 7 and 8 for Iași, there were registered maximum exceedances between 1.7% (for the meteorologically recorded temperature values) and 8.8% (for the statistically calculated temperatures by adding 3 °C to the recorded values). Similarly, for Sibiu was between 1.7% (recorded) and 10.75% (statistic), for Timișoara between 4.1% (recorded) and 18.3% (statistic),
for București between 5.7% \((\text{recorded})\) and 25.9% \((\text{statistic})\), for Cluj-Napoca between 15.8% \((\text{recorded})\) and 39.1% \((\text{statistic})\) and for Constanța between 37% \((\text{recorded})\) and 68.9% \((\text{statistic})\).

### 4.2. Exceeding temperatures

From data tabulated in Appendix A, in tables A1, A2 and A3, the lowest temperatures during winter season and the highest temperatures during summer season were extracted for the calculation of the largest difference between the recorded temperatures and the calculation temperatures, according to technical regulations, as shown in tables 9, 10 and 11.

**Table 9. Maximum difference between recorded temperature and calculation temperature during winter.**

| City            | Minimum recorded temperature | Calculation temperature SR 1907 | Maximum difference |
|-----------------|------------------------------|---------------------------------|--------------------|
| București       | -19.0                        | -15.0                           | -4.0               |
| Iași            | -25.0                        | -15.0                           | -10.0              |
| Timișoara       | -23.0                        | -15.0                           | -8.0               |
| Cluj-Napoca     | -23.0                        | -15.0                           | -8.0               |
| Constanța       | -19.0                        | -15.0                           | -4.0               |
| Sibiu           | -29.0                        | -15.0                           | -14.0              |

**Table 10. Maximum difference between recorded temperature and calculation temperature during summer \(^\circ\text{C}\).**

| City            | Maximum recorded temperature | Calculation temperature I5 – 2010 | Maximum difference |
|-----------------|------------------------------|---------------------------------|--------------------|
| București       | 40.0                         | 35.3                            | 4.7                |
| Iași            | 40.0                         | 36.0                            | 4.0                |
| Timișoara       | 40.0                         | 36.4                            | 3.6                |
| Cluj-Napoca     | 38.0                         | 31.5                            | 6.5                |
| Constanța       | 39.0                         | 30.6                            | 8.4                |
| Sibiu           | 38.0                         | 34.0                            | 4.0                |

**Table 11. Maximum difference between statistic temperature \((\text{recorded} +3 \circ\text{C})\) and calculation temperature during summer \(^\circ\text{C}\).**

| City            | Maximum statistic temperature (recorded +3 \circ\text{C}) | Calculation temperature I5 – 2010 | Maximum difference |
|-----------------|-----------------------------------------------------------|---------------------------------|--------------------|
| București       | 43.0                                                      | 35.3                            | 7.7                |
| Iași            | 43.0                                                      | 36.0                            | 7.0                |
| Timișoara       | 43.0                                                      | 36.4                            | 6.6                |
| Cluj-Napoca     | 41.0                                                      | 31.5                            | 9.5                |
| Constanța       | 42.0                                                      | 30.6                            | 11.4               |
| Sibiu           | 41.0                                                      | 34.0                            | 7.0                |

Although during the winter season the maximum difference between the recorded temperature and the calculation temperature was -14 \(^\circ\text{C}\) (table 9), the increase of the heating capacity in an AHU (air...
handling units) like the one described in chapter 3 is approx. 27% (table 4) compared to the heating capacity for the calculation temperature (149.4 kW instead of 117.8 kW). This difference is acceptable, considering the reserves commonly used by manufacturers when sizing the heating coils.

Authors would like to mention that during winter the relative humidity of the outdoor air does not influence the capacity of the heating coil, having a direct influence only on humidification capacity.

Instead, during the summer season any difference between the recorded temperature and the calculation temperature has a direct and much more significant influence on the cooling capacity. As shown in table 5, in the same AHU as the one described in chapter 3, each additional 2 °C increase between the recorded temperature and the calculation temperature is equivalent an increase of the cooling capacity up to 30% compared to the cooling capacity for the calculation temperature (74.0 kW instead of 58.2 kW). Therefore, for an increase of 6 °C between the recorded temperature and the calculation temperature, the needed cooling capacity will be approx. 90% higher than capacity for the calculation temperature (111.2 kW instead of 58.2 kW).

In addition, during summer season the relative humidity of outdoor air has a direct influence on the total cooling capacity of the coil, considering the sensible component needed for dehumidification. As shown in table 5, in the same AHU like the one described in chapter 3, for an increase between the recorded relative humidity and the calculation relative humidity with 5%, the cooling capacity will increase with approximately 18% compared to the cooling capacity for the calculation of relative humidity (68.8 kW instead of 58.2 kW).

5. Conclusions
This paper studies the extreme weather events recorded during 9-year time period, from 2011 to 2019 in cities of București, Iași, Timișoara, Cluj-Napoca, Constanța and Sibiu and investigates the impact of these climatic changes on design parameters of fresh air ventilation systems.

The results show that for the winter season the outdoor air calculation temperatures provided by the SR 1907-1 standard are valid for all six analyzed cities. However, for summer seasons of the analyzed period, there is a large number of extreme weather events recorded that may affect the calculation temperatures indicated in the I5 – 2010 norm. For two cities, Iași and Sibiu, the difference is below 10% and may be considered satisfactory, but for the rest of four cities from this study, the authors recommend the revision of the calculation temperatures indicated in the I5 – 2010 normative.

The present study clearly demonstrates that for some cities the use of current technical norms may incur major design flaws. Therefore, this type of analysis should be extended to all major cities from Romania, in order to revise the current technical norms and standards.

6. References

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## Table A1. Minimum monthly temperature recorded during extended winter season and calculation temperature according to SR 1907-1 standard (°C).

| Year   | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|--------|------|------|------|------|------|------|------|------|------|
| **București** |      |      |      |      |      |      |      |      |      |
| January | -12.0 | -18.0 | -13.0 | -16.0 | -17.0 | -18.0 | -17.0 | -8.0 | -12.0 |
| February | -14.0 | -19.0 | -4.0 | -12.0 | -8.0 | -5.0 | -10.0 | -10.0 | -6.0 |
| March | -5.0 | -6.0 | -5.0 | 0.0 | -2.0 | -1.0 | -1.0 | -16.0 | -2.0 |
| October | -1.0 | 0.0 | -1.0 | 0.0 | 0.0 | 2.0 | 1.0 | 4.0 | 4.0 |
| November | -6.0 | 0.0 | -4.0 | -2.0 | -1.0 | -3.0 | -2.0 | -7.0 | -1.0 |
| December | -4.0 | -15.0 | -7.0 | -16.0 | -7.0 | -8.0 | -4.0 | -9.0 | -5.0 |
| **SR1907-1** | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 |
| **Iași** |      |      |      |      |      |      |      |      |      |
| January | -15.0 | -18.0 | -16.0 | -20.0 | -18.0 | -17.0 | -16.0 | -16.0 | -13.0 |
| February | -13.0 | -25.0 | -6.0 | -17.0 | -11.0 | -4.0 | -20.0 | -19.0 | -13.0 |
| March | -15.0 | -10.0 | -10.0 | -1.0 | -3.0 | -3.0 | 1.0 | -16.0 | -8.0 |
| October | -3.0 | 1.0 | 0.0 | -7.0 | -2.0 | 2.0 | 2.0 | 2.0 | 2.0 |
| November | -5.0 | -3.0 | -5.0 | -4.0 | -1.0 | -7.0 | 2.0 | -13.0 | -4.0 |
| December | -9.0 | -16.0 | -7.0 | -16.0 | -11.0 | -10.0 | -4.0 | -13.0 | -6.0 |
| **SR1907-1** | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 |
| **Timișoara** |      |      |      |      |      |      |      |      |      |
| January | -15.0 | -12.0 | -12.0 | -7.0 | -17.0 | -13.0 | -16.0 | -4.0 | -15.0 |
| February | -11.0 | -23.0 | -6.0 | -7.0 | -7.0 | -5.0 | -5.0 | -18.0 | -8.0 |
| March | -7.0 | -6.0 | -5.0 | -2.0 | -4.0 | -3.0 | -2.0 | -18.0 | -5.0 |
| October | -4.0 | -2.0 | -2.0 | -1.0 | 0.0 | 0.0 | -1.0 | -1.0 | -1.0 |
| November | -8.0 | 0.0 | -2.0 | -5.0 | -3.0 | -6.0 | -5.0 | -7.0 | -2.0 |
| December | -4.0 | -18.0 | -8.0 | -17.0 | -7.0 | -9.0 | -5.0 | -18.0 | -5.0 |
| **SR1907-1** | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 | -15.0 |
| **Cluj-Napoca** |      |      |      |      |      |      |      |      |      |
| January | -19.0 | -20.0 | -12.0 | -8.0 | -18.0 | -15.0 | -18.0 | -12.0 | -16.0 |
| February | -17.0 | -23.0 | -6.0 | -12.0 | -10.0 | -4.0 | -8.0 | -13.0 | -8.0 |
| March | -10.0 | -11.0 | -8.0 | -3.0 | -5.0 | -4.0 | -3.0 | -16.0 | -6.0 |
| October | -7.0 | -1.0 | -3.0 | -5.0 | -2.0 | 0.0 | -1.0 | -1.0 | -2.0 |
| November | -10.0 | -3.0 | -5.0 | -6.0 | -6.0 | -5.0 | -3.0 | -10.0 | -2.0 |
| December | -9.0 | -17.0 | -11.0 | -17.0 | -11.0 | -11.0 | -5.0 | -13.0 | -9.0 |
| **SR1907-1** | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 |
| **Constanța** |      |      |      |      |      |      |      |      |      |
| January | -14.0 | -17.0 | -12.0 | -15.0 | -17.0 | -16.0 | -19.0 | -8.0 | -13.0 |
| February | -10.0 | -19.0 | -2.0 | -8.0 | -8.0 | -4.0 | -8.0 | -12.0 | -7.0 |
| March | -8.0 | -4.0 | -7.0 | -1.0 | -3.0 | -4.0 | -1.0 | -15.0 | -4.0 |
| October | -1.0 | 0.0 | 2.0 | 2.0 | 2.0 | 0.0 | -1.0 | 2.0 | 2.0 |
| November | -6.0 | -1.0 | -3.0 | -6.0 | 0.0 | -5.0 | -2.0 | -6.0 | -1.0 |
| December | -5.0 | -8.0 | -7.0 | -10.0 | -9.0 | -8.0 | -5.0 | -11.0 | -6.0 |
| **SR1907-1** | -12.0 | -12.0 | -12.0 | -12.0 | -12.0 | -12.0 | -12.0 | -12.0 | -12.0 |
| Year   | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Sibiu  |       |       |       |       |       |       |       |       |       |
| January| -22.0 | -25.0 | -15.0 | -10.0 | -26.0 | -23.0 | -29.0 | -14.0 | -23.0 |
| February| -19.0 | -25.0 | -10.0 | -9.0  | -13.0 | -6.0  | -13.0 | -12.0 | -14.0 |
| March  | -9.0  | -10.0 | -9.0  | -4.0  | -9.0  | -4.0  | -5.0  | -18.0 | -6.0  |
| October| -7.0  | -3.0  | -4.0  | -4.0  | -3.0  | -2.0  | -1.0  | 0.0   |       |
| November| -13.0 | -4.0  | -6.0  | -6.0  | -7.0  | -4.0  | -11.0 | -3.0  |       |
| December| -12.0 | -21.0 | -10.0 | -26.0 | -14.0 | -15.0 | -9.0  | -13.0 | -13.0 |
| SR1907-1 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 | -18.0 |

**Table A2.** Maximum monthly temperature recorded during extended summer season and calculation temperature according to I5 – 2010 normative (°C).

| Year   | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| București |       |       |       |       |       |       |       |       |       |
| April  | 22.0  | 30.0  | 30.0  | 25.0  | 27.0  | 30.0  | 27.0  | 29.0  | 26.0  |
| May    | 29.0  | 31.0  | 32.0  | 30.0  | 29.0  | 31.0  | 30.0  | 31.0  | 28.0  |
| June   | 35.0  | 36.0  | 35.0  | 31.0  | 34.0  | 35.0  | 37.0  | 34.0  | 33.0  |
| July   | 36.0  | 39.0  | 38.0  | 35.0  | 38.0  | 36.0  | 38.0  | 34.0  | 36.0  |
| August | 35.0  | 40.0  | 36.0  | 36.0  | 36.0  | 38.0  | 36.0  | 36.0  | 35.0  |
| September | 34.0 | 33.0  | 30.0  | 30.0  | 35.0  | 32.0  | 34.0  | 33.0  | 32.0  |
| I5 – 2010 | 35.3 | 35.3  | 35.3  | 35.3  | 35.3  | 35.3  | 35.3  | 35.3  | 35.3  |

| Year   | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Iași   |       |       |       |       |       |       |       |       |       |
| April  | 24.0  | 30.0  | 31.0  | 23.0  | 26.0  | 28.0  | 25.0  | 28.0  | 26.0  |
| May    | 31.0  | 31.0  | 30.0  | 30.0  | 29.0  | 28.0  | 29.0  | 31.0  | 28.0  |
| June   | 33.0  | 37.0  | 33.0  | 30.0  | 33.0  | 33.0  | 33.0  | 31.0  | 33.0  |
| July   | 34.0  | 38.0  | 32.0  | 35.0  | 36.0  | 36.0  | 36.0  | 30.0  | 33.0  |
| August | 32.0  | 40.0  | 33.0  | 36.0  | 37.0  | 37.0  | 37.0  | 32.0  | 34.0  |
| September | 31.0 | 31.0  | 26.0  | 32.0  | 37.0  | 31.0  | 32.0  | 31.0  | 33.0  |
| I5 – 2010 | 36.0 | 36.0  | 36.0  | 36.0  | 36.0  | 36.0  | 36.0  | 36.0  | 36.0  |

| Year   | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Timișoara |       |       |       |       |       |       |       |       |       |
| April  | 25.0  | 31.0  | 32.0  | 23.0  | 26.0  | 28.0  | 27.0  | 29.0  | 28.0  |
| May    | 29.0  | 32.0  | 31.0  | 29.0  | 30.0  | 29.0  | 31.0  | 31.0  | 25.0  |
| June   | 34.0  | 36.0  | 35.0  | 34.0  | 34.0  | 34.0  | 33.0  | 33.0  | 33.0  |
| July   | 38.0  | 38.0  | 38.0  | 33.0  | 37.0  | 35.0  | 37.0  | 32.0  | 35.0  |
| August | 37.0  | 38.0  | 37.0  | 36.0  | 37.0  | 36.0  | 40.0  | 36.0  | 37.0  |
| September | 34.0 | 35.0  | 28.0  | 29.0  | 36.0  | 31.0  | 34.0  | 33.0  | 33.0  |
| I5 – 2010 | 36.4 | 36.4  | 36.4  | 36.4  | 36.4  | 36.4  | 36.4  | 36.4  | 36.4  |

| Year   | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  | 2018  | 2019  |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Cluj-Napoca |       |       |       |       |       |       |       |       |       |
| April  | 21.0  | 28.0  | 29.0  | 21.0  | 25.0  | 28.0  | 27.0  | 29.0  | 27.0  |
| May    | 28.0  | 30.0  | 28.0  | 29.0  | 28.0  | 28.0  | 26.0  | 30.0  | 27.0  |
| June   | 32.0  | 32.0  | 31.0  | 31.0  | 32.0  | 34.0  | 34.0  | 30.0  | 32.0  |
| July   | 33.0  | 36.0  | 35.0  | 32.0  | 34.0  | 33.0  | 33.0  | 31.0  | 34.0  |
| August | 33.0  | 38.0  | 35.0  | 35.0  | 35.0  | 32.0  | 37.0  | 32.0  | 33.0  |
| September | 30.0 | 32.0  | 25.0  | 28.0  | 34.0  | 30.0  | 31.0  | 31.0  | 32.0  |
| I5 – 2010 | 31.5 | 31.5  | 31.5  | 31.5  | 31.5  | 31.5  | 31.5  | 31.5  | 31.5  |
| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|------|------|------|------|------|------|------|------|------|------|
| Constanța | | | | | | | | | |
| April | 19.0 | 28.0 | 29.0 | 24.0 | 27.0 | 31.0 | 22.0 | 27.0 | 24.0 |
| May | 28.0 | 31.0 | 29.0 | 29.0 | 28.0 | 29.0 | 28.0 | 29.0 | 29.0 |
| June | 32.0 | 35.0 | 33.0 | 31.0 | 30.0 | 35.0 | 36.0 | 33.0 | 34.0 |
| July | 35.0 | 36.0 | 34.0 | 32.0 | 36.0 | 34.0 | 38.0 | 32.0 | 34.0 |
| August | 33.0 | 39.0 | 34.0 | 35.0 | 36.0 | 36.0 | 39.0 | 35.0 | 34.0 |
| September | 33.0 | 34.0 | 28.0 | 29.0 | 33.0 | 33.0 | 33.0 | 33.0 | 32.0 |
| I5 – 2010 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 |
| Sibiu | | | | | | | | | |
| April | 20.0 | 27.0 | 29.0 | 21.0 | 24.0 | 28.0 | 26.0 | 27.0 | 27.0 |
| May | 26.0 | 28.0 | 29.0 | 26.0 | 28.0 | 27.0 | 26.0 | 29.0 | 26.0 |
| June | 31.0 | 32.0 | 32.0 | 30.0 | 32.0 | 34.0 | 33.0 | 30.0 | 30.0 |
| July | 32.0 | 36.0 | 35.0 | 32.0 | 34.0 | 32.0 | 35.0 | 28.0 | 33.0 |
| August | 33.0 | 38.0 | 35.0 | 27.0 | 35.0 | 30.0 | 35.0 | 30.0 | 33.0 |
| September | 31.0 | 31.0 | 24.0 | 25.0 | 33.0 | 29.0 | 31.0 | 30.0 | 31.0 |
| I5 – 2010 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |

**Table A3. Maximum statistic monthly temperature during extended summer season obtained by adding 3 °C to recorded value and calculation temperature according to I5 – 2010 normative (°C).**

| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|------|------|------|------|------|------|------|------|------|------|
| București | | | | | | | | | |
| April | 25.0 | 33.0 | 33.0 | 28.0 | 30.0 | 33.0 | 30.0 | 32.0 | 29.0 |
| May | 32.0 | 34.0 | 35.0 | 33.0 | 32.0 | 34.0 | 33.0 | 34.0 | 31.0 |
| June | 38.0 | 39.0 | 38.0 | 34.0 | 37.0 | 38.0 | 40.0 | 37.0 | 36.0 |
| July | 39.0 | 42.0 | 41.0 | 38.0 | 41.0 | 39.0 | 41.0 | 37.0 | 39.0 |
| August | 38.0 | 43.0 | 39.0 | 39.0 | 39.0 | 39.0 | 41.0 | 39.0 | 38.0 |
| September | 37.0 | 36.0 | 33.0 | 33.0 | 38.0 | 35.0 | 37.0 | 36.0 | 35.0 |
| I5 – 2010 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 |
| Iași | | | | | | | | | |
| April | 27.0 | 33.0 | 34.0 | 26.0 | 29.0 | 31.0 | 28.0 | 31.0 | 29.0 |
| May | 34.0 | 34.0 | 33.0 | 33.0 | 32.0 | 31.0 | 32.0 | 34.0 | 31.0 |
| June | 36.0 | 40.0 | 36.0 | 33.0 | 36.0 | 36.0 | 36.0 | 34.0 | 36.0 |
| July | 37.0 | 41.0 | 35.0 | 38.0 | 39.0 | 39.0 | 39.0 | 33.0 | 36.0 |
| August | 35.0 | 43.0 | 36.0 | 39.0 | 40.0 | 40.0 | 40.0 | 35.0 | 37.0 |
| September | 34.0 | 34.0 | 29.0 | 35.0 | 40.0 | 34.0 | 35.0 | 34.0 | 36.0 |
| I5 – 2010 | 36.0 | 36.0 | 36.0 | 36.0 | 36.0 | 36.0 | 36.0 | 36.0 | 36.0 |
| Timișoara | | | | | | | | | |
| April | 28.0 | 34.0 | 35.0 | 26.0 | 29.0 | 31.0 | 30.0 | 32.0 | 31.0 |
| May | 32.0 | 35.0 | 34.0 | 32.0 | 33.0 | 32.0 | 34.0 | 34.0 | 28.0 |
| June | 37.0 | 39.0 | 38.0 | 37.0 | 37.0 | 37.0 | 37.0 | 36.0 | 36.0 |
| July | 41.0 | 41.0 | 41.0 | 36.0 | 40.0 | 38.0 | 40.0 | 35.0 | 38.0 |
| August | 40.0 | 41.0 | 40.0 | 39.0 | 40.0 | 39.0 | 43.0 | 39.0 | 40.0 |
| September | 37.0 | 38.0 | 31.0 | 32.0 | 39.0 | 34.0 | 37.0 | 36.0 | 36.0 |
| I5 – 2010 | 36.4 | 36.4 | 36.4 | 36.4 | 36.4 | 36.4 | 36.4 | 36.4 | 36.4 |
| Year  | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|-------|------|------|------|------|------|------|------|------|------|
| Cluj-Napoca |      |      |      |      |      |      |      |      |      |
| April  | 24.0 | 31.0 | 32.0 | 24.0 | 28.0 | 31.0 | 30.0 | 32.0 | 30.0 |
| May    | 31.0 | 33.0 | 31.0 | 32.0 | 31.0 | 31.0 | 29.0 | 33.0 | 30.0 |
| June   | 35.0 | 35.0 | 34.0 | 34.0 | 35.0 | 37.0 | 37.0 | 33.0 | 35.0 |
| July   | 36.0 | 39.0 | 38.0 | 35.0 | 37.0 | 36.0 | 36.0 | 34.0 | 37.0 |
| August | 36.0 | 41.0 | 38.0 | 38.0 | 38.0 | 35.0 | 40.0 | 35.0 | 36.0 |
| September | 33.0 | 35.0 | 28.0 | 31.0 | 37.0 | 33.0 | 34.0 | 34.0 | 35.0 |
| I5 – 2010 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 | 31.5 |
| Constanța |      |      |      |      |      |      |      |      |      |
| April  | 22.0 | 31.0 | 32.0 | 27.0 | 30.0 | 34.0 | 25.0 | 30.0 | 27.0 |
| May    | 31.0 | 34.0 | 32.0 | 32.0 | 31.0 | 32.0 | 31.0 | 32.0 | 32.0 |
| June   | 35.0 | 38.0 | 36.0 | 34.0 | 33.0 | 38.0 | 39.0 | 36.0 | 37.0 |
| July   | 38.0 | 39.0 | 37.0 | 35.0 | 39.0 | 37.0 | 41.0 | 35.0 | 37.0 |
| August | 36.0 | 42.0 | 37.0 | 38.0 | 39.0 | 39.0 | 42.0 | 38.0 | 37.0 |
| September | 36.0 | 37.0 | 31.0 | 32.0 | 36.0 | 36.0 | 36.0 | 36.0 | 35.0 |
| I5 – 2010 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 | 30.6 |
| Sibiu  |      |      |      |      |      |      |      |      |      |
| April  | 23.0 | 30.0 | 32.0 | 24.0 | 27.0 | 31.0 | 29.0 | 30.0 | 30.0 |
| May    | 29.0 | 31.0 | 32.0 | 29.0 | 31.0 | 30.0 | 29.0 | 32.0 | 29.0 |
| June   | 34.0 | 35.0 | 35.0 | 33.0 | 35.0 | 37.0 | 36.0 | 33.0 | 33.0 |
| July   | 35.0 | 39.0 | 38.0 | 35.0 | 37.0 | 35.0 | 38.0 | 31.0 | 36.0 |
| August | 36.0 | 41.0 | 38.0 | 30.0 | 38.0 | 33.0 | 38.0 | 33.0 | 36.0 |
| September | 34.0 | 34.0 | 27.0 | 28.0 | 36.0 | 32.0 | 34.0 | 33.0 | 34.0 |
| I5 – 2010 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 | 34.0 |