The impact of smog on the concentration of particulate matter in the antelope house in the Silesian zoological garden

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Persistent negligence in the field of environmental protection in Poland as well as strong dependance of the energy sector on the fossil fuels have led to serious pollution of the air with particulate matter, which at high concentrations is capable of penetrating into the buildings. The aim of this paper is to assess the impact of particulate airborne pollution on the concentration of particulate matter inside the antelope house in the Silesian Zoological Garden located within the Upper Silesia in Poland. The research was conducted from February to May in 2018. The records taken in the research period show that the concentration of PM10 exceeded the level of 50 µg/m3 outside the building during 26 days and 11 days when it comes to the concentration of particulate matter inside the antelope house. The quantity of particulate matter in the antelope house is strongly correlated with the concentration of the particles in the air. Despite fitting existing ventilation system with a filter that reduces the dust level by 60% during the highest level of smog, particulate matter concentration in the antelope house exceeded acceptable limit for PM10 more than twofold. Particle size-fraction analysis revealed that as much as 85% of the particles detected in the studied compartment constitute PM2.5.

The Impact of Smog on the Concentration of Particulate Matter in the Antelope House in the Silesian Zoological Garden

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Abstract

Persistent negligence in the field of environmental protection in Poland as well as strong dependance of the energy sector on the fossil fuels have led to serious pollution of the air with particulate matter, which at high concentrations is capable of penetrating into the buildings. The aim of this paper is to assess the impact of particulate airborne pollution on the concentration of particulate matter inside the antelope house in the Silesian Zoological Garden located within the Upper Silesia in Poland. The research was conducted from February to May in 2018. The records taken in the research period show that the concentration of PM10 exceeded the level of 50 $\mu g/m^3$ outside the building during 26 days and 11 days when it comes to the concentration of particulate matter inside the antelope house. The quantity of particulate matter in the antelope house is strongly correlated with the concentration of the particles in the air. Despite fitting existing ventilation system with a filter that reduces the dust level by 60% during the highest level of smog, particulate matter concentration in the antelope house exceeded acceptable limit for PM10 more than twofold. Particle size-fraction analysis revealed that as much as 85% of the particles detected in the studied compartment constitute PM2.5.

Introduction

32 Sulfurous smog, also called London smog, is produced in humid air that is strongly polluted with
33 acidic gases, mainly with sulfur dioxide (SO_2), carbon dioxide (CO_2), nitric oxide (NO) and
34 particulate matter (Polivka 2018; Poulopoulos SG. 2016). Particles with the diameter exceeding
35 2.5 μm that are present in smog are generated as a result of mechanical actions, such as grinding
36 or crushing various types of materials (WHO, 2006). These materials either occur naturally –
37 mineral dust, sea salt, or represent anthropogenic substances – produced as a consequence of tire
38 and brake abrasion. Fine particulate matter particles, with the diameter below 2.5 μm, is formed
39 mainly through the burning of fossil fuels in the utilities sector (Seinfeld & Pandis, 2006).
40 Particles present in smog contain metal oxides, acidic condensates, heavy and transition metals
41 (Wróbel et al. 2000), sulfates and nitrates, as well as elemental and organic carbon (Routledge &
42 Ayres 2005).

43 Health and the quality of life, both human and animal, is tightly connected with the condition of
44 the environment. It is assumed that airborne particulate pollution constitutes one of ten most
45 significant threats to global health (Lim et al. 2012). The research into the impact of smog on
46 living organisms revealed that particle pollutants increase the risk of developing asthma and
47 allergy (Chen et al. 2018), cause arrhythmia (Hazari et al. 2009), lung cancer (Pope et al. 2002),
48 chronic obstructive lung disease (Zanobetti et al. 2008), bronchitis (King et al. 2018), as well as
49 decrease fertility (Selevan et al. 2000, Yi et al. 2017) and constitute a risk factor for abnormal
50 fetal development (Perera et al., 2002).

51 Prolonged ignorance as to the environmental conservation in Poland as well as heavy reliance of
52 the energy industry on fossil fuels resulted in substantial increase in the particulate air pollution
53 (www.gios.gov.pl; Tainio et al., 2013) This problem is especially serious in the Upper Silesian
54 Agglomeration where acceptable 24-hour PM10 concentration is exceeded 67 to 102 days per
55 one year (Raport 2018).

56 The research conducted by Massey et al. (2009) and Chen et al. (2016) demonstrated that when
57 air pollution is heavy particles are capable of migrating into the buildings. This problem
58 becomes even more serious in the case of facilities intended for animals where particles penetrate
59 as a result of permeability of the construction as well as through supply ventilation, which
60 constitutes a regular and indispensable element of proper equipment in animal facilities. During
61 winter, when the incidence of smog greatly increases, flow rate for the air exchanged by one

62   animal may amount to as much as 100 m^3/h (Magrin et al. 2017). The problem of excessive

63   particulate pollution concerns not only livestock but also zoo animals and it worsens in autumn

64   and winter months as animals from tropical and subtropical climates spend most of that time

65   inside buildings. Well-being of these animals depends heavily on microclimate inside buildings

66   where they stay (Veasey 2017). By disturbing reproductive system airborne particle pollutants

67   can decease the number of healthy offspring (Selevan et al. 2000; Perera et al., 2002), and as a

68   consequence severely hamper or even prevent the process of saving threatened species – one of

69   the main tasks undertaken by zoological gardens.

70   Available literature does not contain papers dealing with the influence of smog on the

71   microclimate of buildings intended for animals, especially when it comes to zoological gardens.

72   Existing research focuses on the impact of the particles generated as a result of animal

73   production on employees handling animals or involved in degradation of the external

74   environment (Mołocznik 2004; Hulin et al. 2015).

75   As far as the impact of particulate matter on animals kept in the zoos is concerned, careful

76   attention should be focused on antelopes as their high oxygen efficiency and lung capacity make

77   them especially vulnerable to particulate pollution (Hinchcliff et al. 2008; Stafford &Stafford

78   1993).

79   This paper is concerned with assessing the impact of particulate air pollution on the

80   concentration of PM10 and PM2.5 in the antelope house located in the Silesian Zoological

81   Garden in Chorzów.

Materials & Methods

83   The research was conducted during the coldest period in 2018, that is between 27.02.2018 and

84   16.05.2018 (79 days) in the building housing antelopes located in the Silesian Zoological Garden

85   in Chorzów (Fig. 1). The Zoological Garden is located on the border of Chorzów (108 thousand

86   citizens) and Katowice (302 thousand citizens). This object constitutes a part of the Silesian

87   Park. It is surrounded with forest complexes from the north and east. According to the records

88   taken between 2014 and 2017 by the monitoring station of the Voivodship Inspectorate of

89   Environmental Protection, located 2400 m away from the Zoological Garden, there were 290

90   days when the limit value for PM10 was exceeded (Raport 2018).

91   Field experiments were approved by Silesian Zoological Garden in Chorzów (agreement number

92   C/21/2013/WHiBZ). During taking measurements the building was occupied by 19 antelopes:

93   Defassa waterbucks *(Kobus ellipsiprymnus)* – 7 pieces weighing between 112 and 142 kg,

94   addaxes (*Addax nasomaculatus*) – 5 pieces with the weight ranging from 85 to 118 kg and

95   lowland nyalas *(Tragelaphus angasii)* – 7 pieces weighing 65 to 120 kg. Throughout the entire

96   experimental period the animals stayed indoors, inside the boxes, with the possibility to move to

97   the adjacent box only. Cleaning and litter replacement occurred once daily in the morning

98   between 7:00 and 9:00.

99   Cubic volume of that building amounts to 3626 m^3, maximum height to 5,2 m and minimum

100   height to 3,7 m. Total floor space of boxes amounts to 319 m^2 (floor space of a single box for

101   boxes no. 1-7 amounted to 11,5 m2, while for boxes no. 8-20 to 25m^2; Fig.2, Fig. 3). Animal

102   boxes are provided with rubber flooring covered with long wheat straw with approximately 8%

103   moisture content. The floor in the areas used by the visitors and passageways is covered with

104   industrial flooring. The building is equipped with a mechanical supply-exhaust ventilation

105   system, type Golem 4 with the capacity of 10 000 m^3 per hour with class F6 filters. Specific fan

106   power of supply air fans amounted to 1,33 kW/m3/s, while SFP for exhaust air fans to 1,02

107   kW/m3/s. Air flow rate in the supply air ducts reached 2,46 m/s, while in the exhaust air ducts

108   1,94 m/s. Air circulation in the studied building was assessed based on air flow measurements

109   taken using a device Testo 425 (Testo Polska; resolution 0,01 m/s, accuracy 0,03 m/s).

110   Existing ventilation system provides only preliminary air filtration through a pocket filter (G4

111   592x592x360mm 6k/metal), that filtrates the fractions with the size exceeding 10 um with 70%

112   efficiency. Therefore, 30% of the particulate matter sized 10 um migrates inside the building and

113   the fractions with smaller diameter are filtrated to a lesser degree (negligible scope). The

114   ventilation operates 24/7. The ventilation system was not cleaned during taking measurements.

115   The ventilation is cleaned twice yearly in the first week of February and July.

116   The study covered the following measurements: air temperature, relative air humidity, air

117   pressure as well as the concentration of PM10 and PM2.5. The measurements were taken using

118   two university measuring stations (UMS, serial no. U32 and U33, Poland) developed within the

119   framework of the Storm&DustNet project implemented at the Jagiellonian University in Krakow.

120   One measuring instrument was installed inside the studied building 2 m above the flooring, while

121   the second was fitted outside 2 m above the ground at the distance of 30 m from the studied

122   facility (Fig 1, Fig. 2.). The device is fitted with a laser detector SEN0177 (DFRobot, China)

123   that enables measuring the concentration of PM10 and PM2.5 in the air. The measurements of

124   particle concentration and other parameters are taken continuously and the records of average

125   values are compiled every minute. The accuracy of the particulate matter detector was verified

126   by comparing data recorded during previous test measurements with the readings obtained from

127   the reference station EDM107 belonging to GRIM company (Grimm & Eatough 2009). The

128   measurement error for EDM107 station amounts to ±2 µg/m3. This device has obtained a

129   certificate of calibration and equivalency to a gravimetric method (Grimm & Eatough 2009).

130   Comparative measurements included natural ambient air and various particulate matter

131   concentrations. The comparison revealed that measurements for PM2.5 and PM10 in UMS

132   stations are encumbered with an error that does not exceed ±9 µg/m3. Measurements of the air

133   temperature, humidity and pressure were taken using a BME detector fitted into the UMS station

134   (temperature – measuring range from -40 to +85 °C, accuracy: ±1 °C; humidity – measuring

135   range from 10 to 80 % RH; accuracy: ±3 % RH; air pressure – measuring range from 300 to

136   1100 hPa, accuracy: ±1 hPa).

137   UMS stations measure PM concentrations and other parameters several dozen times per minute.

138   Then the average minute values are computed. Later minute values are sent to the server and

139   saved to a database. In the subsequent analyses average minute values are the basis for

140   calculating average hourly and daily values.

141

142   Statistical analyses

143   Statistical analyses were performed using OriginPro 2016 software (OriginLab

144   Corporation, Northampton, MA, USA). Normality distribution for variables was tested using the

145   Shapiro-Wilk test. Due to the fact that obtained measurement results have no normal distribution,

146   they were analyzed employing Spearman's rank correlation coefficient (RS) with determining

147   significance level (p-value). A 2-tailed test of significance was used in all studied cases.

148   **Results**

149   Air flow rate measured in the antelope house during the experiment ranged between 0,14 m/s and
150   0,18 m/s.

151   Daily average concentrations for PM10 and PM2.5 were determined based on particulate matter
152   measurements. Distribution of these PM levels is shown in Fig. 4 and Fig. 5, respectively.

153   The measurements indicated that daily average concentration of 50 $\mu g/m^3$ outside the building
154   within the studied period was exceeded during 26 days.

155   The highest daily average concentration for PM10 in the air was recorded on 6th March 2018
156   (273 $\mu g/m^3$).

157   Measurements taken inside the building indicted that in the studied period there were 11 days
158   when the level of 50 $\mu g/m^3$ was exceeded. The highest indoor daily average for PM10 was also
159   recorded on 6th March and it amounted to 118 $\mu g/m^3$. The concentration for PM10 outside the
160   building was almost always higher than the one recorded indoors. We documented only two
161   instances (19th April and 7th May) when the quantity of particulate matter inside the antelope
162   house was higher by 1$\mu g/m^3$ than outside. However, it must be pointed out that these differences
163   are significantly lower that the measurement error. Spearman's correlation coefficient (RS)
164   computed for the entire study period indicated a strong correlation (p-value<0.01) between the
165   concentration of PM10 inside and outside the building (RS=+0,91).

166   The distribution of daily average concentrations for PM2.5 for the studied period is shown in
167   Fig. 3. According the measurements, in the studied period there where 35 days when the level of
168   particulate matter outside the building exceeded 25 $\mu g/m^3$ and 24 days when it comes to records
169   taken indoors. The highest daily average concentration for PM2.5 was reached on 6th March
170   (245 $\mu g/m^3$ outside the building and 100 $\mu g/m^3$ indoors). The concentration of PM2.5 inside the
171   building has never exceeded the level recorded in the ambient air. Statistical analysis (RS=+0.93)
172   revealed a strong correlation (p-value<0.01) between the concentration of PM2.5 in the
173   atmospheric air and inside the antelope house.

174   Statistical analysis showed a strong correlation between the concentration of PM10 and PM2.5
175   both inside and outside the building.

176   Spearman's correlation coefficient (RS) between PM10 and PM2.5 outside and inside are large
177   and indicate full dependence.

178   Calculation of the ratio for PM2.5 to PM10 concentration inside and outside the antelope house
179   resulted in obtaining very similar values (0.84 and 0.85, respectively).

180   Daily reduction factor (RF) for the entire research period for PM10 was calculated according to
181   Eq. 1, and the distribution in time for this factor is shown in Fig.6.

182    $RF = \dfrac{PM_{outdoor} - PM_{indoor}}{PM_{outdoor}} \times 100$ Eq. 1

183

184   The calculations revealed that high value for reduction factor (RF) occurred between 1st and
185   10th as well as between 13th and 19th March and ranged between 50% and 65%, while on 26st
186   April it reached 86%.

187   Figures 7 and 8 illustrate average daily distribution of hourly values for PM10. In the case of
188   Figure 7 the analysis was conducted for the period with high PM content in the atmospheric air
189   (27.02.2018 – 03.04.2018). The Figure 8 refers to the period when the level of particulate matter
190   in the air was low (04.04.2018 – 16.05.2018).

191   It has been observed that both in the case of high (Fig. 7) and low (Fig. 8) PM content in the
192   atmospheric air, the concentration of particulate matter inside and outside the building followed
193   the same pattern. The only differences were recorded between 7:00 and 9:00.

194   Analysis of the high frequency data – 1 min (Fig. 9) revealed that the change in the PM
195   concentration outside the building resulted in the shift in PM concentration indoors that was
196   delayed only by 14 min. This delay was identified during establishing the maximum Spearman's
197   correlation coefficient as a function of time shift between PM10 distribution measured indoors
198   and outdoors. There is no doubt that it was caused by a mechanical air supply system that
199   operates round-the-clock. As shown in Fig. 9, the distribution of PM concentration outdoors (red
200   line) is irregular and changeable, while the one for indoor PM concentration (black line) is more
201   regular. Irregular distribution of PM outdoors is connected with the changes in air direction and
202   flow rate (wind).

203   Daily average temperature outside the building ranged from -5^0C to 27^0C, while the temperature
204   inside the antelope house was in the range of 17^0C to 27^0C. The distribution of daily average
205   temperatures in described period is shown in Fig.10.

206   Statistical analysis revealed a strong correlation between average hourly temperatures outside
207   and inside the studied building (RS=+0.88). Relative air humidity measured outside the building
208   reached the values from 39% to 68%, while inside it ranged from 20% to 52% (Fig. 11).

209   Atmospheric pressure in the studied period ranged between 965 hPa and 1000 hPa (Fig. 12).

210   Correlation coefficient between average hourly humidity inside the antelope house and humidity
211   in the ambient air amounted to RS=+0.40.

212   The calculations indicated a strong negative correlation between thermal conditions outside the
213   antelope house and the concentration for PM2.5 and PM10 inside the building (RS: -0.62 and -
214   0.63, respectively). We discovered a weak correlation between relative humidity outdoors and
215   the concentration of PM10 and PM2.5 inside the building (RS: +0.35 and +0.39, respectively), as
216   well as a weak correlation between atmospheric pressure and the concentration for PM2.5 and
217   PM10 inside the antelope house (RS = -0.31).

Discussion

218

219 The basic function of a building is to provide people and animals with as good as possible living

220 conditions. Buildings intended for animals shall be equipped with a ventilation system that

221 removes used air and supplies atmospheric air (Collins 1990). When the air outside is heavily

222 polluted, the ventilation, despite improving the quality of the air inside the building, contributes

223 to increasing pollutant levels indoors (Qi et. al. 2017). The measurements taken in the course of

224 the study indicated that during the period of high dust loading in the ambient air, high

225 concentration of particulate matter also occurs inside the antelope house. Unfortunately,

226 available materials fail to provide standards for permissible exposure to particulate matter inside

227 buildings intended for animals. When it comes to people matters related to standards for

228 particulate matter concentration are governed by the Directive CAFE (CAFE 2008). But in the

229 case of animals we can base our assumptions only on the information included in the materials

230 issued by the European Council regarding well-being, stating that the concentration of particulate

231 matter in the buildings where the animals are housed must be maintained on the level that is not

232 harmful to animals (The Council of the European Union. 1998). As far as legislation in Poland is

233 concerned, standards for the maximum permitted PM concentration for animals have not been

234 established yet. For people the average 24-h PM10 concentration cannot exceed 50 μg/m3

235 (powietrze.gios.gov.pl).

236 For that reason we have used in this paper standards established for people. In the studied period

237 we recorded 11 days when PM10 concentration exceeded 50 μg/m^3 and 24 days when PM2.5

238 was higher than 25 μg/m^3 inside the antelope house.

239 The measurements taken indicated that despite fitting air filters in the ventilation system,

240 particulate matter from the atmospheric air migrated into the building and the correlation

241 coefficient between the concentration of particles indoors and outdoors was statistically

242 significant. The building with its ventilation system reduced PM10 concentration by

243 approximately 60% during the highest smog level as compared with the ambient air. Despite

244 considerable reduction, the concentration of particulate matter inside the building exceeded the

245 standard established for people (CAFE 2008) more than twofold. The research conducted by

246 Wenke et. al. (2018) inside the building intended for animals with different ventilation systems

247 and filter types demonstrated that the difference between particulate matter concentration in

248 rooms with and without filters amounts to 10 ±g/m^3 on average. Challoner and Gill (2014) and

249 Massey et. al. (2009) report that efficient reduction of particulate content by means of

250 mechanical or natural ventilation in buildings intended for people is not possible.

251 The increase of PM concentration between 7:00 and 9:00 (Fig. 7) as well as 7:00 and 8:00 (Fig.

252 8) was most probably associated with cleaning and replacing litter, what resulted in additional

253 PM increment inside the building.

254 The number of particles transported with the air inside the respiratory system depends on, among

255 others, the volume of the air inhaled by the animal, that is pulmonary capacity reduced by so-

256 called respiratory dead space. For the Defassa waterbucks the volume of inhaled air amounts to
257 approximately 9 dm^3, for addaxes 6 dm^3 and 4 dm^3 for lowland nyalas (Muir & Hubbell 2012).
258 Assuming that the average number of breaths per minute for these animals in resting state
259 amounts to 25, we are able to estimate that in the period with the highest particle concentration
260 (PM10=118 µg/m^3, PM2.5=100 µg/m^3) the antelopes introduced into the respiratory system
261 approximately 1062 µg of PM10 including 900 µg of PM 2.5. It should be noted that these
262 values are accurate only if we assume that animals were in resting state. Undertaking physical
263 activities is associated with increasing the volume of inhaled air (increased depth of breathing
264 and the number of breaths per minute).

265 During breathing PM2.5-10 migrate into the tracheal and bronchial part of the respiratory
266 system, while PM2.5 reach lungs and through the cardiovascular system may be distributed
267 throughout the body (Wei et. al. 2018, WHO 2013). The measurements taken in the building
268 under the study revealed that as much as 85% of the particulate mass constitutes PM2.5.
269 Migration of the particulate matter inside the antelope house is also associated with introducing
270 other substances, among others, benzo(a)pyrene (BaP), lead (Pb), arsenic (As), cadmium (Cd),
271 nickel (Ni) (Wróbel et al. 2000). Taking into account the average concentration of these
272 substances in the ambient air in the period with the heaviest smog emission (Report 2018) as
273 well as the reduction of the particulate matter quantity by the building, it is possible to calculate
274 that the antelopes inside the facility introduced to their bodies through the respiratory system:
275 94,59 ng/m^3 BaP, 0,18µg/m^3 Pb, 10,62 ng/m^3 As, 8,91ng/m^3 Cd and 4,5ng/m^3 Ni per hour.

276 The negative correlation between the outside air temperature and the concentration of particulate
277 matter indoors indicates that a decrease of temperature is followed by an increase in the quantity
278 of burned fossil fuels used to heat houses, what in turn has influence on the level of particles in
279 the atmospheric air. Particles generated in that way are transported through the ventilation
280 system inside the buildings.

281 The discussion on the air pollution inside the antelope house should also cover the aspects
282 connected with people involved in handling animals. During 8-hour working day at the highest
283 particulate concentration these people inhale on average approximately 1173 µg of PM10,
284 including 972 µg of PM 2.5 (Pocock et al. 2013).

285 Trees are capable of reducing particulate matter concentration (Sæbø et al. 2012). Despite
286 the fact that the antelope house is surrounded by forest complexes filtering polluted air, the
287 amount of PM produced by two neighboring towns (Chorzów and Katowice) is so large that it is
288 impossible for the plants growing around the antelope house to efficiently clean the air (>50
289 µg/m3) in the vicinity of the building (Fig. 4, red line).

290 **Conclusions**

291 The experiment revealed that the quantity of particulate matter inside the building intended for
292 antelopes is strongly correlated with the concentration of particles in the atmospheric air. In spite
293 of the fact that the existing ventilation system is equipped with a reduction filter that lowers the
294 dust level by 60% during the heaviest smog, particulate matter concentration in the antelope
295 house exceeded acceptable limit for PM10 more than twofold. Particle size-fraction analysis
296 revealed that as much as 85% of the particles identified in the studied building constitute PM2.5.
297 These particles are capable of penetrating into the lungs causing its irritation or damage, as well
298 as infiltrate through pulmonary alveolars into the vascular system. These results indicate that it is
299 necessary to install suitable filters in the air supply ducts that would efficiently reduce the level
300 of PM in air supplied from outside. The results obtained in the course of this study also indicate a
301 strong need to conduct further research into the quality of air inside the facilities intended for
302 animals as well as necessity to establish permissible particulate matter concentrations for farm,
303 exotic and household animals.

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Figure 1

A fragment of the orthophotomap showing developments in the immediate vicinity of the antelope house. Taken based on the website www.geoportal.gov.pl .

30 m

Figure 2

Building plan for antelopes
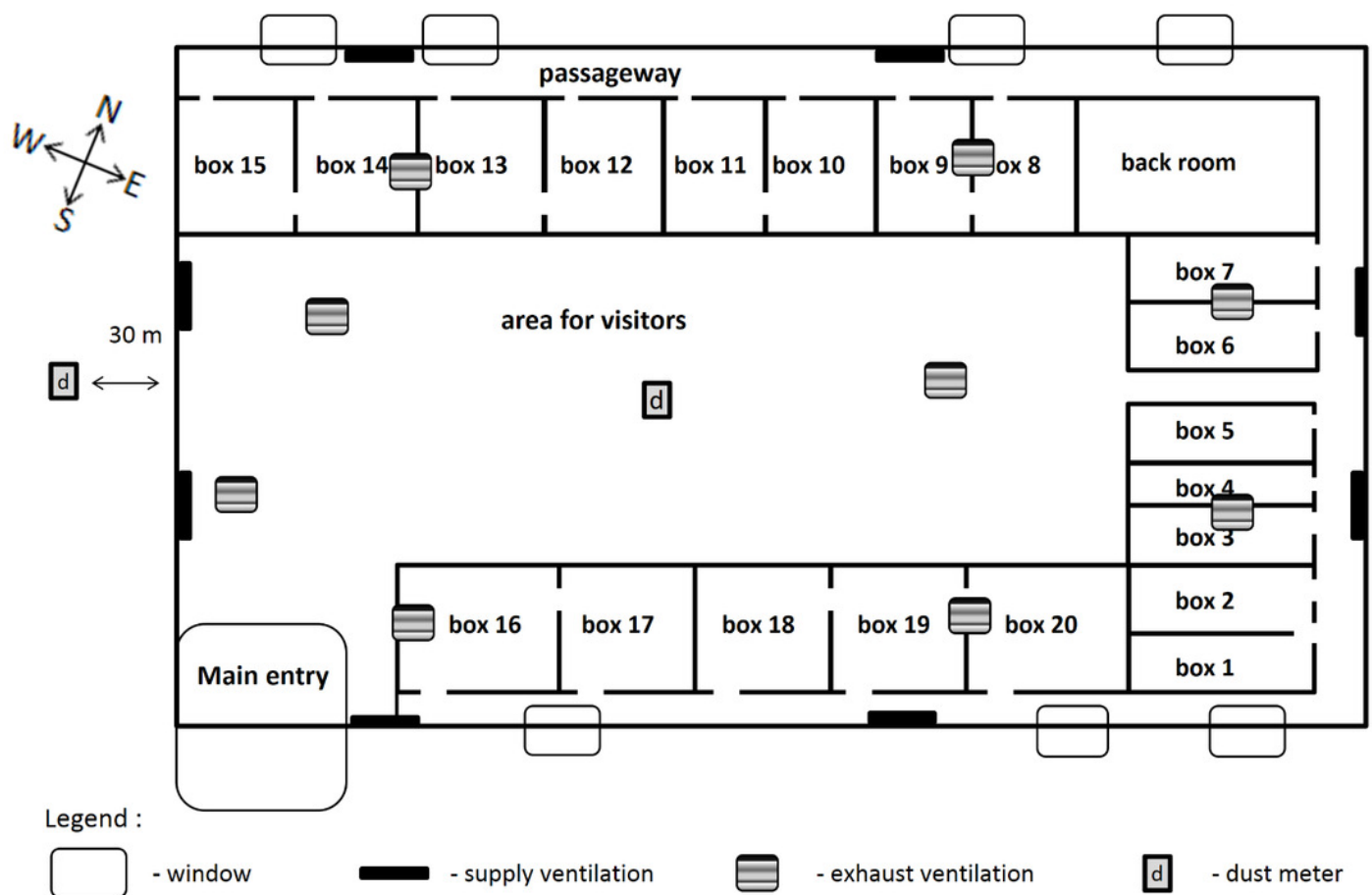
Figure 3

View of box (no. 15) with antelope

Figure 4

Distribution of daily average concentration for PM_{10} determined based on measurements taken inside (black) and outside (red) the antelope house in the period from 27.02.2018 to 16.05.2018.
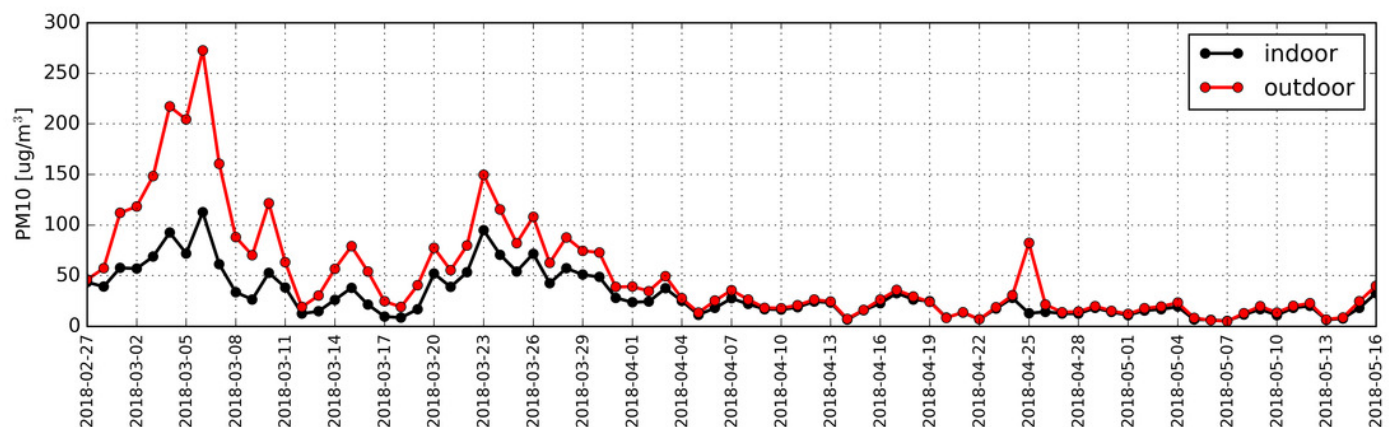
Figure 5

Distribution of daily average concentration for $PM_{2.5}$ determined based on measurements taken inside (black) and outside (red) the antelope house in the period from 27.02.2018 to 16.05.2018.
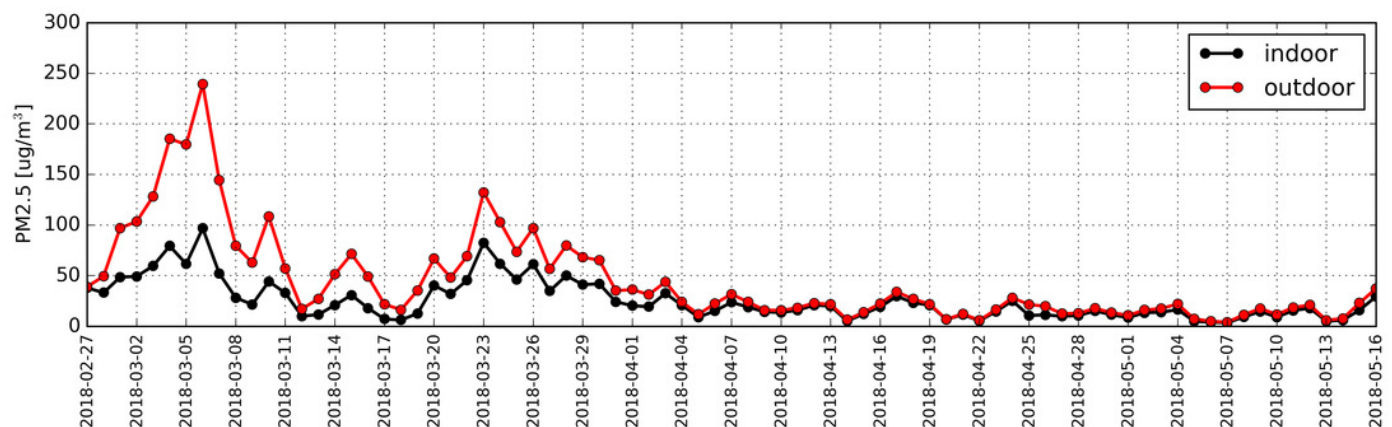
Figure 6

Distribution of daily reduction factor (RF) for PM_{10} calculated based on measurements taken inside and outside the antelope house in the period from 27.02.2018 to 16.05.2018.
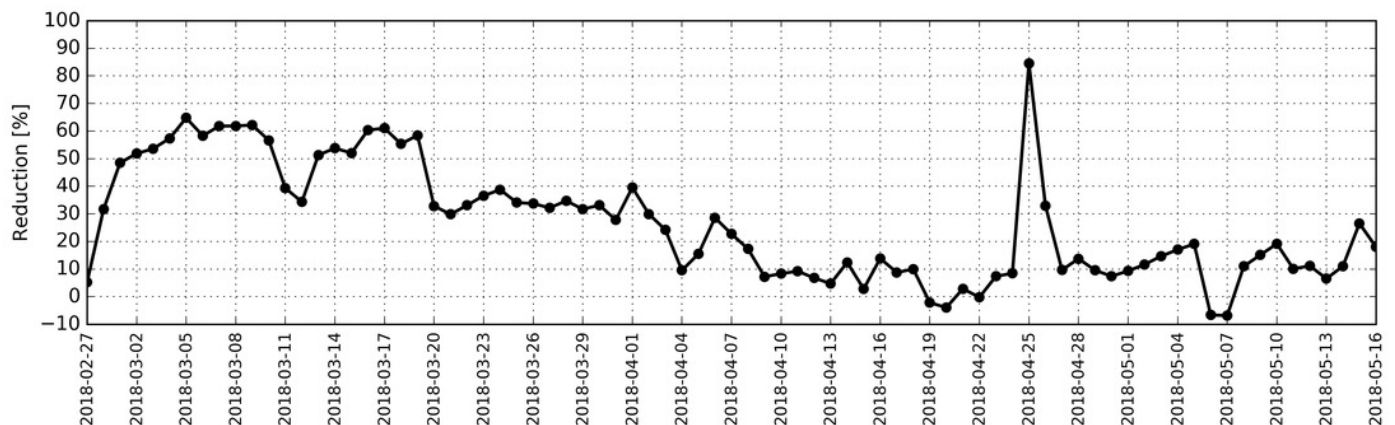
Figure 7

Distribution of daily average PM concentration inside (black) and outside (red) the antelope house based on hourly average for PM_{10} recorded from 27.02.2018 to 03.04.2018, that is in the period of high PM concentration in the atmospheric air.
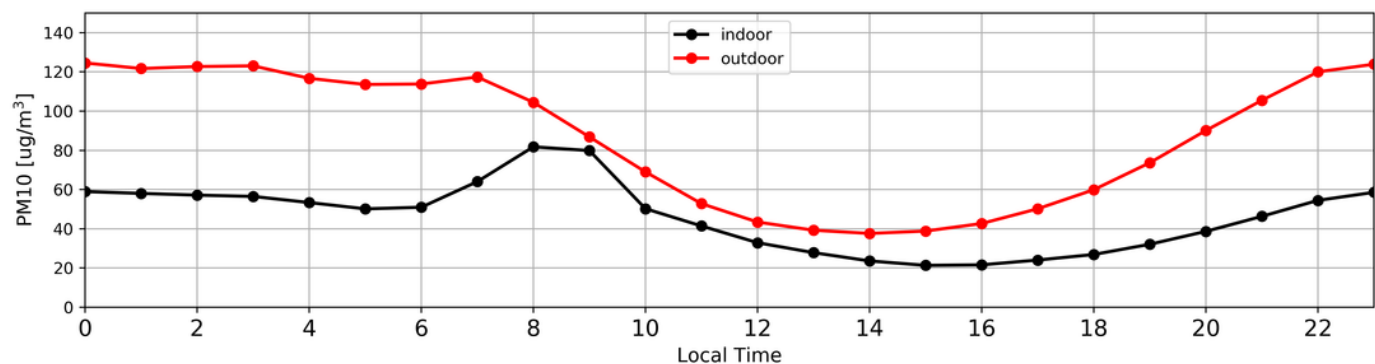
Figure 8

Distribution of daily average PM concentration inside (black) and outside (red) the antelope house based on hourly average for PM_{10} recorded from 04.04.2018 to 16.05.2018, that is in the period of low PM concentration in the atmospheric air.
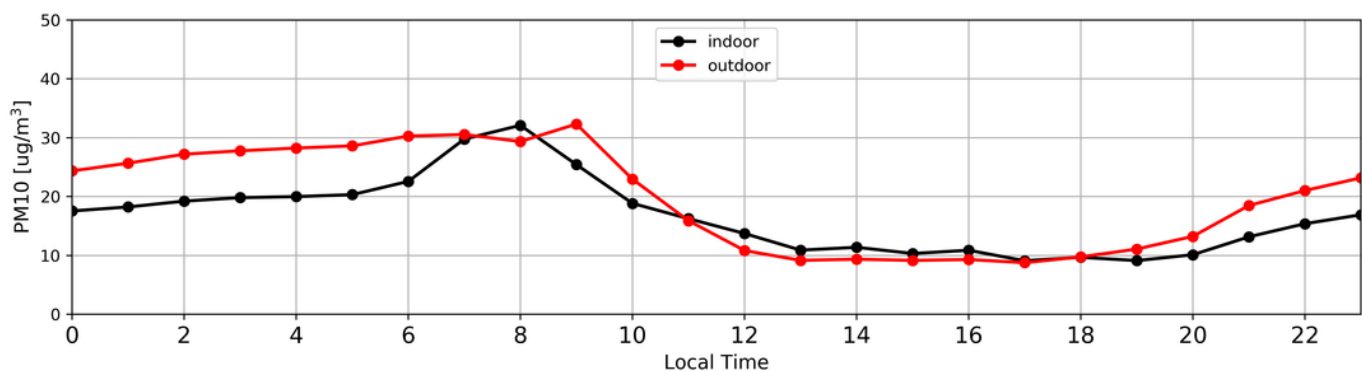
Figure 9

Distribution of PM_{10} (1 min resolution) determined based on measurements taken inside (black) and outside (red) the antelope house in the period from 03.03.2018 to 04.03.2018.
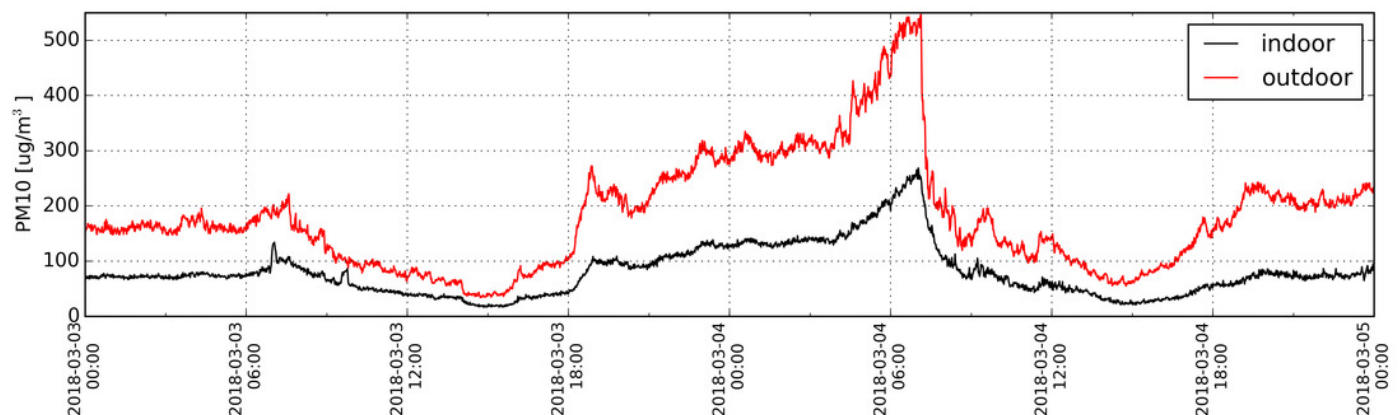
Figure 10

Distribution of daily average temperatures determined based on measurements taken inside (black) and outside (red) the antelope house in the period from 27.02.2018 to 16.05.2018.
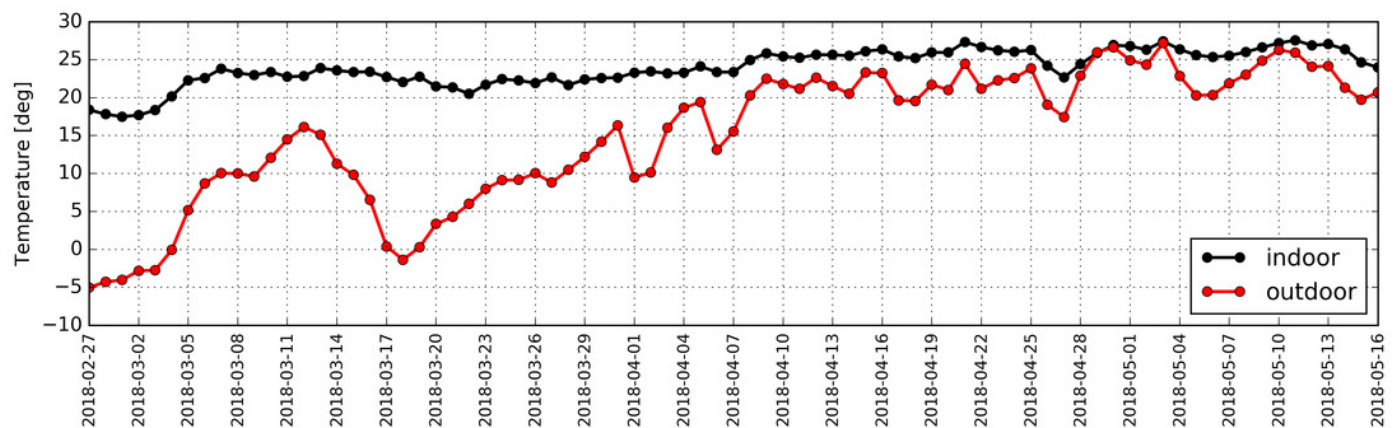
Figure 11

Distribution of daily average relative humidity determined based on measurements taken inside (black) and outside (red) the antelope house in the period from 27.02.2018 to 16.05.2018.
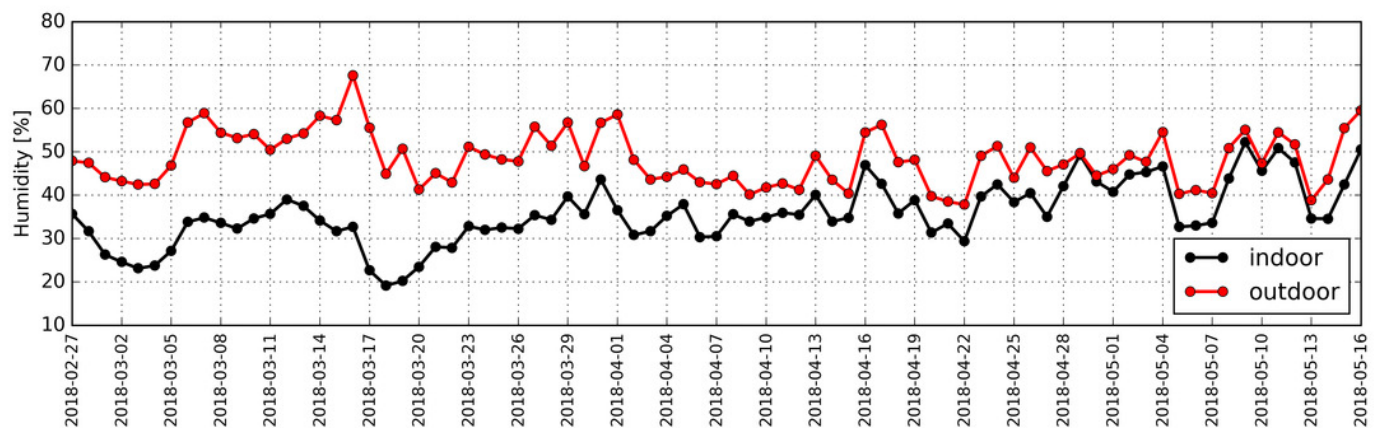
Figure 12

Distribution of daily average air pressure determined based on measurements taken in the period from 27.02.2018 to 16.05.2018.