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Modelling of PM_{10} and $PM_{2.5}$ building infiltration during a dust event in Doha, Qatar

Christos D. Argyropoulos[1], Mishma Abraham[1], Hala Hassan[1], Atif Ashraf[1], Eleni Fthenou[2], Eman Sadoun[2], Konstantinos E. Kakosimos[1*]

[1]*Department of Chemical Engineering and Mary Kay O' Connor Process Safety Centre, Texas A&M University at Qatar, Doha, Qatar*
[2]*Supreme Council of Health, Doha, Qatar*
[*]*k.kakosimos@qatar.tamu.edu*

Abstract

A methodology is presented for investigating particulate matter (PM) building ingress during a dust storm event in Doha, Qatar, by using advanced numerical modelling techniques. More specifically, a combination of Computational Fluid Dynamics (CFD) and multi-zone models were used. The first is adopted for computing the external wind pressures including the meteorological effects, while the latter is a multi-zone model for indoor air quality (IAQ). The use of QUIC-CFD model improves the computation of wind pressures, velocities and pollutant concentrations, while the outputs of CFD model can be used as inputs to CONTAM. This combination is superior for more realistic predictions of airflow and pollutant transport in large buildings. The numerical predictions obtained are compared with measurement data during the dust storm event, presenting satisfactory agreement.

Keywords: Dust storm; Indoor air quality; Infiltration; Modelling; QUIC; CONTAM

1. Introduction

Over the past few decades, the intense industrialization and construction, as well as the rapid economic growth in the Middle East Area (MEA) have caused health problems associated with the exposure to ambient PM. The main sources of PM are transportation, building construction and dust storms (Tsiouri et al., 2015). Dust storms are common in the MEA with major contribution to the increase of air pollution levels.

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The main causes for the creation of dust storms are the lift of giant mass of sand, turbulent winds and convective Habbobs (Goudie, 2014). The occurrence of dust storm events varies during the year and differs for each country in the MEA. March and April periods usually present dust storms events with a peak of occurrence in June and July, while the phenomenon is weakening as September period approaches (Tsiouri et al., 2015). The transport of huge amounts of dust and sand is also responsible for transferring pathogens over large distances and as a result affecting the downwind ecosystem, population (Bu-Olayan & Thomas 2012) and human health (Pope et al., 2009). A large number of studies has been devoted to link the PM with adverse health effects (Pope & Dockery 2006) such as respiratory problems (Hsieh & Liao 2013), cardiovascular diseases (Brook et al., 2010) and dermatological disorders (Onishi et al., 2015).

During a severe dust storm event, the high velocities of dominant turbulent winds result in a rapid increase of the outdoor and indoor air PM concentration levels (Song et al., 2005). Dust storms not only affect the health of those outdoors, but also the people living indoor as the particulate matter infiltrates through the buildings. Despite the fact that MEA countries are suffering from frequent dust storm events, there is still a lack of knowledge regarding the health assessment in indoor environments (e.g. houses and industrial buildings) and the design of appropriate actions and mitigation measures in order to minimize the potential health effects.

The purpose of the present effort is to compute the particulate matter (PM) infiltration in a building during a dust storm event in Doha, Qatar, by using advanced numerical modelling techniques. More specifically, a combination of two available models, namely Quick Urban and Industrial Complex (QUIC) (Wang et al., 2010) by Los Alamos National Lab and CONTAM (Nelson & Brown 2013) by National Institute of Standard and Technology were used. Furthermore, the obtained results were compared with measurement data during a real dust storm event in order to assess the levels of indoor and outdoor airborne particulates in workplaces.

2. Methodology

2.1 Measurements

This study concerns a public building (offices) in the city of Doha which is located next to a very busy road a few kilometers from the beach front. The nearby area is characterized by intense construction activities and low rise buildings. Six stations have been installed for a period of two months. Three outdoor in the vicinity of the building and three more at the reception area on the third floor.

PM ($PM_{2.5}$, PM_{10}) mass sampling was carried out by four identical high volume samplers (LVS16 by GRIMM Aerosol Technik GmbH & Co. KG) over periods of 24 hours. Two samplers were equipped with a $PM_{2.5}$ sampling head and the other two with a PM_{10}, all according to EN 12341. Each sampler was loaded periodically with seven 47 mm quartz fiber filters (Tissurquartz 2500QAT-UP by Pall Life Sciences) and the filter changing took place in the afternoons, during which all previous flow rates (average, standard deviation, minimum, and maximum) were extracted. All the measurements collected between 30 March 2015 and 17 April 2015, while the severe dust storm event took place on 1-2 April 2015.

2.2 Description of models

A combination of multi-zone and CFD models is selected for investigating the building infiltration of PM_{10} and $PM_{2.5}$ during the dust storm event. The use of CFD model (QUIC) improves the computations of wind pressures, velocities and PM concentrations, while the outputs of CFD model can be used as inputs to the multi-zone model (CONTAM). This combination is superior for more realistic predictions of airflow and pollutant transport in large buildings (Srebric et al., 2008).

In CONTAM framework a building is visualized as interconnected zones with airflow paths that act as a link between the individual zones and also the outdoor. It has been widely used as multi-zone IAQ model and is based on the initial algorithms developed by Walton (1989) for AIRNET computer program. The flow of air through doors, windows gaps and cracks due to pressure difference is defined as infiltration. In CONTAM, this phenomenon is governed by Bernoulli's equation:

$$\Delta P = \left(P_1 + \frac{\rho V_1^2}{2} \right) - \left(P_2 + \frac{\rho V_2^2}{2} \right) + \rho g \left(z_1 - z_2 \right) \tag{1}$$

where ΔP is the pressure drop between points 1 and 2, P_1 and P_2 are the inlet and outlet static pressures, g is the gravitational gravity, ρ is the air density, z_1 and z_2 are the inlet and outlet elevation, respectively.

Furthermore, building's pressure field in CONTAM is calculated using the ASHRAE formulation (Swami & Chandra 1988) for low rise rectangular buildings. In order to account for the fluctuating meteorological conditions acting on the building exterior, CONTAM enables the option of entering variable wind pressure data or transient weather data (Ashraf et al., 2016). The appropriate meteorological data were collected from Hamad International Airport, Doha, Qatar.

In the present study, a fast response dispersion model known as QUIC was selected to calculate the external wind pressures during a dust storm event. According to Gowardhan et al. (2011), the QUIC-CFD model is based on the 3-D incompressible Reynolds-Averaged Navier-Stokes (RANS) equations and can be written in Cartesian-tensor notation as follows:

Continuity equation:

$$\frac{\partial \overline{u_i}}{\partial x_i} = 0 \tag{2}$$

Momentum equations:

$$\frac{\partial \overline{u_i}}{\partial t} + \frac{\partial \overline{u_i}\,\overline{u_j}}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\nu \left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i} \right) \right] - \frac{\partial \overline{u_i' u_j'}}{\partial x_j} \tag{3}$$

where $\overline{u_i}$ is the mean velocity component in the *i*-direction, $\overline{u_j}$ is the mean velocity component in the j-direction, t is the time, ρ is the average density, p is the pressure and ν is the kinematic viscosity. The subscripts i and j (=1-3) denote the three space coordinates, while $\overline{u_i' u_j'}$ are the Reynolds-stresses. The QUIC-CFD model calculates the characteristic velocity and length scale by using algebraic expressions. Hence, the turbulence modelling is achieved by a simplified zero-equation model based on the Prandtl's mixing length model (Prandtl, 1925; Cebeci & Smith 1974; Baldwin & Lomax 1978; Argyropoulos & Markatos 2015).

3. Results and discussion

Figure 1 presents the measured and predicted values of indoor PM_{10} during the total period of measurements. The zoom graph depicts the indoor PM_{10} concentration during the severe dust storm event which is the continuation of the highest peak of the main graph.

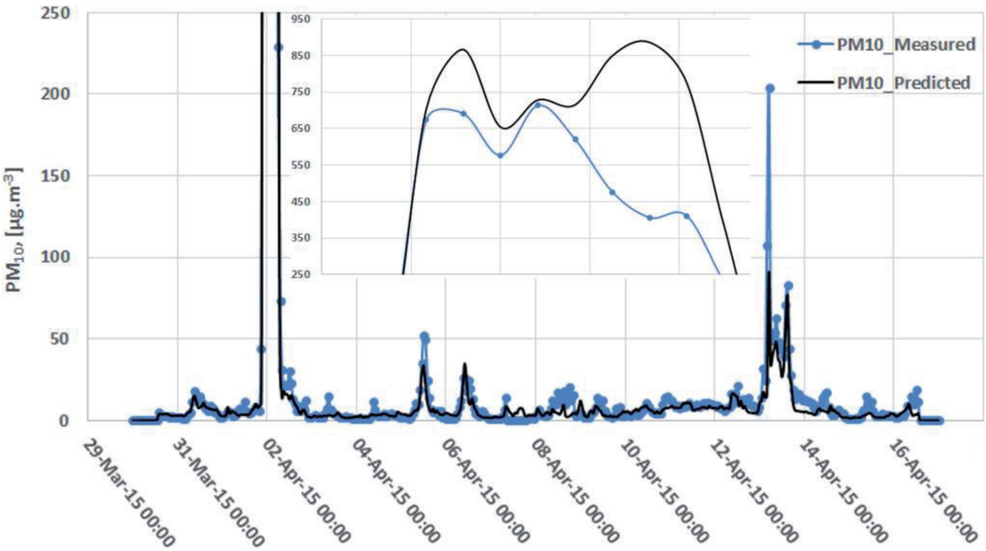

Fig. 1. Comparison of predicted (black solid line) and measured indoor (blue solid line and ●) PM10 levels

In Figure 1, it is observed that the predicted and measured values of indoor PM_{10} follow a relatively similar pattern. It is noticed that the model has a tendency to overestimate the PM_{10} concentration levels during the severe dust storm event. On the other hand, the model underestimates the PM_{10} levels for the secondary dust storm events on 13 April 2015. It is also seen that the model not only provides insights during the severe dust event, but also for normal days. It is worth mentioning that the predicted and measured values of PM_{10} during the severe dust storm event exceed the World Health Organization (WHO, 2006) and Qatar National Air Quality standards (50 $\mu g/m^3$ and 150 $\mu g/m^3$, 24hr average).

Figure 2 illustrates the concentration values for indoor $PM_{2.5}$ during the severe dust storm event and the total measurement period. It is observed that the predicted $PM_{2.5}$ values follow relatively similar motif to measured $PM_{2.5}$ and in a few cases are close to each other. The model also overestimates the measured $PM_{2.5}$ concentrations during the severe dust event and underestimates for the secondary dust storms (13-Apr-2015). Indoor $PM_{2.5}$ present the highest value, equal to 220 $\mu g/m^3$ for the predicted and 180 $\mu g/m^3$ for the measured values, as shown in Figure 2 (zoom graph). Both $PM_{2.5}$ concentration levels are higher than for the WHO guidelines (WHO, 2006) (25 $\mu g/m^3$, 24hr average).

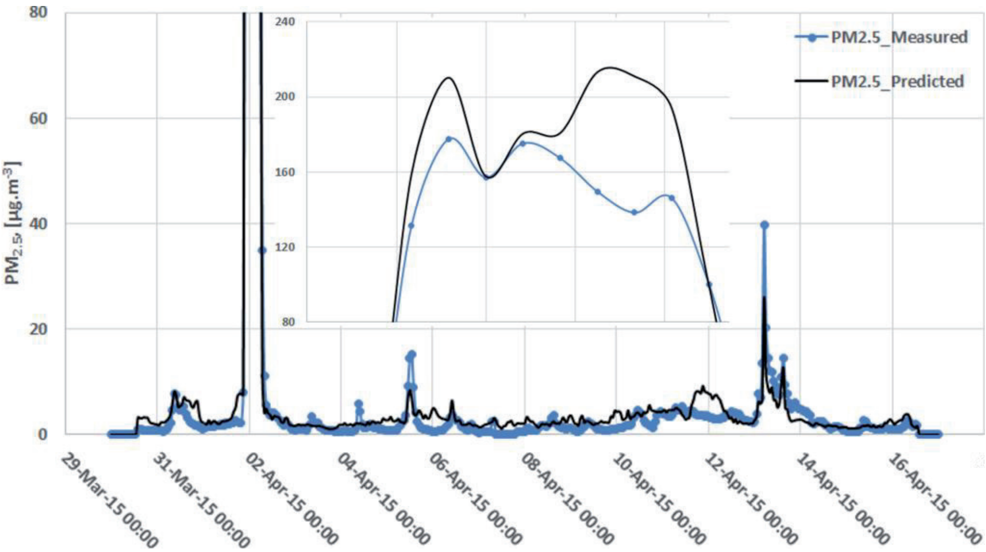

Fig. 2. Comparison of predicted (black solid line) and measured (blue solid line and ●) indoor $PM_{2.5}$ levels

The difference between measured and predicted values of indoor PM by the CONTAM model can be attributed to the fact that the ASHRAE correlation (Swami & Chandra 1988) used in the model caters only to low rise buildings. However, in our case the considered building has more complex geometry.

4. Conclusions

A numerical method was developed to investigate the PM building infiltration during a severe dust storm event. The measurements and predictions indicate that the airborne particulate matter levels are critical in many occasions and above the recommended limit values. The model exhibits encouraging agreement between the predicted and measured levels of PM_{10} and $PM_{2.5}$ during the dust storm event, but also for normal days.

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References

Ashraf A.M., Argyropoulos C.D., Olewski T., Vechot L., Kakosimos K.E. (2016). Comparative study on toxic gas infiltration in a non-process area using CFD and multi-zone models. Proc Hazards 26, Edinburgh, UK.

Argyropoulos C.D., Markatos N.C. (2015). Recent advances on the numerical modelling of turbulent flows. Applied Mathematical Modelling, 39, 693-732.

Baldwin B.S., Lomax H. (1978). Thin layer approximation and algebraic model for separated turbulent flows, AIAA 16, Aerospace Sciences Meeting.

Brook R.D., Rajagopalan S., Pope C.A., Brook J.R., Bhatnagar A., Diez-Roux A.V. et al. (2010). Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. Circulation 121, 2331-2378.

Bu-Olayan A.H., Thomas B.V. (2012). Dispersion model on $PM_{2.5}$ fugitive dust and trace metals levels in Kuwait Governorates. Environmental and Monitoring Assessment 184, 1731-1737.

Cebeci T., Smith A.M.O. (1974). Analysis of Turbulent Boundary Layers, Academic Press, New York.

Goudie A.S. (2014). Desert dust and human health disorders. Environmental International 63, 101-113.

Gowardhan A., Pardyjak E., Senocak I., Brown M. (2011). A CFD-based wind solver for an urban fast response transport and dispersion model. Environmental Fluid Mechanics 11, 439-464.

Hsieh N.H., Liao C.M. (2013). Assessing exposure risk for dust storm events-associated lung function decrement in asthmatics and implications for control. Atmospheric Environment 68, 256-264.

Nelson M, Brown M. (2013). The Quick Urban & Industrial Complex (QUIC) dispersion modelling system. Los Alamos National Laboratory.

Onishi K., Otani S., Yoshida A., Mu H., Kurozawa Y. (2015). Adverse health effects of Asian dust particles and heavy metals in Japan. Asia-Pacific Journal of Public Health 27, NP1719-26.

Pope C.A., Dockery D.W. (2006). Health effects of fine particulate air pollution: Lines that connect. Journal of the Air and Waste Management Association 56, 709-742.

Pope C.A., Ezzati M., Dockery D.W. (2009). Fine-particulate air pollution and life expectancy in the United States. The New England Journal of Medicine 360, 376-386.

Prandtl L. (1925). Report on investigation of developed turbulence. Zeitschrift fuer Angewandte Matematik und Mechanik 5, 136-139.

Song Z., Wang J., Wang S. (2007). Quantitative classification of northeast Asian dust events. Journal of Geophysical Research 112, D04211.

Srebric J., Yuan J., Novoselac, A. (2008). On-site experimental validation of a coupled multizone and CFD model for building contaminant transport simulations. ASHRAE Transactions 114, 1-8.

Swami, M.V., Chandra S. (1988). Correlations for pressure distributions on buildings and calculation of natural-ventilation airflow. ASHRAE Transactions 94,243-266.

Tsiouri V., Kakosimos K., Kumar P. (2015). Concentrations, sources and exposure risks associated with particulate matter in the Middle East Area - a review. Air Quality, Atmosphere and Health 8, 67-80.

Walton, G.N. (1989). AIRNET - A computer program for building airflow network modeling, National Institute of Standards and Technology, NISTIR 89-4072.

Wang L.L., Dols W.S., Chen Q. (2010). Using CFD capabilities of CONTAM 3.0 for simulating airflow and contaminant transport in and around buildings. HVAC&R Research 16, 749-763.

WHO (2006). Air quality guidelines global update 2005 particulate matter, ozone, nitrogen dioxide and sulfur dioxide. World Health Organization, Denmark.