STUDIA UBB CHEMIA, LVIII, 4, 2013 (p. 253-264)
(RECOMMENDED CITATION)

Dedicated to Professor Liviu Literat
On the occasion of his 85th birthday

CONCENTRATION OF PARTICULATE MATTER ASSOCIATED TO A CROSSROAD TRAFFIC FROM CLUJ-NAPOCA CITY

NICOLETA BICAN-BRIȘAN[a, *], TEODORA ENACHE[a], CRISTINA ROȘU[a]

ABSTRACT. Large cities crossroads are areas with high pollution level generated by heavy traffic, especially during rush hours. Furthermore, pollution level is increased by heavy traffic through excessive releases of toxic gases and particulate matter. In order to highlight the quality of urban atmosphere in the area of major crossroads from Cluj-Napoca City, particulate matter concentration was monitored in an important crossroad from the southern part of the city, using a direct-reading instrument, the DustTrak Aerosol Monitor, model 8520. The obtained data include the concentration levels of the particulate matter with a diameter ranging between 0.1 and 10 μm. The results were discussed in relation to the crossroad traffic, thus highlighting the influence of heavy traffic on the particulate matter pollution level. The analysis of medium values showed the poor correlation with meteorological parameters (temperature, relative humidity, wind speed) during the measurement interval.

Key words: *particulate matter, PM_{10}, $PM_{2.5}$, PM_1, urban air quality, crossroad*

INTRODUCTION

Airborne particulate matter (PM) or *aerosol*, is a complex mixture of solid and liquid particles of organic or inorganic origin suspended in the air, whose effective diameter is larger than that of a molecule, but smaller than 100 μm [1]. These result from both natural and anthropogenic processes, while the main sources are mineral dust, emissions from energy generation, transport and marine aerosols.

The various adverse effects associated to these particles have already been researched [2]. Moreover, numerous studies conducted in this field have revealed essential cause-and-effect relationships between PM and

[a] *Babeș-Bolyai University Cluj-Napoca, Faculty of Environmental Science and Engineering, Cluj-Napoca, 30 Fântânele, RO-400294 * nicoleta.brisan@ubbcluj.ro*

an increase in the death rate [3, 4, 5]. Certain connections between fine PM and a series of health problems, such as asthma, bronchitis, and other respiratory symptoms, both acute and chronic were demonstrated [6].

The size of the PM, their concentration and chemical composition have the most significant influence on their behavior in the atmosphere, as well as on their impact on the respiratory tract [7]. Hence, the smaller dimensions of the PM are the bigger impact on human health [8, 9].

Concerning its impact both on the health and the environment (acid rains, fog and dry deposition, impact on Earth's radiative balance and subsequently on climate changes), the airborne PM pollution of the atmosphere represents one of the current global problems [10, 11, 12].

The analysis of the PM concentration evolution in a highly urban environment is a key activity in air quality assessment and an effective means to facilitate the monitoring and regulation of PM limit values in ambient air, in order to reduce the risk of respiratory illnesses.

Considering the gravity of the respiratory tract [13, 14, 9, 15] and cardiovascular system [16, 17] affections and depending on the dimension of the inhalable PM (PM_{10}, $PM_{2.5}$, PM_1), regulations limiting the emissions of PM were globally imposed.

Beginning with 1971, when the US Environmental Protection Agency (US-EPA) developed the first legislative regulations for PM, the established limits were subjected to countless modifications through time, depending on the outcomes achieved after the measurements (www.who.int*;* www.epa.gov*;* www.ec.europa.eu). Some specific regulations set by the World Health Organization (WHO) experts during the 2005 meeting in Bonn, included stricter standards for PM (the medium value of $PM_{2,5}$ within one year must not exceed 10 μg/m^3 and 25 μg/m^3 along 24 hours). In 2006, US-EPA included PM on the list of major pollutants, along with CO, Pb, NO_2, SO_2 and O_3. According to the international air quality standards, the average level over three consecutive years must not exceed 15 μg/m^3 and the 24-hour mean is 35 μg/m^3. In the European Union (EU), the Directive 2008/50/CE includes the latest amendments regarding the fine PM. This was transposed to the Romanian legislation through the law 104/2011, as the mean value of $PM_{2.5}$ in one year was established at de 25 μg/m^3. Concerning the 24-hour concentration level, in 2004, during the Clear Air for Europe program, a limit of 35 μg/m^3 was proposed but this was not approved by the legislation. In terms of PM_{10}, the daily limit value is 50 μg/m^3 which cannot be exceeded for more than 35 days within one year and the annual limit is 40 μg/m^3.

The high amount of PM is an important problem that creates discomfort for the inhabitants in Cluj-Napoca City. Previous studies developed in different locations of the city represented by playgrounds, crossroads [18] and courtyards of buildings in different neighborhoods [19] have revealed high concentrations of atmospheric PM. Heavy traffic, activities in constructions and industry are supposed to be the main sources of PM_{10} and $PM_{2.5}$.

RESULTS AND DISCUSSIONS

The influence of traffic on PM during the working days

Road transport is an essential factor in the urban areas and it represents one of the major sources of PM [23, 24].

PM emission is a particularity of the diesel engine, as compared to the gasoline engine. Depending on the combustion process and the engine's operating mode, emissions largely contain carbon particles, such as aerosols or sulfites. In this case, PM emissions include the fuel and engine oil related to exhaust gases, particles resulted from friction processes associated with tire deterioration or traces of brake, as well as the dusting generated by vehicles movement, especially the large size vehicles.

The relation between the PM concentration and the number of vehicles which have passed through the crossroads during the measurement period is graphically presented in Figure 1.

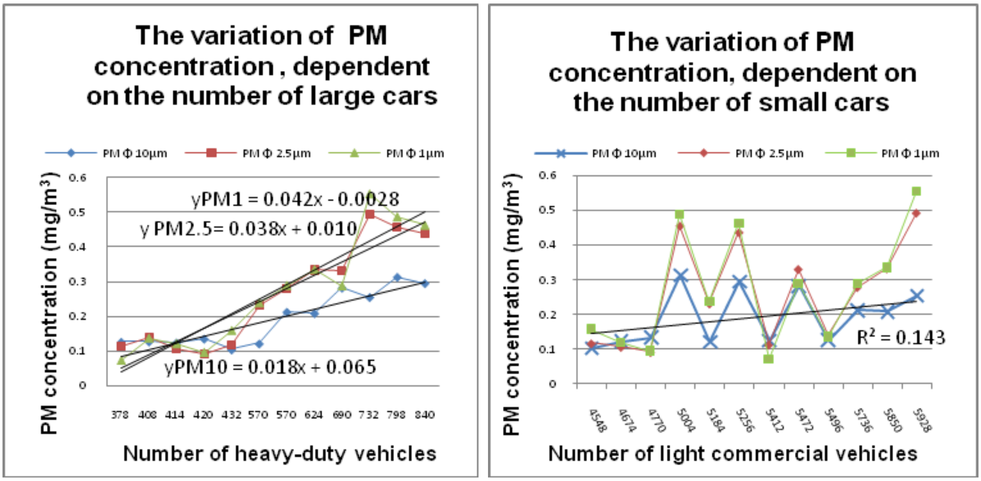


Figure 1. The variation of PM concentrations in relation to traffic

In the case of heavy-duty vehicles, a strong correlation is observed between the two types of values, for all PM sizes, especially for small diameter ones (PM_1 and $PM_{2.5}$). This fact is normal, because the fine PMs are the direct product of engine combustion, especially for the vehicles using Diesel fuel. The coarse particulate matter (PM_{10}) do not show such a spectacular increase related to the number of vehicles, therefore the increasing slope is much smaller (18% as compared to fine PM, whose increasing slope is 38% and 42%). This is explained by the rotation movement of the tires on the road, but also by the pressure of the exhaust gases, as they stimulate the nearby dust particles, although the lack of intense air-mass movement results in phenomenon decrease.

The analysis of the graph illustrating the relation between the number of light commercial vehicles and the PM concentration revealed a poor connection (R^2=0,143), especially in the median zone of the values. This can indicate the relative upgrade of these types of vehicles with non-pollutant equipment. However, in the case of extreme values of vehicles passing through the crossroad (4548 and 5928 vehicles), large variations of all PM types concentration were noticed, especially the fine ones. This can be explained by the passing of heavy-duty vehicles through the study area.

For a better understanding of the PM concentrations variation, Figure 2 includes the graphs illustrating the ratio between fine and coarse PM.

One can notice that this dependence is remarkable in terms of the heavy-duty cars, as it presents 8% slopes in the case of PM_1 and 7% slopes in the case of $PM_{2.5}$.

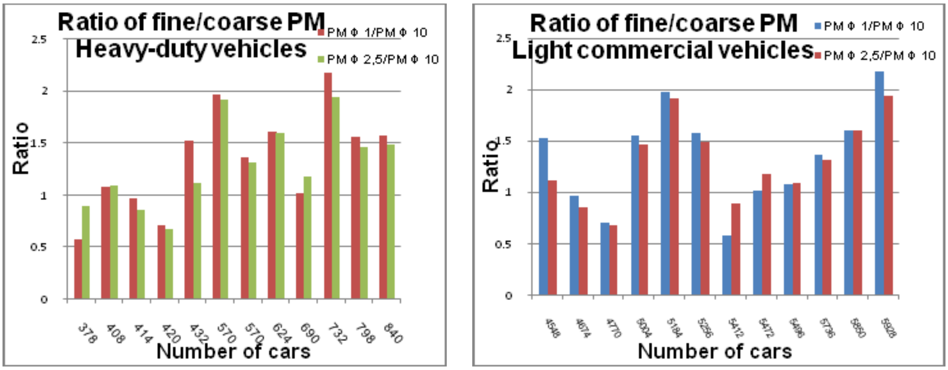


Figure 2. The ratio of fine/coarse PM concentrations in relation to vehicles types

One can state that a direct proportional connection has been emphasized between the number of heavy-duty vehicles and the PM concentrations of all types, as well as a poorer dependence between the two values, in the case of light commercial vehicles, which are less polluting. This difference can be accounted for by the fact that, according to literature data, the medium level of pollution caused by a heavy-duty vehicle is 20 times higher than that caused by light vehicles and, as a result, the immediate effect is much more visible and easier to record, in the case of heavy-duty vehicles.

The influence of weather conditions on the PM concentrations

Studies have revealed that the level of PM concentrations was not exclusively influenced by the local transport emissions, but by a function of the weather conditions [25, 26].

Hereinafter, the influence of each meteorological parameter on the PM_{10}, $PM_{2.5}$ and PM_1 values is presented in order to get a full comprehension of the way these exert a greater influence on the pollution level, as well as a relation (direct, inverted or indifferent) between them.

a. The influence of the ambient temperature on PM emissions during the working days

As the air temperature variations during the days of measurement were very small, the differences in the contaminant values, caused by this parameter are not likely to be significant. Generally, the instability and the thermo inversion are factors strongly influencing the PM concentration variations in the atmosphere. These phenomena did not occur during the days of measurement.

The difference between the temperature of pollutants emitted by polluting sources and the temperature of the ambient atmosphere influences the diffusion. In this case, the temperature of the pollutant, when emitted, is often similar to the temperature of exhaust systems, while the ambient temperature is low, close to 0ºC. Therefore, insignificant variations of PM concentrations are expected to occur, depending on the ambient temperature.

The graphic representations and the associated analysis were conducted separately for the heavy-duty vehicles (high level of polluting) and for the much more eco-friendly light vehicles.

The analysis of the graphs in Figure 3 indicates a decrease of PM values along with the increase of temperature: the evolution curves of the trend lines are small and almost equal (1.73%, respectively 1.81%), and the R^2 indicator shows a poor dependence between the two parameters in the given conditions.

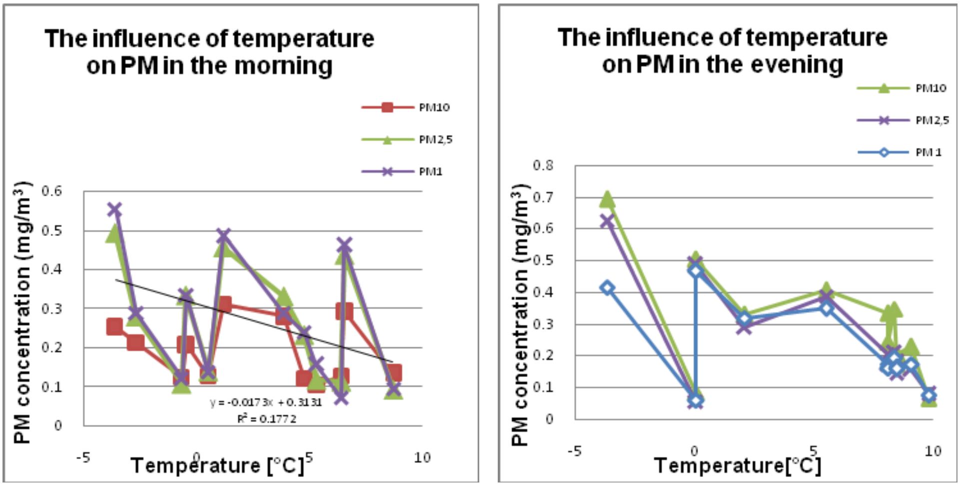


Figure 3. The variation of PM concentration in relation to temperature

It is important to observe the fact that the average morning and evening temperatures are different, but low (2.5°C in the morning, respectively 5.38°C in the evening). Negative values were recorded in 33.3% of the cases in the morning, respectively in 8% of the cases (once) in the evening. The difference between the temperature of the air and that of the pollutant, when emitted (i.e. the temperature of exhaust gases) influences the dispersion of gases. As this difference is significant, the ascensional speed of the pollutant will increase.

b. The influence of wind speed on the PM emissions during the working days

The graphs in Figure 4 represent the variations of different PM concentrations, in order to observe whether the PM concentrations show determinable variations for small values of this parameter.

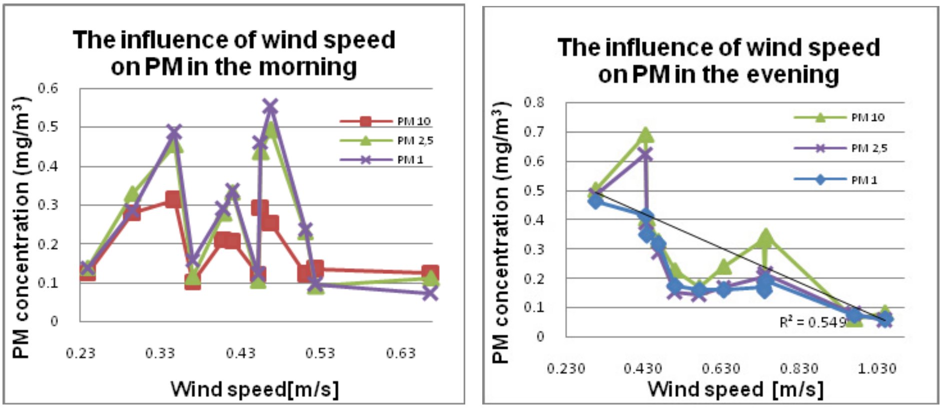


Figure 4. The variation of PM concentration in relation to wind speed

Generally, great wind speeds can have strong effects on the PM concentrations, due to dispersion and dilution phenomena. As this parameter had relatively small values in the field measurements, a very clear correlation between the two types of values has not been noticed.

Therefore, the expression PM=f(ws) shows no correlation between the parameters (wind speed and PM).

The graphs in Figure 5 indicate a different evolution of PM concentrations, depending on the variations of air-mass speed, as follows: in the morning, the variation of PM concentrations shows no definitive trend, because of the very low wind speed. However, during the measuring interval, when the wind speed exceeds 0.5 m/s, the fine PM concentrations decrease to the minimum value corresponding to the measuring periods: $PM_{2.5}$=0.092 mg/m^3, respectively PM_1=0.073 mg/m^3, due to the dilution process. In the evening, when the measured values are higher, a clear decrease tendency of fine PM concentration can be noticed, along with the increase of wind speed (R^2=0.76 for PM_1, respectively R^2= 0.58 for $PM_{2.5}$). This does not apply to PM_{10}, because, in this case, the concentration increases (PM_{10}=0.333 mg/m^3), as the air-mass velocity intensifies to the value of 0.737 m/s.

c. The influence of humidity on the PM emission during the working days

The influence of relative humidity on PM concentrations in Figure 5 is unclear. Therefore, can be notice that is not correlation between humidity and PM values.

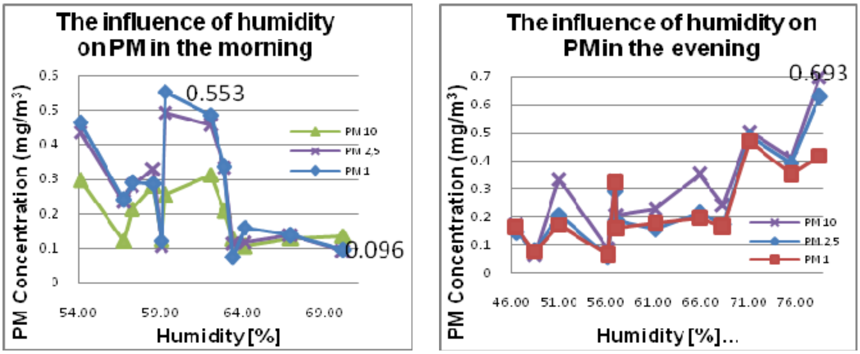
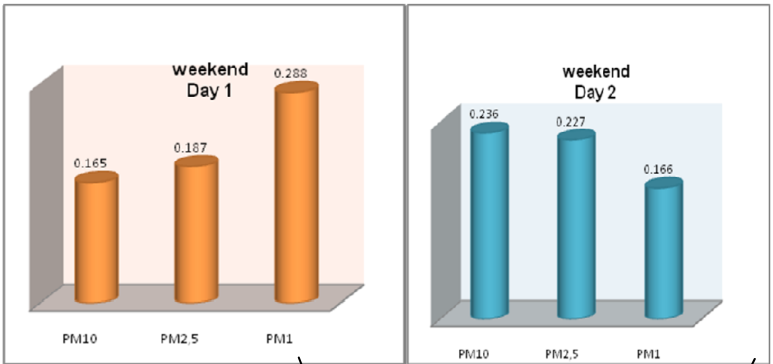


Figure 5. The variation of PM concentration in relation to relative humidity

The comparison between working days data and weekend days data

The objective of analyzing these measurements is to present a comparative study to reveal the similarities and differences in PM concentrations during the weekend days, in relation to the working days. Hence, the authors explain the reduced number of days when measurements were conducted (only two Saturdays), but also the different time schedule (during the 16^{10} - 17^{40} interval).



	Day 1	Day 2
Avg. temperature	2.13 [°C]	-0.81 [°C]
Relative humidity	55.51%	70.72%
Wind speed	0.588 m/s	0.510 m/s
Nr heavy-duty vehicles	138	108
Nr light vehicles	3696	3324

Figure 6. The PM values, weather conditions and traffic during the weekends

The measurements conducted during the weekends illustrate PM values when the traffic, in general, and the public transport traffic, in particular, are significantly reduced (an average of 123 heavy-duty vehicles during the weekends, counted in 90 minutes, representing 21.46% of the working days traffic). Moreover, the number of small cars which have passed through the crossroads was 29.7% smaller than recorded during the working days (3760 as compared to 5277 cars counted daily, in a 90-minutes interval).

The graphs indicate that the average PM value measured during the weekend is 2 or even 3 times smaller than the average PM values measured during the working days. This can be explained by the traffic reduction at the crossroads and also by the cease of several polluting activities in the proximity of the study area (industrial activities, construction works), during the above-mentioned period.

The objective of the two representations is to emphasize the differences that may occur during the low traffic days, but in non-identical meteorological conditions. Still, the number of measurements conducted during the non-working days is very small and therefore it is difficult to draw global conclusions.

CONCLUSIONS

The measurements highlighted the fact that the influence of traffic is important in relation to the PM concentrations, in the case of PM_{10}, but also for PM_1 and $PM_{2.5}$. Values of PM_{10} (coarse particulates) concentrations were noticed to be 23.32% higher in the evening, as compared to those recorded in the morning, due to continuous dusting, but also to the ongoing pollutant activities (industrial activities, construction works etc.).

In the medium and long term, it is extremely important to continue the research on various diameters PM concentrations in the crowded crossroads of the Cluj-Napoca city, in order to observe the efficiency of the measures imposed by governmental policies concerning environmental protection, such as:

a. The stimulation of Romanian vehicle fleet replacement, by means of the RABLA program, but also by the acquisition of new non-polluting motor haulage vehicles.

b. The construction of belt highways for the large cities, in order to reduce the traffic and the residence times or extremely low speed traffic times, which induce strong polluting effects.

c. The use of alternative, less polluting runways, like railways existing in the area.

d. The promotion of the use of non-pollutant fuel motor vehicles equipped with efficient filters, type Euro 4, Euro 5, Euro 6.

e. The systematic washing of the road, in order to eliminate the dusting through the action of tires, corroborated by high wind speeds.

f. The implementation of more severe motor check-ups, along with the increase of fines and sanctions, concerning pollutants emissions, which can be accomplished by setting up mobile measurement laboratories.

g. The location of tire washing areas, to be used for the motor vehicles passing through back roads or fields, construction areas, in order to remove the most part of the different origin and size dust.

h. The start-up of intensive planting programs to green spaces or reforestation establishments, in order to protect and purify the environment.

i. The removal, to the possible extent, of the heavily polluting factories from the intensely inhabited areas, but also the relocation of some activities during the nighttime, in order to enable environmental self-purification.

In order to prevent environmental destruction, the environmental awareness of large cities inhabitants should be increasingly built, using all the necessary methods (school education, mass-media) to induce an adequate civil behavior and attitude, meant to sustain clean environment, healthy ecosystems and purified air to ensure human and environmental health.

EXPERIMENTAL SECTION

The study area is located in the proximity of the Calea Turzii and Observatorului crossroads roundabout, with the coordinates 46.75549º N and 23.596289º E and an average altitude of 360 m. This intersection belongs to the marginal area of the Zorilor neighborhood, also associated to the Observator area and located in the southern part of Cluj-Napoca City.

The measurement points selection criteria concern the architecture and morphology of the study area, as the main buildings located in this intersection are tall blocks of flats in the West, the Sigma Shopping Mall, along with the adjacent parking lot and the UTC-N Laboratories in the North, and house ensembles in the East and North-East, whereas the southern part is prevailed by the wide Calea Turzii. Therefore, this area is not located inside an enclosed neighborhood, in terms of circulation of the air-masses, as the small houses and the parking lots enable a loose circulation of the air. The velocity of the air streams is significantly reduced and these are even diverted in the western part and, partially, the northern part, due to the presence of tall and imposing buildings.

In order to highlight the range of PM concentration, the measurements were performed at 60 cm above the road surface after a well established schedule, as follows.

The measurements were conducted on a weekly basis during the 24th October 2011 – 20th November 2011 period. Throughout this period, the authors have chosen the Mondays, Wednesdays and Fridays together with two Saturdays for a good comparison between working days data and weekends data. During the working days, three 30 minutes measurements per day were performed, for each size category (PM_1, $PM_{2.5}$ and PM_{10}), during the 7^{40}- 9^{10} time interval in the morning, and 19^{00} - 20^{30} in the evening. In order to compare the working days and weekend values, the measurement were also performed during the weekends, but only in the 16^{10}- 17^{40} time interval in the afternoon. Thus, PM_1, $PM_{2.5}$ and PM_{10}, averages were obtained.

As the concentration level of PM generally depends on the atmosphere conditions and meteorological parameters [10, 20, 21], measurements of air temperature, relative humidity and wind speed were also performed. The vehicles passing through the roundabout were counted throughout the time of performing the measurements. These vehicles were classified in two types: light commercial vehicles and heavy-duty vehicles, last including buses and mini-buses).

The concentration of PM of different sizes (PM_1, $PM_{2.5}$ and PM_{10}) was monitored with a direct-reading aerosol monitor - TSI's DustTrak Aerosol Monitor (Model 8520). The real-time measurements in milligrams per cubic meter (mg/m^3) conducted by means of a laser photometer based on a 90° light scattering sensor type. They operate by illuminating a PM as it passes through an optic chamber (sensing volume) and by measuring the light scattered by all the particles at a given scattering angle relative to the incident beam. As the number of PM increases, the light reaching the detector increases. Moreover, the PMs are isolated in the chamber by a sheath air system in order to keep the optics clean and improve the reliability [22].

The data obtained by the DustTrak Aerosol Monitor was also analyzed by the *TRAKPRO™ Data Analysis Software* that generates time dependent PM concentration graphs and multiple reports of the measurements results.

The meteorological parameters were determined using the Testo 608-H1 Termohygrometer for temperature and humidity and AIRFLOW™ Model TA430 Thermal Anemometer for wind speed.

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