PAPER #3.04

METHODOLOGY FOR QUANTIFICATION OF EXHALED POLLUTANT EMISSIONS IN RESIDENTIAL BUILDINGS

Robiel Eilyn Manzueta Felix[a], César Martín-Gómez[a], Amaia Zuazua-Ros[a], Juan Carlos Ramos González[a], Leonardo De Brito Andrade[b], Arturo H. Ariño[a]

[a]Universidad de Navarra, Spain

[b]Federal University of Santa Caterina, Florianópolis, Brazil

How to cite

Manzueta Felix, Robiel Eilyn, César Martín-Gómez, Amaia Zuazua-Ros, Juan Carlos Ramos González, Leonardo De Brito Andrade, and Arturo H. Ariño. "Methodology for quantification of exhaled pollutant emissions in residential buildings" In *Proceedings of 3rd Valencia International Biennial of Research in Architecture. Changing priorities*. Valencia. 2022. https://doi.org/10.4995/VIBRArch2022.2022.15172

ABSTRACT

It is known that indoor air is affected by outdoor air, thanks to the various studies that have been conducted in this area, the causes can be varied, from infiltration of buildings, natural or mechanical ventilation. Although it is known that transportation is one of the major contributors to this problem, studies have concluded that there is a proportion of pollutants coming from 'non-specific sources of human origin', all this emphasizes the importance of identifying and quantifying the sources of air pollution.

The intention of this research project, is to characterize and quantify the pollutants that are emitted from residential buildings through their ventilation systems, and how such exhalation affects urban air quality both outdoors and, through recapture, indoors.

The design of a viable methodology for monitoring two residential buildings in Pamplona (Spain) has been proposed, involving aspects such as the extension of the city where the buildings selected for the project are located, their typology, the areas destined for the ventilation systems, the equipment chosen for the quantification of pollutants and the procedure to be followed. All this procedure represents the core of the monitoring process.

Thanks to this methodology, the researchers intend to present results of the quantification of pollutants such as Carbon Dioxide (CO_2), Carbon Monoxide (CO), Methane (CH_4), Particulate Matter (PM), Volatile Organic Compounds (VOC), resulting from the exhalation of residential buildings. These results are the foundation for demonstrating how residential buildings can become another source of pollution for urban environments.

KEYWORDS

Ventilation systems; I/OAQ; atmospheric pollution; emission; building services; monitoring; cities; urban.

1. INTRODUCTION

Outdoor air pollutants are significant factors influencing the levels of the main indoor air pollutants (Hänninen and Goodman 2019) (Karagulian et al. 2015). Research on the relationship between type of residence and health is being carried out, but evidence is still partial and fragmentary, and often subjective or difficult to adscribe to specific causes rather than general factors. For example, some results indicate that the residents' perceptions of the quality of the urban environment and satisfaction with their residential situation are determined by a large number of different residential aspects, one of these being environmental hygiene where air pollution is a factor (Bonnefoy et al. 2004). In another example, in densely populated cities where residents live in high-rise buildings, pollutants are susceptible to propagate through emissions from building ventilation ducts and facilitate transmission in the community, contributing to a deterioration of both outdoor and indoor air quality through outdoor air reintake. The most affected areas of buildings are those on the upper floors, near the vent pipe (Guo et al. 2022).

Quality monitoring data are necessary to establish the air quality-health interplay, as well as ensuring air quality improvement through prevention and reaction to shifting air conditions. Research is being carried out to improve monitoring. For example, a new method for air monitoring and emergency management at construction where edge computing and Building Information Modelling (BIM) are used has been proposed (Xu, Ran, and Rao 2022) that could be fed data from sensor suites to accomplish real-time analysis.

We have designed an experimental setup trying to accomplish such integrated monitoring using real-life data. Our current research project 'Quantifying pollutants originated by the exhalation of buildings in urban environments'- EXHAL (Ariño et al. 2020), hypothesizes that the air exhaled from the inside through the ventilation systems of residential buildings contains pollutants that can become another source of pollution (Dorregaray-Oyaregui et al. 2022) in Fig. 1. Our setup integrates a suite of sensors in real buildings and measures the exhalation of contaminants from ventilation systems coming out of residential units.

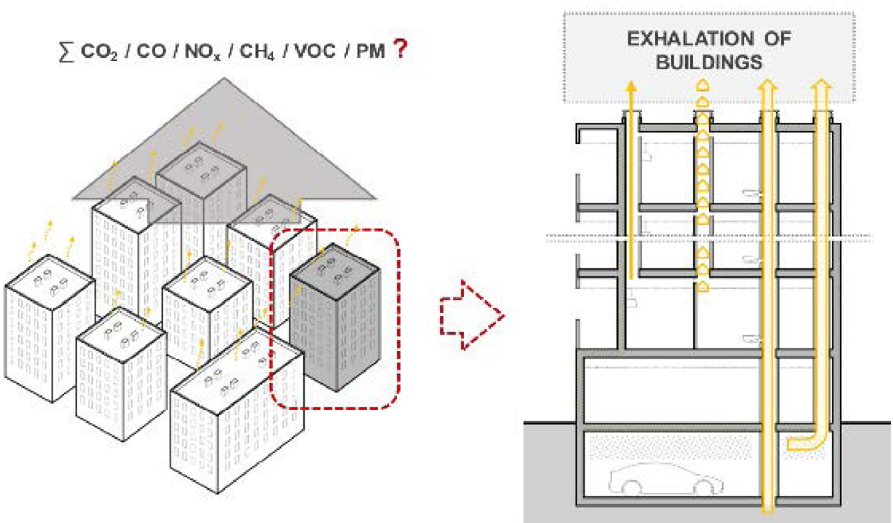

Figure 1. Concept image of research project EXHAL. Source: (Ariño et al. 2020)

2.CONTEXT

2.1. Pollutants

We have selected five main pollutants that can be generated in residential buildings from various common sources or processes and that can be therefore exhaled through ventilation systems: carbon monoxide (CO) from incomplete combustion such as smoking, internal combustion engines (ICE) in garages, or physiological processes; carbon dioxide (CO2) from combustion such as stoves, ICEs or respiration; methane (CH4) from organic matter decomposition such as e.g. in sinks; particulate matter (PM) from multiple processes, combustion, ICEs and outdoor air intake; and volatile organic compounds (VOC) from various household chemical, cleaning agents, woodchip furniture degassing, or toiletries, among other sources. Some of these pollutants are regulated in guidelines and regulations. A summary of the recommendations and/or regulations for concentrations in Spanish, European or international guidelines is shown in Fig.2.

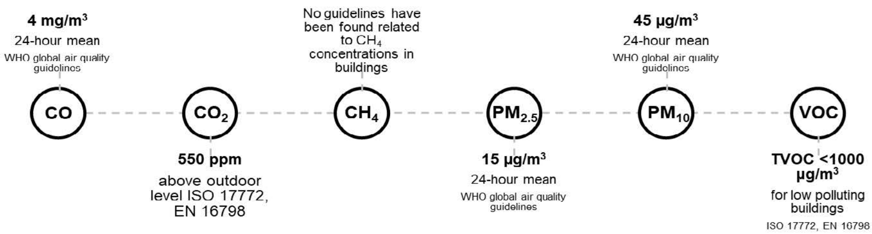

Figure 2. Summary of recommended and/or regulated concentration values of the pollutants considered in this paper. Source: (Robiel Manzueta 2022)

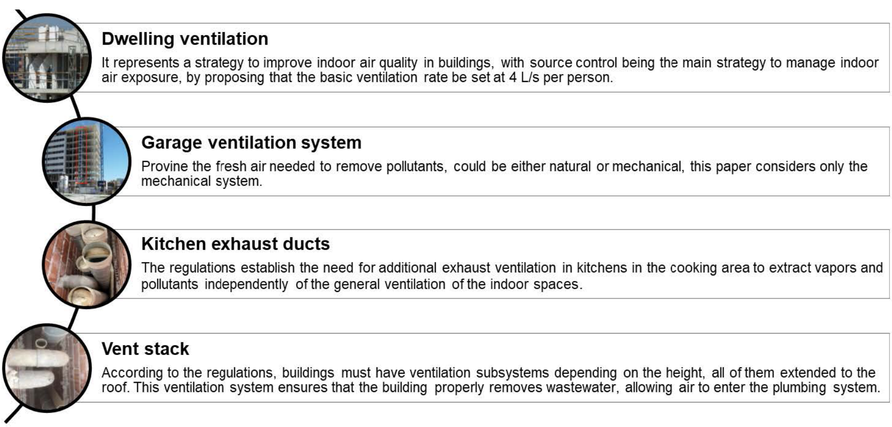

Figure 3. Summary of ventilation system considered in the EXHAL research project. Source: (Robiel Manzueta 2022)

2.2. Ventilation system

We adopted the classification of ventilation systems set out in the Spanish regulations (Gobierno de España 2019) as a reference for the quantification of exhalation in buildings (Fig.3): dwelling ventilation, garage ventilation system, kitchen exhaust ducts, and vent stack.

2.3. Buildings

We selected two tower-typology buildings for this study, named AB and AC in Fig.4, located in one of the new extensions of the city of Pamplona, Navarra, Spain to test our quantification methodology. The buildings have a similar construction methodology and are surrounded by green areas. Their expanse was designed to create a sustainable area that builds a sense of community, leading to a better and more sustainable lifestyle. Both were built following the 2006 Spanish Building Code (Gobierno de España 2019): the buildings were designed with specific areas for installations, where ducts are used for indoor air extraction and kitchen hood (one for each house), garage, vent stack and auxiliary ventilation.

2.4. Equipment

Gas analyzer platform

For the continuous quantification of gaseous pollutants (CO, CO_2, CH_4 and VOC) we used a research-class multi-gas analyzer (GASERA ONE) based on an infrared photoacoustic spectroscopy engine with a patented ultra-sensitive cantilever pressure sensor, designed for use in laboratory, light industry or relatively clean environments and capable of measuring very low concentrations of pollutants (Gasera Ltd. 2017), having detection limits typically in the sub-ppb range, coupled with a 12-probe programmable sampler, fitted with particle filters, and installed such as to avoid potential interference from out-of-range conditions such as condensation or excessive vibration using moisture traps and shock-absorbing surfaces. Insulated metal tubes were run from the building outlets to the multi-sampler. The sampling schedule was programmed to ensure excess flushing of the sample probes between measurements, providing an approximate 15-minute cycle between consecutive samples from the same probe.

Figure 4. Location of AB and AC buildings in Pamplona, Spain. Source: (Sara Dorregaray-Oyaregui 2020)

PM concentration meters

We used two PM meters:

a) The real-time electrometric module of a Dekati® eFilterTM gravimetric assembly. Continuous sample airflow through the whole assembly was ensured by an external mechanical pump providing a 25 l·min-1. The real-time module can measure particles of up to 3 µm, with a minimum particle size of 4 nm at 5 kV. The device's sensitivity is 1 µg/m3 for 70 nm particles and the measurement frequency is 1 s (Dekati Ltd. 2018). A 12-mm low-density polyethylene (LDPE) tube was run to the sampling point. Bypass valves allowed calibration by diverting inflow air through a particle filter for calibration.

b) Low-cost optical particle counters (OPC), Plantower PMS5003, connected to a battery-operated Arduino Mega 2560 platform fitted with real-time clock and SD-card memory reader. Operation was ensured by an ad-hoc application program (Alba et al., unpublished). Each sensor was placed directly inside the ventilation stack. Measuring range was set to 2.5-10 µm. Design resolution was 1 µg/m³, but the consistency error is actually up to 10 µg/m³ for the low end of the concentration range typically found in indoor air (0~100µg/m³).

Flow meters

We calculated ventilation flow by measuring air speed directly in the vent pipes or in constant-section extension tubes. We used hot-wire anemometers (Testo 405i) with a 9-mm probe for smaller pipes and vane anemometers (Testo 410i) for large-section ducts such as garage ventilation systems. All were rigged with DC supply for continuous operation and communicated via Bluetooth to a receiving Android tablet for data recording. Measuring range was 0-30 m/s with a 0.01 m/s resolution.

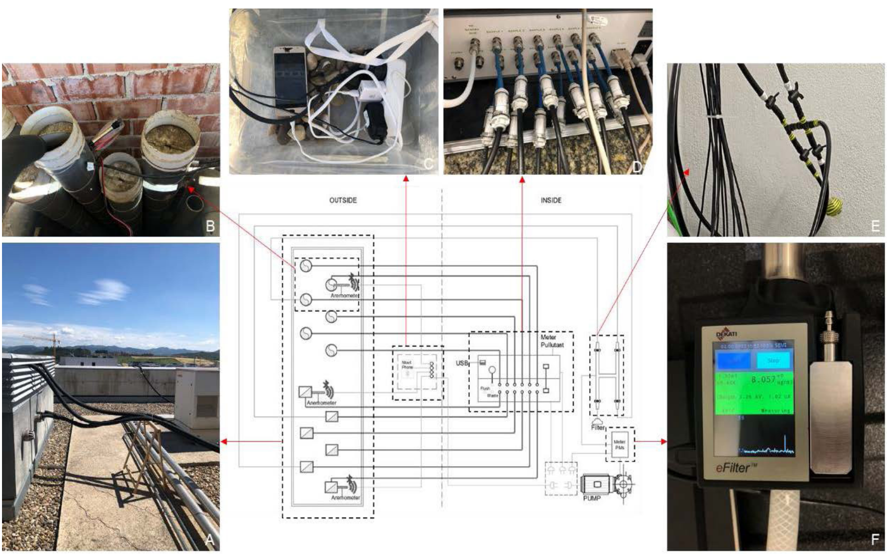

Figure 5. Scheme of quantification methodology. Source: (Robiel Manzueta 2022)

3. METHODOLOGY

We show the measurement methodology schematics in Fig.5 with an example from the AC building. Fig.5A shows the ventilation systems cabin from where the tubes are connected and Fig.5B displays several ducts with gas and airflow probes. Fig.5C is the cabinet containing DC sources and receiving device for airflow meters. Fig.5D shows the particle filters at the multi-probe gas sampler inlets and the probes running to various ducts, while Fig.5E shows the pipes, valves and calibration running to the Dekati particle meter shown in operation in Fig.5F, with the electrometric unit shown at right.
Measurements were taken in 2 to 4 week stretches in each building of continuous operation covering various climatological conditions, alternating buildings by relocating the equipment. During the initial tests and runs, we identified a number of issues that required specific solutions, often leading to re-runs of the experiments. Among these, we can cite:

- Weather sensitivity and extreme temperature fluctuations, leading to condensation and requiring insulation and moisture traps at the lowest probe points;
- Potential turbulent flow in pipes, requiring careful positioning of the airflow probes within the laminar flow regions of the pipes and speed integration and modelling;
- Occasional loss of signal (LOS) from sensors communicating with receiver devices leading to data gaps, requiring longer or repeated measurements for integration and careful placement of probes within range and line-of-sight, as well as frequent data collection;
- Occasional clogging of smaller probes due to insect activity, that could be detected by analyzing the data, leading to periodical pressure-cleaning of the probes;
- Vibration and noise transmitted from the gas analyzer, multi-sampler and pumps to the building, requiring acoustic and vibration insulation;
- Static buildup in PM probes, requiring large-section probes and high airflow to minimize particle adsorption to the probe walls.

4. RESULTS

As the EXHAL project is still underway, the latest research findings are not yet available. We present here
a preliminary summary of results for some of the pollutants quantified in each building, showing the
averages of one month of data in each building, that can give a fair idea of the levels measured overall.
Table 1 lists the specific duct sampled in each building that was sampled.

Sample number/ Building	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8	Sample 9	Sample 10	Sample 11	Sample 12
AB	Environment A	Environment B	Fecal A	Garage A	Bathroom B	Bathroom C	Bathroom D	Bathroom A	Kitchen A	Kitchen B	Kitchen C	Kitchen D
AC	Kitchen A	Kitchen B	Environment A	Bathroom A	Bathroom B	Fecal A	Bathroom C	Bathroom D	Environment B	Kitchen B	Kitchen B	Fecal B

Table 1. Ducts and vents sampled in each building

4.1. AB building

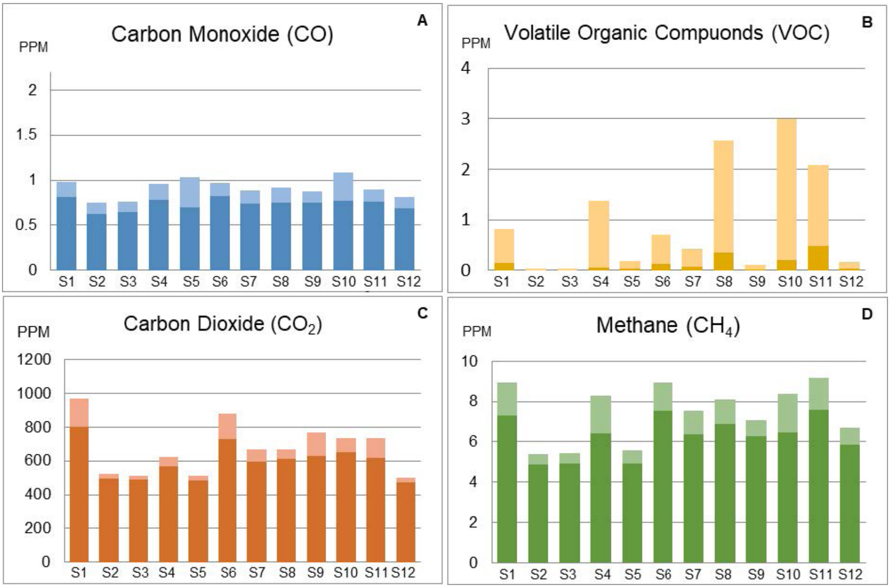

Figure 6. Averages (dark color) and standard deviations (light color) of a) CO, b) VOC, c) CO_2 and d) CH_4, concentrations (ppm) in AB building; measurements for one month of data

The average CO level measured was less than 1 ppm (Fig.6A), well within the range considered normal for urban areas without much traffic.
VOC levels, however, were extremely variable (Fig.6B). We run a series of tests using VOC probes and found no particular calibration problems, so we must assume that such variations can be normal within buildings. This remains an area under active research.
In most of the samples, the mean CO_2 concentrations (Fig. 6C) were consistent with current ambient levels (400 ppm) and generally did not exceed 700 ppm, which is consistent with the levels of natural urban air. However, the ambient air had a concentration generally higher than the indoor air. We cannot discard that, as observed b6 our ambient probe could be biased by boiler exhaust also venting from the top of the building.
Methane levels (Fig.6D) were measured in the range of 4-6 ppm and showed little variation between probes. We had expected a higher level in the vent stack, but it did not materialize in these first samples.

4.2. AC building

The CO levels (Fig.7A) in the AC building were also consistent with a low emission, giving only increased levels for two samples one instance of dwelling ventilation and the vent stack.
We also observed a higher variation in the VOC levels (Fig.7B), but contrary to the AB building some ducts were consistently stable. As the measurement spanned only one month of data

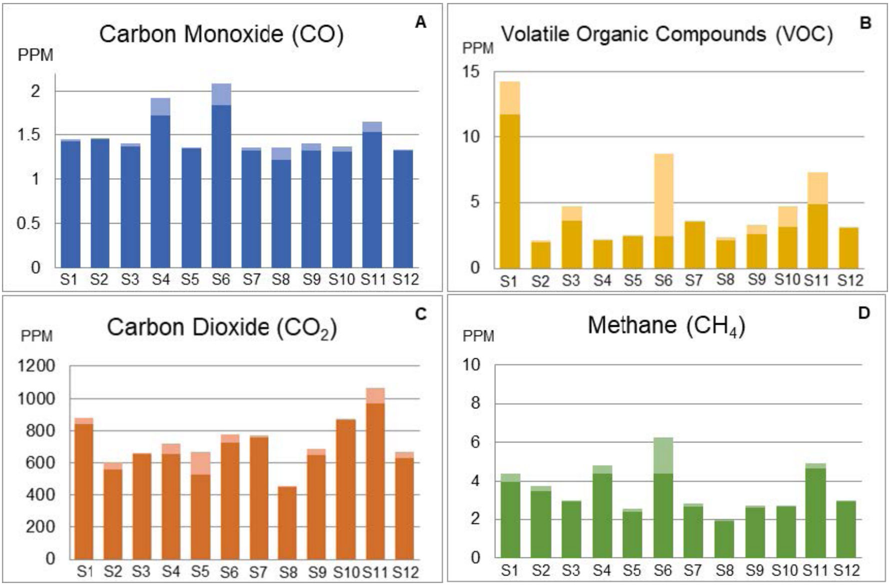

Figure 7. Averages (dark color) and deviations (light color) of a) CO, b) VOC, c) CO_2 and d) CH_4, concentrations (ppm) in AC building; measurements for a month

that did not overlap with that of the AB building, we cannot discard that the activity in the units being measured showed an occupation pattern that was different in both buildings.

CO_2 averages (Fig.7C) were consistent with expected values for indoor air, reaching a maximum in one kitchen. These values may vary depending on the ventilation habits by the unit inhabitants.

Methane levels were generally lower, however, than those observed in the AB building.

5. CONCLUSIONS

In the absence of literature on similar measurement methodologies, we developed and tested a procedure for quantifying the concentrations of pollutants exhaled by ventilation systems into urban air.

The methodology developed is complex and difficult to carry out because of all the factors to be considered (type of pollutants, ventilation systems, type of equipment/sensor, measurement units, measurement range, stations, building typology, transport and calibration of equipment, data collection and data interpretation). Based on these aspects, the following conclusions have been obtained:

- Quantification of pollutants from exhalation from residential buildings can be done using the proposed methodology.
- None of these studies have been conducted before, which makes the methodology complex, considering that the sensors on the market may not correspond to all the requirements of the project.
- Implementing the methodology requires a great deal of effort and requires constant calibration, checking, and data collection.

- Due to inconsistent values and potential technical failures of the equipment, the particle matter measurement has been discarded. The equipment protocol will be reviewed and new measurements will be conducted at other stations.
- According to results, one of the buildings measured had CO in excess of the value considered normal in natural air in urban environments (0.02ppm) and CH4 higher than is, which indicates increased levels of pollutants within the natural environment.
- Consequently, the measurements support the hypothesis of the existence of another source of air pollution due to the exhalation of pollutants from buildings into urban environments.

6. FUTURE STEPS

As the EXHAL research project, with which this paper is associated, is an ongoing project, the following steps must be followed:

- Measurements should be taken at different stations to make comparisons and conclusions that will benefit society.
- Unexpected trends and values have been observed for some pollutants without any reasonable explanation, so further analysis will be carried out by integrating new variables.
- Integration of new, low-cost equipment with a view to expanding accessibility is highly recommended.
- Simplify the methodology of quantification of pollutants exhaled from buildings into urban environments.

ACKNOWLEDGEMENTS

The Spanish Ministry of Science, Innovation and Universities for funding the research project 'Quantifying pollutants originated by the exhalation of buildings in urban environments' n. PID2019-104083RB-I00.

Federal University of Santa Catarina for financial the postdoctoral. Leonardo De Brito Andrade.

PhD fellowship FPU20/04936 Ministry of Universities (Spain). Robiel Manzueta.

REFERENCES

Ariño, Arturo H., Leonardo De Brito Andrade, Sara Dorregaray-Oyaregui, Robiel Manzueta, César Martín-Gómez, Juan Carlos Ramos, Bruno Sánchez Sáiz-Ezquerra, and Amaia Zuazua-Ros. “Cuantificación de Contaminates Originados de La Exhalación de Los Edificios En Entornos Urbanos - EXHAL.” 2020, https://ambiun.com/exhal/.

Bonnefoy, Xavier R, Isabella Annesi-Maesano; Luis, Moreno Aznar, Matthias Braubach, Ben Croxford, Maggie Davidson, et al. 2004. “Review of Evidence on Housing and Health.” In *Fourth Ministerial Conference on Environment and Health*, 1–24.

Dekati Ltd. “Dekati ® EFilterTM Brochure.” 2018, https://www.dekati.com/.

Dorregaray-Oyaregui, Sara, Arturo H. Ariño, Leonardo De Brito Andrade, Amaia Zuazua-Ros, Juan Carlos Ramos, Robiel Manzueta, Bruno Sánchez Sáiz-Ezquerra, and César Martín-Gómez. “The Conceptualization of Exhalation in Buildings.” *CLIMA 2022 Conference*, no. SE-Health & Comfort (May), https://doi.org/10.34641/CLIMA.2022.424.

Gasera Ltd. 2017. “GASERA ONE User Manual.” Gasera Lemminkäisenkatu 59 FIN-20520 Turku Finland. 2017, https://www.gasera.fi/product/gaseraone/#.

Gobierno de España. “Documento Básico HS Salubridad.” *Código Técnico de La Edificación (CTE)*, 2019, https://www.codigotecnico.org/pdf/Documentos/HS/DBHS.pdf.

Guo, Guang Ze, Yong Yu, K.C.S. Kwok, and Yu Zhang. “Air Pollutant Dispersion around High-Rise Buildings Due to Roof Emissions.” *Building and Environment* 219 (July): 109215, https://doi.org/10.1016/j.buildenv.2022.109215.

Hänninen, Otto, and Patrick Goodman. “Outdoor Air as a Source of Indoor Pollution.” In *Issues in Environmental Science and Technology*, 2019 January: 35–65, Royal Society of Chemistry. https://doi.org/10.1039/9781788016179-00035.

Testo SE & Co. KGaA. “Anemómetro Térmico Testo 405i Para Smartphone.” 2018, https://doi.org/1985 1723/cg/ITSA/07.2018.

Xu, Zhao, Yinsai Ran, and Zezhi Rao. “Design and Integration of Air Pollutants Monitoring System for Emergency Management in Construction Site Based on BIM and Edge Computing.” *Building and Environment* 211 (March) 2022: 108725, https://doi.org/10.1016/j.buildenv.2021.108725.

Zhou, Yong; Zheng, Haoxin. “Digital Universal Particle Concentration Sensor PMS7003. Data Sheet.” 2016, https://www.aqmd.gov/docs/default-source/aq-spec/resources-page/plantower-pms5003-manual_v2-3.pdf.