Indoor environment: Is it possible to use outdoor air in densely populated areas as an indicator of indoor air quality in Swedish buildings

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Abstract*— In the last few decades, indoor air problems have increased in Swedish housing, office and school buildings. The problems that are mentioned are mucosal and respiratory symptoms, asthma, skin symptoms, fatigue and headache. In the environmental health report compiled by the responsible authorities, it is shown that the scope of the problem has been constant since the early 1990s. This is done despite the fact that extensive efforts have been made and extensive resources have been used in research, government investigations with new industry directives and through measures taken in buildings. There is a great need for validated analysis and measurement methods, as well as finding level values for the air environment in Swedish housing, office and school buildings. The purpose of this project is to evaluate whether outdoor air can be used as an indicator and level sensor for the quality of the indoor air environment. Outdoor air is an indicator where the number of particles, preferably those larger than 5.0 µm, is a valuable parameter. The long-term goal should be to build a bank with values from the outdoor air. This bank should include values with an even distribution that include temporal variations, the Swedish seasonal variations and the longer-term variations that occur annually. In addition, it should cover a uniform distribution across the whole of Sweden. This bank should be a better basis for assessing the environment in each object, instead of using the value of the level outside the building at the current time of measurement. An important issue is the calibration of measuring instruments to make the results comparable. In this project, this is not a problem since only one and the same instrument is used, but when using several instruments, the relationships actualized.*

Keywords: Air quality, Hygiene and Health, Indoor Environment, Particle Amount, Particle Measurements, Particle Size.

I. INTRODUCTION

In the last few decades, indoor air problems have increased in Swedish housing, office and school buildings. The problems mentioned are mucosal and respiratory symptoms, asthma, skin symptoms, fatigue and headache. The environmental health report shows that the problem scope has been constant since the early 1990s.[1] The Swedish Parliament has set the following environmental quality objectives which the relevant authorities must comply with:

1. The overall objective of environmental policy is to pass to the next generation a society where the major environmental problems have been solved, and this should happen without causing environmental and health problems beyond Sweden's borders[2, 3]
2. With the extensive indoor environment-related health problems, the goal that buildings and their properties will not adversely affect health by 2020, not to be achieved.[4, 5]

It is well known that the problems associated with the indoor environment are diffuse and that no connections have been identified, dose-response relationship, between the health-related concerns that are being said and the shortcomings in the technical status of buildings. There is a great need for validated analysis and measurement methods as well as leveling values for the air environment in Swedish housing, office and school buildings. Due to the lack of validated methods, industry actors have created their own methods and limits that lack scientific basis, yet allowed to control the development.[6]

The purpose of this project is to evaluate whether outdoor air can be used as an indicator and level sensor for the quality of the indoor air environment. The literature study has shown, as regards the measurement procedures that the authorities refer to for the analysis of the air environment, that the gravimetric method is that recommended.[7] For construction products, there are further reports SIS-CEN / TR 16797-2: 2015 "Assessment of Dangerous Substances - Guidance for Statistical Assessment of Declared Values", which consists of two writings, Part 1 and Part 2.[8, 9] Part 2 on page 5 refers to the Dutch Soil Quality Decree system, a statistically based system for soil and water management.[10 - 12] The results from the survey show that there are deficiencies with the responsible authorities and that they lack the necessary basis for the environmental health report. Consequently, there are major question marks about the environmental quality target, which states, "With the extensive indoor environment-related health problems, the goal is that buildings and their properties will not adversely affect health by 2020, this goal will not be achieved." If you cannot detect a dose-response relationship, the logic falls into the set target. An important prerequisite is that reliable analytical and measurement methods are available. The measurement procedures referred to by the authorities are based on a statistically based system that deals with soil and water management. In addition, from market participants, there are self-composed methods and limit values that do not help the situation. The first question is how the process can be used in the field of the indoor environment and on this issue the authorities have not been able to provide answers.[13]

II. METHODOLOGY

This cross-sectional descriptive type of observational study was conducted in Sweden.

The air inhaled by humans contains regular pollutants in the form of particulate and chemical compounds, and the amount, content and distribution of these contaminants are factors that affect air quality. As regards the outdoor environment in Sweden, there is an environmental quality standard that the municipalities are responsible for complying.[7] This air quality regulation refers to air quality outdoors, and the following division is made:

- PM10: Particles which are not larger than that they can pass through a selective intake which, with 50 percent efficiency, differs from particles with an aerodynamic diameter of 10 μm.
- PM2.5: Particles which are not larger than that they can pass through a selective intake which, with 50 percent efficiency, differs from particles with an aerodynamic diameter of 2.5 μm.

In order to protect human health, the Air Quality Regulation states that for particulate matter, PM2.5, from 1 January 2015 may not occur in the outdoor air with more than an average of 25 micrograms per cubic meter of air for one calendar year (annual average).[7] The national level of average exposure to the population should not exceed 20 micrograms per cubic meter of air.[7] The particulate pollutants are added to the Swedish outdoor air as follows:

- PM10 swirls mainly from roads and roads. The particles have been formed by the wear of roadways, from brakes and tires on vehicles, and from the sand spread on roads and streets.
- PM1 is derived mainly from emissions in other countries. Wherever the transport to Sweden takes place depends on the winds, as these finer particles can stay in the atmosphere for a number of days".[14]

For the reference method for sampling and measurement of particulates, the authorities refer to the following reports: [15]

- SS-EN 12341: 2014 "Outdoor air - Standard method for gravimetric determination of mass concentration of PM10 or PM2.5 fraction of suspended dust in air".[16]
- SS-EN 14907: 2005 "Outdoor air - Gravimetric standard method for determining the mass fraction of PM2.5 of suspended particles.[17]

Gravimetric measurement means that particles are sorted from a filter that has captured the particles and the analysis is done using a gas flow in a tube chamber where the conditions have been defined previously. Dust amount is calculated by weighing the filter, that is, using a weight measurement and by differential pressure measurement, the extracted volume is determined. Using these values, the dust concentration is calculated. Gravimetric analysis is based on converting the investigated substance into a soluble compound that is isolated, washed, dried and weighed. On the basis of the mass of the resulting precipitate, the mass of the investigated substance is calculated. The precipitation is generally carried out from a hot diluted solution, the precipitation reagent, which is added in small portions while stirring the solution. The precipitate is kept in a heater or oven so long that its´ mass is no longer changing. How this procedure may be applicable for assessment of indoor environments has not been clarified, but the authorities still refer to this form of management. [7,18]

In recent decades, a lot of research has been done on indoor air pollution in schools, preschools, offices and housing. The levels of contamination there are low in relation to the dose-response relationship established by the authorities and in the case of chemical compounds no higher levels in relation to outdoor air have been identified.[19 - 20] For air quality indoors, the air environment outside the current building is the level sensor, as regular communication takes place through windows, doors and densities, etc. This means that under normal conditions it is not possible to create a better air environment indoors than the quality of the air surrounding the building. Studies have shown that outdoor air can be used as a level sensor for indoor air. It is necessary that the analytical and measurement procedures used are calibrated, both with respect to the measuring instruments and with respect to the analysis procedure. In previous projects, studies have been conducted regarding the relationship between indoor air and air outside the building concerned, by calculating the ratio of air indoors to air outdoors.[20] In this project one and the same instrument, TSI laser sampler model 8220, has been used for all measurements, which solves the problem of calibration of measurement methodology. In order to use this measurement methodology on a larger scale, it is required that the method be developed with regard to both instrument calibration and how to practice the methodology at different occasions and places. The instrument measures six compartment sizes on particles: 0.3, 0.5, 1.0, 3.0, 5.0 and 10.0 µm. In this report, the results are presented in two ways:

A. In the open intervals, particles greater than 0.3, 1.0 and 5.0 µm, respectively, and within the range of 0.3 - 1.0 µm. The purpose of this approach is that the report results follow the template used by Swedish authorities, PM 2.5 µm and PM 10 µm, so that an adequate comparison of the results can be made. It should be noted that particles in the range greater than 5.0 µm are not included in the authorities' reports, although it has been confirmed that particles in this range are contaminants that cause health effects. This means that the amount of particles in this size correlates with human health.[21]

B. In particle intervals; a) the open intervals for the respective fraction and b) within the respective ranges of 0.3 - 0.5, 0.5 - 1.0, 1.0 - 3.0, 3.0 - 5.0, 5.0 - 10.0 µm with the purpose of obtaining increased information within each fraction.

At each measuring point, the instrument is programmed for the measurement time, one minute per measurement. A measuring series comprises five individual measurements, which means that approximately 15 liters of air are processed. For the five individual values, the average is calculated, which is used as a comparative value in the assessment between the different environments. The results of the measurements in this project are reported in the number of particles per cubic meter of air. The measurements cover geographically different parts of Sweden as well as different times during the year. In addition, a local air study is conducted in central Stockholm, Sweden's most densely populated place and, for Swedish conditions, the most affected environment.

III. RESULT

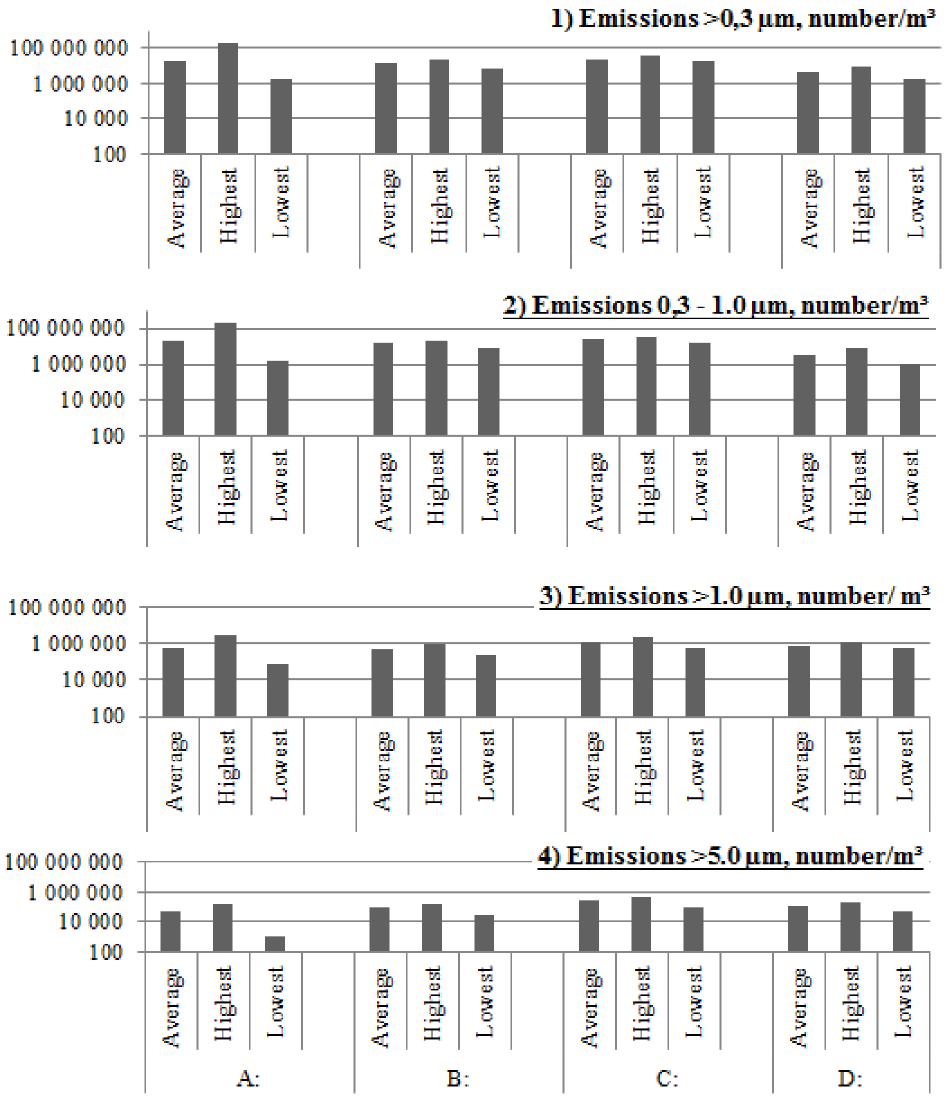
From the outdoor measurements carried out during the period 2010-2017, the results from over seventy representative sites in Sweden are presented, including the local studies conducted in Stockholm, Sweden's most densely populated place. The measurements in the urban environment have been carried out at different times and at different localities, with varying degrees of load on the air environment and complements the other measurements. Furthermore, the environment in and around 45schools geographically distributed across Sweden has been studied. The results show that the air environment in Swedish schools has hygienic shortcomings. In this project four representative schools, out of the 45, were selected. As a validated work model was used with a calibrated measuring instrument, emission sources could be identified and eliminated, which resulted in significant improvements to the indoor environment. The model used for analysis was not limited to solving problems in the construction of the building, but it was expanded and also included the loads generated by the business itself.

Overall, the results of this project show that the measurement methodology used in the project provides illustrative results and that the parameters in the outdoor air are a valuable indicator for evaluating indoor air quality. The results show that the largest number of particles is in the range of 0.3 - 1.0 µm in the outdoor air. The number of particles in the open range greater than 1.0 µm is in this ratio modest. In the open range, particles larger than 5.0 µm, the number may be considered negligible in comparison with the range of less than 1.0 µm. (Table 1 & Figure 1)

Table 1
Emissions (µm), number millions/m^3

Emissions (µm), number millions/m^3 (Number in thousands)		**>0,3**	**0.3-1.0**	**>1,0**	**>5,0**
Seventy difference place in Sweden, over the years 2010-2017:	Average	20 448	19 870	578	57
	Highest	198 900	195 890	3 010	174
	Lowest	1 600	1 531	69	1
Four central place in Stockholm, No rushhouer, 2017-03-12:	Average	14 872	14 354	518	88
	Highest	21 745	20 801	943	174
	Lowest	7 610	7 374	235	29
Four central place in Stockholm, No rushhouer, 2017-03-13:	Average	24 754	23 479	1 274	258
	Highest	38 676	36 053	2 623	517
	Lowest	18 235	17 660	574	101
Four central place in Stockholm, No rushhouer, 2017-03-16:	Average	4192	3 407	784	121
	Highest	9 251	8 044	1 206	214
	Lowest	1 549	1 002	547	59

Figure 1 (Logarithmic scale)



Location

A: Seventy diffrence place in Sweden
B: Four central place in Stockholm, no rushhouer, 2017-03-12
C: Four central place in Stockholm, rushhouer 2017-03-13
D: Four central place in Stockholm, rushhouer 2017-03-16

The number of emissions in the outside air, A: In seventy different places distributed from northern to southern Sweden in 2010 - 2017 and B - D: At three metrics, the average of four locations in the inner city of Stockholm. The diagrams show the average and the highest and lowest measured values.

- Diagram 1: Particles larger than 0.3 µm.
- Diagram 2: Particles in the range 0.3 - 1.0 µm.
- Diagram 3: Particles larger than 1.0 µm.
- Diagram 4: Particles larger than 5.0 µm.

The purpose of the measurement in Stockholm, Sweden's most densely populated place, is to study whether outdoor air is more stressed than elsewhere in Sweden (as the results show that this is not the case). Only with regard to the range, particles larger than 5.0 µm, the highest value is to be collected in Stockholm air. However, it is a rather modest level considering the levels measured indoors, see Figure 3 and Table 6.

The number of emissions in the outdoor air particles: larger than 0.3 µm, in the range of 0.3-1.0 µm, larger than 1.0 µm and larger than 5.0 µm. Measurements have been made at seventy different places distributed from northern to southern Sweden and at three occasions at four locations in central Stockholm. The purpose of the measurements in Stockholm, Sweden's most densely populated place, is to study whether outdoor air is more stressed than elsewhere in Sweden (as the results show that this is not the case). The table presents the results on average, highest and lowest measured values. (Table 1)

There are large percentage variations between the highest and lowest levels in all ranges, but in most cases the variation is by far the largest in the range 0.3 - 1.0 µm. In the open range, particles greater than 0.3, the highest value is 198 900 000 pieces/m^3 air and the lowest value is 1 600 300 pieces/m^3 air. It is noteworthy that the emission levels in Stockholm do not differ from the rest of the country and that the highest measured values cannot be obtained from Sweden's most densely populated area. The local study of the outdoor air in Stockholm is shown in Figure 2 and in Tables 2-5.

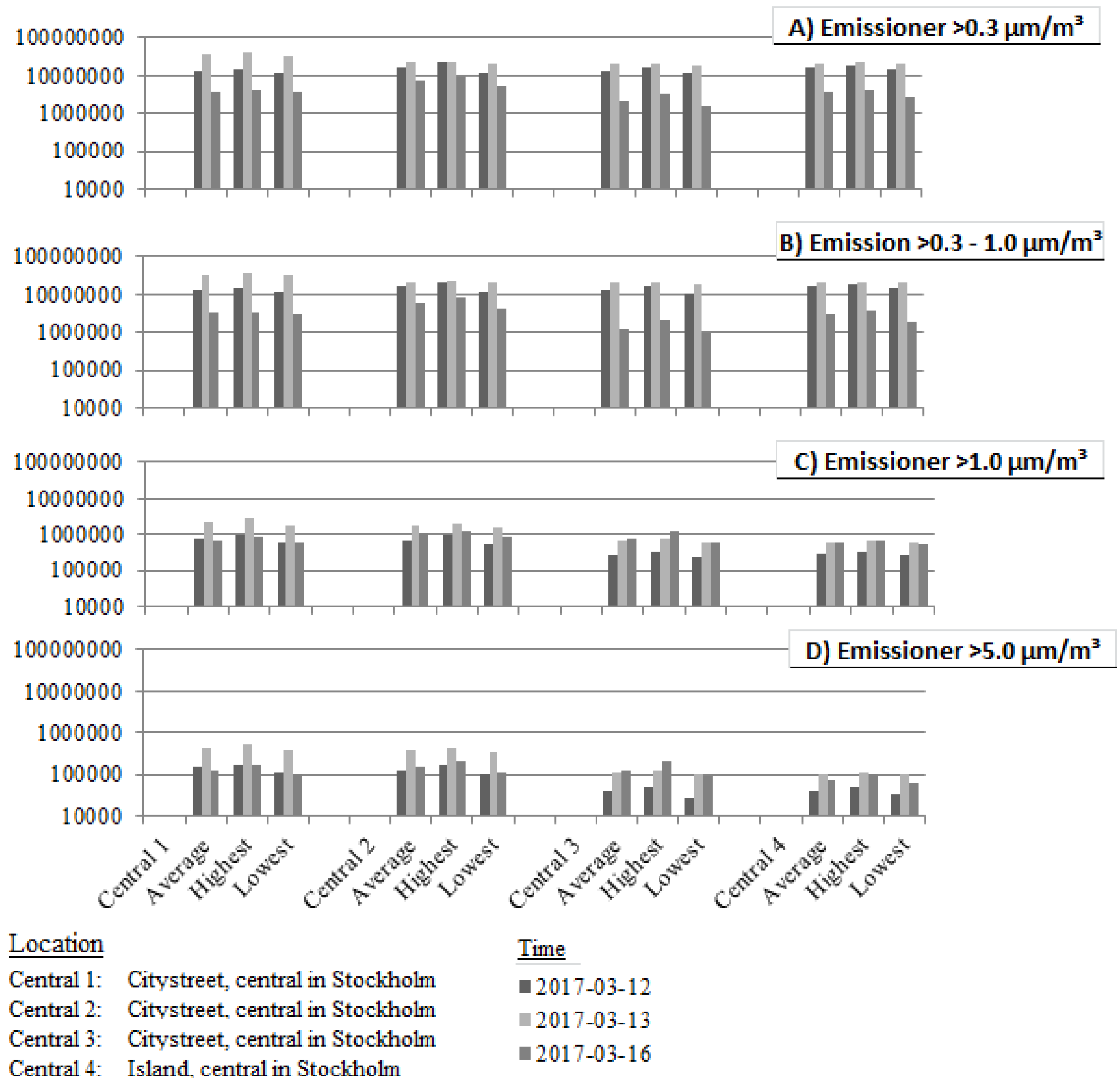
The number of emissions in the outdoor air at three occasions, in low traffic, 2017-03-12 and on two occasions during rush hours 2017-03-13 and 2017-03-16, from four locations in the inner city of Stockholm. The diagrams show the average and the highest and lowest measured values:

- Diagram (A): Particles larger than 0.3 µm, for more information on numbers, see Table 2.
- Diagram (B): Particles in the range of 0.3 - 1.0 µm, for more information on numbers, see Table 3.
- Diagram (C): Particles larger than 1.0 µm, for more information on numbers, see Table 4.
- Diagram (D): Particles larger than 5.0 µm, for more information on numbers, see Table 5.

The number of emissions in the outdoor air, particles larger than 0.3 µm per cubic meter of air, measured values at three occasions at four locations in central Stockholm. The table shows the average and highest and lowest measured values for each location. (Table 2)

The number of emissions in the outdoor air, particles in the range 0.3-1.0 µm per cubic meter of air, measured values at three occasions at four locations in central Stockholm. The table shows the average and highest and lowest measured values for each location. (Table 3)

Figure 2
(Logarithmic scale)



The number of emissions in the outdoor air, particles larger than 1.0 µm per cubic meter of air, measured values at three occasions at four locations in central Stockholm. The table shows the average and highest and lowest measured values for each location. (Table 4)

The number of emissions in the outdoor air, particles larger than 5.0 µm per cubic meter of air, measured values at three metrics at four locations in central Stockholm. The table shows the average and highest and lowest measured values for each location. (Table 5)

These results also show that the largest number of particles is in the range of 0.3 - 1.0 µm. In the open range, particles lager than 1.0 µm, the number is modest relative to the fraction particles less than 1.0 µm. For particles larger than 5.0 µm, the number may be considered negligible in comparison with particles in the range of less than 1.0 µm. With the focus on particles less than 1.0 µm in the air environment that occurs in Sweden, there is a risk that particles in the larger fractions will be neglected. The attached figures and tables show that emissions larger than 5.0 µm, in number, are modest in relation to emissions in the smaller intervals, except for the indoor environment reported before measures. The relationship is clarified in Fig. 3 and in Table 6.

Table 2

Emissions>0.3 µm/m^3 (Number in thousands)		**2017-03-12**	**2017-03-13**	**2017-03-16**
Central 1	Average	13 535	35 078	3 882
	Highest	14 972	38 686	4 237
	Lowest	12 010	31 826	3 609
Central 2	Average	16 497	22 641	7 247
	Highest	21 799	23 959	9 263
	Lowest	11 791	20 722	5 219
Central 3	Average	12 869	20 178	2 030
	Highest	15 640	21 186	3 210
	Lowest	11 071	18 273	1 590
Central 4	Average	16 588	21 120	3 610
	Highest	18 672	21 529	4 331
	Lowest	14 356	20 224	2 530

Table 3

Emissions>0.3-1.0 µm/m^3 (Number in thousands)		**2017-03-12**	**2017-03-13**	**2017-03-16**
Central 1	Average	12 734	32 936	3 174
	Highest	14 017	36 053	3 377
	Lowest	11 384	30 060	3 001
Central 2	Average	15 798	20 955	6 203
	Highest	20 801	22 074	8 044
	Lowest	11 282	19 209	4 362
Central 3	Average	12 600	19 510	1 258
	Highest	15 309	20 466	2 031
	Lowest	10 846	17 660	1 002
Central 4	Average	16 285	20 516	2 995
	Highest	18 349	20 888	3 643
	Lowest	14 085	19 656	1 983

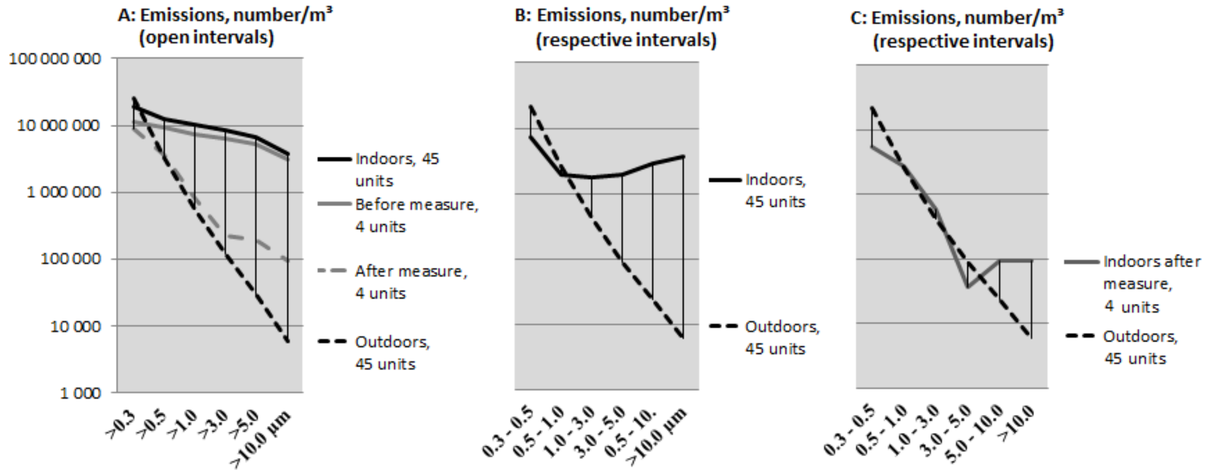
Table 4

Emissions>1.0 µm/m^3 (Number in thousands)		**2017-03-12**	**2017-03-13**	**2017-03-16**
Central 1	Average	800	2 142	708
	Highest	954	2 632	860
	Lowest	626	1 765	608
Central 2	Average	699	1 685	1 044
	Highest	998	1 884	1 218
	Lowest	508	1 512	856
Central 3	Average	268	668	771
	Highest	330	719	1 179
	Lowest	225	612	588
Central 4	Average	303	603	614
	Highest	323	640	687
	Lowest	271	568	547

Table 5

Emissions>5.0 µm/m³ (Number in thousands)		2017-03-12	2017-03-13	2017-03-16
Central 1	Average	150	438	127
	Highest	176	526	166
	Lowest	118	371	97
Central 2	Average	120	372	152
	Highest	167	430	207
	Lowest	98	337	110
Central 3	Average	40	115	129
	Highest	51	129	214
	Lowest	27	99	92
Central 4	Average	41	106	76
	Highest	50	115	100
	Lowest	32	101	59

Figure 3 (Logarithmic scale)



The number of emissions, particles per cubic meter of air.

- Diagram (A): Particles from the open range, larger than 0.3 µm. The diagram shows indoor air in 45 schools as well as outdoor air around the 45 school buildings. 4 schools of these 45 schools were selected for measures aimed at reducing emissions. This is shown by separate graphs in the chart, before and after measures.
- Diagram (B): Particles in respective ranges from 0.3 and up to 10.0 µm and larger than 10 µm. The diagram shows indoor air in 45 schools and outdoor air around the 45 school buildings, the same units as shown in Chart A.
- Diagram (C): Particles in respective ranges from 0.3 and up to 10.0 µm and larger than 10 µm. The diagram shows indoor air in 4 schools, where measures were taken to reduce emissions and outdoor air around the 45 school buildings reported in Chart A.

For more information on the figures, see Table 6

Emission levels, number of particles per cubic meter of air. The table shows the average of the emissions from the following locations:

A. Indoor air in 45 schools and outdoor air around the 45 school buildings, particles in the open intervals, from larger than 0.3 µm and up to larger than 10.0 µm. In addition, 4 representative schools were selected from the 45 schools for measures aimed at reducing emissions, and this is reported separately in the table, before and after measures.

From diagram A, indoor air in 45 schools and from the indoor air in the 4 representative schools where measures were taken to reduce emissions. The emissions are reported in respective ranges from 0.3 µm and up to 10 µm and in the open range larger than 10 µm.

Table 6

(Number in thousands) A: Emissions>0.3 number/m^3 (Open Intervals)	**>0.3**	**>0.5**	**>1.0**	**>3.0**	**>5.0**	**>10.0 µm**
Indoors, 45 units	19 431	12 301	10 369	8 623	6 631	3 694
Before measure, 4 units	11 527	9 115	7 435	6 320	5 163	3 117
After measure, 4 units	8 971	3 544	824	227	190	94
Outdoors, 45 units	24 949	3 206	544	118	30	6
B: Emissions, number/m^3 (respective Intervals)	**0.3-0.5**	**0.5-1.0**	**1.0-3.0**	**3.0-5.0**	**5.0-10.0**	**>10.0 µm**
Indoors, 45 units	7 130	1 932	1 746	1 992	2 937	3 694
Indoors after measure, 4 units	5 427	2 720	597	37	96	94
Outdoors, 45 units	21 743	2 662	426	88	24	6

The following results are shown:

1. In the outdoor air, there are high particle levels in the range of 0.3 - 0.5 µm in order to reduce drastically in the range of 0.5 - 1.0 µm and larger sizes and in the largest intervals only a few thousands of particles/m^3.
2. The indoor environment curve shows that the number of particles in the minimum range 0.3 - 05 µm is lower indoors than outdoors, and the number decreases indoors in the range of 0.5-1.0 µm, in order to dramatically increase again in numbers in the range of 1.0-3.0 µm relative to the outside environment.

The results indicate that hygiene is inadequate and this creates a basis for health problems. Following the measures carried out in four representative units, of forty five schools, it appears that the contours of the two curves better correlate Fig. 3, diagram C. Overall, from this study, it appears that outdoor air is a useful parameter as a hygienic indicator for the indoor air environment and can be used as follows:

- The contour on the air profile curve indoors should follow the corresponding curve for the outdoor air.
- The number of particles in each interval should harmonize between the air outdoors and the air indoors.

IV. DISCUSSION

It is important to take into consideration the healthily demonstrated relationships regarding particles in the range larger than 5.0 µm [21]. The results in this study show that the ratio, the large number of particles less than 1.0 µm in the air, is part of the nature created on earth. Table 6 and Fig. 3, diagram B clearly show how the curve structure differs between the outdoor environment and the indoor environment. As for the outdoor environment, the emissions decrease, the greater the particles, unlike indoors, where the number of particles even increases in the largest particle sizes. This relationship must be taken into account, evaluated and required, and the authorities must begin work to rectify the identified deficiencies. Notably, the number of particles in the range of 3.0 - 5.0 μm increases sees the graph structures in Chart C in Fig. 3. This is normal in view of the activities that are going on indoors, in a limited volume that buildings are and where the air exchange with the outside environment is always delayed. The difference is reflected in the curve contours in Chart B in Fig. 3 and is tangible in comparison with Chart C, where significant environmental improvements can be identified. Some important parameters to consider in further studies are as follows:

A. An overall goal should be to build a bank with many outdoor air values, which gives a more neutral value to use for each object rather than using only the level at a specific time outside the building.

B. The shortcomings found in the work model currently used with a one-sided focus on the building, which must be corrected. Authorities do not take into account all the factors that affect the environment in the building and the environments outside the affected building that affect human health.

C. Correct the ambiguity caused by the division, PM2.5 and PM10, to assess the hygienic status of the air environment.

D. The importance of being able to illuminate the hygienic status of the indoor environment with understandable substrates that identify air quality.

This study also depict that hygiene is inadequate and this creates a basis for health problems. Following the measures carried out in four representative units, of forty five schools, it appears that the contours of the two curves better correlate Figure 3, diagram C. Overall, from this study, it appears that outdoor air is a useful parameter as a hygienic indicator for the indoor air environment. This possibility is not taken into consideration by the authorities. There are no technical conditions for further reducing the indoor level in this range due to the regular communication through doors and windows, which regularly occurs between the outdoor and indoor environment. Responsible authorities act, with the support of business interests, as if this were possible[22 - 24] The handling by authorities makes it easy to misunderstand the problems in the indoor environment and a gap has been created that favors various special interests. In order to correct the problems, more clarity is required in various issues of concern from interested parties. It is important to be able to identify the sources of emission to develop the indoor environment so that people are not affected by health problems. Unfortunately, the results of various studies show that an imbalance prevails when business interests can control, which creates additional environmental risks in buildings.[25-27]

V. CONCLUSION

The results from this project show that outdoor air can be used as an indicator of the indoor air environment. This study also depict that hygiene is inadequate and this creates a basis for health problems. The contour on the air profile curve indoors should follow the corresponding curve for the outdoor air. The number of particles in each interval should harmonize between the air outdoors and the air indoors. The following results are shown:

1. In the outdoor air, there are high particle levels in the range of 0.3 - 0.5 μm in order to reduce drastically in the range of 0.5 - 1.0 μm and larger sizes and in the largest intervals only a few thousands of particles/m^3.
2. The indoor environment curve shows that the number of particles in the minimum range 0.3 - 05 μm is lower indoors than outdoors, and the number decreases indoors in the range of 0.5-1.0 μm, in order to dramatically increase again in numbers in the range of 1.0-3.0 μm relative to the outside environment.

CONFLICT OF INTEREST

None declared till now.

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