ANALYSIS AND MODELLING OF INDOOR PARTICLE MATTER POLUTION AND IMPACT OF AN AIR PURIFIER

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Abstract. Following the economic, industrial, and social rapid development, the last 50 years has brought significant improvements in the materials and products aimed for indoor use, people remain exposed to various harmful materials and pollutants. Furthermore, technology is steadily moving towards higher efficiency and lower emissions. However, it is important to note that in some developing countries, and metropolitan cities face issues with ambient air pollution which ultimately infiltrates indoors and reduces the indoor air quality. The quality of the indoor air can be further hindered by various indoor pollution sources. In this paper a model of indoor air pollution is developed. The developed model is based upon mass conservation equation and is used to simulate indoor air pollution with particles of diameter lower than 2.5μm ($PM_{2.5}$). Additionally, the model includes the effects of an air purifier in a given room. An analysis on the impact of the air purifier on some of the coefficients in the model is also presented. A verification experiment for the model is defined, and the model is successfully verified.

Keywords: Particulate matter pollution, mathematical modelling, model verification.

AIMS AND BACKGROUND

Indoor air contains a wide range of harmful matter both from organic and non-organic origin, various particles, and microbes[1]. A wide range of human activities especially in living spaces contribute towards the deterioration of indoor air quality.

The most common pollutants of indoor air are:

- Particulate matter – PM;
- Carbon monoxide;
- Volatile Organic Compounds VOCs.

Particulate matter is commonly considered the most harmful pollutants of indoor air, an opinion which is greatly supported by the analysis of premature death by the European Environment Agency[3]. PM is the term which is used for describing the mixtures of solid particles and liquid droplets found in the air[3]. PM comes in many sizes, and shapes and can contain various chemicals. Commonly PM is grouped by its aerodynamic profile, and the groups that are most commonly of interest are:

- PM_{10} - diameters of 10µm and smaller.
- $PM_{2.5}$ - diameters of 2.5 µm and smaller.

It is important to know that there are various factors which impact indoor air quality. Indoor air quality is in essence a function of the concentration of various pollutants. A graphical representation of the various factors that impact indoor air quality can be seen in Fig 1.

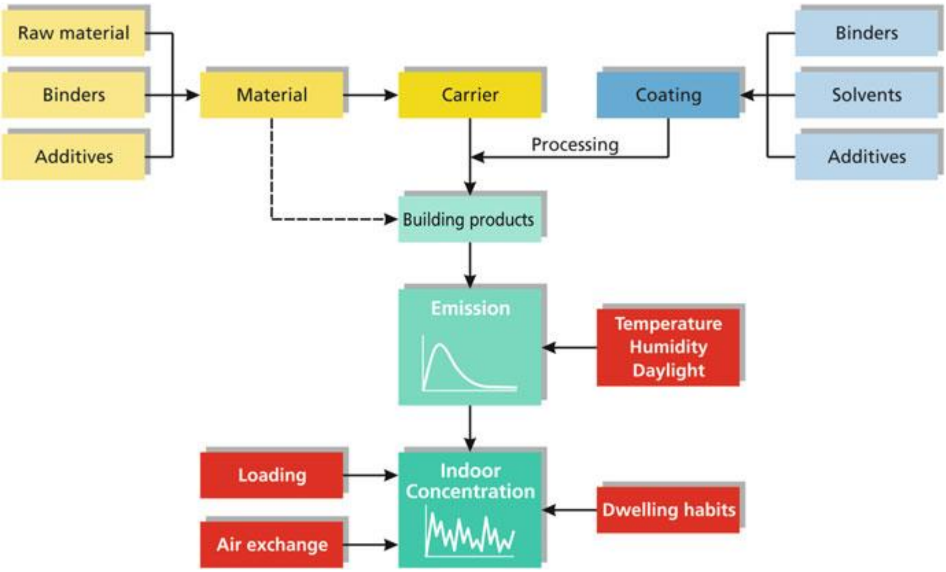

Fig. 1. Graphical representation of various factors that impact indoor pollutant concentration1

In this paper the aim is to develop a robust mathematical model which can be used to simulate the indoor $PM_{2.5}$ concentration, incorporating an air purification device which helps improve the indoor air quality by removing the PM from the air.

The goal of the developed model is not to incorporate every possible factor, but rather to create a baseline from which further simulations can start. Special attention is given on the impact of an air purifier, which impacts the mixing of the air. The developed model is verified in an experiment, with several operational modes of the purifier that allow an evaluation of the accuracy and acceptable operational range of the model.

EXPERIMENTAL

EXISTING MODELS AND COEFFICIENT VALUES

The mass balance equation can be used as a starting point for modelling indoor pollution for different pollutants. Different authors have had the same approach for modelling indoor air pollution (IAP). An example of this is given in Eq 1.

Eq. 1 –Mass balance equation form for IAP modeling[4]

$$V\frac{dc}{dt} = Q(pc_a - c) - (k + k_d)Vc + \dot{S}$$

All the parameters of the equation are given in table 1.

Table 1. Parameters in equation 1

Symbol	**Meaning**
V	Room volume
c	pollutant concentration
$\dot{S}$	pollutant source strength
Q	airflow through room
c_a	ambient/outdoor pollutant concentration
k_d	deposition rate coefficient
k	decay rate coefficient
p	Penetration factor

The authors of the same paper, provide a more practical solution, where Eq. 1 is divided by the room, giving the form shown in Eq. 2.

Eq. 2. - Mass balance equation form for IAP modeling[4]

$$\frac{dc}{dt} = k_v pc_a - (k + k_d + k_v)c + s$$

where all the parameters/variables of equation 1 take a specific form (divided by room volume). It is important to know that the form of the equations above can be applied to various pollutants. In this paper only the definition and coefficients for particulate matter pollution are analyzed. The values of the coefficients that are used by the authors[4] are shown in table 2.

Table 2. Proposed values for coefficients[4]

Symbol	**Meaning**	**Value and unit**
p	penertration factor	0.6 h^{-1}
k	decay rate coefficient	0.01 h^{-1}
k_d	deposition coefficient	0.2 h^{-1}
s	indoor pollution source (human activity)	600μg/h^{-1}
k_v	ventilation coefficient (correlated to penetration factor)	h^{-1}

Other sources[5] state the recommended decay coefficient as 0.27 h^{-1}, while similar values are recommended for the penetration factor.

The deposition coefficient is in practice quite a bit more problematic. It's value for PM2.5 it can be between[6] 0.18-6.55 h^{-1}, this coefficient can drastically vary, and it highly impacted by the mixing of the air in the room. Because of this it is safe to assume that an air purifier increases the value of the deposition coefficient, and all models should use the higher end of the suggested values.

For the inclusion and analysis of the effect of an air purifier in a given room it is more useful to define a model and coefficients in the timeframe of seconds instead of hours. For this purpose, a verification experiment is devised, explained later in the paper. The proposed equation by the authors of the paper is shown in equation 3, and the used parameters are given in table 3

Eq. 3. Proposed equation with air purifier

$$\frac{dc}{dt} = k_v p c_a - (k_v + k_d + k)c - \eta \frac{Q_p}{V} c$$

Table 3. Used coefficients and values

Symbol	Meaning	Unit/value
Q_p	purifier airflow	(Variable) m^3/s
c	pollutant concentration	(measured/simulated)$\mu g/m^3$
c_a	ambient pollutant concentration	(Variable, not included in experiment)$\mu g/m^3$
k_v	ventilation coefficient	(Assumed 0 for experiment) s^{-1}
k_d	deposition coefficient	$6.55[h^{-1}] = 1.812 * 10^{-3}\ [s^{-1}]$
k	decay coefficient	$0.27[h^{-1}] = 7.5 * 10^{-5}[s^{-1}]$
p	penetration factor	1

VERIFICATION EXPERIMENT SETUP

The base premises of the verification experiment is to set up an air purifier in a nearly hermetically sealed room with a volume of $25m^3$ and an adequately placed sensor and pollution source.

The Sensirion SPS30[7] – MCERT certified sensor[8] is used, which is set at the height of 1.5m, compliantly with the suggestions of ISO 16000-1:2004[9]. The purifier with HEPA 13 filter material is placed centrally in the room, and it is controlled with a controller placed outside the room.

The final setup is shown in figure 3, and is similar to other experiments shown in the work of the researchers from Institut für Energie- und Umwelttechnick - IUTA[10,11].

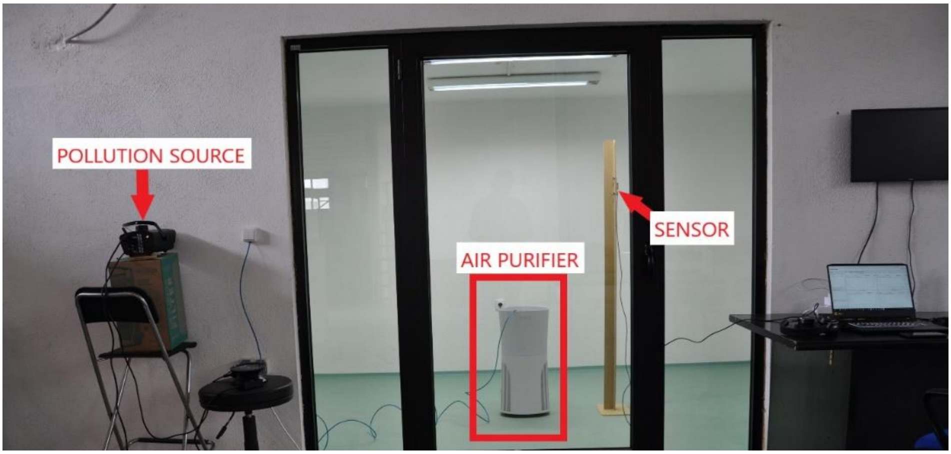

Fig. 2. Verification experiment setup

For this setup the flow of the purifier is set at a few different flow levels (73.92, 174.16 and 764.4 m^3/h). The measurement starts from 1000 $\mu g/m^3$ PM2.5, and is maintained until a reasonably low concentration is achieved. While the measurement lasts, the flow of the air purifier is maintained at a constant level.

RESULTS AND DISCUSSION

The results obtained from the proposed experiment are shown in figures 4, 5, and 6, for each of the flow levels.

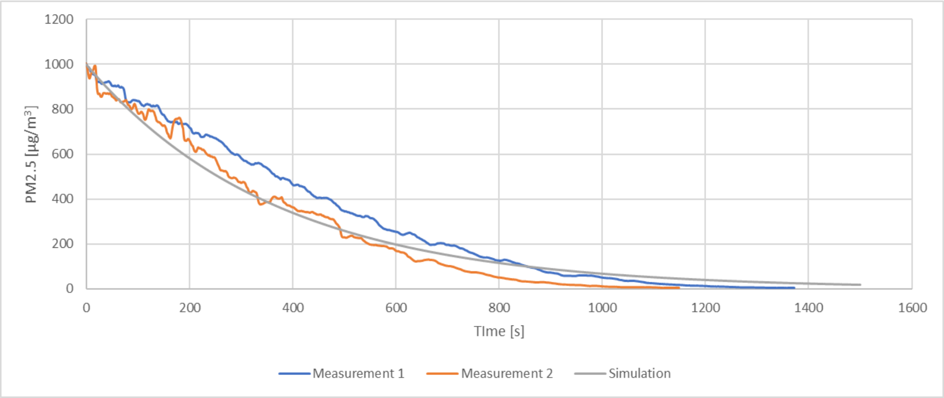

Fig. 4. Simulated vs. measured results at 73.92 m^3/h

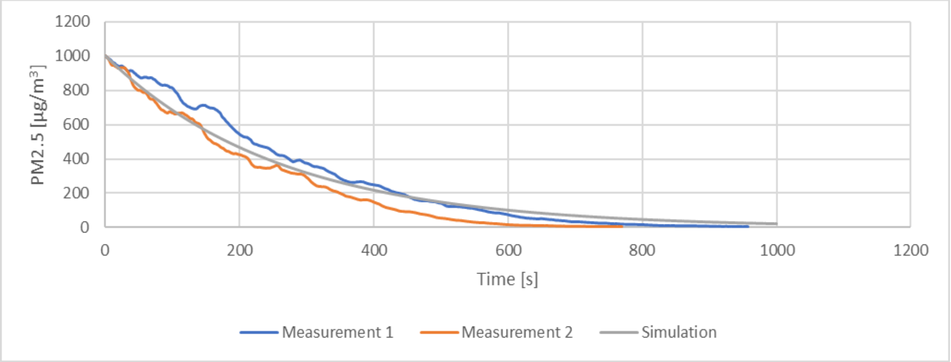

Fig. 5. Simulated vs. measured results at 174.16 m^3/h

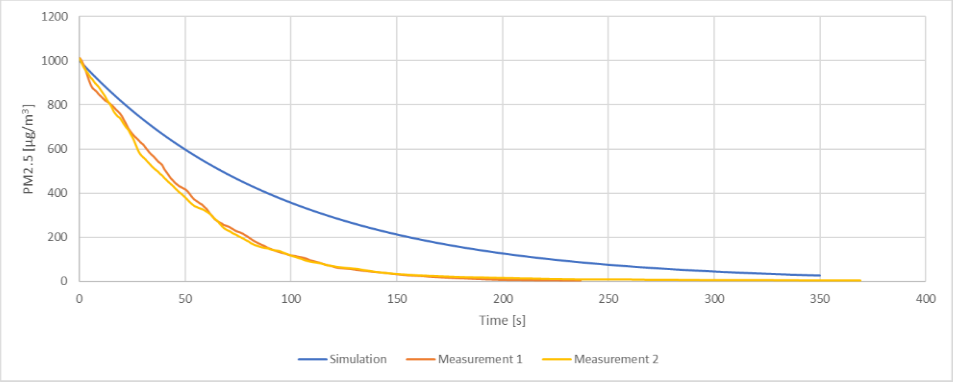

Fig. 6. Simulated vs. measured results at 764.4 m^3/h

CONCLUSIONS

The results shown in figures 4 and 5prove that indoor PM pollution can be simulated with adequate precision in the timescale of seconds, and all the relevant coefficients remain the same as simulations on an hourly scale. Although figure 6 seems to point towards a problem in the model/equation definition, this result is rather to be expected. This is because the flow for the given room is absurdly high, and this especially impacts the deposition coefficient which as stated above is of particular interest because of its variability.

Finally it is shown that the effect of an air purifier can be included in mathematical models of indoor particulate matter pollution.

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