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Analysis of health impact assessment to outdoor and indoor air pollution in a prototype building in Madrid (Spain)

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Abstract. People spend major part of their time inside places such as homes and offices, so it is very important to know the indoor and outdoor pollution in this type of studies. The atmospheric dispersion model WRF/Chem is used to know the outdoor pollution and meteorological conditions with high spatial (1 km) and temporal (1-hour) resolution and the building energy model EnergyPlus to simulate the indoor contaminants. EnergyPlus model is used to investigate the dynamic behaviour of pollutants with a single package using a multi-zone approach. 2016 year is used for the simulations with hourly outputs. Outdoor and indoor pollutions are linked to through the simulated infiltration process. The evaluation of outdoor, indoor air quality and human health effects was carried out considering different exposure profiles, for people working and living in an office and house located in the same building in the Madrid city center. The study takes into account different ventilation modes in the building and indoor emission scenarios (oven for heating, cooking, photocopy machine, smoke cigarettes). Health impact assessment considered mortality and hospital admissions, associated with exposure to PM_{2.5} and NO₂ taking into account the differences between the exposure profiles, which have been used to describe the time activity patterns of the people. The health impacts of emitting sources are highest in the warm months due to the operation of the air conditioning system. The health impact of indoor emission sources is higher than the outdoor pollution. People in the zone where the emitting sources are located would experience a mortality and morbidity of 2.5 times more than in the non-emitting zones.

Keyword: *Indoor pollution, exposure, health impact, buildings.*

1. Introduction

This work can be seen as a first step on the long road to a full understanding of the health effects of indoor air quality, enabling the design and implementation of strategies to control and mitigate the effects. Simulation models are useful tools for quantifying air pollutants as well as for estimating exposures in situations where measurements are not available. The concentrations of pollutants in outdoor and indoor air are key data to take into account in health impact assessments because people spend a large part of time in indoors places and a minimum part of their time outside. Epidemiological studies of air pollution have identified short-term associations of people's daily mortality and morbidity with the respective daily air pollution data [1]. Traditionally, the studies [2] focus on how



concentrations of air pollutants affect the health of the population and use measured outdoor air quality data and do not take indoor air pollution into account [3], although most citizens spend most of their time indoors [4]. Concentrations of air pollutants are often much higher inside buildings than outside because of indoor emissions [5]. When using data on measured concentrations in static outdoor locations, people's exposure to pollutants is not adequately taken into account, as people move around and spend a lot of time inside buildings. The concentrations inside buildings do not only depend on what comes in from outdoors, but also on the internal emission sources [6]. In the case of indoor pollution, it is affected by many factors, such as the concentration of outdoor pollutants, outdoor meteorology, infiltration rates, the intensity of emission sources, human activities in the building, the operating of heating, ventilation and air conditioning (HVAC) systems, etc. Therefore, this type of studies, are a challenge and although they may present some uncertainties, their results can help us to study the quality of air breathed and how it affects our health. Due to air exchange, indoor contaminant levels are generally higher when outdoor levels increase. However, higher levels can be found indoors when combustion sources are present [7] as presented in the results of this study. The novelty of this study is that it uses external concentrations and simulated external meteorology to know the indoor concentrations of the building, since until now the studies of levels of indoor contamination have used data measured by nearby control stations. Our simulation tool allows future simulations of indoor and outdoor pollution as described in the following sections, making it a simulation and prediction tool.

2. Material and methods

This section provides the description of the implemented methodologies into the simulation tool and the description the proposed case study. Outdoor air quality and meteorological simulation has been run with the EMIMO-WRF/Chem modelling system. WRF-Chem [8] is the Weather Research and Forecasting (WRF) model coupled with Chemistry. WRF is 3-D non-hydrostatic prognostic model that simulates mesoscale atmospheric circulations. Chem model simulates the emission, transport, mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology. Emissions are provided by the EMIMO model (UPM) [9]. WRF/Chem configuration is based on the International Air Quality Assessment Experiment Model Assessment Initiative joint simulation experiment. Indoor air quality and energy simulations have been run with the EnergyPlus [10] model for an office and house buildings. EnergyPlus is the U.S. Department of Energy's 3rd generation dynamic building energy simulation engine for modeling building, heating, cooling, lighting ventilating and indoor pollution. The Generic Contaminant Model in EnergyPlus allows for the integrated modelling of multizone contaminant and dynamic thermal behavior within a single simulation package. Short-term health impact assessment of different indoor emission scenarios has been done following BENMAP (EPA) methodology for the target person [11]. The percentage change in mortality/morbidity due to change in ambient exposure variable is derived from relative risks (RR) as estimated in epidemiological studies, assuming log-linear relationships between exposure and RR. Then can define $\beta = \ln(RR)/\text{Change}$. For this experiment, the following RRs have been used: Published RRs from: Health risks of air pollution in Europe – HRAPIE project. Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide (WHO Regional Office for Europe, 2013).

Using the health impact assessment module we calculate the estimated change in human mortality and morbidity between different emissions. The impacts are calculated from a base scenario without indoor emissions called S0. Table 1 describes the emission scenarios. For all scenario the NO₂ deposition rate is 2.0E-4 m³/s [12] and for PM_{2.5} 5.0E-5 m³/s [13]. The simulations have been run for the year 2016 with a time resolution of 1 hour. For the outdoor simulation, three computational domains have been setup with resolutions: 25 km (Iberian Peninsula), 5 km (Community of Madrid) and 1 km (Madrid City Council). These are 3D simulations, with 33 vertical levels up to 50 mb. A two floor building has been simulated for indoor air simulation, the upper floor is the house and the lower floor is an office. Each of the floors has 130 m² of surface. The office has three rooms with ten people

working from 6:0 to 18:00. The house has four rooms: bedroom, bathroom, kitchen and living room. The building is north facing and it has been simulated as if it was in the centre of Madrid, where the levels of pollutants are very high as shown in the results section. The comfort temperature range is set from 22° (heating) and 24° (cooling). In the office, there is only mechanical ventilation and in the house, there is natural ventilation for one hour through bedroom window. The cooling system (On in summer) is electrical and the heating is using gas (On in winter). There are two people living in the house. Both work and live in the same office and house. Activity patterns have been defined to calculate the exposure of an individual person; Figure 1 shows the defined profile for a weekday. For a weekend day, the time in the bedroom has been extended three hours and the office time has been changed to outdoor time

Table 1. Description of the emission scenarios

Scenario	Emission source	Location of the source	Time Profile	Emissions	Reference
S0	No emissions	-	-	-	-
S1	Photocopy machine	North room of the office	Weekdays 07-18	PM2.5: 6.7E-9 m3/s	[14]
S2	Gas stove	Kitchen of the house	Weekdays: 7:30 to 08:00, 14:00-15:00 and 21:00 to 22:00 Weekend days: 10:30 to 11:00, 14:00-15:00 and 22:00 to 23:00 Cold periods ;	NO ₂ : 56 ug/s PM2.5: 1.56 mg/min	[15]
S3	Oven for heating	Living room of the house	Weekdays: 15:00 to 16:00 and 22:00 to 00:00 Weekend days: 15:00 to 17:00 and 23:00 to 01:00	NO ₂ : 3.0E-8 m3/s	[16]
S4	One person, two cigarettes/hour	Living room of the house	Weekdays: 15:00 to 16:00 and 22:00 to 00:00 Weekend days 15:00 to 17:00 and 23:00 to 01:00	PM2.5: 0.33 mg/min	[17]
S5	Two people, two cigarettes/hour	Living room of the house	Weekdays: 15:00 to 16:00 and 22:00 to 00:00 Weekend days 15:00 to 17:00 and 23:00 to 01:00	PM2.5: 0.66 mg/min	[18]

3. Results and discussions

Figure 2 shows an example of the outputs from the EMIMO-WRF/Chem modelling tool. It is the outdoor concentrations of NO₂ in the Community of Madrid (5 km spatial resolution) corresponding to the annual average for 2016 and the corresponding mean wind vectors on the simulation area. It can be seen perfectly as the highest concentrations are observed in the central area of the domain that would correspond to the city of Madrid, where traffic flows are higher. Also in this central area, we can see how the winds are lower than the winds from the external areas. The NO₂ values reach of up to 49 µg/m³ that exceeds the limit value established by the European directive on air quality, which says that a city may not exceed 40 µg/m³ of NO₂ annual average; then the city of Madrid is a place with air pollution problems and the road traffic is one of the most important causes. The next step in the modeling chain has been the implementation of indoor simulations, for the scenarios described in Table 1. In all these simulations, the outdoor hourly meteorological and air quality data (as presented

in figure 2) generated by the WRF/Chem model have been used as input (temperature, radiation, humidity, wind and outdoor concentrations) to the EnergyPlus model.

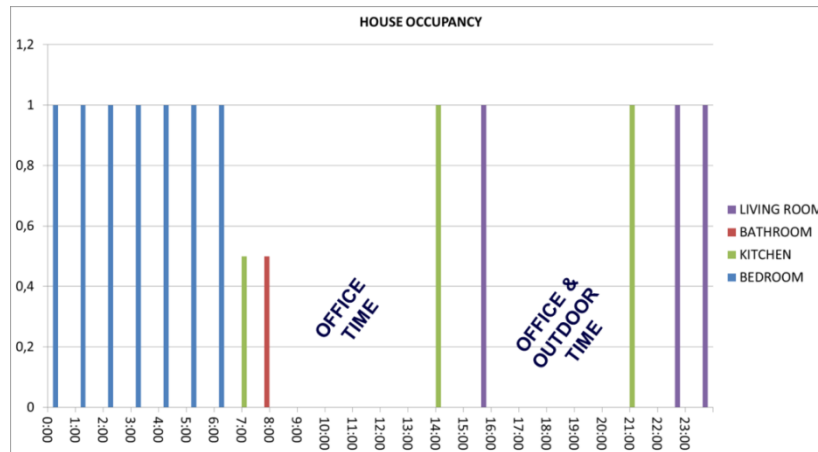
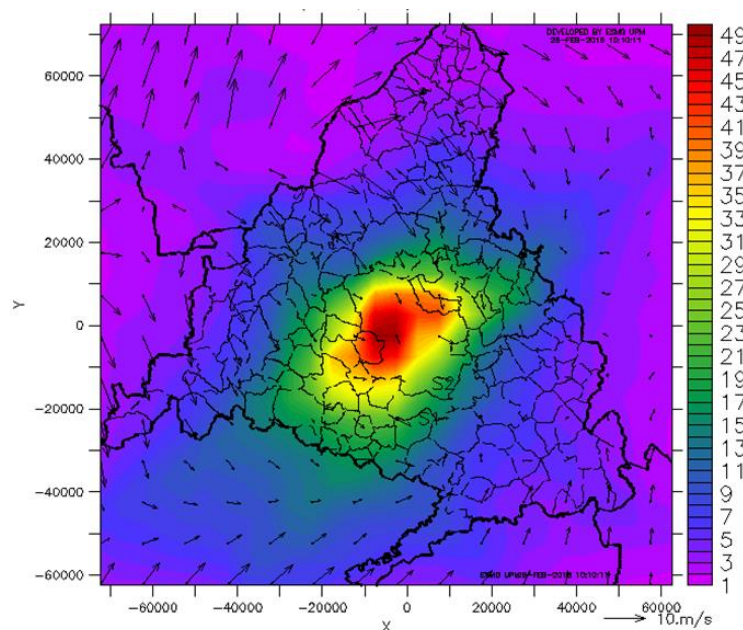


Figure 1. Activity pattern for a weekday



NO₂ (ug/m³) YEARLY AVERAGE 2016

Figure 2. 2016 mean NO₂ concentration (μg/m³) and wind vectors for Madrid Community (5 km spatial resolution).

Outdoor simulation evaluation is performed based on comparison of simulated and observed air pollution concentrations at 43 monitoring stations of the Madrid air quality monitoring networks for the year 2016. The main results of the evaluation process are that the values of R^2 are between 0.7 and 0.8. In all station locations, the mean square error of the central root (CRMSE) is less than 1 and values are between 0.5 and 1.0. The ratios of the standard deviation between modelled and measured values are around 1. These statistical parameters show a good performance of the outdoor simulation (WRF/Chem). In the case of the indoor simulation, the results could not be evaluated due to the lack of physical measurements and the simulation on a prototype building. The next step in the investigation will be the simulation of a real building where measurements can be made. In the case of indoor

simulations, the most important factor is not the precise concentrations of each room but the differences between the simulated scenarios. This allows us to present results without an exhaustive evaluation of the uncertainty of the individual data of each scenario. For the reference person, the concentrations to which he or she has been exposed have been calculated for each of the scenarios and the differences between these scenarios have been used in the health impact assessment.

Now we are going to present in summarized form the main data extracted from the study, the average annual mortality increase due to NO₂ emissions from cooking is 0.59%. While the average annual increase in mortality from the use of the heating oven is 0.21 %. The photocopy machine produces an increase of 0.27% (annual mean) in hospital admissions due to respiratory causes. The particles emitted when smoking 2 people, increases the daily hospital admissions in 0.21% of yearly average. As a more detailed example of the indoor emissions health impacts and to show the capabilities of the modeling system we present the figure 3. It shows the daily variability of the mortality change due to gas stove emissions. The impacts are higher in the warm period due to the operation of the air conditioning. In the months of March and October are observed the days of lower impacts, not having to operate the HVAC to maintain the temperature range (22 °C - 24 °C).

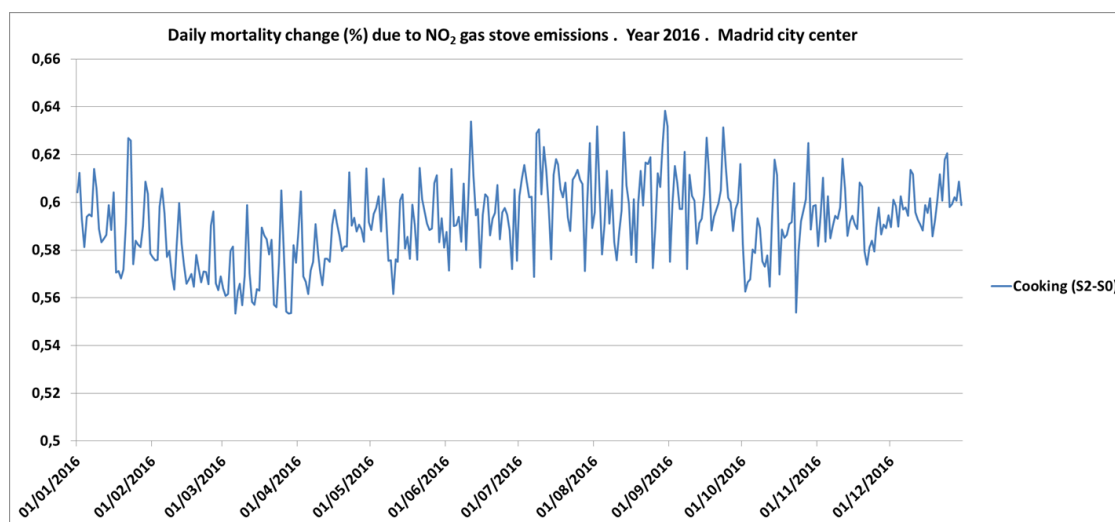


Figure 3. Daily mortality change (%) due to NO₂ gas stove emissions. Year 2016. Madrid city center.

4. Conclusions

An assessment of the short-term health impact of different indoor emission scenarios has been carried out. The concentrations to which the reference person has been exposed have been calculated because of predefined activity patterns. To calculate the exposure it was necessary to carry out one outdoor simulation and two indoor simulations: in the office and at home. The outdoor air quality simulation was performed with the EMIMO-WRF/Chem model (emission-meteorological-chemical model). Indoor simulations were performed with the EnergyPlus model, which also takes into account the energy consumed and the functioning of the air conditioning system (thermal and ventilation process). In general, the ventilation increases indoor pollution coming from outdoor sources, especially in high-polluted environments. The highest impact on health is produced by the emissions that are released when cooking and the health impacts of emitting sources are highest in the warm months due to the operation of the air conditioning system.

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References

- [1] Analitis A, Katsouyanni K, Dimakopoulou K et al. Short-Term Effects of Ambient Particles on Cardiovascular and Respiratory Mortality. *Epidemiology*. 2006;17(2):230-233. doi:10.1097/01.ede.0000199439.57655.6b
- [2] Bell M, Dominici F, Samet J. A Meta-Analysis of Time-Series Studies of Ozone and Mortality With Comparison to the National Morbidity, Mortality, and Air Pollution Study. *Epidemiology*. 2005;16(4):436-445. doi:10.1097/01.ede.0000165817.40152.85
- [3] Atkinson R, Carey I, Kent A, van Staa T, Anderson H, Cook D. Long-Term Exposure to Outdoor Air Pollution and Incidence of Cardiovascular Diseases. *Epidemiology*. 2013;24(1):44-53. doi:10.1097/ede.0b013e318276ccb8
- [4] Schweizer C, Edwards R, Bayer-Oglesby L et al. Indoor time–microenvironment–activity patterns in seven regions of Europe. *J Expo Sci Environ Epidemiol*. 2006;17(2):170-181. doi:10.1038/sj.jes.7500490
- [5] Spengler J, Sexton K. Indoor air pollution: a public health perspective. *Science*. 1983;221(4605):9-17. doi:10.1126/science.6857273
- [6] Shrubsole C, Ridley I, Biddulph P et al. Indoor PM_{2.5} exposure in London's domestic stock: Modelling current and future exposures following energy efficient refurbishment. *Atmos Environ*. 2012;62:336-343. doi:10.1016/j.atmosenv.2012.08.047
- [7] Levy J. Impact of Residential Nitrogen Dioxide Exposure on Personal Exposure: An International Study. *J Air Waste Manage Assoc*. 1998;48(6):553-560. doi:10.1080/10473289.1998.10463704
- [8] Grell G, Peckham S, Schmitz R et al. Fully coupled “online” chemistry within the WRF model. *Atmos Environ*. 2005;39(37):6957-6975. doi:10.1016/j.atmosenv.2005.04.027
- [9] San José R, Pérez J, Morant J, González R. European operational air quality forecasting system by using MM5–CMAQ–EMIMO tool. *Simulation Modelling Practice and Theory*. 2008;16(10):1534-1540. doi:10.1016/j.simpat.2007.11.021
- [10] Crawley D, Lawrie L, Winkelmann F et al. EnergyPlus: creating a new-generation building energy simulation program. *Energy Build*. 2001;33(4):319-331. doi:10.1016/s0378-7788(00)00114-6
- [11] Sacks J, Lloyd J, Zhu Y et al. The Environmental Benefits Mapping and Analysis Program – Community Edition (BenMAP–CE): A tool to estimate the health and economic benefits of reducing air pollution. *Environmental Modelling & Software*. 2018;104:118-129. doi:10.1016/j.envsoft.2018.02.009
- [12] Persily A, Musser A, Emmerich S. Modeled infiltration rate distributions for U.S. housing. *Indoor Air*. 2010;20(6):473-485. doi:10.1111/j.1600-0668.2010.00669.x
- [13] Long C, Suh H, tros Kout P. Using Time- and Size-Resolved Particulate Data To Quantify Indoor Penetration and Deposition Behavior. *Environ Sci Technol*. 2001;35(22):4584-4584. doi:10.1021/es011283d
- [14] Destailats H, Maddalena R, Singer B, Hodgson A, McKone T. Indoor pollutants emitted by office equipment: A review of reported data and information needs. *Atmos Environ*. 2008;42(7):1371-1388. doi:10.1016/j.atmosenv.2007.10.080
- [15] Turner W, Logue J, Wray C. A combined energy and IAQ assessment of the potential value of commissioning residential mechanical ventilation systems. *Build Environ*. 2013;60:194-201. doi:10.1016/j.buildenv.2012.10.016
- [16] Burke J, Zufall M, Özkaynak H. A population exposure model for particulate matter: case study results for PM_{2.5} in Philadelphia, PA. *J Expo Sci Environ Epidemiol*. 2001;11(6):470-489. doi:10.1038/sj.jea.7500188
- [17] Fabian P, Adamkiewicz G, Levy J. Simulating indoor concentrations of NO₂ and PM_{2.5} in multifamily housing for use in health-based intervention modeling. *Indoor Air*. 2011;22(1):12-23. doi:10.1111/j.1600-0668.2011.00742.x
- [18] Klepeis N, Apte M, Gundel L, Sextro R, Nazaroff W. Determining Size-Specific Emission Factors for Environmental Tobacco Smoke Particles. *Aerosol Science and Technology*. 2003;37(10):780-790. doi:10.1080/02786820300914