THE INFLUENCE OF TEMPERATURE INVERSIONS ON THE AIR POLLUTION IN THE CITY OF SIBIU

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Abstract. - The influence of temperature inversions on the air pollution in the city of Sibiu. The temperature inversions are likely to occur in Sibiu area due to its position inside a depression of contact between the Southern Carpathians and the Transylvanian Plateau. The effects of these inversions involve not only very low temperatures but also a stable air stratification that does not allow convective air movements; that increases air pollution in the city. The aim of this research is to identify the level of air pollution in days with temperature inversions. There were analysed the daily medium concentrations of the following atmospheric pollutants: sulfur dioxide SO_2, nitrogen dioxide NO_2, carbon monoxide CO and ozone O_3, in days with or without inversions. The concentration of two of the above mentioned pollutants is maximum in days with general temperature inversions, high atmospheric pressure and slow wind speed.

Key words: temperature inversions, air pollution, the city of Sibiu

1. Introduction

It is known for a long time that urban areas are confronted with specific difficulties and one of them is air pollution. Beyond certain limits, pollution is extremely dangerous because of the risks implied and that is why there must exist evidence and control over all the pollutants that alter human health.

A special attention must be paid to the pollutants of chemical origin because many various types result from sources inside urban areas. The usual concentration of each pollutant is diminished immediately after its spreading by means of dispersion, diffusion and absorbtion through chemical reactions with various components of the air. Because of its location, surface, number of inhabitants and the existent functions, air pollution gets inevitable in Sibiu; as long as the level of pollutants is low, the phenomenon itself is not dangerous.

However, there are meteorological circumstances that inhibit the aeration of the atmosphere and the reduction of the concentration, and one of the factors encouraging these situations is the location of the city within a negative relief shape, such as inside a depression of contact (Fărcaş, 1999).

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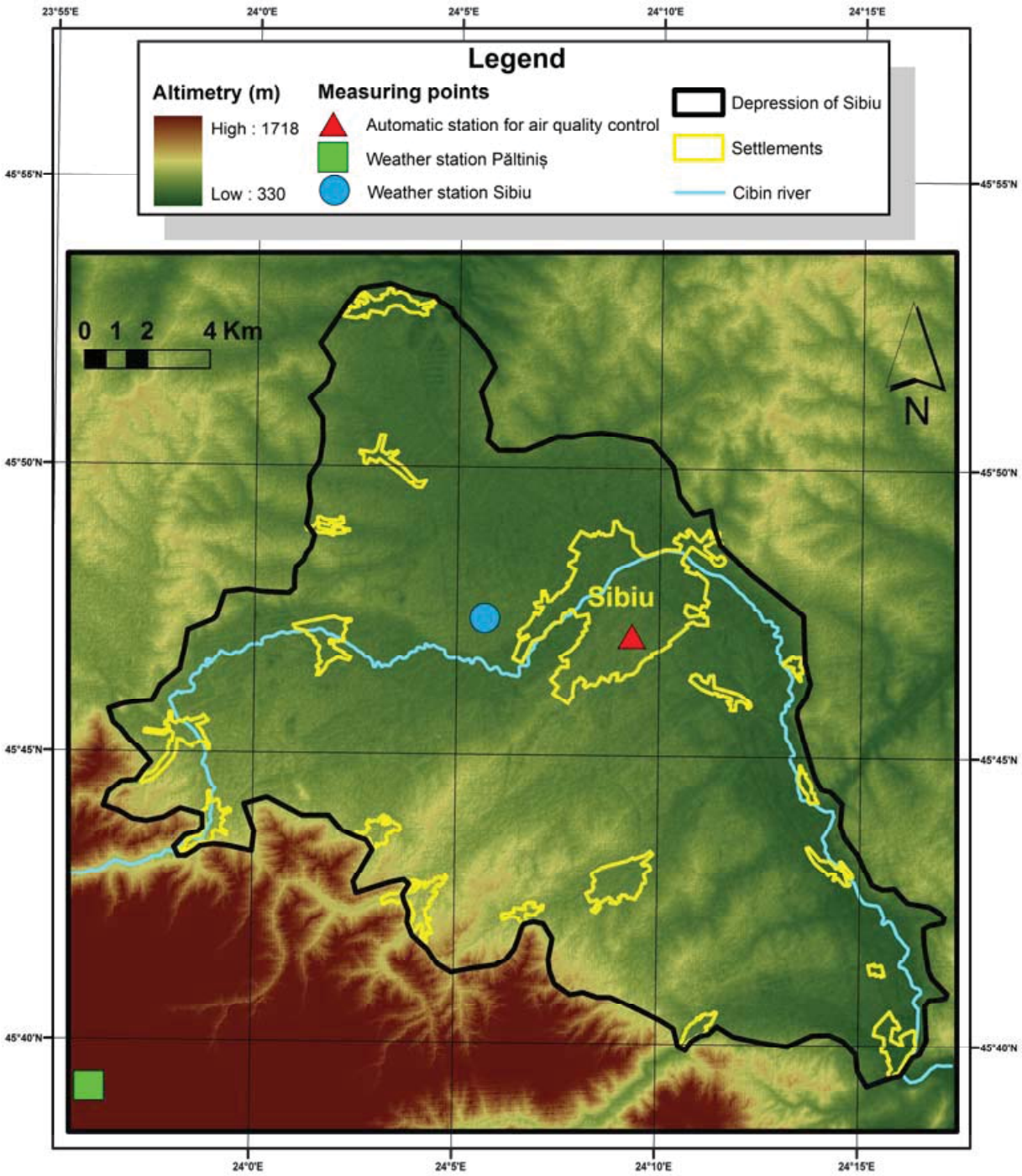

Fig. 1 Hypsometric map of the Sibiu Depression

Generally speaking, dispersion and diffusion of pollutants is much weaker when there is a low air dynamics, which is a stable vertical thermic stratification. This does not allow the development of convective movements of air and appears not only at a high atmospheric pressure in an anticyclonic air mass but also with temperature inversions (Fărcaş, 1999). These inversions happen especially during the cold season in depressions, both in the intermountain depressions and in the

contact ones, because the local orography allows the gravitational streaming down on the slope and the progressive accumulation of the cold, thicker air, originated in higher regions at the bottom of depressions (Fărcaş, 1983).

The city of Sibiu lies within the homonymous depression, where the Southern Carpathians meet the Transylvanian Plateau. Although the location is not an intermountain depression, it is firmly bounded on the south and south-west by the northern slopes of the Cindrel Mountains and Lotru Mountains and on the west, north, north-east and east by the steep slopes of the Amnaş and Hârtibaciu Plateaux (Ciulache, 1997). This configuration of the relief allows the accumulation of cold air in the lowest regions of the depression, specifically in the flood plain of Cibin river, where the city of Sibiu lies. As a consequence, there will be a stable stratification of air because of the rise of temperature depending on the altitude, and the air movements both on vertical and horizontal line will be very weak or non-existent.

The sources of chemical pollutants are numerous within urban area; most of them result from the process of transport, manufacture, construction and from the steam-generating stations (Fărcaş, 1999; Ursu, 1981). But the most important on the above list is the road transport, as Sibiu is transited by two important main roads that go together along the depression. There are also a lot of district and local roads in the depression, and a whole street network system inside the city. Because of the intense traffic, most of the pollutants are directly emitted after the combustion of fossil fuel or indirectly produced by chemical reactions. Another source of pollution is represented by the factories located in the city, most of them in the western and eastern industrial areas, where they produce car components, wrappers, food, ready-made clothes, electronic components.

The aim of this research paper is to analyse to what extent the situations of atmospheric stability generated by temperature inversions could increase the gravity of atmospheric pollution.

2. Data and methods used

In order to work out this research paper, the author used and studied various information referring to maximum and minimum daily values of air temperature in Celsius degrees registered by the meteorological stations Sibiu (444 m) and Păltiniş (1450 m), to identify the days with temperature inversions as well as the medium daily values of some reference pollutants such as sulfur dioxide SO_2, nitrogen dioxide NO_2, carbon monoxide CO and ozone O_3, by the automatic station for controlling the quality of air, from the Regional Agency for Environment Protection in Sibiu, located on the central-southern area of the city; these data were collected between 2008 and 2010 but, unfortunately, the series of information is not complete, so that the results are uncertain. The author also used data taken from the online records of the Russian Meteorological Server (http://meteo.infospace.ru/main.htm), in order to find out the wind speed and the atmospheric pressure.

The methods used in this research paper are: the analytical method through mathematical and statistical ways (arithmetical means, maximum and minimum values) and the comparative method to point out the difference among various situations of atmospheric pollution.

3. Results

Analysing the frequency of the temperature inversions, the author makes a difference among the three types of inversions, depending on the moment of their appearance. There exist night inversions when the minimum temperature registered in Sibiu, that is on the bottom of the depression, is lower than the minimum temperature in Păltiniş, that is the intermountain region. Day inversions occur when the maximum temperature in Sibiu is lower than the one in Păltiniş, and the situation of general inversion occurs when both the minimum temperature and the maximum one are lower within the depression than in the mountain region. The general temperature inversions are less frequent because the inversion layer formed during the night is usually destroyed during the day by the heating of the air within low regions.

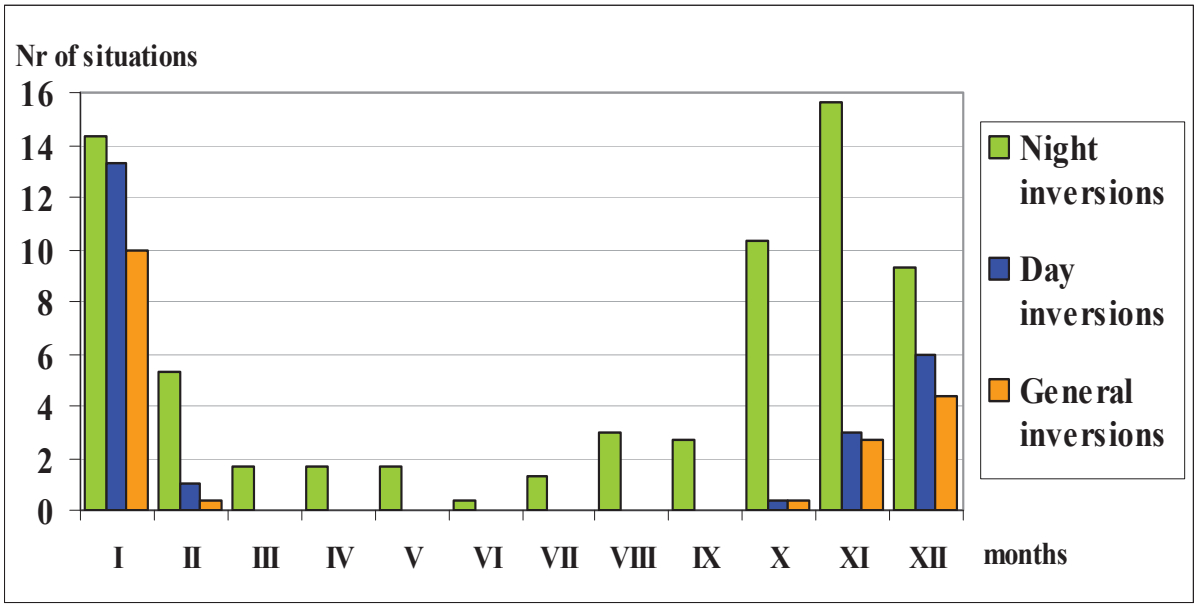

Fig. 2 Number of situations with temperature inversions in Sibiu, 2008-2010

Most of the temperature inversions are recorded especially during winter and at the end of autumn. Between 2008 and 2010 a high frequency of appearance of the three types of inversion was registered on the average in January, with at least, 10 situations or more. The number of day and general inversions is maximum during this month compared with other months, and most of the cases of night inversions are recorded on the average in November, during more than a half of the

month. The night inversion may occur during any month of the year, that is warmer seasons, but less frequent and in a few situations. During the examined period of time there were not registered any day and general inversions between March and September (included).

Therefore, the probability of a negative influence over the situations of atmospheric pollution is maximum during cold weather when the temperature inversions occur most frequently and persist for more consecutive days. After analysing and centralizing the data about the medium daily concentration of pollutants, here is the following diagram:

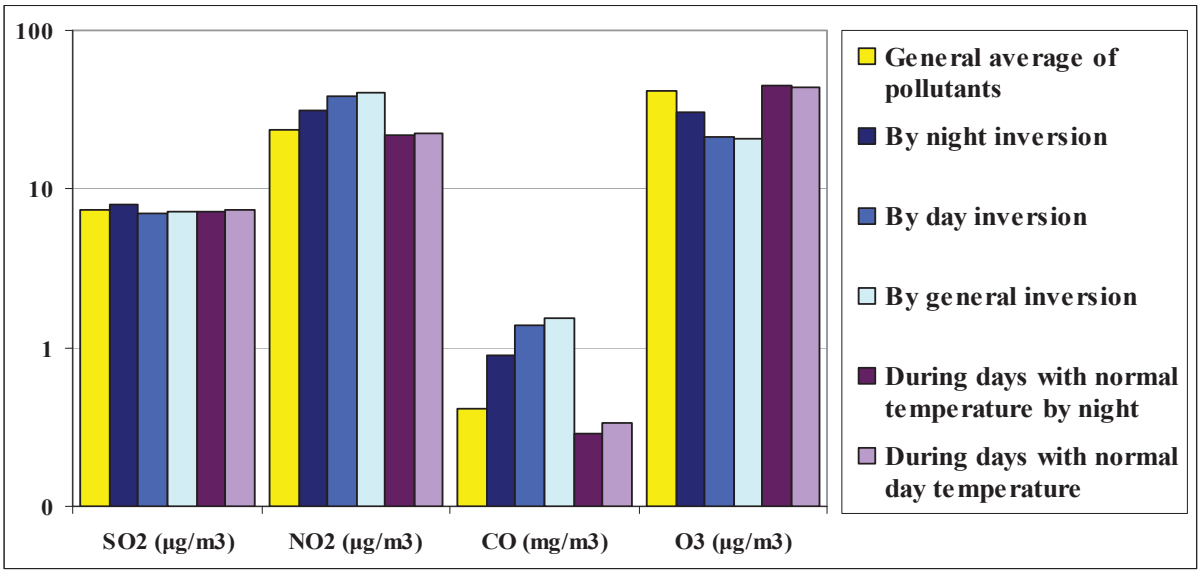

Fig. 3 Medium daily concentration of pollutants in various atmospheric conditions between 2008-2010 in Sibiu (logarithmic scale)

For a better description of the determined data, the author used a logarithmic scale because the average values of the carbon monoxide are lower than those of the ozone, and are presented in mg/m^3, that is a unit of measure that is different from the others ($\mu g/m^3$)

It was noticed that the influence of the temperature inversions has a different effect on every pollutant separately and that is justified by the big number of elements acting over the pollutants and also by their different properties. One must take into account that polluting activities are more numerous and more intense during daylight while the activities of transport and construction are significantly reduced at night; theoretically speaking, the concentration of pollutants is supposed to be increased in the case of day inversions, when the sources of pollution are numerous and the pollutants are captured within the inversion layer immediately after their emission. The biggest concentrations occur when the inversion layer persists day and night, especially during consecutive days with general inversions.

In case of two of the pollutants, the analysis can prove the clear influence that the temperature inversions have upon their concentration registered at the station. The general average value of the nitrogen dioxide is 23,57 μg/m^3; the values calculated for days with inversion are higher, compared with the general average, specifically 31,12 μg/m^3 for night inversions, 38,33 μg/m^3 for day inversions and 40,31 μg/m^3 for general inversions, and that represents an increase of 171% compared with the general average. By comparison, the values of nitrogen dioxide are slightly reduced compared with the general average during the days with normal temperature, when there are no inversions in Sibiu Depression. These values are: 21,75 μg/m^3 at night and 22,53 μg/m^3 during daylight, that is a diminution to 92%, respectively to 95% of the medium concentration of the pollutants.

The temperature inversions have more important influence over the concentration of the carbon monoxide, calculated as 0,41 mg/m^3 for the period 2008-2010. During the days with any type of temperature inversions, the concentration increases considerably: 0,90 mg/m^3 for night inversions, 1,38 mg/m^3 for day inversions and the maximum of 1,53 mg/m^3 for general inversions. Being referred to the average value of the concentration of carbon monoxide, the rise is extremely high: 219% for night inversions, 336% for day inversions and even 373% for general inversions, that is 3,7 times the average concentration. On the other hand, it is evident that carbon monoxide has a lower concentration during the days with normal temperature, 0,29 mg/m^3 at night and 0,34 mg/m^3 during daylight, that is 70%, respectively almost 83% of average concentration.

The concentrations of sulfur dioxide do not reveal the same tendency as the nitrogen dioxide or the carbon monoxide, but has different values, slightly dependent on the presence of the temperature inversions. The fluctuation of these concentrations depends on some other factors like good solubility in water, the reaction upon other chemical elements in the atmosphere and its own mass (it is heavier than air). The average concentration calculated for the period of time analysed is 7,38 μg/m^3; the highest concentration of the sulfur dioxide was registered during days with night inversions, 7,99 μg/m^3, that is a rise of only 108% compared with the average. A possible explanation could be the high level of moisture content, frequent with night inversions, that encourages the suspension of pollutants in the urban atmosphere because of its increased solubility in water. For the situations with day and general inversions, the concentration decreases under general average, to 7,08 μg/m^3 and 7,14 μg/m^3; that is almost 96% and 97% of average value. A little higher are the values calculated for the days with normal temperatures, 7,24 μg/m^3 at night and 7,40 μg/m^3 during daylight. These concentrations are generally approximated to multiannual average with no significant increase or decrease, as it happens with the carbon monoxide.

The concentration calculated for ozone shows that this pollutant does not accumulate in urban air, but it arises as a secondary result of some photo-chemical

reactions in certain conditions: the presence of nitrogen dioxide and volatile organic compounds in the atmosphere (Zagăr, 2011) and the action of solar ultraviolet radiations, partially absorbed, concomitantly with the distribution of thermal energy (Ciulache, 2004). According to average values of the cloudiness in Sibiu (Ciulache, 1997) and to the above factors, one could explain why the concentration of ozone is bigger in the days with normal temperature than in situations with inversions: if for getting ozone there must exist ultraviolet radiations, that is sun rays, then cloudiness should be extremely reduced. The lowest values of the cloudiness are recorded in Sibiu during summer and at the beginning of autumn when the temperature inversions have the lowest frequency. As a consequence, the ozone appears especially in hot season, during days with normal temperature, and has average concentrations of 44,58 μg/m^3 at night and 43,33 μg/m^3 during daylight, compared with the average value of 41,90 μg/m^3. Thus, in situations with temperature inversions more frequent in cold weather with high cloudiness, the ozone has lower values than the general average for the period of time that was studied: 30,48 μg/m^3 for night inversions, 21,07 μg/m^3 for day inversions and 20,57 μg/m^3 for general inversions.

Table 1. Maximum values of daily medium concentrations of pollutants in various atmospheric conditions between 2008-2010 in Sibiu

	SO_2 (μg/m^3)	**NO_2 (μg/m^3)**	**CO (mg/m^3)**	**O_3 (μg/m^3)**
Maximum values of pollutants	24,83	105,19	3,72	120,65
Pollutants in days with night inversions	18,29	87,93	2,00	92,96
Pollutants in days with day inversion	17,59	66,13	1,38	45,10
Pollutants in days with general inversion	14,71	105,19	3,72	64,67
Pollutants in days with normal temperature	24,83	94,42	2,24	120,65

The degree of influence of air pollution by the temperature inversions in Sibiu can be also estimated according to daily maximum values of the pollutants in various atmospheric conditions. The highest concentration during some general inversions was recorded for two out of the four pollutants.

The maximum value of the concentration of nitrogen dioxide, 105,19 μg/m^3 was measured on the 15th of January 2008 in conditions of general inversion. At 2,6 ºC, its intensity was weaker and invariable during the day but there must be taken into consideration the fact that the maximum value of the nitrogen dioxide was recorded after a series of 6 consecutive days with situation of general temperature inversion, with big intensity up to 9 ºC at night and 9,7 ºC during daylight. There also existed a situation of general inversion during 4 previous

consecutive days but of extremely high intensity, 11,2 ºC. All this determined a gradual accumulation of amounts of nitrogen dioxide in the urban atmosphere because the air stratification was stable for a longer period of time, at a very high pressure, up to 1038 hPa (referred to sea level) and low wind speed (in general 1-3 m/s). High values of the nitrogen dioxide were measured also in days with normal temperature, 94,42 μg/m^3 on the 22nd of February 2008, but this could be explained by the constant high level of the atmospheric pressure after the registration of the maximum value, so that the air stratification was still stable and the amounts of nitrogen dioxide and ozone maintained at a high level.

The biggest concentration of carbon monoxide was recorded on the 15th of January 2009, 3,72 mg/m^3, and the explanation for this phenomenon is similar to the previous one: the respective day was the end of a period of 7 consecutive days with general temperature inversion. During that day the intensity of the inversion was high at night (5,4 ºC) and medium during daylight (3,00 ºC), but previously the intensity was exceptionally high: 12,1 ºC on the 12th of January during daylight and 16,8 ºC on the night of the 13th of January. The daily minimum temperatures were very low for almost 3 previous weeks and during the same interval the atmospheric pressure was extremely high, of 1045 hPa, with wind speed of 1-3 m/s. During the 7 consecutive days with general temperature inversion, the concentration of the carbon monoxide increased almost gradually from 1,53 mg/m^3 to the maximum of 3,72 mg/m^3, while the pollutants were captured inside the inferior layer of an inversion of high intensity. Big amounts of carbon monoxide were stored in days with normal temperatures, but they were more reduced, of maximum 1,60 mg/m^3 on the 6th of December 2010. The atmospheric pressure reached quite normal values, about 1013 hPa, and there were also recorded isolated situations of temperature inversions the previous days, that permitted an insignificant accumulation of pollutants in urban air, that could not be quickly dispersed.

The maximum values of the sulfur dioxide and ozone were recorded in days with normal temperatures. The biggest concentration of sulfur dioxide, 24,83 μg/m^3, was measured on the 10th of April 2008, when the air stratification was normal at a slightly low atmospheric pressure of 1005 hPa (referred to sea level), a relative humidity of 65% and wind speed, weak to moderate, of 2-5 m/s. Taking into consideration the concentrations of the pollutant the previous days, and the proper atmospheric conditions, it is possible to report an additional, isolated emission of sulfur dioxide from a certain source, that led to a higher increase of the measured concentration. This increase started 2 days before the instability of air and the high wind speed did not allow the accumulation of a significant quantity of pollutant in urban atmosphere. Maximum concentrations of sulfur dioxide in days with temperature inversions are lower, no matter what type of inversion is present; causes are numerous and they must be correlated with physical and chemical properties of this pollutant.

The most significant concentration of ozone, 120,65 μg/m^3 was recorded on the 28th of April 2009, during a day with normal temperature. On that day, the

meteorological conditions were suitable for the formation of the ozone in urban air because the atmospheric pressure was normal, 1013 hPa, the relative humidity was low, 30% and there existed a minimum cloudiness that allowed the direct penetration of solar ultraviolet radiations up to the terrestrial surface. The amount of ozone in the atmosphere could have been bigger unless the wind speed had periodically registered significant increases of wind squalls up to 11 m/s, because the ozone maintained at a high level during the month of April. The concentrations measured during temperature inversions are much lower than the rest, less than a half of the absolute maximum value in day inversions (45,10 $\mu g/m^3$). During cold weather, when there is a maximum frequency of temperature inversions, the cloudiness increases to its highest values, so that the appearance of the ozone is significantly reduced because of the smaller amounts of ultraviolet radiations that reach the terrestrial surface.

4. Conclusions

The presence of temperature inversions, that is of a stable air stratification, does not have the same effects upon various pollutants. Their accumulation inside the inferior layer, that is urban air, depends on the characteristics of the pollutants and their conduct in natural free air, because there are stable pollutants that are hard to disperse by weak movements in the atmosphere and react slowly with the other air components; among these, the nitrogen dioxide and the carbon monoxide. But there also exist pollutants that once dispersed in the atmosphere, immediately tend to take part in chemical reactions, the sulfur dioxide, and pollutants that are the result of such reactions, the ozone. Anyway, there must be a closer control over all the pollutants that could persist, in a higher concentration, within the area of the city, and there must be an urgent warning of the citizens if there is an exceeding of the limit values that could affect human health. These values were established by the Law nr. 108 on the 15th of June 2011, referring to the quality of the environmental air, and the values related to the pollutants analysed in this paper are presented in the following chart:

Table 2. Reference values for pollutants analysed in Law nr 104/2011

REQUIREMENTS	MEDIATION	SO_2	NO_2	CO	O_3
LONG-TERM OBJECTIVES	8 HOURS	—	—	—	120 $\mu g/m^3$
LIMIT VALUE	HOURLY	350 $\mu g/m^3$	200 $\mu g/m^3$	—	—
	DAILY	125 $\mu g/m^3$	—	—	—
	ANNUAL	—	40 $\mu g/m^3$	—	—
	8 HOURS	—	—	10 mg/m^3	—
LEVEL OF INFORMATION	HOURLY	—	—	—	180 $\mu g/m^3$
LEVEL OF ALERT	HOURLY	500 $\mu g/m^3$ (3h cons.)	400 $\mu g/m^3$ (3h cons.)	—	240 $\mu g/m^3$

If we compare the daily medium concentrations measured with the maximum values accepted by law, the conclusion is that, fortunately, the city of Sibiu was not seriously affected by air pollution between 2008 - 2010. Even the long periods of temperature inversions did not aggravate the situation up to reaching dangerous concentrations, because neither the limit values, nor the level of alert were attained. But the relative short period of observation does not allow a general conclusion for a long period of time of the situation presented because extreme and rare cases of pollution were not subject of the analysis.

Unless new emission sources occur, the risk of pollution of the urban air is at a low level, although Sibiu is one of the most prosperous cities in Romania and has numerous perspectives of economic development. An important step to reduce the emission of pollutants was represented, both at national and european level, by establishing certain regulations, and at the local level, by placing filters inside the emission sources, by limiting road traffic in the center of the city and by opening in December 2010 the surrounding road to direct the traffic out of the city.

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