The conceptualization of exhalation in buildings

Sara Dorregaray-Oyaregui [a], Arturo Ariño [b], Leonardo Andrade De Brito [d], Amaia Zuazua-Ros [a], Juan Carlos Ramos [c], Robiel Manzueta [a], Bruno Sánchez Sáiz-Ezquerra[a], César Martín-Gómez [a]

[a] Universidad de Navarra, Department of Construction, Building Services and Structures, Campus Universitario, 31009, Pamplona, Spain.

[b] Universidad de Navarra, Department of Environmental Biology, Campus Universitario, 31009, Pamplona, Spain.

[c] Universidad de Navarra, TECNUN School of Engineering, Department of Mechanical Engineering and Materials, Thermal and Fluids Engineering Division, Paseo de Manuel Lardizábal 13, 20018 San Sebastián, Spain.

[d] Department of Rural Engineering. Federal University of Santa Catarina. Florianopolis-SC, 88034-000, Brazil.

Abstract. Among the sources of urban air pollution, the gases and airborne particles coming out from residential buildings through normal ventilation outlets are often neglected or poorly understood. Yet, it carries the potential to deeply affect urban air quality, given the universal ubiquity and function of dwellings. The climate emergency declaration approved by the European Parliament on November 28th, 2019, calls for urgent science-based action to curtail it. Our research explores the concept of building exhalation, through research aimed at characterizing and quantifying pollutants leaving residential buildings through their ventilation systems, and how such exhalation impacts urban air quality both outside and, through recapture, inside dwellings. We have set an intensive monitoring system in residential buildings in Pamplona (Spain) to obtain hard data about selected pollutants and their exhalation from buildings, thereby helping define the complete impact of buildings as inhabited units in cities. The verification of this main statement lays on the resolution of several future research questions, which are stated in order to set the boundaries and define the path of this text, developing the concept of exhalation of buildings and the factors involved. To confirm the validity of this hypothesis, an experimental campaign is being carrying out in the city of Pamplona (Spain), which has the goal of quantifying the pollutants exhaled by residential buildings through the ventilation systems. This project is included in the global concern about the unknown pollutants sources and the need of defining the complete impact of buildings as inhabited units in cities.

Keywords. pollutant emissions; ventilation systems; residential buildings; I/OAQ.
DOI: https://doi.org/10.34641/clima.2022.424

1. Introduction

For more than one-third of humankind, breathing in their homes can eventually lead to disease and even death from chronic exposure to contaminants such as toxic gases and particles (1). Ventilation is a way to reduce the concentration of such pollutants in dwellings, but it is evident that (i) indoor air may be fouled by external contaminant sources through ventilation exchange; that (ii) the same used, polluted indoor air that sickens people will thus be ultimately expelled to the environment, that is, the city for urban buildings, and that (iii) once outside, some of this polluted air may re-enter the building if dissipation does not act fast or long enough, cycling back to (i). How much is thus the outdoor air pollution generated by a building? What are the pollutants that are exhaled by the buildings? Can we develop the concept of 'exhalation of buildings'? Our research project aims at contributing to solve these questions.

The results should allow the establishment of strategies to e.g. minimize the emission of such pollutants into the atmosphere by mimicking the action of vehicle catalyzers in fossil fuel engines, or recapture useful components such as residual methane (CH_4), which will also be measured in this project.

1.1 Proposal motivation in the scientific and technical context

Numerous studies have been carried out in relation to the air quality from different perspectives and in different environments, but most often air quality has been contextualized in terms of its impact in public health.

According to the World Health Organization (WHO), air pollution may be the greatest environmental risk to health in the (3). A recent study (2019) developed by the Forum of International Respiratory Societies' Environmental Committee suggests that air pollution affects many organs beyond the lungs (1) and "although air pollution affects people of all regions, ages, and social groups, it is likely to cause greater illness in those with heavy exposure and greater susceptibility". A similar conclusion is achieved in (4), where the interpretation of the results states that "ambient air pollution contributed substantially to the global burden of disease in 2015, which increased over the past 25 years, due to population ageing, changes in non-communicable disease rates, and increasing air pollution in low-income and middle-income countries." Thus, it becomes a transversal matter affecting the whole society, emphasizing inequalities.

The relation between the outdoor and indoor air has also been subject of several studies. Even though indoor air is certainly affected by indoor sources, outdoor air has been proven a major contributor to indoor levels of pollutants, through building infiltration and mechanical ventilation systems (5).

The effect of outdoor pollution on indoor air quality appears to have worsened over the years. One of the factors that might cause this decrease in air quality is the construction of buildings designed to be more airtight. These solutions can cause a reduced regeneration of the indoor atmosphere, in order to improve energy efficiency (6). This type of construction might also contribute to unpredicted inequality, since it has been recently found that families with a higher socioeconomic status are at greater risk of being exposed to chemical contaminants such pesticides. On the contrary families with a lower socioeconomic status are at risk of being exposed to other type of contaminants, such as lead (7).

The air quality in indoor environments is a risk for the human health as human beings spend between 80 and 90% of their time indoors (8), where they are exposed to different types of chemical pollutants, which in low concentrations can cause headache, dizziness, fatigue, nausea, and in the long-term produce harmful effects on health.

In indoor spaces, the sources of pollutants are diverse, with emissions coming from construction materials, decoration, tobacco smoke, cleaning products, and external or internal activities. On the other hand, inadequate ventilation favors the increase in pollutant levels, which depend on the emitting source and the dilution caused by the ventilation (9). These air contaminants of indoor air have prompted numerous epidemiological researches related to building uses and typologies, such as those involving the schools and children contaminants exposure and health (10) and other studies state the health impact due to air quality (indoor/outdoor), especially respiratory diseases.

1.2 Hypothesis and research questions

Based on the context outlined above, the following hypothesis is proposed: The exhaled air from buildings contains pollutants that become another source of contamination, affecting the global air quality of cities.

The verification of this main statement lays on the resolution of several future research questions, which are stated in order to set the boundaries and define the path of the research area, being each research question related to a general objective:

1. What do we mean by 'exhalation of buildings', and what are the factors involved?

2. How does the residential buildings polluted air extracted comply the Spanish Regulation CTE HS?

3. Is it possible to mitigate, minimize, or eliminate the amount and variety of environmental pollutants exhaled by buildings to the urban environment? How can it be achieved?

From these starting points, the following sections of this document inform about the potentials of this project proposal as an effective and efficient study in terms of the use of human resources and of existing material resources.

2. Exhalation of buildings

2.1. Ventilation systems

As the energy performance of the building improves as a result of the regulations that require buildings to be more airtight, it has an inevitable impact on indoor air quality (11).

Two recently built residential buildings have been selected to measure the air exhalation given two main reasons. On the one hand, the lower air exchanges per hour and the smaller and more airtight spaces in residential buildings, as compared to other building typologies such as offices, commercial buildings or schools, might cause higher pollutant concentration indoors that must eventually be released, making them priority. On the other hand, given the sizable residential building stock, to start these measurements in residential typology is considered primary.

As it will be shown, four identified, localized air exhalation sources come in handy to lay out the pollutant measurement strategies: dwelling ventilation, kitchen exhaust ducts, garage ventilation and drain-waste-ventilation. The project is designed around the classification of ventilation according the Spanish regulations. Specifically, the reference is made to the following sections of the

Spanish Regulation CTE: CTE DB HS: Healthiness; HS3 Indoor Air Quality; HS 5 Water Evacuation (12).

-Dwelling ventilation: The increasing airtightness of our home's places new demands on residential ventilation, such as ensuring occupants a good indoor ambient at low energy consumption, which combined with the expected adequate ventilation, presents a challenge in the market (13). The CTE-HS3 stipulates that, buildings will have means to adequately ventilate their indoor spaces, eliminating the pollutants that occur regularly during normal use, meaning that an enough outdoor air flow of can be provided and their extraction and expulsion can be guaranteed. The dwelling ventilation is the mechanical ventilation that ensures a certain air changes per unit time within the dwelling apartments. The current regulation for residential buildings in Spain specifies the requirement for air changes in indoor spaces. Two types of ventilation systems can provide the necessary changes per hour. (1) Single-flow controlled mechanical ventilation: In these systems air is introduced passively throughout the apartment, e.g. through micro-ventilation slits in windows and infiltration while it is extracted mechanically to the roof through the wet rooms (kitchen and bathrooms). (2) Dual-flow controlled mechanical ventilation: These systems both introduce and extract the air mechanically, usually from the facades, through a heat recovery unit.

-Kitchen exhaust ducts: This ventilation is independent from the house ventilation. The regulation states that in the cooking area of kitchens the installation of a system that allows the extraction of fumes produced when cooking is mandatory.

-Garage ventilation system: While the ventilation of the garage could be either natural or mechanical, we are considering only the more common mechanical system given that natural ventilation requires openings in opposed facades. The extraction of the garage exhaust air is made through the rooftop and the regulations require both minimum ventilation rates and a carbon monoxide detection system to activate the fans when attaining a threshold concentration.

-Drain-waste-ventilation system: This ventilation system ensures the air a proper removal of blackwater allowing air entering the plumbing system. According to the Spanish regulations, the buildings must have ventilation subsystems depending on the height, all of them extended up to the roof. Special attention will be paid to the presence of methane in these systems.

Residential buildings complying with current regulations will be selected for the experimental study. They tend to be more airtight and better insulated in order to meet the passive house standards and energy requirements. It is initially proposed to focus the study on the Soto de Lezkairu neighborhood in Pamplona **Fig.1**. It is a newly created neighborhood with a high density ratio (approximately 70 dwellings per hectare).

Fig. 1 – Image of some residential buildings already constructed of the neighborhood of Soto de Lezkairu in Pamplona, Spain (sept. 2018).

2.2. Pollutants

In an indoor space, there is a wide variety of pollutants: carbon dioxide, carbon monoxide, nitrogen oxides, sulfide oxide, ozone, volatile organic compounds, particles… and so on.

They come from various sources: materials used to the construction, improper or excessive use of cleaning and hygiene products, combustion gases, standing water and the environment itself, where outside pollutants come in through the air renewal system or by infiltration. Given the wide variety of contaminants, the following factors have been use to select those to be evaluated.

Those factors are: 1. Impact on health. Pollutants that have the greatest known effects on human health. 2. Impact on the environment. Pollutants likely significant for environmental change, e,g. methane. 3. Preponderance of use. Contaminants linked to building materials, cleaning products and accessories, associated with the characteristics of the building, the environment and human activities.

3. Description of the analyzed buildings

The two buildings selected in Soto de Lezkairu are named as AC building and AB building. Both were designed with the current Spanish regulation. Their high-rise typology aids to have a higher concentration of analyzable houses.

The dwelling area, at the roof, follows a replicable structure that provides an easy working and mobility for systematic measuring.

3.1 Building AB

AB building, located at Adela Bazo street, is an 8-storey building. It contains 36 flats with an average area of approximately 75 m^2, distributed in a lineal typology around two vertical communication systems. The main typology is a two-bedroom apartment with a kitchen, living room and two bathrooms. Ducts are located in two different areas of the house. One for kitchen ducts, and the other for bathroom and fecal (see **Fig.2**).

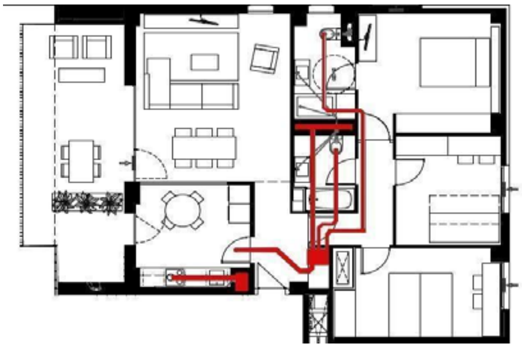

Fig. 2 – Image of AB house typology. Ventilation system in red.

3.2 Building AC

AC building, located at Calle Cataluña 16 is a nine-floor building with two garage floors. Each level has four flats, connected through a vertical communication system. Each flat has three bedrooms, a living room, two bathrooms and a kitchen The average floor area is around 80 m (see **Fig.3**). Ducts are located in one shaft per vertical aggrupation of houses. So in the roof will be found four ventilation shaft terminals. The particularity is that on the ground floor there is a commercial area, that modifies the floor connection making independent the tower and the underfloor levels. Garage ventilation goes independently and exhales at the roof of the commercial area.

Fig. 3 – Image of AC house typology. Ventilation system in red.

4. Methodology

It is essential to take into account the plans, the typology and the structure of the building, since twelve independent tubes needs to be located.

The measured gases are: methane ($CH_4$4), carbon monoxide (CO), carbon dioxide (CO_2), water (H_2O) and volatile organic compounds (TVOC), each of them has different properties and will be affected independently by the surrounding atmosphere given natural phenomena. The initial data analysis served to ensure the reliability of the data acquired and to determinate the measuring points. Besides, it is essential to register or collect the information about the atmospheric conditions during the measurements (wind, temperature, rain…) and to be aware of the surrounding activities and traffic. These factors are the main variables that need be evaluate and take into account during the measurements interpretation.

The measurements have been done with a Gasera One combined with a Multipoint and a Dekati® eFilter™. Gasera One is a "photoacoustic multi-gas analyzer platform that can be configured to a wide variety of research and industrial applications. The performance is based on a photoacoustic infrared spectroscopy engine with a patented ultra-sensitive cantilever pressure sensor." The Dekati® eFilter™ is a unique instrument that combines a standard gravimetric filter holder and sensitive real-time PM detection in one compact instrument.

Actual shafts aren´t prepared to be monitored nether manually nether technologically. The identification of each type of duct is done by plans and by knowledge of installations function. Dwelling ventilation normally plastic ducts with no mechanical needs, can be circular or square. Kitchen exhaust ducts, circular metallic or high resistant to fire plastic with double butterfly valves. Drain-waste ventilation circular plastic ducts characterized of the smell.

Fig. 4. – Taking measurements in AB Building.

Fig. 5. – Taking measurements in AC Building.

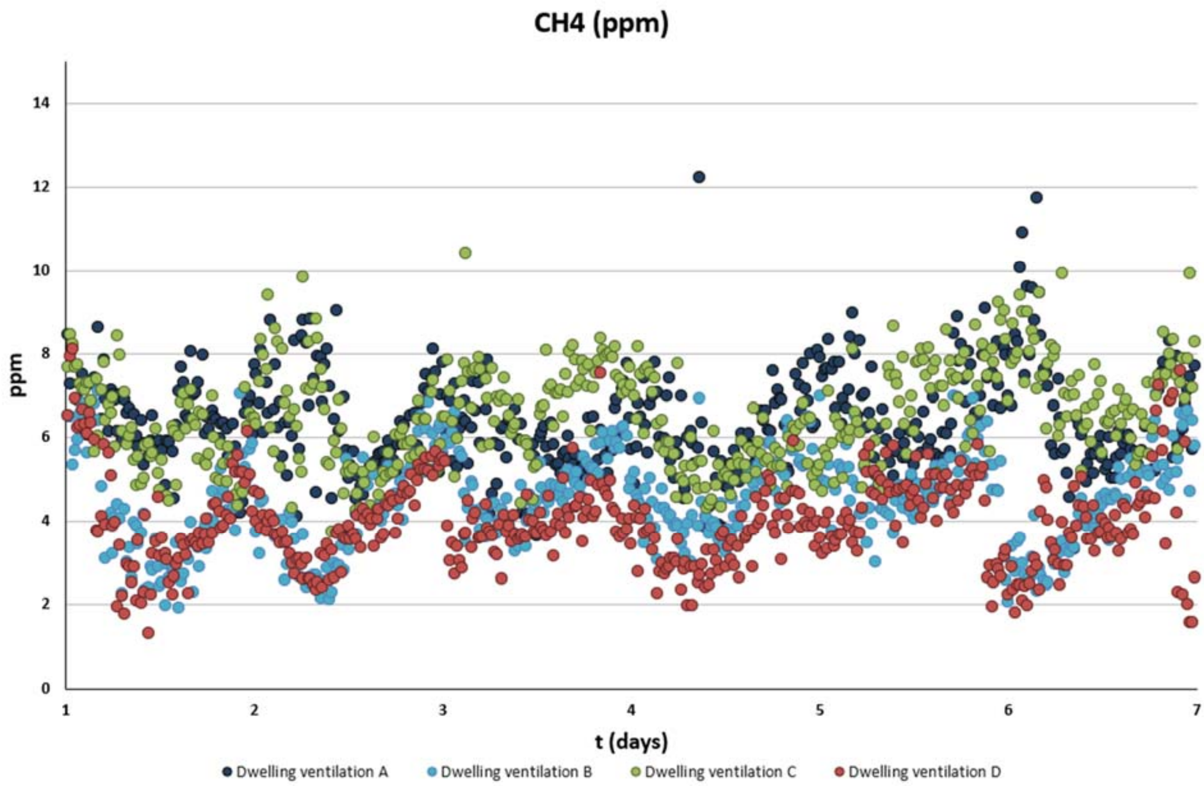

Fig. 6 – Image of methane fluctuation during a week.

After all measurable elements are identified. Cables will be located and properly introduced at ducts, (**Fig. 4, Fig. 5**) they will be fixed with temporal elements, searching a secure measure sample of each element. The sampling is collected during one minute and half at periods of twelve minutes.

5. Preliminary results and conclusions

The information that has been received from the measuring equipment needs to be meticulously analyzed to discard the spurious measurements. The amount of data registered is relevant, thus, the work needs to be slow and justified. The process supposes a comprehension of the environment and the conditions under which the measurements were carried out.

The measured pollutants are methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), water (H_2O) and volatile organic compounds (TVOC). During one month at each building. The image below is a graphical representation of measured fluctuation of methane gas during one week at AC building such as an example of the results, (see **Fig. 6**)

As can be seen in **Fig. 6**, the values and the variation of the methane in dwelling ventilation is similar for the 4 apartments of Building AC. The highest values are obtained during the three first days of the week and with low fluctuations. After Thursdays, the fluctuation is higher with peak values on the middle hours of the day**.**

This paper has presented the theoretical parameters that define the concept of building exhalation, the methodology for the data monitoring and an example of the preliminary results obtained.

In any case, this research continues to record and analyze data within the project in which it is enrolled and which is scheduled to end in 2024. So, the results are still being analyzed and interpreted. Searching variables that could affect in the future and comparing with other measures.

6. Acknowledgement

Ministerio de Ciencia, Innovación y Universidades. Proyectos de I+D+i Retos Investigación. n. PID2019-104083RB-I00 "Cuantificación de parámetros contaminantes de la exhalación de los edificios en entornos urbanos EXHAL Quantifying pollutants originated by the exhalation of buildings in urban environments".

Federal University of Santa Catarina for financial support during the postdoctoral fellowship of Dr. Leonardo de Brito Andrade at Escuela Técnica Superior de Arquitectura of Universidad de Navarra.

Ayudas para la Formación de Profesorado Universitario (FPU2020) of Ministerio de Universidades (Spain) received by Robiel Manzueta.

The datasets generated during and/or analysed during the current study are not available because it is on process of study but the authors will make every reasonable effort to publish them in near future.

7. References

1. Schraufnagel DE, Balmes JR, Cowl CT, de Matteis S, Jung S-H, Mortimer K, et al. Air Pollution and Noncommunicable Diseases. Chest [Internet]. 2019 Feb;155(2):409–16. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0012369218327235

2. WHO. WHO guidelines for indoor air quality: selected pollutants. World Health Organization. 2010. 484.

3. WHO. World health statistics 2016: monitoring health for the SDGs, sustainable development goals. World Health Oraganization (WHO). Switzerland; 2016.

4. Cohen AJ, Brauer M, Burnett R, Anderson HR, Frostad J, Estep K, et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. The Lancet [Internet]. 2017;389(10082):1907–18. Available from: http://dx.doi.org/10.1016/S0140-6736(17)30505-6

5. Hänninen O, Goodman P. Outdoor Air as a Source of Indoor Pollution. In: Issues in Environmental Science and Technology [Internet]. Royal Society of Chemistry; 2019 [cited 2021 Jun 7]. p. 35–65. Available from: http://ebook.rsc.org/?DOI=10.1039/9781788016179-00035

6. Gil Hormazábal L, Adonis M. Calidad de aire de interiores: contaminantes y sus efectos en la salud humana. Revista Panamericana de Salud Pública. 1998;4(6).

7. Montazeri P, Thomsen C, Casas M, de Bont J, Haug LS, Maitre L, et al. Socioeconomic position and exposure to multiple environmental chemical contaminants in six European mother-child cohorts. International Journal of Hygiene and Environmental Health [Internet]. 2019;222(5):864–72. Available from: https://doi.org/10.1016/j.ijheh.2019.04.002

8. Klepeis NE, Nelson WC, Ott WR, Robinson JP, Tsang AM, Switzer P, et al. The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. Journal of Exposure Analysis and Environmental Epidemiology. 2001;11(3):231–52.

9. Gallego E, Roca FJ, Perales JF, Guardino X. Experimental evaluation of VOC removal efficiency of a coconut shell activated carbon filter for indoor air quality enhancement. Building and Environment. 2013 Sep 1;67:14–25.

10. Annesi-Maesano I, Baiz N, Banerjee S, Rudnai P, Rive S. Indoor air quality and sources in schools and related health effects. Journal of Toxicology and Environmental Health - Part B: Critical Reviews [Internet]. 2013 Nov 17 [cited 2021 May 25];16(8):491–550. Available from: https://www.tandfonline.com/action/journalInformation?journalCode=uteb20

11. Seppänen OA, Fisk WJ, Mendell MJ. Association of Ventilation Rates and CO2 Concentrations with Health andOther Responses in Commercial and Institutional Buildings. Indoor Air [Internet]. 1999 Dec;9(4):226–52. Available from: https://doi.org/10.1111/j.1600-0668.1999.00003.x

12. Of SM of H. CTE - Spanish Building Technical Code [Internet]. 2007. Available from: https://www.codigotecnico.org/DocumentosCTE/DocumentosCTE.html

13. Händel C. Residential Ventilation – Needs, Trends and Expectations. REHVA Journal [Internet]. 2017 [cited 2020 Oct 5];6:11–7. Available from: https://www.rehva.eu/rehva-journal/chapter/residential-ventilation-needs-trends-and-expectations