

D3 – Exposure model for indoor PM2.5 exposure originating from outdoor PM2.5

Report

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Executive Summary

As people spend more and more of their time in enclosed buildings, concern about the quality of the indoor air we breathe is growing. However, although it is well known that indoor pollutants concentrations differ from outdoor concentrations, exposure to indoor pollutants is often modelled on the basis of outdoor concentrations.

The present report describes the work done in the task 1.5 « Novel methodology for assessing the burden of indoor exposures to outdoor stressors » encompassed in the WP1 « Burden of disease methodology for outdoor air pollution and noise» of the EU-funded BEST-COST project. In particular, the aim of this report is to present the methodology used to estimate indoor fine particles ($PM_{2.5}$) and NO_2 concentrations from the immediate outdoor concentrations. The infiltration factor and the indoor generated concentrations of these two pollutants are estimated using the simplified mass-balance model (Healthvent approach) and the French database from the indoor environmental quality observatory (CNL2) containing information on 571 dwellings measured over one week between 2020 and 2023 in various regions of France.

The analysis of the results obtained during this study leads us to propose standard/reference values of air exchange rate, infiltration factors and indoor generated concentrations for $PM_{2.5}$ and NO_2 that may be used in the case where the actual values are not available and when the dwelling conditions are similar to those of the CNL2 dwellings.

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Overview

BEST-COST

The BEST-COST overall objective is to *"improve methodologies for the socio-economic cost assessment of environmental stressors to i) enhance regular usage of economic and health modelling in policy impact assessments and policy evaluation by EU and national public authorities, and ii) promote harmonised and consensual population health, quality of life and economic metrics for integrative socio-economic assessments of environmental pollution in Europe and health impact and cost-benefit assessments of related policies"* (BEST-COST 2021).

The BEST-COST project proposes to use the burden of disease (BOD) approach to estimate the health impact of environmental stressors such as air pollution and noise. The estimation of the environmental BOD can be conducted through different methods such those described by Prüss-Üstün et al. in their introductory guide to BOD (Prüss-Üstün et al. 2003). In this project the BOD is defined as the *"population health impact of a disease or risk factor, commonly expressed in terms of Disability-Adjusted Life Years (DALYs), which reflect the healthy life years lost due to disability and/or death"*. The DALYs attributable to environmental stressors are calculated using comparative risk assessment (CRA) (a.k.a. exposure-based approach) (Figure 1).

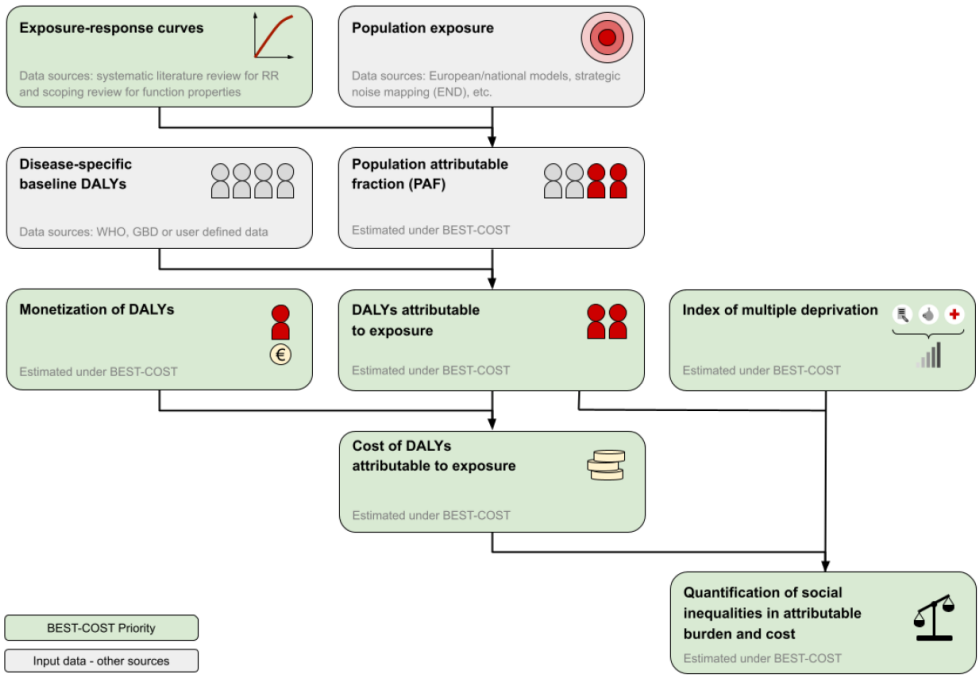


Figure 1. Overview of the BEST-COST methodological framework (BEST-COST 2021).

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WP1 - Burden of disease methodology for outdoor air pollution and noise

The specific objective of WP1 is to provide an improved and consensual burden of disease framework for estimating the health impact of environmental stressors. Beyond the state of the art, the actions included in the WP1 work plan are: i) critically assess the current burden of disease framework, ii) generate new evidence to support BOD assessments, iii) propose new methodology for taking into account correlated outdoor exposures, and iv) develop an harmonized approach for indoor and outdoor exposures to the same stressors.

WP1 seeks to strengthen the current CRA framework by generating up-to-date inputs and by developing and integrating novel methods to deal with correlated exposures and to assess indoor exposure to stressors originating from the outdoor environment. The recommended methods will be tested in WP5 (Implementation in EU countries).

Table 1 presents the 6 tasks that constitute WP1.

Table 1. Titles of WP1 tasks.

Task	Title
T1.1	Disease models of outdoor air pollution and noise based on current evidence
T1.2	Systematic literature review for establishing exposure -response functions
T1.3	Consensus methodology for quantifying the burden of environmental stressors
T1.4	Novel methodology for assessing the burden of correlated exposures
T1.5.	Novel methodology for assessing the burden of indoor exposures to outdoor stressors
T1.6	Methodological protocol for quantifying environmental burden of disease

Task 1.5 - Novel methodology for assessing the burden of indoor exposures to outdoor stressors

Worldwide, but especially in developed countries, people spend a great amount of their time indoors and are consequently exposed to indoor pollution. In 2001, Neil E. Klepeis et al. using the database of the National Human Activity Pattern Survey (NHAPS) conducted from 1992 to 1994 in the United States, concluded that people spend an average of 87% of their time in enclosed buildings (Klepeis et al. 2001). With such a high percentage, indoor air quality has received more attention in recent decades.

Part of the air pollution in indoor environments is generated directly indoors due to daily activities, construction materials, furniture, etc. However, another part is infiltrated from outside adding complexity to exposure modelling on the population level. Several approaches have been applied to modelling indoor exposure to $PM_{2.5}$, NO_2 and ozone, including the mass-balance model taking into account aerosol properties, penetration rate and deposition rate.

The indoor $PM_{2.5}$ includes particles emitted by indoor sources, as well as outdoor particles penetrating indoors and indoor particles formed by chemical reactions (Jorquera et al. 2018). Household activities such as cleaning, cooking, smoking and the use of candles and incense

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are known to be common indoor sources of $PM_{2.5}$ (Jorquera et al. 2018; Abt et al. 2000; W. Zhao et al. 2006; B. Zhao and Wu 2007; Abdullahi et al. 2013; Barraza et al. 2014; Torkmahalleh et al. 2017; Wangchuk et al. 2017). Outdoor particles may enter households through three mechanisms: natural convection, mechanical convection and infiltration (Chen and Zhao 2011).

The main indoor sources of NO_2 are gas stoves and heating or hot-water production appliances, in the case of faulty outdoor connections. Smoking and all forms of incomplete combustion can also form NO_2. However, the main contribution of NO_2 to indoor environments generally comes from outdoor air: road traffic, industrial sources and photochemical activities (ANSES 2013).

The indoor ozone in residential buildings mainly comes from two sources: outdoor atmosphere (infiltration through cracks in the building envelope) and indoor ozone produced by electrical devices such as photocopying, air purifying and disinfecting devices (Huang et al. 2019).

The HEALTHVENT project, funded by the EU, used ventilation rates specific to each country to create an exposure model tailored for the EU26 nations based on a single compartment, complete mixing mass-balance model (HEALTHVENT approach). The HEALTHVENT approach based on data from 2010 enables the evaluation of different policies to reduce health risks from indoor exposures. In this context and taking this approach as reference, the task 1.5 “Novel methodology for assessing the burden of indoor exposures to outdoor stressors” arises.

The first Task 1.5 objective is to update some parameters of the HEALTHVENT approach (air exchange rate, infiltration factor and indoor generated concentration) using newly collected data from representative dwellings across France focusing on $PM_{2.5}$ and NO_2 concentrations[1].

In indoor BOD or HIA[2], the indoor pollutant exposure is modelled based on the outdoor levels. In turn, the exposure response functions for indoor exposures are generally based on epidemiological studies assessing outdoor exposures. Considering that exposure-response functions can also be considered relevant for indoor exposures originating from the outdoors, the second Task 1.5 objective is to convert the exposure-response functions from outdoor to indoor exposures of $PM_{2.5}$ in accordance with the modelling of indoor exposure based on outdoor levels (Figure 2). The work related to this objective will be presented at a later stage.

[1] The term concentration refers to the amount of pollutant present in the air to which an individual may be exposed (potentially available to be inhaled).

[2] Health Impact Assessment (HIA): According to WHO, HIA is “a combination of procedures, methods and tools by which a policy, program or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population”. BOD assessment and HIA follow similar steps in defining counterfactual situations and comparing the health impacts between the various situations.

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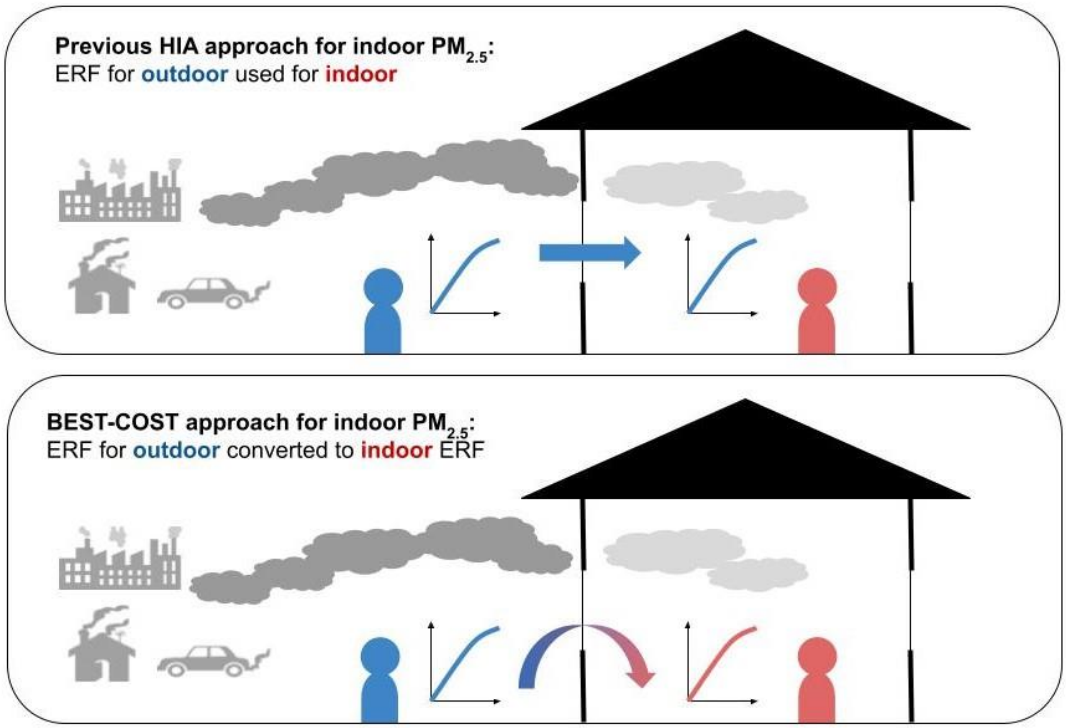


Figure 2. BEST-COST approach for health impact assessment (HIA) for indoor exposures originating from the outdoor environment. While previous HIA combined modelled indoor exposure (red) with exposure-response functions (ERFs) for outdoor stressors (blue), BEST-COST will combine updated models of indoor exposure with converted ERFs (both red) (BEST-COST 2021).

The following sections of this report provide a detailed description of the model and database used in this project as well as the methodology employed to update the aforementioned parameters.

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Mass-balance model

According to the « single compartment, complete mixing mass-balance model » equation (Dockery and Spengler 1981)(Eq. 1), the variation of the concentration over time depends on four terms:

- The inputs from the outside (the part of the outside concentration that managed to pass through the wall)
- The indoor concentration multiplied by the rate at which the outside air replaces the inside air
- The indoor concentration that is in suspension
- The indoor emissions at a given volume (volume of the indoor space)

$$\frac{dC}{dt} = P \cdot \frac{Q}{V} \cdot C_{ext} - a \cdot C_{int} - k \cdot C_{int} + \frac{G}{V} \qquad \textit{Eq. 1}$$

a : Air exchange rate (h^{-1})
C_{ext} : Outdoor concentrations ($\mu g.m^{-3}$)
C_{int} : Indoor concentrations ($\mu g.m^{-3}$)
G : Indoor emission ($\mu g.h^{-1}$)
k : Decay rate of the pollutant indoors (h^{-1})
P : Penetration efficiency (dimensionless)
Q : Ventilation rate ($m^3.h^{-1}$)
V : Volume of the indoor space (m^3)

Air exchange rate describes the amount (fraction) of indoor air replaced by 'fresh' outdoor air in an hour (h^{-1}). In mechanical ventilation systems it is mainly controlled by the fans in the air intake and air exhaust vents, but also by the operation of windows and doors as well as the tightness of the building envelope itself. Window and door frames, water pluming, electricity tubing and all joints and cracks in the wall, floor and ceiling structures themselves lead to infiltration of air from outside indoors. Building tightness is linked to the insulation of the building and it typically tighter in colder climates but may be high also in southern buildings designed for energy efficient cooling. Air exchange rates can be measured via air flows, which is subject to errors due to the air flows through the building envelope, or using marker substances such as S_6F_6 or CO_2. Air exchange cannot be less than zero, but there is no upper limit. Wind speed and temperature differences between indoor and outdoor air provide the basic physical forces for air exchange, besides the possible electric fans. Higher air exchange rates lead to more efficient introduction of outdoor air pollution indoors and more efficient dilution of indoor generated pollution.

The decay rate (k) depends on the surface to volume ratios of the indoor space and the aerosol size distribution. Ultrafine particles and coarse particles have substantially higher and increasing deposition rates when moving away (below or above) from particle sizes of 100-300 nm. Therefore, in small low apartments with high furniture density the deposition rates are higher than in voluminous and less tightly furnished apartments. At particle sizes below 1 µm in diameter the deposition rate remains below 0.15 but increases rapidly as the particle size increases and can reach 0.5 at Dp=2µm. Therefore, the effective deposition rate depends strongly on the aerosol size distribution. However, in typical conditions with secondary

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inorganic and organic aerosols dominating, decay rate values around 0.15-0.20 can be recommended. For coarse-dominated aerosols even values larger than these may be considered.

Similarly, the penetration efficiency (P) depends on crack sizes and openings, most importantly, occupant use of open windows for ventilation. Penetration efficiency is, by definition, limited to range 0 – 1, approaching the upper theoretical limit when windows are open in windy weather. During heating season and closed windows lower values can be expected. When the air exchange occurs via cracks in the building envelope, such as leaks in window and door frames, electric and water pipe connections etc., the crack dimensions and particle sizes affect penetration efficiency. The smaller the cracks, the lower the penetration efficiency. In very tight modern energy efficient buildings penetration efficiencies below 0.5 can be expected.

According to the Healthvent approach for $PM_{2.5}$, pollen and volatile organic compounds (VOCs) (Hänninen et al. 2004), the variation of the concentration during the sampling period can be considered zero for 24 hours or longer sampling periods (Eq. 2). This steady-state assumption (a, k and P remain constant over a given time period) is commonly used to simplify the solution of the mass conservation balance equation since its development by Dockery and Spengler in 1981 (Dockery and Spengler 1981).

$$\frac{dC}{dt} = 0 \qquad \textit{Eq. 2}$$

The Healthvent approach consider:

$$F_{inf} = \frac{aP}{a+k} \qquad \textit{Eq. 3}$$

$$C_{ig} = \frac{Q}{V(a+k)} \qquad \textit{Eq. 4}$$

$$a = Q/V \qquad \textit{Eq. 5}$$

F_{inf} : Infiltration factor (dimensionless)
C_{ig} : Indoor generated concentration (µg.m^{-3})

These considerations lead to an equation that allows to calculate the indoor concentration from the outdoor concentration (Eq. 6).

$$C_{int} = F_{inf} \cdot C_{ext} + C_{ig} \qquad \textit{Eq. 6}$$

The French Agency for Food, Environmental and Occupational Health and Safety (ANSES) and the Scientific and Technical Center for Building (CSTB) collected and analyzed data from the scientific literature regarding the impact of outdoor pollution on indoor air quality (ANSES 2019). The distribution of mean values of indoor and outdoor concentrations and F_{inf} per occurrence in dwellings worldwide were calculated for $PM_{2.5}$ (Table 2) and for NO_2 (Table 3). The distribution of mean values of P is only available for $PM_{2.5}$. According to this study, in

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dwellings worldwide, the mean F_{inf} for $PM_{2.5}$ ($F_{inf_PM2.5}$) is 0.59, the mean P for $PM_{2.5}$ ($P_{PM2.5}$) is 0.85 and the mean F_{inf} for NO_2 (F_{inf_NO2}) is 0.65. For these three factors, the mean value is equal or close to the median value.

Table 2. Distribution of mean values of indoor and outdoor concentrations, infiltration factor (F_{inf}) and penetration efficiency (P) of $PM_{2.5}$ per occurrence in dwellings worldwide (ANSES 2019).

$PM_{2.5}$ ($\mu g.m^3$)	N	Min	Max	Median	Mean	Standard deviation
C_{ext_mean}	78	3.3	38.3	15.2	17.4	8.0
C_{int_mean}	91	0.6	68.7	17.3	19.8	11.2
F_{inf_mean}	132	0.04	0.95	**0.61**	**0.59**	0.14
P_{mean}	16	0.54	1.11	**0.84**	**0.85**	0.16

Table 3. Distribution of mean values of indoor and outdoor concentrations and infiltration factor (F_{inf}) of NO_2 per occurrence in dwellings worldwide (ANSES 2019).

NO_2 ($\mu g.m^3$)	N	Min	Max	Median	Mean	Standard deviation
C_{ext_mean}	75	0.65	115	34	37.2	18.4
C_{int_mean}	80	8.00	77.5	23.6	26.9	14.8
F_{inf_mean}	11	0.28	0.94	**0.65**	**0.65**	0.20

The ANSES-CSTB review also presents the distribution of mean values of indoor and outdoor concentrations and F_{inf} of $PM_{2.5}$ and NO_2 per occurrence in French dwellings (Table 4 and Table 5). According to the author, the only data available for the calculation of the mean $F_{inf_PM2.5}$ in French dwellings are those from a Paris empty-apartment study carried out by CSTB and LHVP laboratory using different ventilation scenarios (Kirchner et al. 2001; 2002). The mean $F_{inf_PM2.5}$ of French dwellings, deduced from regressions of indoor and outdoor concentrations (0.70), is higher than these of dwellings worldwide (0.59). This difference is probably due to the absence of furniture in the apartment, which leads to a surface/volume ratio of around 2, lower than in conventional housing. As a result, particle losses on surfaces were lower. The mean F_{inf_NO2} of French dwellings is 0.75, which is higher than the value found for dwellings worldwide (0.65).

Table 4. Distribution of mean values of indoor and outdoor concentrations and infiltration factor (Finf) of $PM_{2.5}$ per occurrence in French dwellings (ANSES 2019).

$PM_{2.5}$ ($\mu g.m^3$)	N	Min	Max	Median	Mean	Standard deviation
C_{ext_mean}	10	11.0	27.2	14.0	15.6	4.79
C_{int_mean}	12	12.3	68.7	24.7	27.2	15.9
F_{inf_mean}	7	0.50	0.83	**0.70**	**0.70**	0.10

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Table 5. Distribution of mean values of indoor and outdoor concentrations and infiltration factor (F_{inf}) of NO_2 per occurrence in French dwellings (ANSES 2019).

NO_2 ($\mu g.m^3$)	N	Min	Max	Median	Mean	Standard deviation
C_{ext_mean}	23	0.65	115	33.3	36.2	22.6
C_{int_mean}	24	12.7	56.0	27.2	28.0	11.0
F_{inf_mean}	6	0.42	0.94	**0.78**	**0.75**	0.18

Many experiments have been performed to estimate the mean k value for different particle sizes in indoor environments. Table 6 presents the mean k values for $PM_{2.5}$ found in various studies worldwide. Results from these studies show a wide degree of variability with the lowest mean $k_{PM2.5}$ value of 0.10 h^{-1} (study of 9 homes in Boston, U.S.) and the highest mean $k_{PM2.5}$ value of 3.61 h^{-1} (study of 14 houses in Australia with normal ventilation conditions). This variability can be explained by the variations in the conditions under which decay rates were measured: measurement method, airflow conditions, nature of furnishing, etc.

Table 6. Mean decay rate values (k) for $PM_{2.5}$ found in various studies worldwide.

Study	Sample	Measurement year(s)	Mean k [h^{-1}]*
PTEAM (Ozkaynak et al. 1996)	178 residences in Riverside, California, U.S.	1990	0.39 ± 0.16
(Long et al. 2001)	9 homes in Boston, U.S.	1998	Summer: 0.15 ± 0.04 Winter: 0.10 ± 0.03
RIOPA (Relationship of Indoor, Outdoor and Personal Air) (Meng et al. 2005)	114 residences at three U.S. cities: Houston (Texas), Los Angeles (California), and Elizabeth (New Jersey)	1999-2001	1.5
(Allen et al. 2003)	44 residences in Seattle, U.S.	2000-2001	0.20 ± 0.16
Research Triangle Park (RTP) PM Panel study (Williams et al. 2003)	37 residences in North Carolina, U.S.	2000-2001	0.42 ± 0.19
(Diapouli 2008)	7 residences and 1 office in Athens, Greece	2005-2006	0.17
(Xie et al. 2020)	1 house in Changzhou China	2017-2018	0.46 h^{-1} (from 0.30 to 0.69 h^{-1}) from experimental data and 0.39 h^{-1} from calculations
(Thatcher et al. 2002)	1 isolated room in Berkeley, U.S. using three different indoor furnishing levels (bare,	---	k value according to the mean airspeed (V) in a fully furnished room: • 0.93 if fans off • 1.07 if V=5.4 $cm.s^{-1}$

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	carpeted, and fully furnished) and four different air flow conditions.		• 1.32 if V=14.2 cm.s^{-1} • 1.60 if V=19.1 cm.s^{-1}
(He et al. 2005)	14 houses in Australia with minimum and normal ventilation conditions	---	• 2.01 ± 1.11 for min. ventilation conditions (air exchange rate of 0.61 ± 0.45 h^{-1}) • 3.61±2.6 for normal ventilation conditions (air exchange rate of 3 ± 1.23 h^{-1})

*The presented values correspond to the mean ± confidence interval

Figure 3 presents a summary of the decay rate values (or deposition rate) of three size fractions (UFPs[3], $PM_{2.5}$ and PM_{10}) from several studies worldwide from a review done by Diapouli et al. (Diapouli et al. 2013). According to this review, the k is greatly influenced both by the building construction characteristics, as well as the indoor or ambient conditions. The $k_{PM2.5}$ values range between 0.1 h^{-1} and 0.4 h^{-1}.

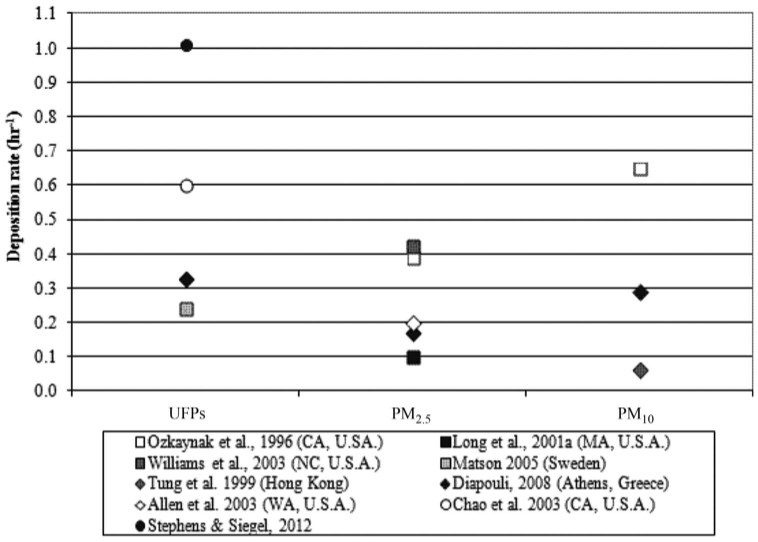


Figure 3. Summary of decay rate values from several studies worldwide (Diapouli et al. 2013).

[3] UFPs : ultrafine particles

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CNL2 Database

The CNL2 French database (Ramalho et al. 2025) containing information on 571 dwellings measured during one week (Figure 4) between 2020 and 2023 has been made available for the Task 1.5 purposes. Some of the information contained in this database are:

- The description of dwellings (construction year, materials, ventilation and heating systems, etc.)
- Occupancy schedules and occupant activities extracted from the occupancy forms filled out by the inhabitants during the week of the measurements
- Weakly mean $PM_{2.5}$ and NO_2 indoor concentrations
- Weekly mean outdoor NO_2 concentrations
- Continuous CO_2 indoor concentrations (10 minutes time-step)

The outdoor $PM_{2.5}$ concentrations were not directly measured outside the houses but estimated from measurements taken at the nearest weather stations to each house taking into account parameters such as altitude, climate, urban density, traffic and the distance between the houses and the weather station (Chimère model) (Real et al. 2022; Mailler et al. 2017). Ozone was not part of the substances measured during the campaigns.

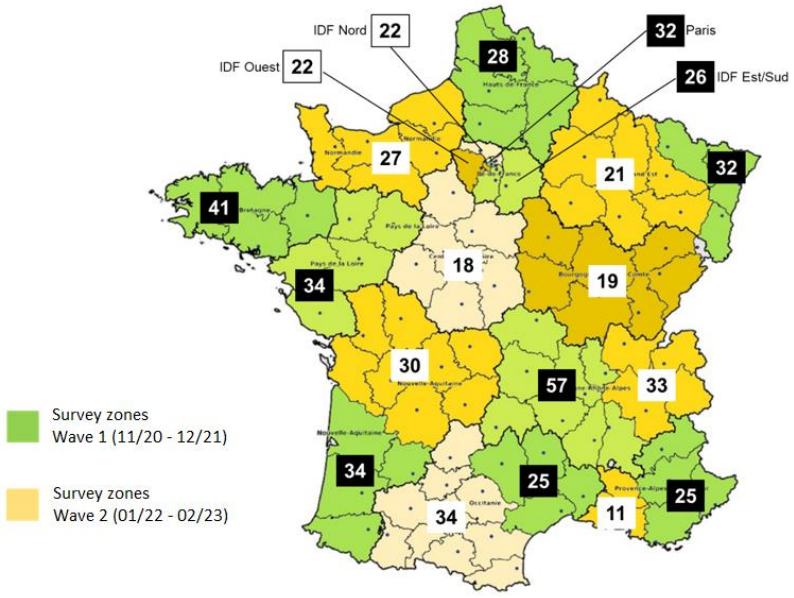


Figure 4. Location of the French houses measured in the CNL2 campaign (Ramalho et al. 2025).

Table 7 presents the location in the dwelling where measurements of the above-mentioned substances were taken and the technology used for sampling.

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Table 7. Sampling technology for CO_2, NO_2 and $PM_{2.5}$.

Substance	Place of measurements	Sampling technology
CO_2	Master bedroom	Nondispersive infrared sensor (or NDIR sensor) with a 10 minutes time-step
NO_2	Master bedroom	Passam Ag ® passive sampler containing triethanolamine reagent
	Outside the dwelling	
$PM_{2.5}$	Living room	Active air pumping at a flow rate of 2 L/min through a sampling head (PEMS, Ecomesure) adapted to collect the $PM_{2.5}$ fraction on a pre-weighed 37mm diameter PTFE Teflon filter (membrane) (2 µm porosity, Teflo type with polypropylene ring)
	Outside the dwelling	Chimère model

Figure 5 presents the periods during which the construction of the CNL2 dwellings was completed. The construction period of 39 dwellings was not provided by their occupants. The period with the highest number of dwellings is 1975-1981 (58 dwellings, 10.2% of the total) and the period with the lowest number of dwellings is 1962-1967 (25 dwellings, 4.4 % of the total).

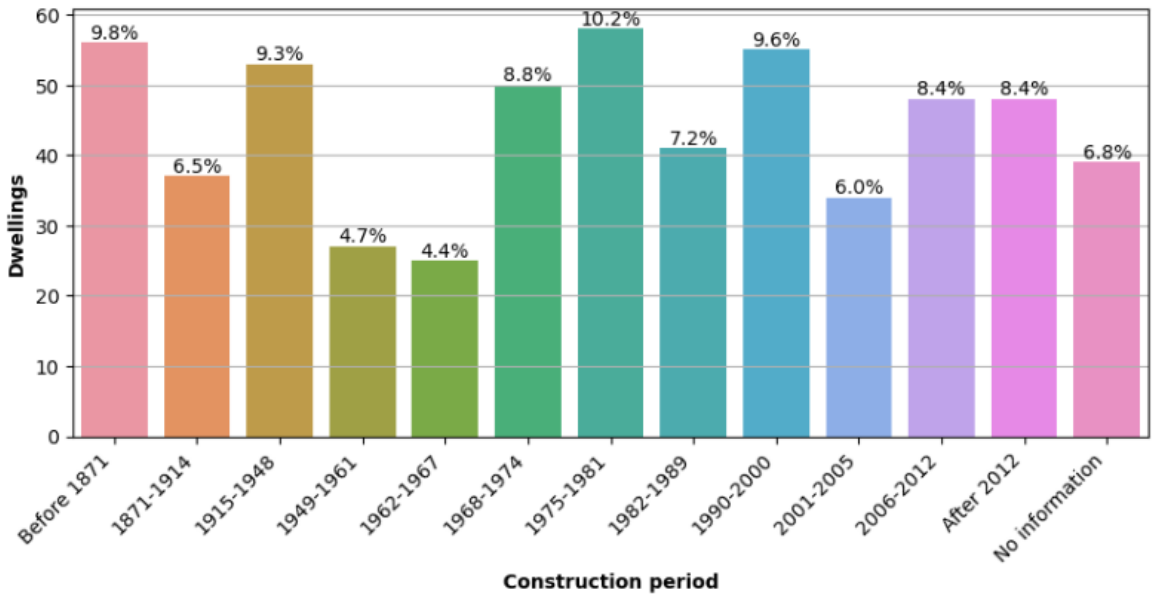


Figure 5. Periods during which the construction of the dwellings was completed (n=571).

Table 8 presents some of the main characteristics of the dwellings: 74.1 % are occupied by couples with or without children, 70.1% are individual houses, 28.8 % are apartments (only one dwelling has another kind of typology), 94% have a total area superior to 50 m², 34.2% have never been renovated (change of windows or insulation of exterior walls, roof or attic) and all dwellings are equipped with a heating system (more than half use an individual central heating system).

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Table 8. Description of CNL2 dwellings (household composition, type of dwelling, total area, renovation, and heating system).

Description		Dwellings	
		Number	Percentage (%)
Household composition	Single person	105	18.4
	Couple without children	170	29.8
	Couple with child(ren)	253	44.3
	Single parent with child(ren)	30	5.3
	Other	13	2.3
Type of dwelling	Individual house	400	70.1
	Apartment	170	29.8
	Dwelling in a building for professional use	1	0.2
Total dwelling area	Inferior to 50 m²	34	6.0
	Between 50 and 100 m²	204	35.7
	Between 101 and 150 m²	206	36.1
	Between 151 and 200 m²	87	15.2
	Superior to 200 m²	40	7.0
Renovation involving either a change of windows or insulation of exterior walls, roof or attic	Less than 5 years ago	172	30.1
	Between 5 and 10 years ago	87	15.2
	More than 10 years ago	92	16.1
	Never	195	34.2
	No information	25	4.4
Heating system	District heating	70	12.3
	Individual central heating	322	56.4
	Individual heating	179	31.3

Figure 6 presents the type of ventilation systems installed in the dwellings: mechanical, natural (trickle vents in windows) or absent (no ventilation system installed). Most of the dwellings are equipped with a mechanical or natural ventilation system (69.3%). The most used mechanical ventilation system is the single flow system (76.1%) followed by a punctual system such as automated opening of windows or ventilators in damp rooms (19.6%) and the double flow system (4.2%). More than half of dwellings equipped with a natural ventilation system use top and bottom grids in service rooms (56.4%). The other dwellings equipped with a natural ventilation system use extract ducts with natural draught (43.6%).

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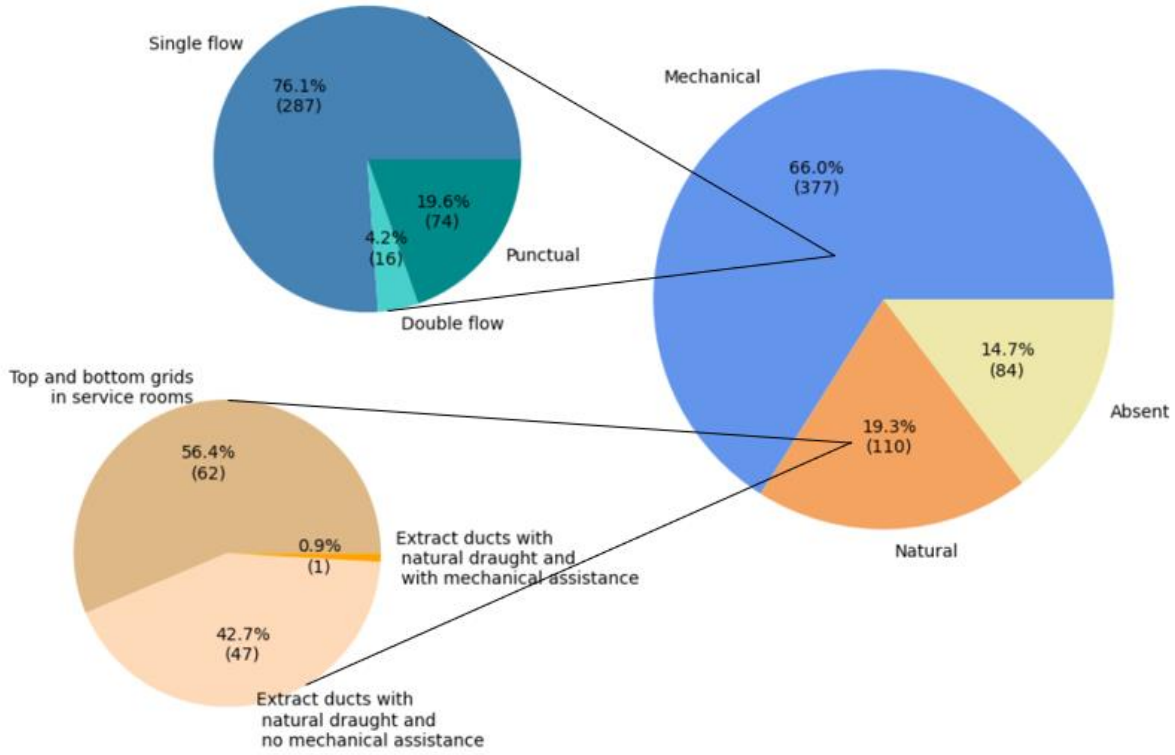


Figure 6. Ventilation systems installed in CNL2 dwellings (n=571).

The construction materials of the main walls are presented in Figure 7. The main walls of the dwellings are usually built with only one type of material: 26.3% exclusively with concrete blocks, 17.5% exclusively with stone, 15.4% exclusively with concrete and 14.2% exclusively with brick.

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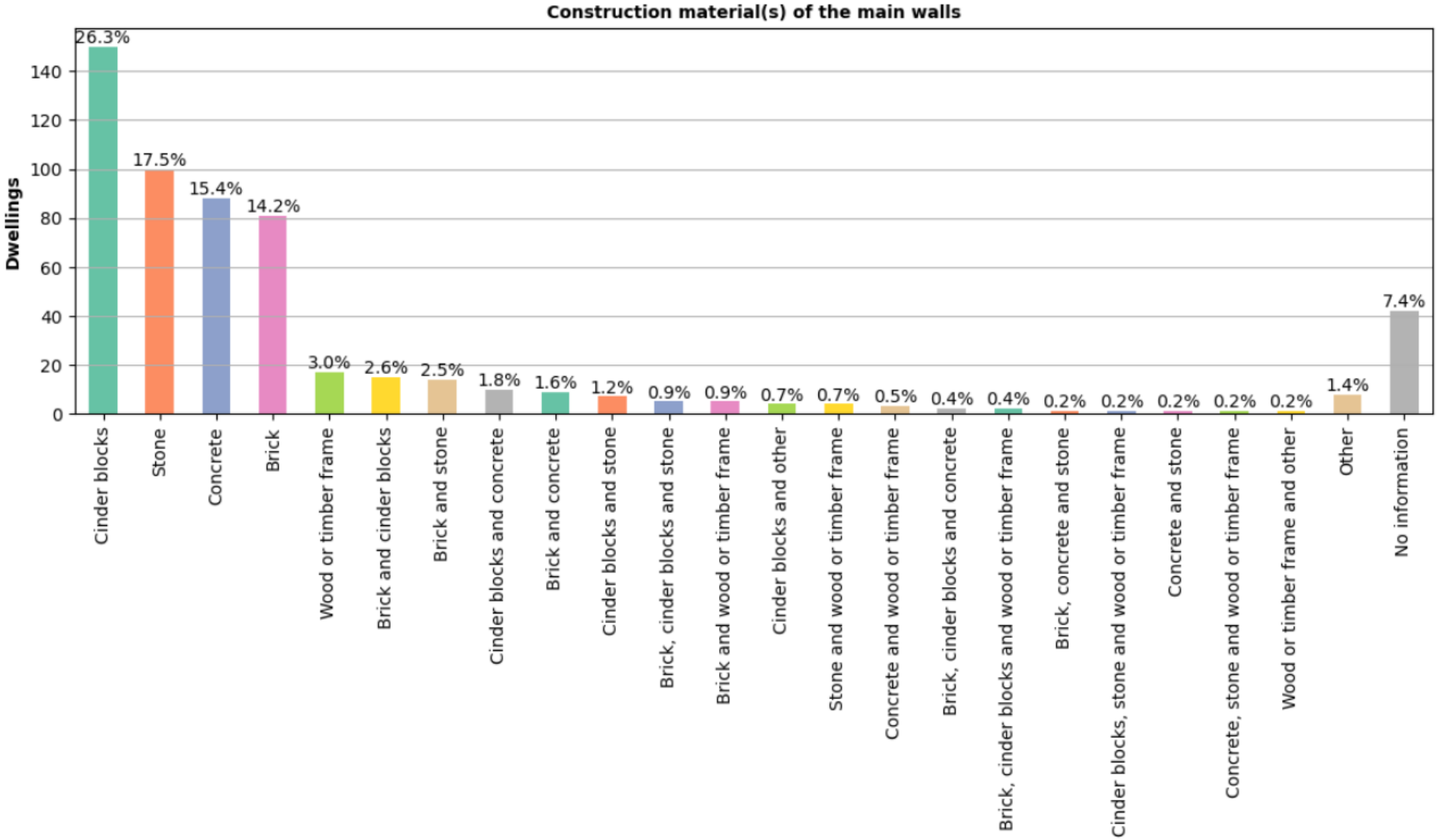


Figure 7. Construction material(s) of the main walls of CNL2 dwellings (n=571).

Methodology

This section explains the methodology used to exploit the CNL2 French database in order to update the input values for the Healthvent approach (Eq. 6) for $PM_{2.5}$ and NO_2: a, F_{inf} and C_{ig}.

Air exchange rate (a)

The calculation of a was performed based on the CO_2 indoor and outdoor concentrations (Eq. 7).

$$a = \frac{\frac{Q_{night}}{V_{night}} \cdot 270 + \frac{Q_{day}}{V_{day}} \cdot 1170}{270 + 1170} \qquad \textit{Eq. 7}$$

Where 270 corresponds to 270 minutes, which is the duration of the night period from 1:00 a.m. to 5:30 a.m.; similarly, 1170 corresponds to 1170 minutes, which is the complementary period from 5:30 a.m. to 1:00 a.m. V is the volume considered to be affected by the CO_2 measurements taken in the master bedroom. This volume depends on the state of the door of the bedroom (open or closed). If the door is closed, the volume is considered as that of the room, otherwise the volume is no longer limited to the bedroom, but concerns a proportion α of the dwelling. The proportion α according to the typology and the number of main rooms in the dwelling are presented in Table 9.

Table 9. Proportion α of the volume of the dwelling taken into account in the calculation of the air exchange rate if the door of the master bedroom is open.

Type of dwelling	Number of main rooms	α
Apartment	1	0.66
	2	0.80
	3	0.47
	4	0.50
	5	0.25
	6	0.60
	7	0.60
	8	0.60
	9	0.60
	10	0.60
Individual house	1	0.66
	2	0.70
	3	0.43
	4	0.45
	5	0.30
	6	0.30
	7	0.30
	8	0.30
	9	0.30
	10	0.30

Q_{night} is the quotient between the total CO_2 concentration produced and the difference between indoor and outdoor CO_2 concentrations, both over the night periods of the week (Eq. 8). Since

the CO_2 outdoor concentrations were not measured during the campaigns, they are considered as the minimum indoor concentration over the week of each dwelling if they are inferior to 500 ppm, otherwise as 400 ppm. Q_{day} is calculated in the same way as Q_{night} but using daytime concentrations.

$$Q_{night} = \frac{C_{CO2_total_prod_night}}{(C_{CO2_int_night} - C_{CO2_ext})} \quad \textit{Eq. 8}$$

$C_{CO2_int_night}$: Mean indoor concentration of CO_2 over the night periods of the week.
C_{CO2_ext}: Mean outdoor concentration of CO_2 over the week.

The total CO_2 concentration in a volume ($C_{CO2_total_prod}$) is the sum of the CO_2 concentrations produced by all people present in the volume over a given period (day or night). The CO_2 production rate of people ($Q_{prod_CO2_occupant}$) depends on their gender, age and activities. The rates used in this study are presented in Table 10. Night-time production is calculated from « Sleep » values, while daytime production is calculated from « Sedentary » values.

$$C_{CO2_total_prod} = \sum_{occupants} C_{CO2_prod}{}_{occupant} = \sum_{occupants} Q_{CO2_prod_occupant}\,(age, gender) \cdot occupancy_{occupant} \quad \textit{Eq. 9}$$

The occupancy of the volume for a given period, day or night, is calculated by counting the number of time steps of the survey week during which the person was present in this volume and dividing by the number of time steps over the survey week (Eq. 10).

$$Occupancy_{occupant} = \frac{N_{time-steps_occupant_present}}{N_{time-steps_in_period}} \quad \textit{Eq. 10}$$

$N_{time-steps_occupant_present}$: Number of time steps where the occupant is present in the volume for the period (day or night).
$N_{time-steps_in_period}$: Number of time steps in the period (day or night).

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Table 10. CO_2 production rate for men and women according to their age and activity (sleep or sedentary).

Age	Man		Woman	
	Sleep ($l.h^{-1}$; 0.7 met*)	Sedentary ($l.h^{-1}$; 1.2 met*)	Sleep ($l.h^{-1}$; 0.7 met*)	Sedentary ($l.h^{-1}$; 1.2 met*)
0	1.2	2.1	1.2	2.1
1	2.5	4.3	2.5	4.3
2	3.1	5.3	3.1	5.3
3	3.5	6	3.5	6
4	3.9	6.6	3.9	6.6
5	4.3	7.3	4.3	7.3
6	4.6	7.9	4.6	7.9
7	5	8.5	5	8.5
8	5.4	9.3	5.4	9.3
9	5.8	10	5.8	10
10	6.3	10.8	6.3	10.8
11	6.8	11.6	6.8	11.6
12	7.3	12.5	7.4	12.7
13	7.8	13.5	8	13.7
14	8.6	14.7	8.5	14.5
15	9.3	16	8.9	15.3
16	9.8	16.8	9.1	15.5
17	10.3	17.6	9.1	15.5
18	10.5	18	9.1	15.6
19	10.5	18.2	9.1	16.5
20	10.5	18.3	9.1	16.1
21	10.5	18.4	9.1	17.5
22 or more	10.8	18.4	9.2	15.8

*Met: metabolic level. One met corresponds to the metabolism of a seated individual at rest (1 met = 58 $W.m^{-2}$).

Infiltration factor (F_{inf})

F_{inf} can be calculated as the ratio between indoor and outdoor concentrations (C_{int}/C_{ext}) in the case where there are no internal sources of pollutants. NO_2 emissions come from activities that involve combustion, which means that the calculation of F_{inf_NO2} is possible for CNL2 dwellings where there have not been any of these activities during the measurement week. It is preferable to calculate F_{inf} with winter measurements since the opening of windows is less frequent in this season and therefore the inputs from outside are less. However, in this study the F_{inf} has been calculated for each season to provide information to support or reject this premise.

Figure 8 presents the stages for selecting the dwellings considered free of indoor NO_2 sources in all seasons. Only 242 dwellings meet the full requirements. The type of heating system installed in the dwelling (powered by electricity or any other type of energy) was not a criterion for the selection of the sample since, being an emetic system, the NO_2 contributions from these systems are null inside the dwelling. The results were classified by ventilation system installed in the dwelling: mechanical, natural or absent. The F_{inf_NO2} calculated for each house

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was then compared to the mean F_{inf_NO2} values from ANSES: 0.65 for worldwide dwellings and 0.75 for French dwellings.

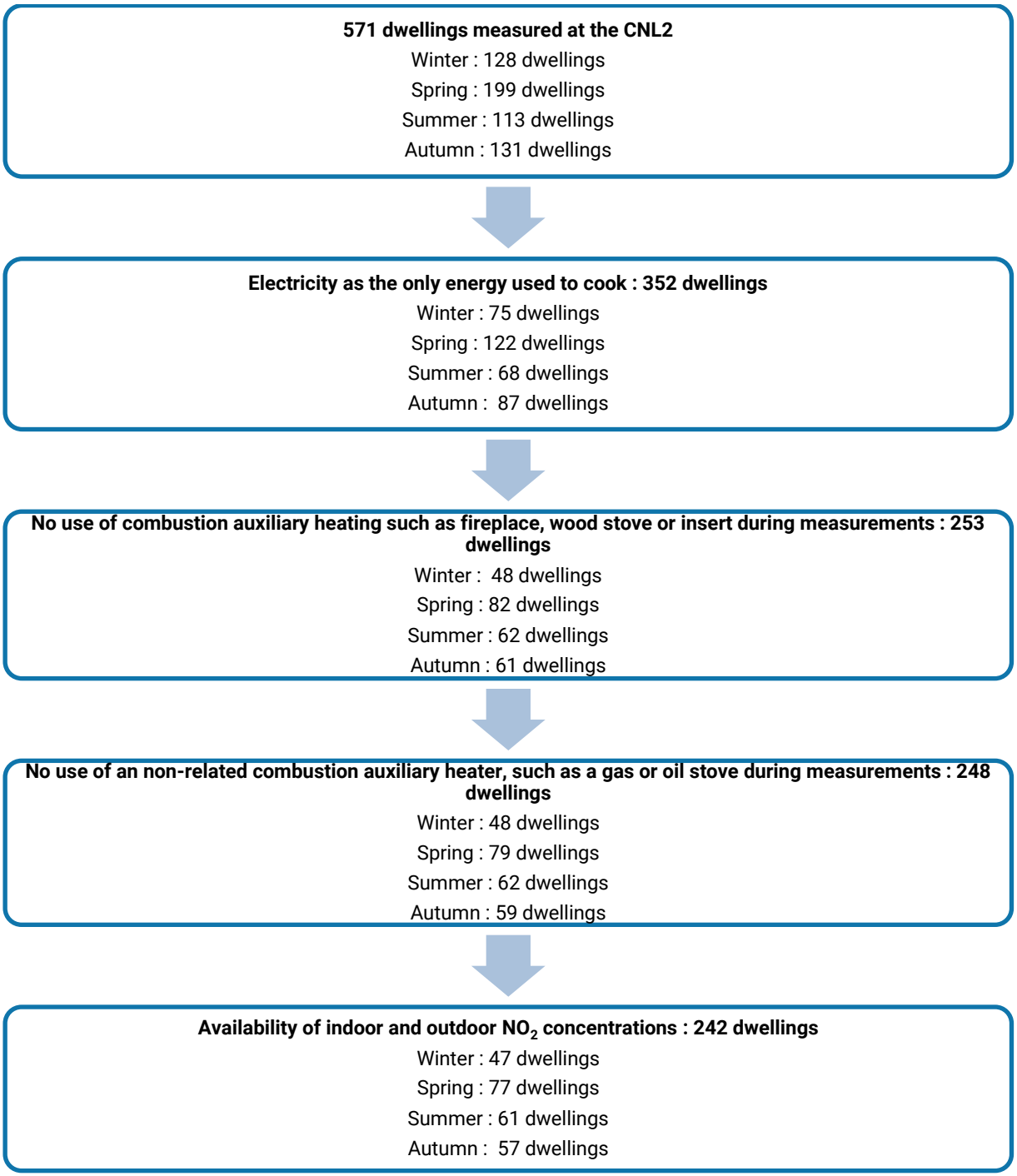


Figure 8. Sample dwelling selection process for the calculation of the infiltration factor for NO_2.

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It is not possible to calculate $F_{inf_PM2.5}$ using the method described before for F_{inf_NO2} because all dwellings have $PM_{2.5}$ indoor sources. $F_{inf_PM2.5}$ have been estimated using Eq. 3 and considering:

- $P_{PM2.5}$ equal to 0.85 according to the ANSES and CSTB study (ANSES 2019), four $k_{PM2.5}$ values (0.1 h^{-1}, 0.2 h^{-1}, 0.3 h^{-1} and 0.4 h^{-1} according to the values presented by Diapouli et al. in Figure 3) and the a of each dwelling
- $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1} (k value recommended in typical conditions with secondary inorganic and organic aerosols dominating)
- $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}

The results were classified by ventilation system installed in the dwelling: mechanical, natural or absent. The $F_{inf_PM2.5}$ calculated for each dwelling was then compared to the mean $F_{inf_PM2.5}$ values from ANSES: 0.59 ≈ 0.60 for worldwide dwellings and 0.70 for French dwellings.

Indoor generated concentration (C_{ig})

$C_{ig_PM2.5}$ and C_{ig_NO2} were calculated according to the Healthvent approach (Eq. 11) for all meteorological seasons: winter (December 1st to February 28th), spring (Mars 1st to May 31st), summer (June 1st to August 31st) and autumn (September 1st to November 30th). The F_{inf} used for calculations were:

- $F_{inf_PM2.5}$ calculated for each type of ventilation system and season considering $P_{PM2.5}$ equal to 0.85 and four $k_{PM2.5}$ values from the range found by Diapouli et al. in worldwide studies: 0.1 h^{-1}, 0.2 h^{-1}, 0.3 h^{-1} and 0.4 h^{-1}
- $F_{inf_PM2.5}$ calculated for each type of ventilation system and season considering $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1}
- $F_{inf_PM2.5}$ calculated for each type of ventilation system and season considering $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}
- $F_{inf_PM2.5}$ of 0.60 for worldwide dwellings (ANSES)
- $F_{inf_PM2.5}$ of 0.70 for French dwellings (ANSES)
- F_{inf_NO2} calculated for each type of ventilation system and season
- F_{inf_NO2} of 0.65 for worldwide dwellings (ANSES)
- F_{inf_NO2} of 0.75 for French dwellings (ANSES)

$$C_{ig} = C_{int} - F_{\text{inf}} \cdot C_{ext} \qquad \textit{Eq. 11}$$

Exposure period

In order to address the exposure time to indoor pollutants during the CNL2 campaign, the percentage of dwellings occupied for at least one person during the measurement week was calculated using the forms filled out by the inhabitants (30 minutes time step). Considering that the inhabitants habits vary throughout the year, the results were presented by season.

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Results

This section presents the results of the calculation of the mass-balance model (HealthVent approach) parameters a, F_{inf} and C_{ig} for $PM_{2.5}$ and NO_2 based on the CNL2 database. It also presents the percentage of dwellings occupied during the measurement week by season.

Air exchange rate (a)

Figure 9 and Table 11 present the distribution of a values found in 413 CNL2 dwellings by season and by ventilation system. The 158 dwellings that do not have continuous CO_2 measurements (measurement problem) were removed from the sample.

For all seasons and all ventilation systems:

- Mean a values range from 0.61 to 1.77 h^{-1}.
- Median a values range from 0.47 to 1.17 h^{-1}.
- Median a values are inferior to mean a values. The ratio between the median and the mean (P50/mean) ranges between 0.62 and 0.91.
- Dwellings measured in summer present the highest mean, the highest median and the greatest difference between the first and third quartile for all ventilation systems (1.12 $h^{-1}$for mechanical, 1.76 h^{-1} for natural and 1.04 $h^{-1}$for absent).
- Natural ventilation system in summer presents the highest mean, the highest median and the greatest difference between the first and third quartile.
- Natural ventilation system in winter presents the lowest mean and median.
- Natural ventilation system in spring presents the lowest difference between the first and third quartile (0.19 h^{-1}).

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Table 11. Distribution of the air exchange rate of the CNL2 dwellings.

	a_{WINTER} (h^{-1})			a_{SPRING} (h^{-1})			a_{SUMMER} (h^{-1})			a_{AUTUMN} (h^{-1})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	52	24	13	117	25	23	64	13	15	39	17	11
Mean	**0.79**	**0.61**	**0.64**	**0.90**	**0.65**	**0.74**	**1.40**	**1.77**	**1.29**	**0.68**	**0.72**	**1.19**
Std	0.70	0.32	0.30	0.59	0.52	0.45	1.23	1.80	1.20	0.40	0.41	1.23
Min	0.16	0.19	0.27	0.21	0.25	0.16	0.20	0.27	0.12	0.22	0.17	0.14
P25	0.38	0.38	0.47	0.51	0.36	0.43	0.58	0.73	0.57	0.38	0.41	0.50
P50	**0.58**	**0.47**	**0.55**	**0.67**	**0.48**	**0.65**	**0.96**	**1.17**	**0.89**	**0.62**	**0.60**	**0.74**
P75	0.84	0.78	0.79	1.16	0.55	0.90	1.70	2.49	1.61	0.81	1.04	1.29
Max	4.21	1.29	1.25	3.13	2.34	1.69	5.84	7.02	4.52	1.74	1.52	4.20

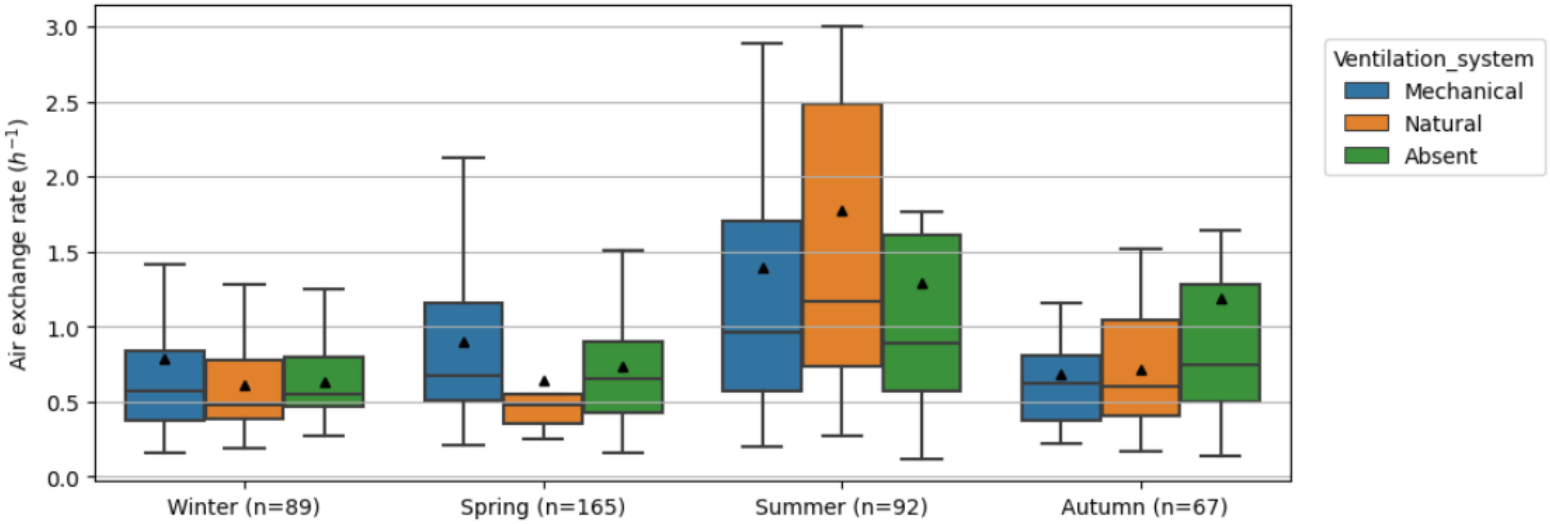


Figure 9. Distribution of the air exchange rate of the CNL2 dwellings.

Infiltration factor (F_{inf})

Particle matter - $PM_{2.5}$

$F_{inf_PM2.5}$ was calculated for the 369 dwellings having a a value (calculated from continuous indoor CO_2 concentrations) and $PM_{2.5}$ concentrations considering the following combinations:

1) The a of each dwelling, $P_{PM2.5}$ equal to 0.85, and $k_{PM2.5}$ equal to 0.1 h^{-1} (Figure 10 and Table 13).
2) The a of each dwelling, $P_{PM2.5}$ equal to 0.85, and $k_{PM2.5}$ equal to 0.2 h^{-1} (Figure 11 and Table 14)
3) The a of each dwelling, $P_{PM2.5}$ equal to 0.85, and $k_{PM2.5}$ equal to 0.3 h^{-1} (Figure 12 and Table 15)
4) The a of each dwelling, $P_{PM2.5}$ equal to 0.85, and $k_{PM2.5}$ equal to 0.4 h^{-1} (Figure 13 and Table 16)
5) The a of each dwelling, $P_{PM2.5}$ equal to 0.90, and $k_{PM2.5}$ equal to 0.2 h^{-1}(Figure 16 and Table 17)
6) The a of each dwelling, $P_{PM2.5}$ equal to 0.95, and $k_{PM2.5}$ equal to 0.2 h^{-1}(Figure 17 and Table 18)

The mean and median $F_{inf_PM2.5}$ values obtained for each combination and for each season and ventilation system are very close. In fact, the difference between these values is in the range of [-0.01 ; 0.03].

As depicted in Eq. 3, an increase in the k value leads to a decrease in the F_{inf} value. This equation also depicts that an increase in the P value leads to an increase in the F_{inf} value. These decreases and increases can be observed in the ranges of mean and median $F_{inf_PM2.5}$ values for all seasons and ventilation systems presented in Table 12. An increase of 0.1 h^{-1} in the $K_{PM2.5}$ value leads to a decrease of up to 0.1 in the mean and median $F_{inf_PM2.5}$ values for all seasons and ventilation systems. Similarly, an increase of 0.05 in the $P_{PM2.5}$ value leads to an increase of up to 0.05 in the mean and median $F_{inf_PM2.5}$ values for all seasons and ventilation systems.

The range of mean F_{inf} values using $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.2, 0.3 and 0.4 h^{-1} contains the ANSES mean value found for dwellings worldwide (0.6). In turn, the ANSES mean value found for French dwellings (0.7) is present in the range of mean F_{inf} values for the following combinations of $P_{PM2.5}$ and $k_{PM2.5}$:

- $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.1 h^{-1}
- $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.2 h^{-1}
- $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1}
- $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}

The interquartile range (P75-P25) of $F_{inf_PM2.5}$ also varies depending on the $P_{PM2.5}$ and $k_{PM2.5}$ values (Table 12). The shortest range is found with $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.1 h^{-1} ([0.05 ; 0.10]) and the longest with $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.4 h^{-1} ([0.11 ; 0.21]).

Table 12. Ranges of mean, median and P75-P25 of $F_{inf_PM2.5}$ values obtained for different $P_{PM2.5}$ and $k_{PM2.5}$ values.

$P_{PM2.5}$	$k_{PM2.5}$	$F_{inf_PM2.5}$		
		Range of mean	Range of median	Range of P75-P25
0.85	0.1	[0.70 ; 0.77]	[0.70 ; 0.78]	[0.05 ; 0.10]
	0.2	[0.60 ; 0.70]	[0.60 ; 0.73]	[0.09 ; 0.16]
	0.3	[0.53 ; 0.66]	[0.52 ; 0.68]	[0.11 ; 0.19]
	0.4	[0.47 ; 0.61]	[0.46 ; 0.63]	[0.11 ; 0.21]
0.90	0.2	[0.64 ; 0.75]	[0.63 ; 0.77]	[0.09 ; 0.16]
0.95	0.2	[0.67 ; 0.79]	[0.67 ; 0.81]	[0.09 ; 0.18]

Dwellings measured in summer present the highest mean and median for all ventilation systems and for all $P_{PM2.5}$ and $k_{PM2.5}$ combinations. This is because the infiltration factor depends on a, and as seen above, the highest values of a were found in summer for all ventilation systems.

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Table 13. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.1 h^{-1}.

	$F_{inf_PM2.5_WINTER}$			$F_{inf_PM2.5_SPRING}$			$F_{inf_PM2.5_SUMMER}$			$F_{inf_PM2.5_AUTUMN}$		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	48	21	11	104	24	21	57	13	12	32	17	9
Mean	**0.72**	**0.71**	**0.71**	**0.74**	**0.70**	**0.71**	**0.76**	**0.77**	**0.74**	**0.71**	**0.72**	**0.72**
Std	0.06	0.06	0.05	0.06	0.06	0.08	0.06	0.07	0.10	0.07	0.07	0.11
Min	0.52	0.56	0.62	0.58	0.61	0.53	0.57	0.62	0.45	0.59	0.54	0.49
P25	0.67	0.68	0.68	0.71	0.66	0.68	0.73	0.75	0.73	0.68	0.68	0.70
P50	**0.72**	**0.71**	**0.71**	**0.74**	**0.70**	**0.74**	**0.77**	**0.78**	**0.76**	**0.73**	**0.73**	**0.75**
P75	0.75	0.75	0.74	0.78	0.73	0.77	0.80	0.82	0.78	0.76	0.78	0.80
Max	0.83	0.79	0.79	0.82	0.82	0.80	0.84	0.84	0.83	0.80	0.80	0.83

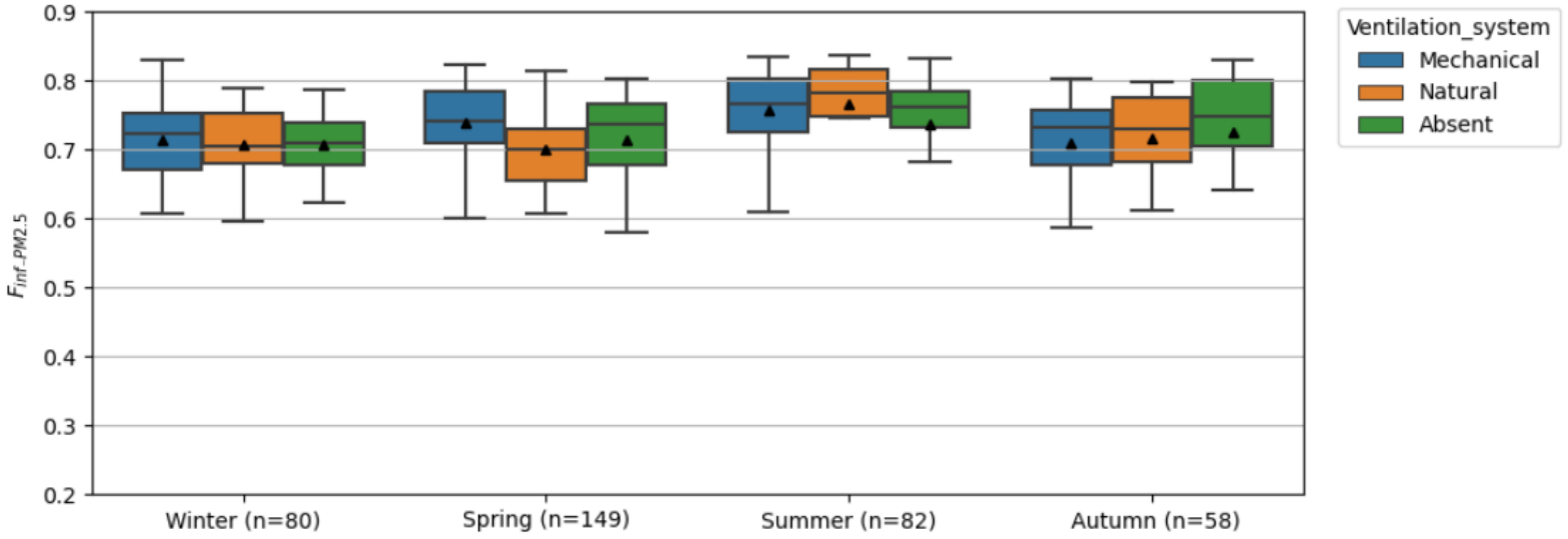


Figure 10. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.1 h^{-1}.

Table 14. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

	$F_{inf_PM2.5_WINTER}$			$F_{inf_PM2.5_SPRING}$			$F_{inf_PM2.5_SUMMER}$			$F_{inf_PM2.5_AUTUMN}$		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	48	21	11	104	24	21	57	13	12	32	17	9
Mean	**0.62**	**0.61**	**0.61**	**0.66**	**0.60**	**0.62**	**0.69**	**0.70**	**0.66**	**0.62**	**0.63**	**0.65**
Std	0.09	0.09	0.07	0.08	0.09	0.11	0.09	0.10	0.13	0.10	0.10	0.15
Min	0.38	0.41	0.49	0.44	0.47	0.38	0.43	0.49	0.31	0.45	0.39	0.35
P25	0.55	0.57	0.57	0.61	0.53	0.56	0.63	0.67	0.64	0.56	0.57	0.60
P50	**0.63**	**0.60**	**0.61**	**0.66**	**0.60**	**0.65**	**0.70**	**0.73**	**0.69**	**0.64**	**0.64**	**0.67**
P75	0.67	0.67	0.66	0.73	0.64	0.70	0.76	0.79	0.73	0.68	0.71	0.76
Max	0.81	0.73	0.73	0.80	0.78	0.76	0.82	0.83	0.81	0.76	0.75	0.81

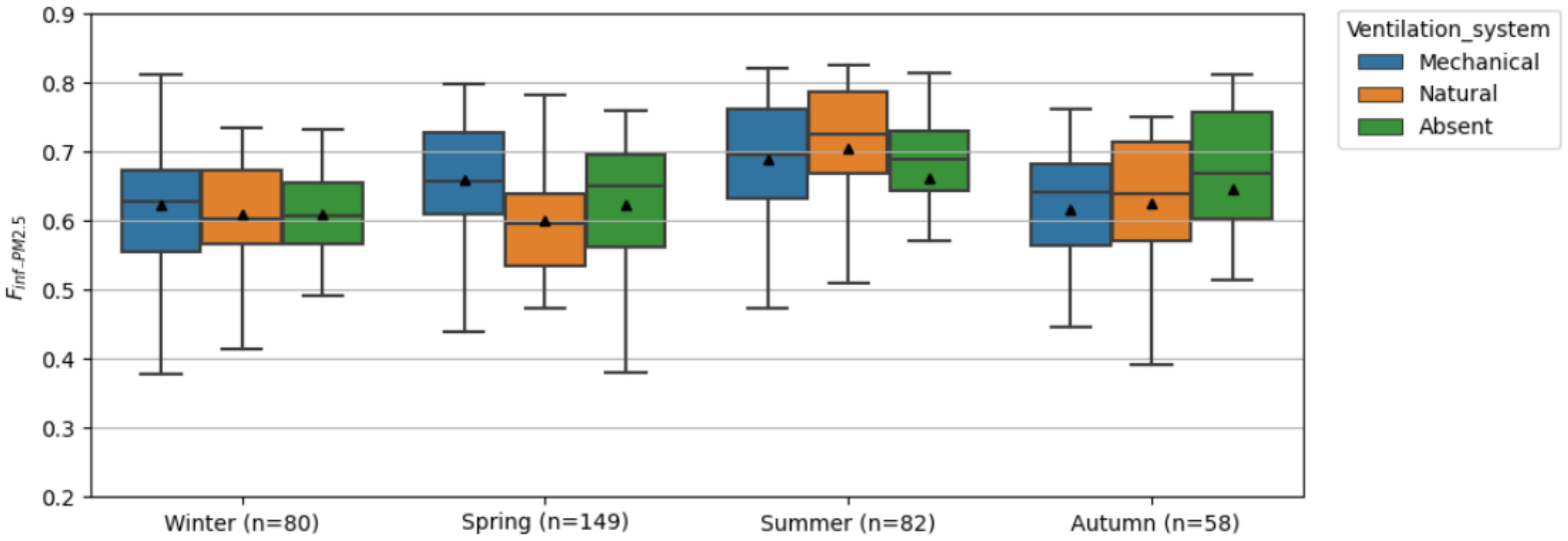


Figure 11. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

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Table 15. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.3 h^{-1}.

	$F_{inf_PM2.5_WINTER}$			$F_{inf_PM2.5_SPRING}$			$F_{inf_PM2.5_SUMMER}$			$F_{inf_PM2.5_AUTUMN}$		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	48	21	11	104	24	21	57	13	12	32	17	9
Mean	**0.55**	**0.54**	**0.54**	**0.60**	**0.53**	**0.56**	**0.64**	**0.66**	**0.61**	**0.55**	**0.56**	**0.59**
Std	0.11	0.10	0.09	0.10	0.11	0.12	0.11	0.13	0.15	0.11	0.12	0.17
Min	0.30	0.33	0.41	0.35	0.39	0.30	0.34	0.40	0.24	0.36	0.31	0.27
P25	0.47	0.49	0.48	0.53	0.45	0.48	0.56	0.60	0.57	0.48	0.49	0.53
P50	**0.56**	**0.53**	**0.53**	**0.59**	**0.52**	**0.58**	**0.64**	**0.68**	**0.63**	**0.57**	**0.57**	**0.61**
P75	0.61	0.61	0.59	0.68	0.57	0.64	0.72	0.76	0.68	0.62	0.66	0.72
Max	0.79	0.69	0.69	0.78	0.75	0.72	0.81	0.82	0.80	0.73	0.71	0.79

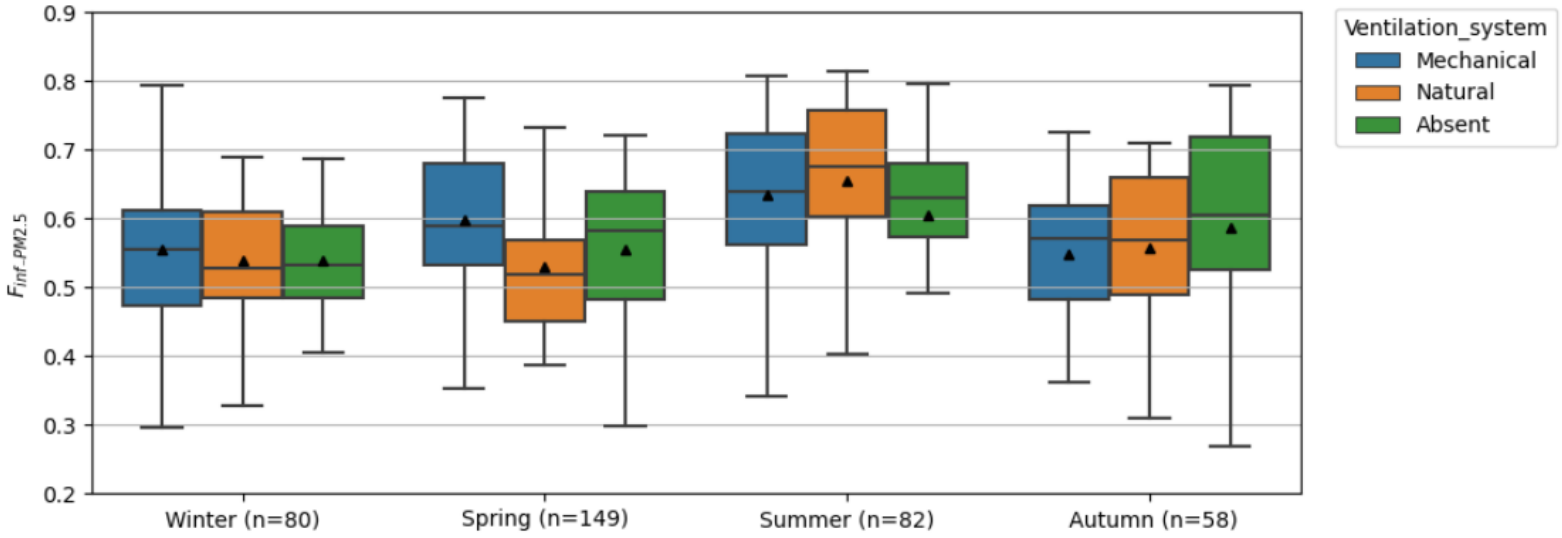


Figure 12. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.3 h^{-1}.

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Table 16. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.4 h^{-1}.

	$F_{inf_PM2.5_WINTER}$			$F_{inf_PM2.5_SPRING}$			$F_{inf_PM2.5_SUMMER}$			$F_{inf_PM2.5_AUTUMN}$		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	48	21	11	104	24	21	57	13	12	32	17	9
Mean	**0.50**	**0.48**	**0.48**	**0.55**	**0.47**	**0.50**	**0.59**	**0.61**	**0.56**	**0.49**	**0.50**	**0.54**
Std	0.12	0.10	0.09	0.11	0.12	0.13	0.12	0.14	0.15	0.12	0.12	0.18
Min	0.24	0.27	0.35	0.30	0.33	0.24	0.28	0.34	0.19	0.30	0.25	0.22
P25	0.41	0.42	0.42	0.47	0.39	0.42	0.50	0.55	0.52	0.42	0.43	0.47
P50	**0.50**	**0.47**	**0.47**	**0.54**	**0.46**	**0.53**	**0.59**	**0.63**	**0.58**	**0.52**	**0.51**	**0.55**
P75	0.56	0.56	0.53	0.64	0.51	0.59	0.69	0.73	0.64	0.57	0.61	0.68
Max	0.78	0.65	0.64	0.75	0.73	0.69	0.80	0.80	0.78	0.69	0.67	0.78

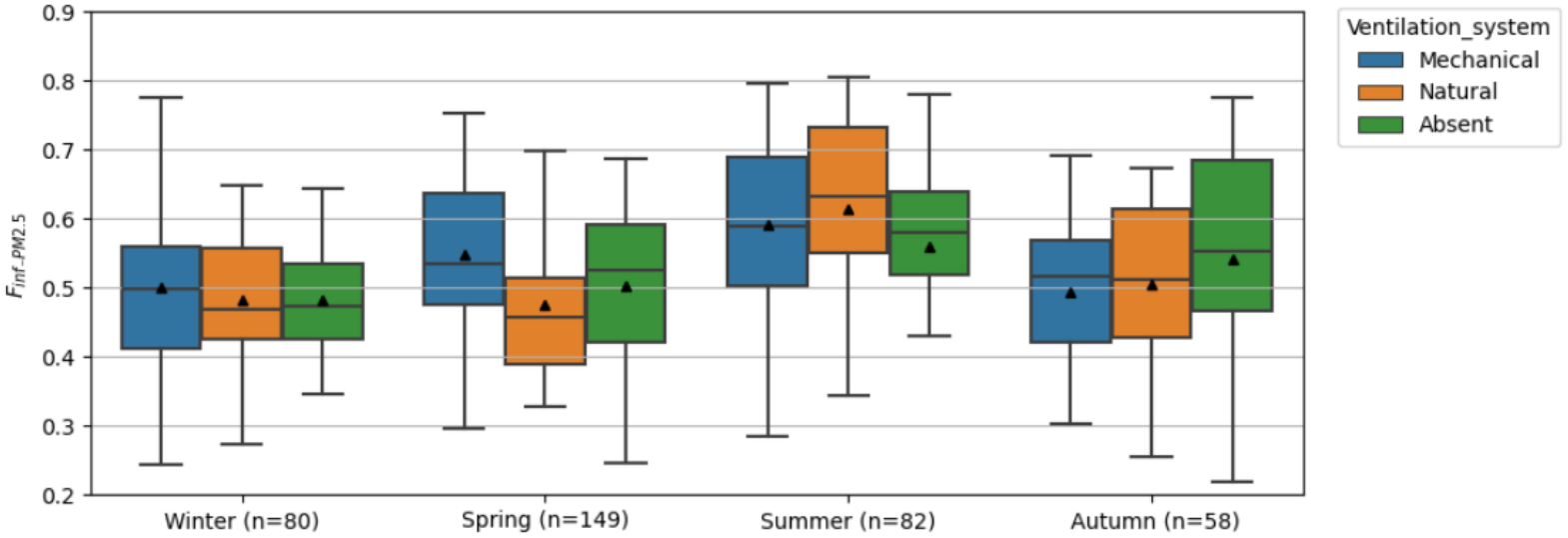


Figure 13. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.4 h^{-1}.

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Table 17. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

	$F_{inf_PM2.5_WINTER}$			$F_{inf_PM2.5_SPRING}$			$F_{inf_PM2.5_SUMMER}$			$F_{inf_PM2.5_AUTUMN}$		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	48	21	11	104	24	21	57	13	12	32	17	9
Mean	**0.66**	**0.65**	**0.65**	**0.70**	**0.64**	**0.66**	**0.73**	**0.75**	**0.70**	**0.65**	**0.66**	**0.68**
Std	0.10	0.09	0.08	0.09	0.10	0.11	0.09	0.11	0.14	0.10	0.11	0.16
Min	0.40	0.44	0.52	0.46	0.50	0.40	0.45	0.52	0.33	0.47	0.41	0.37
P25	0.59	0.60	0.60	0.64	0.57	0.60	0.67	0.71	0.68	0.60	0.60	0.64
P50	**0.67**	**0.64**	**0.64**	**0.70**	**0.63**	**0.69**	**0.74**	**0.77**	**0.73**	**0.68**	**0.68**	**0.71**
P75	0.71	0.71	0.69	0.77	0.68	0.74	0.81	0.83	0.77	0.72	0.76	0.80
Max	0.86	0.78	0.78	0.85	0.83	0.80	0.87	0.88	0.86	0.81	0.80	0.86

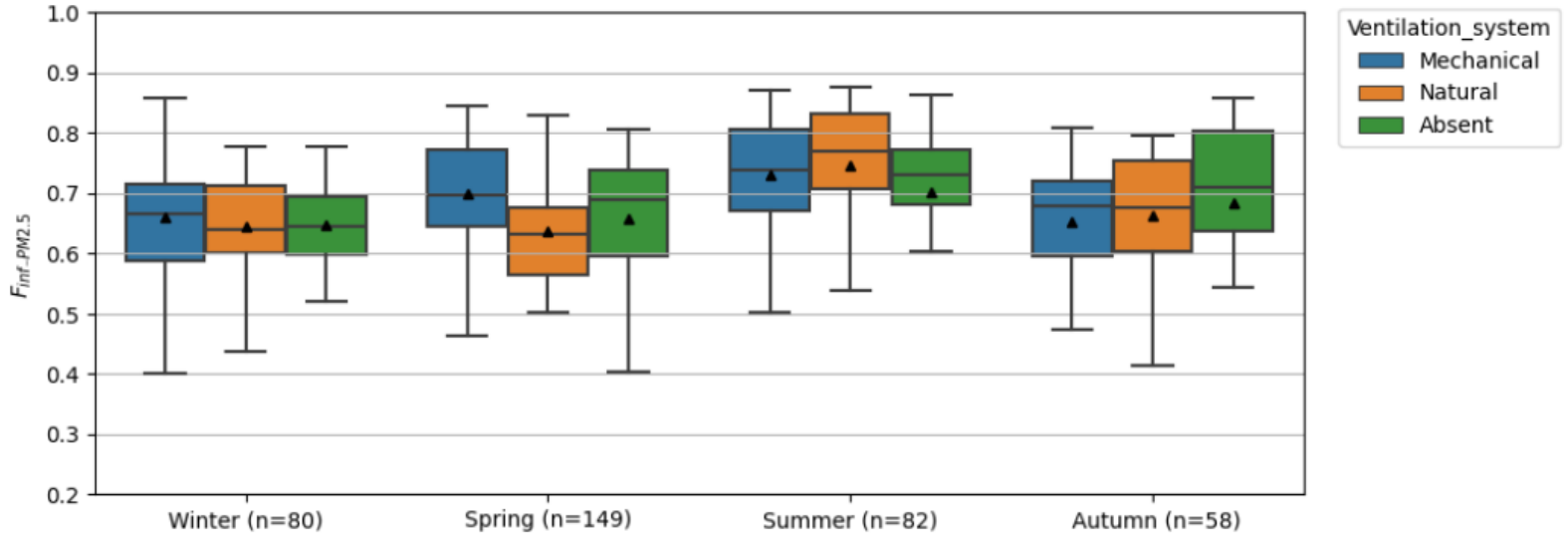


Figure 14. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

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Table 18. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

	$F_{inf_PM2.5_WINTER}$			$F_{inf_PM2.5_SPRING}$			$F_{inf_PM2.5_SUMMER}$			$F_{inf_PM2.5_AUTUMN}$		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	48	21	11	104	24	21	57	13	12	32	17	9
Mean	**0.70**	**0.68**	**0.68**	**0.74**	**0.67**	**0.70**	**0.77**	**0.79**	**0.74**	**0.69**	**0.70**	**0.72**
Std	0.10	0.10	0.08	0.09	0.10	0.12	0.10	0.12	0.15	0.11	0.11	0.16
Min	0.42	0.46	0.55	0.49	0.53	0.43	0.48	0.55	0.35	0.50	0.44	0.39
P25	0.62	0.63	0.63	0.68	0.60	0.63	0.71	0.75	0.72	0.63	0.64	0.67
P50	**0.70**	**0.67**	**0.68**	**0.73**	**0.67**	**0.73**	**0.78**	**0.81**	**0.77**	**0.72**	**0.71**	**0.75**
P75	0.75	0.75	0.73	0.81	0.71	0.78	0.85	0.88	0.81	0.76	0.80	0.85
Max	0.91	0.82	0.82	0.89	0.88	0.85	0.92	0.92	0.91	0.85	0.84	0.91

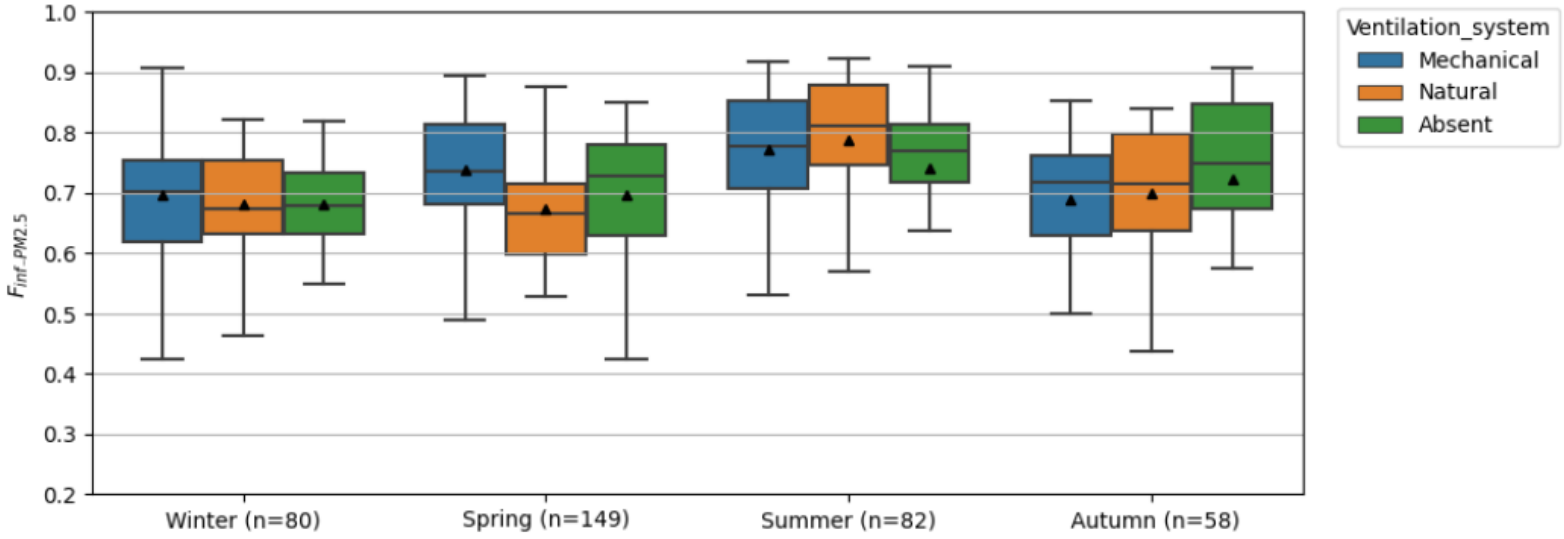


Figure 15. Distribution of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

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Nitrogen dioxide – NO_2

Figure 16 and Table 19 present the distribution of NO_2 infiltration factors found in the 242 dwellings considered free of indoor sources of NO_2 in all seasons. Median and mean values are relatively close for all seasons and ventilation systems. In fact, the ratio between the median and the mean (P50/mean) ranges between 0.79 and 1.21.

The mean F_{inf_NO2} in winter are closest to the ANSES value found for dwellings worldwide (0.65) than for French dwellings (0.75): 0.56 for mechanical ventilation system, 0.53 for natural ventilation system and 0.50 for dwellings that are not equipped with any ventilation system. The mean F_{inf_NO2} in spring and autumn are close to the ANSES value found for French dwellings. In summer the mean F_{inf_NO2} is close to 1 regardless of the type of ventilation system.

A F_{inf} equal to one implies that the walls of the dwelling allow complete passage of contaminants from the outside to the inside which is the case when windows or doors are open. In France, people often open windows in summer, especially at night, to try to refresh dwellings. Therefore, a F_{inf_NO2} close to 1 in summer in French dwelling is a logic result.

The median F_{inf_NO2} in winter are lower than the ANSES values found for dwellings worldwide and for French dwellings: 0.44 for mechanical ventilation system, 0.50 for natural ventilation system and 0.42 for dwellings that are not equipped with any ventilation system. In spring and autumn, the median F_{inf_NO2} ranges between 0.58 and 0.87 (the ANSES values for dwellings worldwide and for French dwellings are included in this range). In summer the median F_{inf_NO2} is close to 1 regardless of the type of ventilation system.

Table 19. Distribution of F_{inf_NO2} of the CNL2 dwellings considered free of indoor sources of NO_2.

	$F_{inf_NO2_WINTER}$			$F_{inf_NO2_SPRING}$			$F_{inf_NO2_SUMMER}$			$F_{inf_NO2_AUTUMN}$		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	32	12	3	56	10	11	45	10	6	36	7	14
Mean	**0.56**	**0.53**	**0.50**	**0.83**	**0.73**	**0.72**	**1.00**	**1.10**	**1.07**	**0.84**	**0.67**	**0.78**
Std	0.44	0.24	0.43	0.50	0.49	0.31	0.69	0.91	0.26	0.66	0.21	0.34
Min	0.09	0.21	0.12	0.16	0.25	0.23	0.10	0.47	0.75	0.17	0.35	0.19
P25	0.22	0.37	0.27	0.56	0.47	0.45	0.65	0.76	0.94	0.45	0.52	0.53
P50	**0.44**	**0.50**	**0.42**	**0.87**	**0.58**	**0.87**	**0.96**	**0.89**	**1.02**	**0.79**	**0.73**	**0.84**
P75	0.84	0.65	0.70	0.97	0.86	0.95	1.02	0.98	1.22	0.98	0.82	0.95
Max	2.07	0.96	0.97	3.43	1.94	1.11	3.92	3.64	1.46	4.15	0.89	1.53

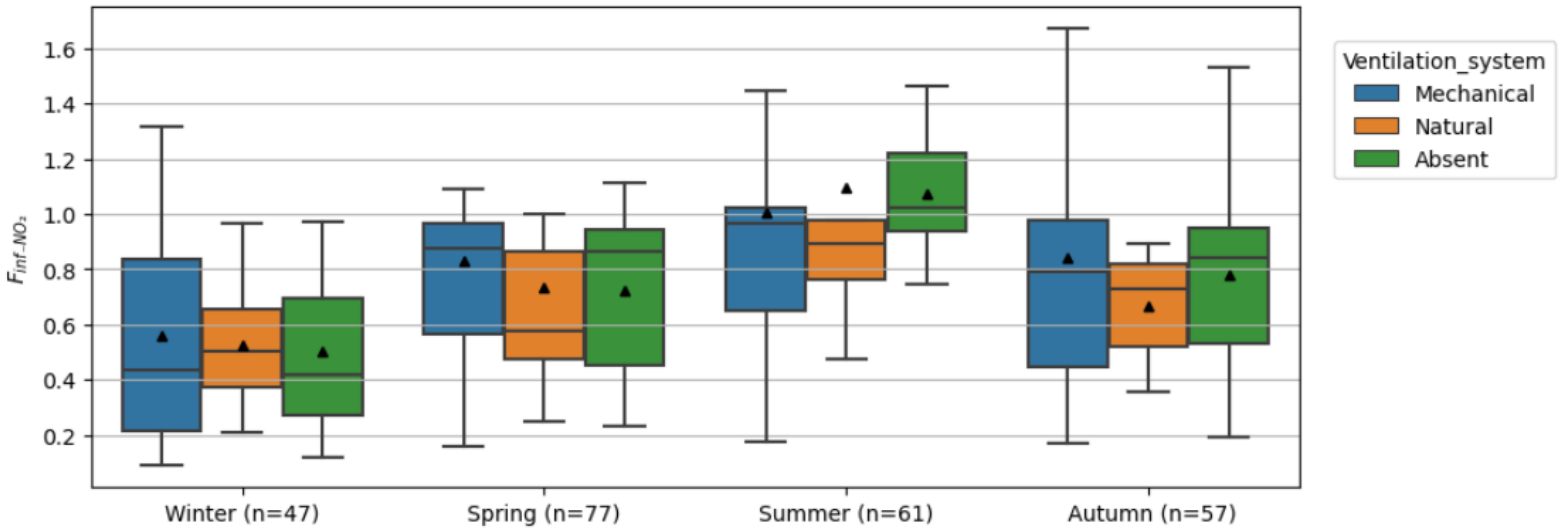


Figure 16. Distribution of F_{inf_NO2} of the CNL2 dwellings considered free of indoor sources of NO_2.

Indoor generated concentration (C_{ig})

This section presents the C_{ig} of $PM_{2.5}$ and NO_2 estimated using different F_{inf}. Some dwellings were removed from the sample at each calculation due to two situations:

1) No indoor and/or outdoor concentration(s)
2) A negative C_{ig} value. This occurs when the outdoor concentration is higher than the indoor concentration. In this case, it is not possible to differentiate which part of the interior concentration is generated inside from that corresponding to infiltration from outside.

Particle matter - $PM_{2.5}$

The $C_{ig_PM2.5}$ was estimated considering different values of $F_{inf_PM2.5}$:

- $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and four $k_{PM2.5}$ values:
  - $k_{PM2.5}$ equal to 0.1 h^{-1} (Figure 17 and Table 21)
  - $k_{PM2.5}$ equal to 0.2 h^{-1} (Figure 18 and Table 22)
  - $k_{PM2.5}$ equal to 0.3 h^{-1} (Figure 19 and Table 23)
  - $k_{PM2.5}$ equal to 0.4 h^{-1} (Figure 20 and Table 24)
- $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1}(Figure 21 and Table 25)
- $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}(Figure 22 and Table 26)
- $F_{inf_PM2.5}$ equal to 0.60 which is the ANSES mean value found for worldwide dwellings (Figure 23 and Table 27)
- $F_{inf_PM2.5}$ equal to 0.70 which is the ANSES mean value found for French dwellings (Figure 24 and Table 28)

56 dwellings were removed from the sample because they have no information about the $PM_{2.5}$ indoor concentration (measurement problem):

- 40 dwellings equipped with a mechanical ventilation system
- 4 dwellings equipped with a natural ventilation system
- 12 dwellings without a ventilation system

In the cases where the $F_{inf_PM2.5}$ was calculated using the air exchange rate of each dwelling, 146 dwellings that have not this information were also removed from the sample.

Dwellings that presented a negative $C_{ig_PM2.5}$ value were then removed from the sample. Table 20 presents the number of dwellings with a negative $C_{ig_PM2.5}$ value according to the $F_{inf_PM2.5}$ considered and the ventilation system installed in the dwelling.

Table 20. Number of dwellings with a negative $C_{ig_PM2.5}$.

$F_{inf_PM2.5}$	Ventilation system	Number of dwellings with a negative $C_{ig_PM2.5}$
Calculated using a of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.1 h^{-1}	Mechanical	31
	Natural	5
	Absent	4
	All systems	**40**
Calculated using a of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.2 h^{-1}	Mechanical	20
	Natural	4
	Absent	3
	All systems	**27**
Calculated using a of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.3 h^{-1}	Mechanical	17
	Natural	2
	Absent	2
	All systems	**21**
Calculated using a of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.4 h^{-1}	Mechanical	13
	Natural	2
	Absent	2
	All systems	**17**
Calculated using a of each dwelling, $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1}	Mechanical	27
	Natural	5
	Absent	4
	All systems	**36**
Calculated using a of each dwelling, $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}	Mechanical	31
	Natural	5
	Absent	4
	All systems	**40**
0.60*	Mechanical	27
	Natural	10
	Absent	4
	All systems	**41**
0.70**	Mechanical	44
	Natural	16
	Absent	8
	All systems	**68**

a: Air exchange rate
K: Deposition rate
P: Penetration efficiency
* ANSES mean value found for worldwide dwellings
** ANSES mean value found for French dwellings

The lowest number of dwellings removed due to a negative $C_{ig_PM2.5}$ value in the cases where $F_{inf_PM2.5}$ was calculated using the air exchange rate of each dwelling was found with $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.4 h^{-1} (17 dwellings removed). In fact, in the four samples using $P_{PM2.5}$ equal to 0.85, the number of removed dwellings decreases when the $k_{PM2.5}$ value increases. In the three samples using $k_{PM2.5}$ equal to 0.2 h^{-1}, the number of removed dwellings increases when the $P_{PM2.5}$ value increases.

The number of removed dwellings is the same for the following combinations (31 with mechanical ventilation system, 5 with natural ventilation system and 4 without ventilation system):

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- $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.1 h^{-1}
- $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}

In the cases where $F_{inf_PM2.5}$ was fixed (0.6 or 0.7), the number of removed dwellings was fewer for the lowest $F_{inf_PM2.5}$ value:41 dwellings removed with $F_{inf_PM2.5}$ equal to 0.6. This number of removed dwellings is close to that found by the combinations mentioned above (40 removed dwellings).

Table 29 presents the ratio between the median and the mean estimated $C_{ig_PM2.5}$ values (P50/mean) using different $F_{inf_PM2.5}$ values. The median $C_{ig_PM2.5}$ values are inferior or equal to the mean $C_{ig_PM2.5}$ values for all seasons and ventilation systems using all $F_{inf_PM2.5}$ values. Median and mean values are very close in winter without ventilation system and in autumn with natural ventilation system using all $F_{inf_PM2.5}$ values (ratio between 0.87 and 1).

There is no clear correlation between the increase of the mean $C_{ig_PM2.5}$ and the increase or decrease in $k_{PM2.5}$ and $P_{PM2.5}$. In other words, an increase of 0.1h^{-1} in the $k_{PM2.5}$ value or an increase of 0.05 in the $P_{PM2.5}$ value does not necessarily lead to an increase or decrease of the $C_{ig_PM2.5}$ value. This lack of correlation is also seen in the comparison of mean $C_{ig_PM2.5}$ values obtained with $F_{inf_PM2.5}$ equal to 0.6 and 0.7.

The precedent analysis was also conducted using the median $C_{ig_PM2.5}$ values. This time:

- The median $C_{ig_PM2.5}$ values show a systematic increase when the $k_{PM2.5}$ value increase. The exceptions were autumn with natural ventilation system and without ventilation system using $k_{PM2.5}$ equal to 0.2 h^{-1}.
- The median $C_{ig_PM2.5}$ values tends to decrease when the $P_{PM2.5}$ value increase. The exceptions were winter and spring with mechanical ventilation system and summer without ventilation system.
- The median $C_{ig_PM2.5}$ values obtained using $F_{inf_PM2.5}$ equal to 0.6 and 0.7 shows that an increase of 0.1 in the $F_{inf_PM2.5}$ leads to a decrease of up to 1.54 µg.m^{-3} in the median $C_{ig_PM2.5}$. The only exception was autumn without ventilation system with an increase of 0.30 µg.m^{-3}.

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Table 21. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.1 h^{-1}.

	$C_{ig_PM2.5_WINTER}$ ($\mu g.m^{-3}$)			$C_{ig_PM2.5_SPRING}$ ($\mu g.m^{-3}$)			$C_{ig_PM2.5_SUMMER}$ ($\mu g.m^{-3}$)			$C_{ig_PM2.5_AUTUMN}$ ($\mu g.m^{-3}$)		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	39	20	11	92	22	19	54	13	11	25	15	8
Mean	**21.15**	**37.54**	**22.88**	**24.42**	**18.48**	**37.62**	**10.06**	**14.57**	**24.10**	**9.35**	**9.07**	**21.56**
Std	31.41	53.56	14.22	35.37	16.46	56.96	17.58	26.53	48.52	12.83	6.11	21.65
Min	0.70	0.77	4.22	0.08	2.98	1.18	0.20	1.64	3.54	0.04	1.64	1.38
P25	3.28	7.75	9.28	5.37	6.59	7.42	2.69	4.27	6.06	2.99	5.26	5.29
P50	**7.46**	**17.06**	**22.99**	**9.94**	**10.61**	**17.08**	**5.02**	**8.65**	**7.40**	**3.66**	**7.92**	**16.06**
P75	26.18	55.64	34.91	30.36	31.49	49.18	7.25	12.12	11.68	9.12	10.18	27.78
Max	169.74	235.65	43.03	257.97	68.07	244.76	81.18	101.65	168.77	45.33	26.22	62.81

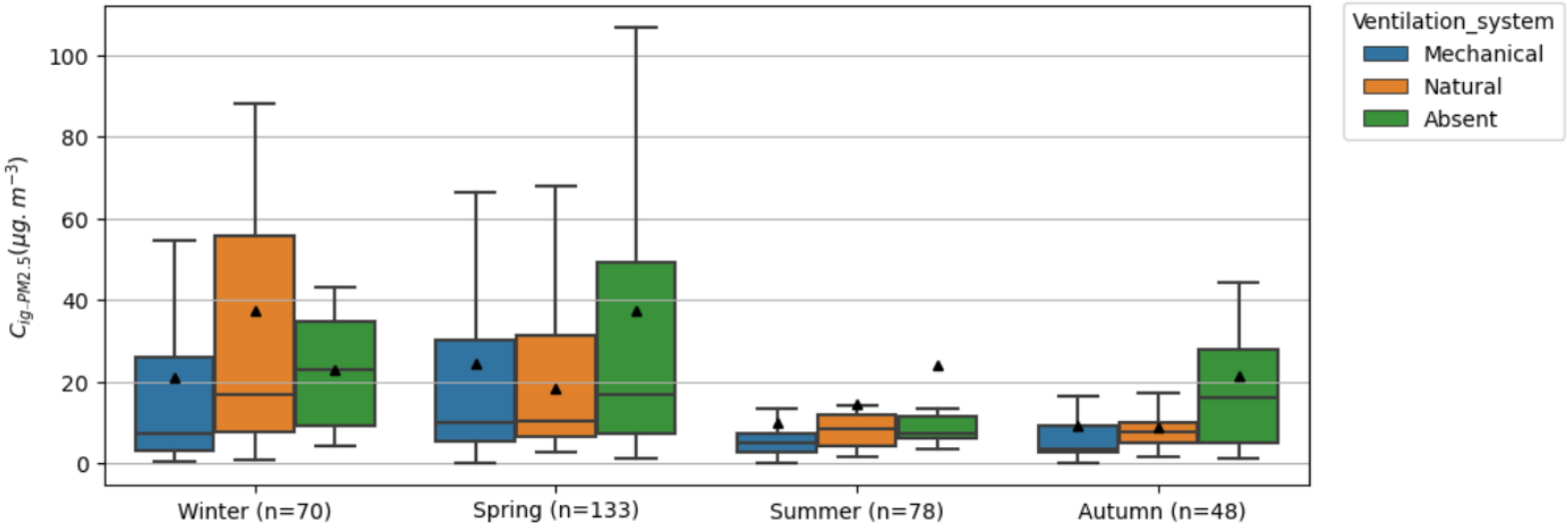


Figure 17. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.1 h^{-1}.

Table 22. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

	$C_{ig_PM2.5_WINTER}$ (µg.m^{-3})			$C_{ig_PM2.5_SPRING}$ (µg.m^{-3})			$C_{ig_PM2.5_SUMMER}$ (µg.m^{-3})			$C_{ig_PM2.5_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	44	20	11	95	23	19	56	13	12	26	15	8
Mean	**19.79**	**38.72**	**24.09**	**24.37**	**18.40**	**38.39**	**10.17**	**15.04**	**22.71**	**9.67**	**9.76**	**22.23**
Std	30.32	53.68	14.24	35.06	16.74	57.11	17.36	26.45	46.79	12.66	6.17	21.61
Min	0.15	1.59	5.76	0.38	0.21	1.86	0.04	2.49	0.20	0.15	2.20	1.57
P25	3.16	8.53	10.49	5.69	7.07	7.97	3.22	4.51	6.44	3.81	5.87	6.09
P50	**7.77**	**18.79**	**23.80**	**10.18**	**11.36**	**18.04**	**5.28**	**8.79**	**7.91**	**4.31**	**8.94**	**16.93**
P75	26.33	56.37	35.58	30.58	31.34	50.04	7.68	12.62	11.14	9.11	10.63	28.04
Max	170.57	237.77	45.76	258.62	69.37	246.07	81.64	101.94	169.44	45.75	26.52	63.40

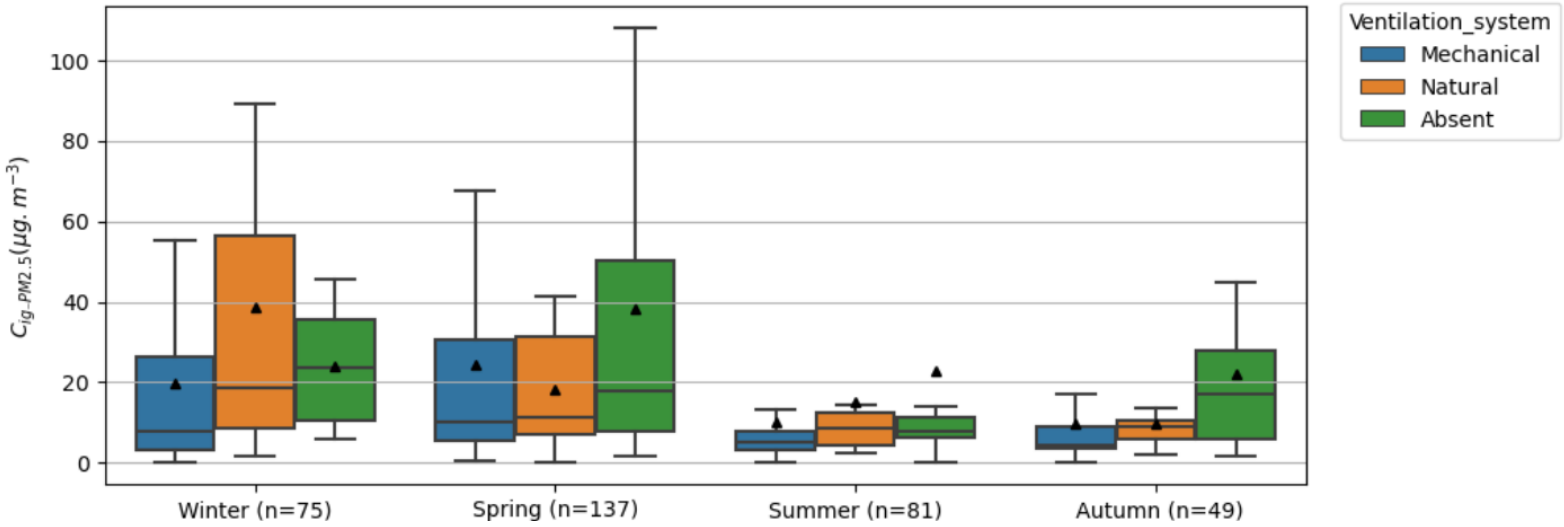


Figure 18. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

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Table 23. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.3 h^{-1}.

	$C_{ig_PM2.5_WINTER}$ (µg.m^{-3})			$C_{ig_PM2.5_SPRING}$ (µg.m^{-3})			$C_{ig_PM2.5_SUMMER}$ (µg.m^{-3})			$C_{ig_PM2.5_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	45	20	11	96	23	19	56	13	12	27	17	9
Mean	**20.16**	**39.59**	**24.98**	**24.67**	**18.97**	**38.95**	**10.55**	**15.41**	**23.20**	**9.84**	**9.08**	**20.23**
Std	30.11	53.75	14.26	34.96	16.83	57.20	17.35	26.41	46.79	12.50	6.69	21.54
Min	0.43	2.28	6.83	0.26	1.26	2.31	0.48	3.02	0.80	0.59	0.10	0.36
P25	3.87	9.23	11.52	6.09	7.72	8.40	3.55	4.74	6.85	4.40	5.72	6.16
P50	**7.97**	**19.94**	**24.45**	**10.73**	**11.84**	**19.04**	**5.59**	**8.92**	**8.60**	**4.81**	**7.94**	**12.90**
P75	26.59	56.92	36.11	30.91	31.72	50.62	8.15	12.87	11.42	9.03	9.90	22.54
Max	171.16	239.18	47.55	259.17	70.21	246.91	81.98	102.22	170.02	46.10	26.78	63.80

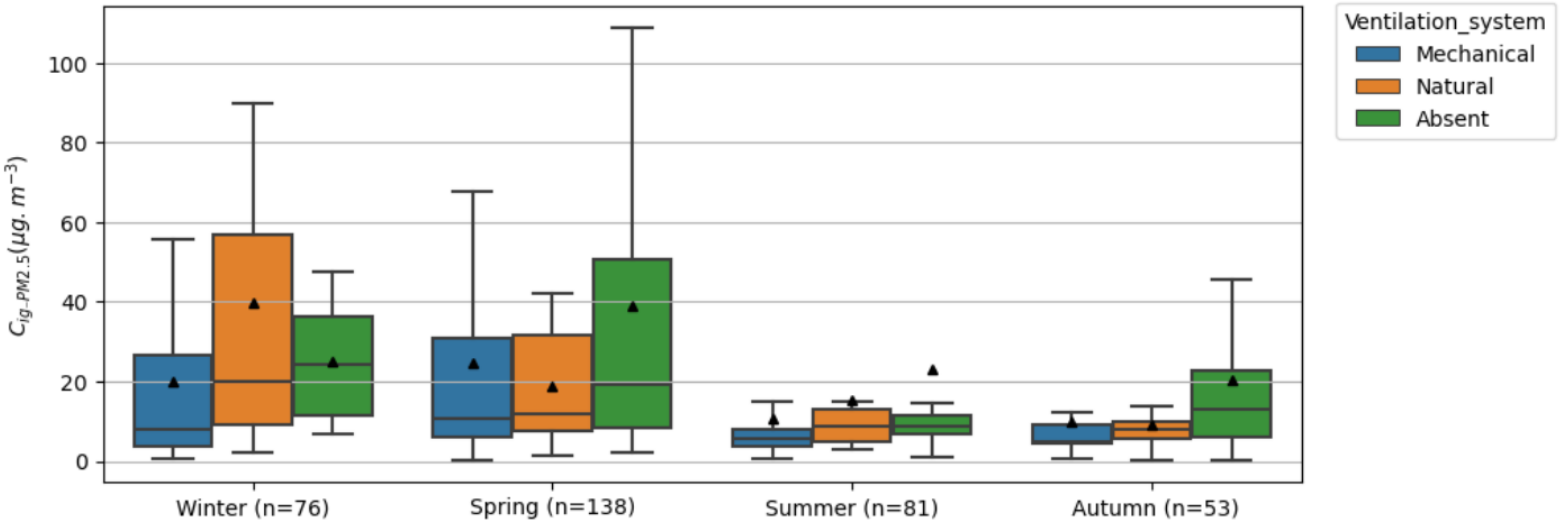


Figure 19. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.3 h^{-1}.

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Table 24. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.4 h^{-1}.

	$C_{ig_PM2.5_WINTER}$ (µg.m^{-3})			$C_{ig_PM2.5_SPRING}$ (µg.m^{-3})			$C_{ig_PM2.5_SUMMER}$ (µg.m^{-3})			$C_{ig_PM2.5_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	46	20	11	98	23	19	56	13	12	28	17	9
Mean	**20.34**	**40.27**	**25.65**	**24.61**	**19.39**	**39.39**	**10.86**	**15.72**	**23.61**	**9.89**	**9.47**	**20.63**
Std	29.90	53.78	14.26	34.79	16.90	57.26	17.35	26.39	46.81	12.37	6.70	21.51
Min	0.56	2.87	7.61	0.34	1.98	2.63	0.86	3.36	1.31	0.47	0.56	0.92
P25	4.21	9.82	12.33	6.02	8.20	8.74	3.86	4.94	7.20	4.63	6.03	6.66
P50	**8.23**	**20.76**	**25.00**	**11.21**	**12.21**	**20.29**	**5.79**	**9.04**	**9.13**	**5.27**	**8.58**	**13.29**
P75	26.78	57.35	36.54	30.31	31.99	51.04	8.43	13.09	11.68	8.99	10.53	22.90
Max	171.60	240.18	48.80	259.63	70.80	247.50	82.25	102.47	170.52	46.40	27.00	64.09

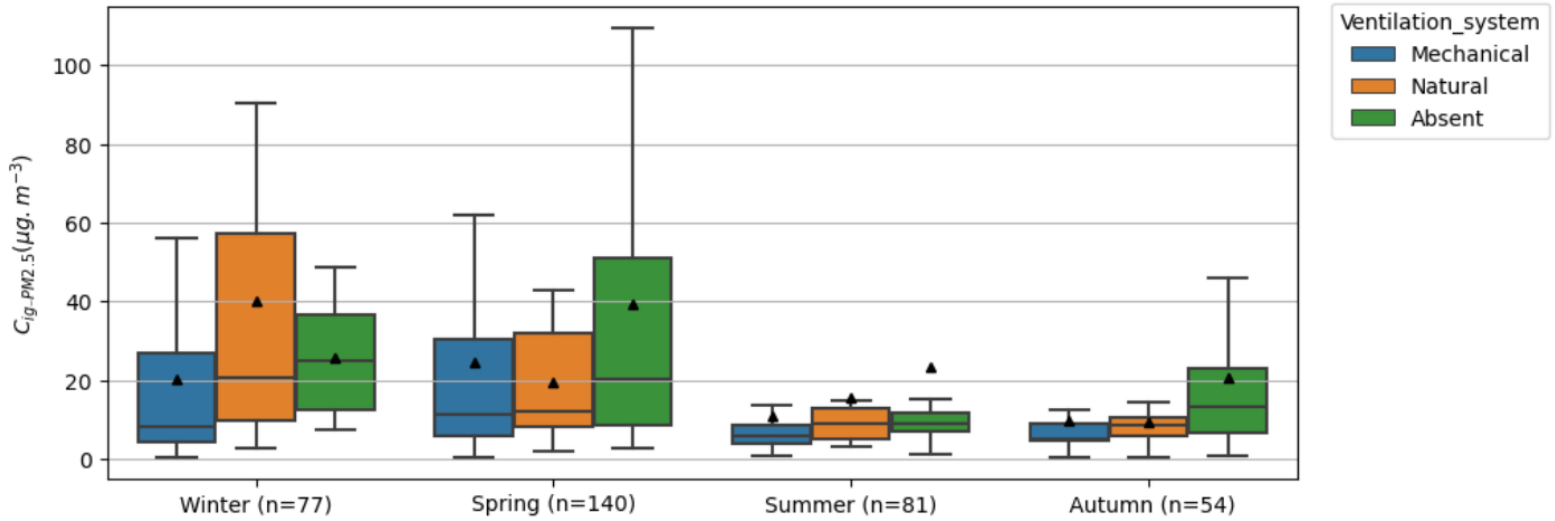


Figure 20. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.4 h^{-1}.

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Table 25. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

	$C_{ig_PM2.5_WINTER}$ (µg.m^{-3})			$C_{ig_PM2.5_SPRING}$ (µg.m^{-3})			$C_{ig_PM2.5_SUMMER}$ (µg.m^{-3})			$C_{ig_PM2.5_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	41	20	11	93	22	19	55	13	11	25	15	8
Mean	**20.81**	**38.29**	**23.68**	**24.55**	**18.97**	**38.09**	**10.08**	**14.71**	**24.42**	**9.81**	**9.49**	**21.91**
Std	30.97	53.70	14.24	35.24	16.62	57.11	17.49	26.39	48.45	12.77	6.19	21.66
Min	0.12	1.05	5.36	0.64	3.61	1.71	0.15	2.27	4.00	0.18	1.79	1.27
P25	3.98	7.99	9.99	5.59	7.43	7.76	2.98	4.15	6.73	3.53	5.56	5.59
P50	**8.09**	**18.39**	**23.37**	**10.22**	**11.25**	**17.80**	**5.00**	**8.57**	**8.11**	**4.09**	**8.66**	**16.62**
P75	26.56	56.10	35.25	30.30	32.08	49.80	7.33	12.17	11.80	9.33	10.42	27.70
Max	170.32	237.28	45.16	258.21	69.09	245.78	81.48	101.41	168.96	45.48	26.28	63.26

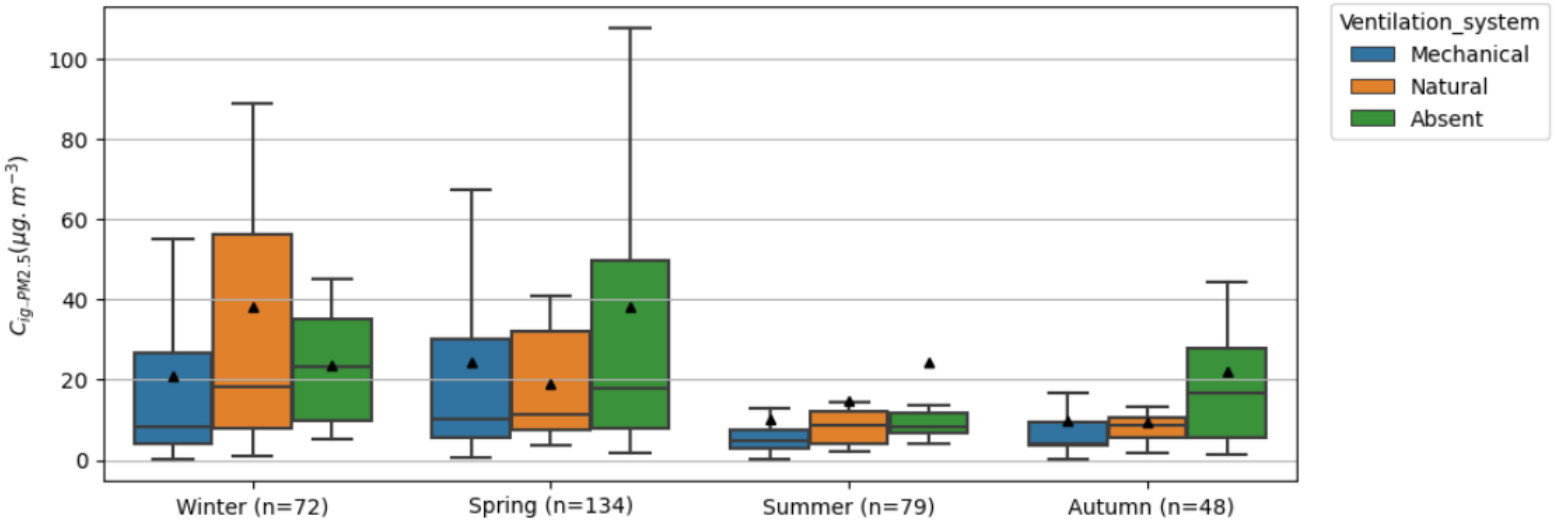


Figure 21. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

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Table 26. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

	$C_{ig_PM2.5_WINTER}$ (µg.m^{-3})			$C_{ig_PM2.5_SPRING}$ (µg.m^{-3})			$C_{ig_PM2.5_SUMMER}$ (µg.m^{-3})			$C_{ig_PM2.5_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	40	20	11	93	22	19	52	13	11	25	15	8
Mean	**20.92**	**37.87**	**23.27**	**24.22**	**18.71**	**37.80**	**10.37**	**14.38**	**24.09**	**9.56**	**9.22**	**21.59**
Std	31.22	53.72	14.24	35.22	16.60	57.11	17.86	26.33	48.39	12.78	6.20	21.71
Min	0.28	0.50	4.96	0.27	3.37	1.55	0.07	1.90	3.59	0.02	1.37	0.96
P25	3.43	7.46	9.54	5.07	7.06	7.54	2.86	3.78	6.52	3.32	5.30	5.08
P50	**7.77**	**17.98**	**22.95**	**9.54**	**11.01**	**17.57**	**4.83**	**8.34**	**7.78**	**3.78**	**8.34**	**16.32**
P75	26.23	55.81	34.91	30.07	31.89	49.56	7.15	11.71	11.49	9.18	10.21	27.36
Max	170.07	236.78	44.56	257.79	68.81	245.50	81.33	100.88	168.48	45.21	26.05	63.12

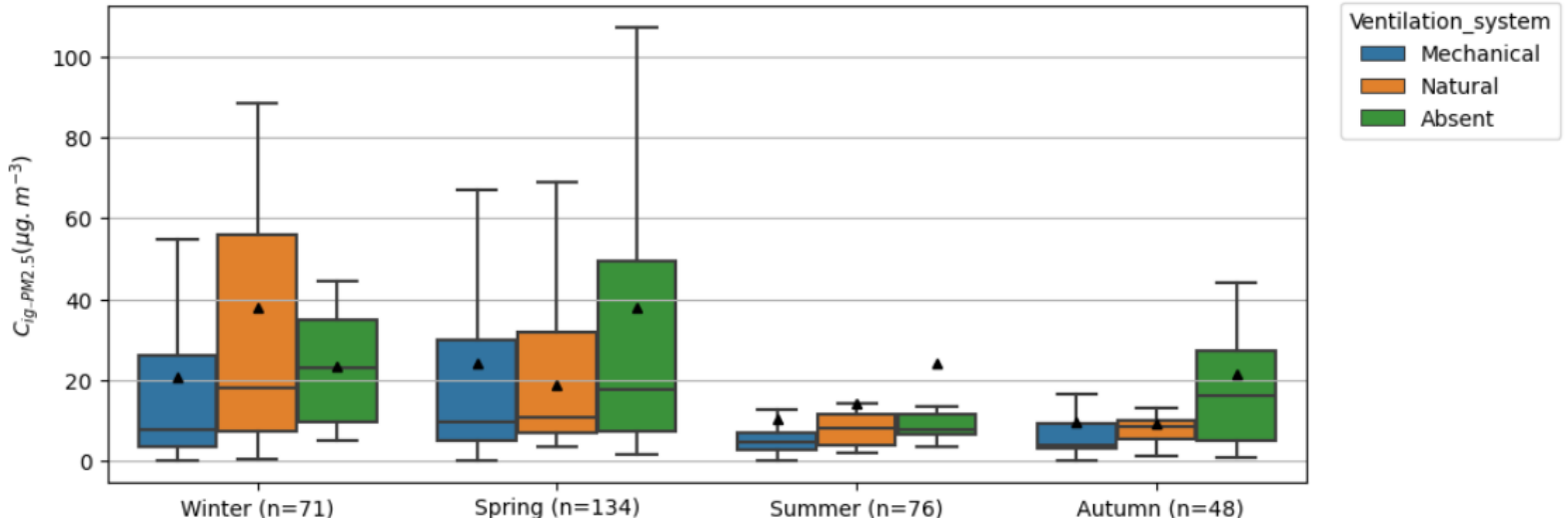


Figure 22. Distribution of estimated $C_{ig_PM2.5}$ considering the $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}.

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Table 27. Distribution of estimated $C_{ig_PM2.5}$ considering $F_{inf_PM2.5}$ equal to 0.6.

	$C_{ig_PM2.5_WINTER}$ (µg.m^{-3})			$C_{ig_PM2.5_SPRING}$ (µg.m^{-3})			$C_{ig_PM2.5_SUMMER}$ (µg.m^{-3})			$C_{ig_PM2.5_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	64	28	16	119	27	24	73	17	12	54	24	16
Mean	**19.23**	**28.60**	**29.53**	**29.40**	**17.59**	**34.55**	**10.87**	**15.97**	**23.26**	**10.20**	**9.40**	**13.19**
Std	31.74	47.70	22.54	64.92	15.49	51.79	16.58	24.70	47.11	19.45	6.71	17.82
Min	0.55	0.18	4.96	0.03	3.45	1.35	0.59	1.88	1.47	0.00	1.11	0.33
P25	3.03	3.31	11.62	5.13	7.31	5.89	3.77	5.21	6.13	2.87	5.84	2.27
P50	**7.64**	**11.42**	**26.54**	**10.64**	**10.72**	**18.02**	**5.96**	**9.71**	**7.82**	**4.30**	**8.66**	**7.02**
P75	23.84	37.63	41.15	28.05	27.29	49.28	9.08	14.14	12.03	7.20	10.30	14.76
Max	170.34	236.25	97.75	615.03	68.27	244.93	81.63	104.17	170.81	125.38	27.48	63.00

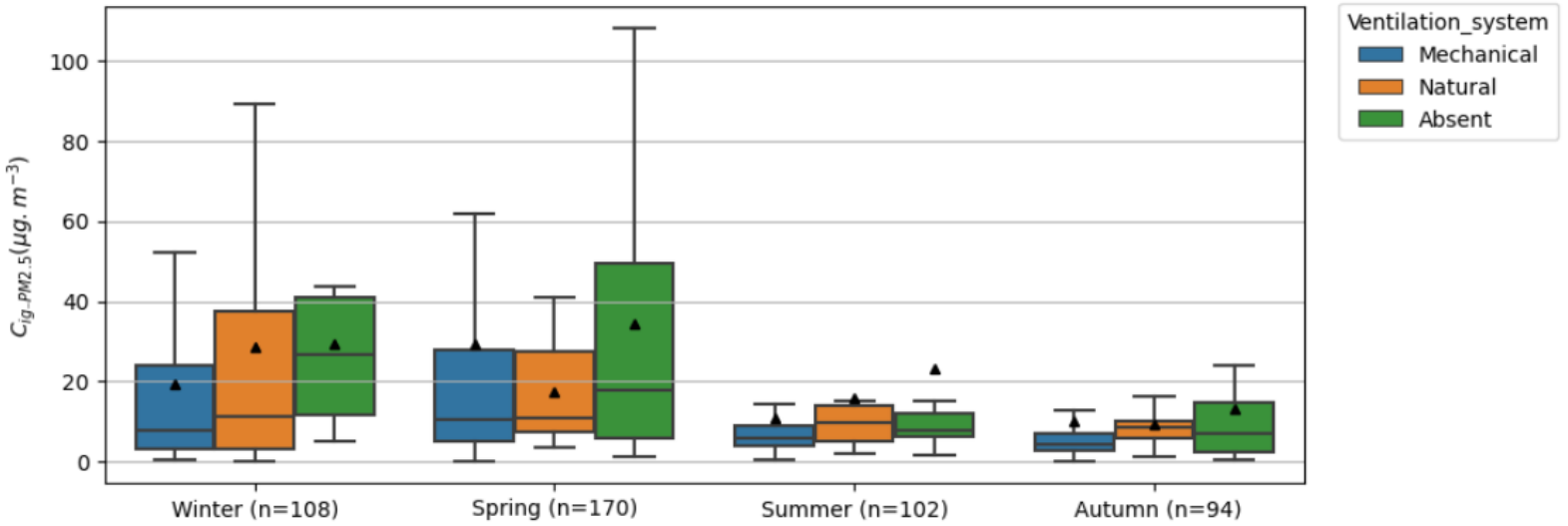


Figure 23. Distribution of estimated $C_{ig_PM2.5}$ considering $F_{inf_PM2.5}$ equal to 0.6.

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Table 28. Distribution of estimated $C_{ig_PM2.5}$ considering $F_{inf_PM2.5}$ equal to 0.7.

	$C_{ig_PM2.5_WINTER}$ (µg.m^{-3})			$C_{ig_PM2.5_SPRING}$ (µg.m^{-3})			$C_{ig_PM2.5_SUMMER}$ (µg.m^{-3})			$C_{ig_PM2.5_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	60	23	16	113	27	24	73	17	12	47	23	12
Mean	**19.31**	**33.50**	**28.44**	**30.04**	**16.78**	**33.67**	**10.16**	**15.18**	**22.38**	**10.83**	**8.96**	**16.59**
Std	32.40	50.72	22.59	66.25	15.44	51.77	16.62	24.64	47.03	20.48	6.66	18.91
Min	0.08	0.69	3.68	0.10	2.68	0.82	0.05	1.21	0.35	0.19	1.30	1.90
P25	2.55	5.86	10.47	5.64	6.35	4.74	3.24	4.69	5.21	2.63	5.55	5.49
P50	**6.83**	**10.96**	**25.26**	**10.42**	**9.79**	**16.48**	**5.37**	**9.23**	**7.00**	**3.70**	**7.83**	**7.32**
P75	25.69	53.30	40.17	30.18	26.70	48.41	8.06	13.11	11.38	8.06	10.41	21.11
Max	169.61	234.60	96.83	614.09	67.28	243.94	81.19	103.04	169.67	124.42	26.78	62.53

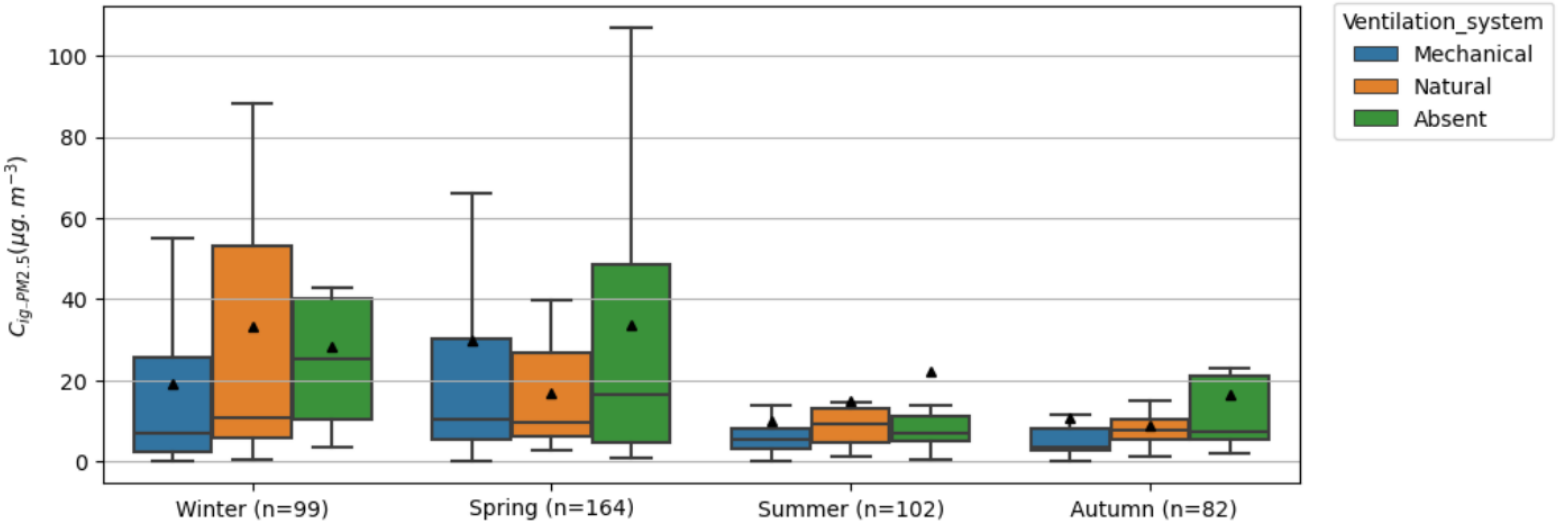


Figure 24. Distribution of estimated $C_{ig_PM2.5}$ considering $F_{inf_PM2.5}$ equal to 0.7.

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Table 29. Ratio between the median and the mean estimated $C_{ig_PM2.5}$ values (P50/mean) using different $F_{inf_PM2.5}$ values.

	WINTER			SPRING			SUMMER			AUTUMN		
$F_{inf_PM2.5}$	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
Calculated ($P_{PM2.5}$ = 0.85 and $k_{PM2.5}$ = 0.1 h^{-1})*	0.35	0.45	1.00	0.41	0.57	0.45	0.50	0.59	0.31	0.39	0.87	0.74
Calculated ($P_{PM2.5}$ = 0.85 and $k_{PM2.5}$ = 0.2 h^{-1})*	0.39	0.49	0.99	0.42	0.62	0.47	0.52	0.58	0.35	0.45	0.92	0.76
Calculated ($P_{PM2.5}$ = 0.85 and $k_{PM2.5}$ = 0.3 h^{-1})*	0.40	0.50	0.98	0.43	0.62	0.49	0.53	0.58	0.37	0.49	0.87	0.64
Calculated ($P_{PM2.5}$ = 0.85 and $k_{PM2.5}$ = 0.4 h^{-1})*	0.40	0.52	0.97	0.46	0.63	0.52	0.53	0.58	0.39	0.53	0.91	0.64
Calculated ($P_{PM2.5}$ = 0.90 and $k_{PM2.5}$ = 0.2 h^{-1})*	0.39	0.48	0.99	0.42	0.59	0.47	0.50	0.58	0.33	0.42	0.91	0.76
Calculated ($P_{PM2.5}$ = 0.95 and $k_{PM2.5}$ = 0.2 h^{-1})*	0.37	0.47	0.99	0.39	0.59	0.46	0.47	0.58	0.32	0.40	0.90	0.76
0.6	0.40	0.40	0.90	0.36	0.61	0.52	0.55	0.61	0.34	0.42	0.92	0.53
0.7	0.35	0.33	0.89	0.35	0.58	0.49	0.53	0.61	0.31	0.34	0.87	0.44

* $F_{inf_PM2.5}$ calculated using the air exchange rate (a) of each dwelling.

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Nitrogen dioxide - NO_2

Figure 25 and Table 30 present the estimated C_{ig_NO2} of 312 CNL2 dwellings by season and by ventilation system using the mean infiltration factor calculated for the dwellings considered free of indoor sources of NO_2. The following dwellings were removed from the sample:

- 13 dwellings that have no information about the NO_2 indoor and/or outdoor concentration (measurement problem):
  - 6 dwellings equipped with a mechanical ventilation system
  - 6 dwellings equipped with a natural ventilation system
  - 1 dwellings without a ventilation system
- 246 dwellings that presented a negative C_{ig_NO2} value:
  - 179 dwellings equipped with a mechanical ventilation system
  - 44 dwellings equipped with a natural ventilation system
  - 23 dwellings without a ventilation system

Figure 26 and Table 31 present the estimated C_{ig_NO2} of 369 CNL2 dwellings by season and by ventilation system using an F_{inf_NO2} equal to 0.65 (ANSES mean value found for worldwide dwellings). The following dwellings were removed from the sample:

- 13 dwellings that have no information about the NO_2 indoor and/or outdoor concentration (measurement problem): same dwellings presented before.
- 189 dwellings that presented a negative C_{ig_NO2} value:
  - 132 dwellings equipped with a mechanical ventilation system
  - 36 dwellings equipped with a natural ventilation system
  - 21 dwellings without a ventilation system

Figure 27 and Table 32 present the estimated C_{ig_NO2} of 340 CNL2 dwellings by season and by ventilation system using an F_{inf_NO2} equal to 0.75 (ANSES mean value found for French dwellings). The following dwellings were removed from the sample:

- 13 dwellings that have no information about the NO_2 indoor and/or outdoor concentration (measurement problem): same dwellings presented before.
- 218 dwellings that presented a negative C_{ig_NO2} value:
  - 153 dwellings equipped with a mechanical ventilation system
  - 39 dwellings equipped with a natural ventilation system
  - 26 dwellings without a ventilation system

The lowest number of dwellings removed due to a negative C_{ig_NO2} value was found using F_{inf_NO2} equal to 0.65 (189 dwellings removed).

Given that winter use to be the season with the least contribution of contaminants from the outside (less opening of windows and doors), it is preferable to focus on the C_{ig_NO2} of this season.

Table 33 presents the ratio between the median and the mean estimated C_{ig_NO2} winter values (P50/mean) using different F_{inf_NO2} values. The median values are inferior to the mean values for all ventilation systems with a ratio between 0.23 and 0.71.

Mean winter C_{ig_NO2} values calculated in the three ways are relatively close. Mean winter C_{ig_NO2} values range from 3.25 to 9.64 $\mu g.m^{-3}$ using the calculated F_{inf_NO2}, from 2.57 to 9.86 $\mu g.m^{-3}$ using F_{inf_NO2} equal to 0.65 and from 2.29 to 9.77 $\mu g.m^{-3}$ using F_{inf_NO2} equal to 0.75.

Median winter C_{ig_NO2} values calculated in the three ways present greater differences than mean values. Median winter C_{ig_NO2} values range from 0.93 to 3.19 µg.m^{-3} using the calculated F_{inf_NO2}, from 1 to 4.68 µg.m^{-3} using F_{inf_NO2} equal to 0.65 and from 0.53 to 3.21 µg.m^{-3} using F_{inf_NO2} equal to 0.75.

The comparison of mean winter C_{ig_NO2} values obtained using F_{inf_NO2} equal to 0.65 and 0.75 shows that an increase of 0.1 in the F_{inf_NO2} leads to a decrease in the mean C_{ig_NO2}.of:

- 0.75 µg.m^{-3} in dwellings equipped with a mechanical ventilation system
- 0.09 µg.m^{-3} in dwellings equipped with a natural ventilation system
- 0.28 µg.m^{-3} in dwellings without a ventilation system

Similarly, the comparison of median winter C_{ig_NO2} values obtained using F_{inf_NO2} equal to 0.65 and 0.75 shows that an increase of 0.1 in the F_{inf_NO2} leads to a decrease in the median C_{ig_NO2}.of:

- 0.76 µg.m^{-3} in dwellings equipped with a mechanical ventilation system
- 1.47 µg.m^{-3} in dwellings equipped with a natural ventilation system
- 0.47 µg.m^{-3} in dwellings without a ventilation system

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Table 30. Distribution of estimated C_{ig_NO2} considering an F_{inf_NO2} according to the season and the ventilation system installed in the dwellings.

	$C_{ig_NO2_WINTER}$ (µg.m^{-3})			$C_{ig_NO2_SPRING}$ (µg.m^{-3})			$C_{ig_NO2_SUMMER}$ (µg.m^{-3})			$C_{ig_NO2_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
F_{inf_NO2}	0.56	0.53	0.50	0.83	0.73	0.72	1.00	1.10	1.07	0.84	0.67	0.78
N	34	17	10	84	19	21	32	3	12	42	21	17
Mean	**3.25**	**9.64**	**3.81**	**3.58**	**4.21**	**2.58**	**3.11**	**3.15**	**3.81**	**2.49**	**3.53**	**2.18**
Std	4.02	22.22	4.43	4.90	4.00	3.21	3.58	2.71	2.43	3.79	3.58	3.86
Min	0.04	0.84	0.60	0.05	0.36	0.24	0.00	0.18	0.02	0.09	0.32	0.04
P25	0.74	0.96	0.94	0.28	0.51	0.48	0.07	1.98	2.15	0.26	0.73	0.27
P50	**0.93**	**3.19**	**2.26**	**1.84**	**3.05**	**0.58**	**2.27**	**3.79**	**3.75**	**1.35**	**2.14**	**0.46**
P75	4.11	8.42	4.74	5.46	5.69	2.97	4.93	4.64	5.11	3.20	5.48	1.39
Max	17.66	94.71	15.30	27.26	12.84	10.30	17.20	5.49	9.12	19.76	12.88	15.59

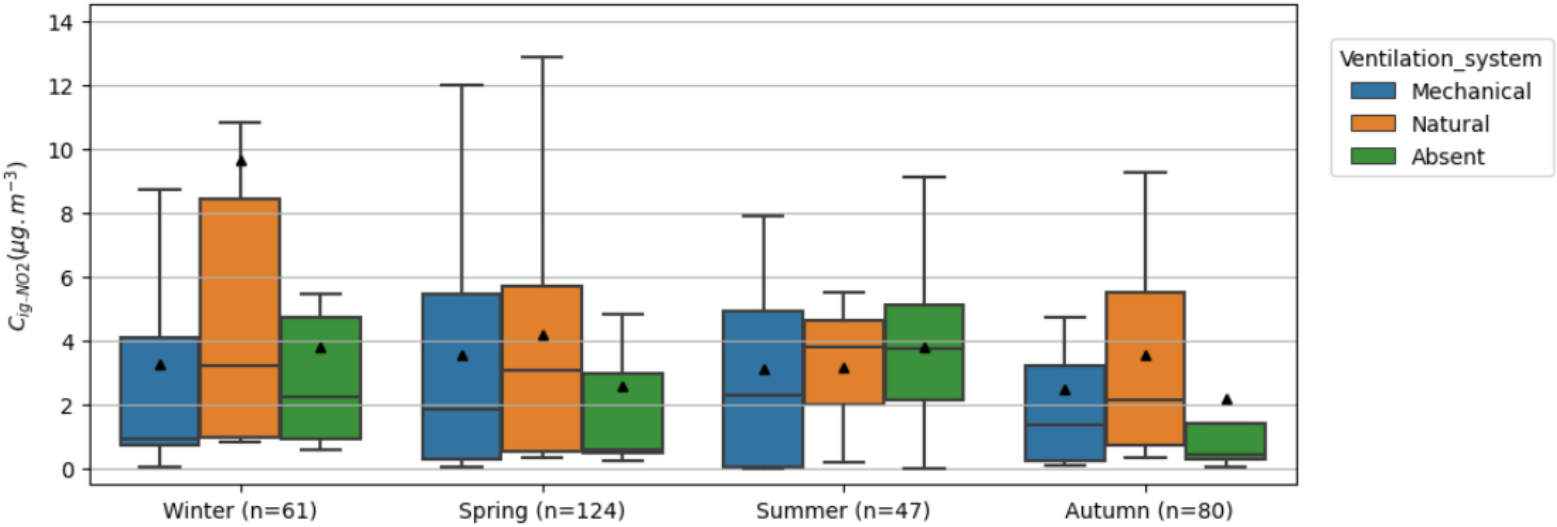


Figure 25. Distribution of estimated C_{ig_NO2} considering an F_{inf_NO2} according to the season and the ventilation system installed in the dwellings.

Table 31. Distribution of estimated C_{ig_NO2} considering F_{inf_NO2} equal to 0.65.

	$C_{ig_NO2_WINTER}$ (µg.m^{-3})			$C_{ig_NO2_SPRING}$ (µg.m^{-3})			$C_{ig_NO2_SUMMER}$ (µg.m^{-3})			$C_{ig_NO2_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	27	15	8	94	19	21	63	13	15	55	21	18
Mean	**3.26**	**9.86**	**2.57**	**4.17**	**4.79**	**2.95**	**2.91**	**2.86**	**5.15**	**2.83**	**3.64**	**2.84**
Std	3.74	23.17	3.53	4.92	4.19	3.25	3.21	2.79	3.56	3.68	3.58	4.10
Min	0.44	0.45	0.45	0.00	0.54	0.53	0.02	0.62	0.72	0.16	0.36	0.56
P25	0.61	0.62	0.63	0.69	0.70	0.65	0.74	0.75	3.02	0.68	0.78	0.70
P50	**2.31**	**4.68**	**1.00**	**2.67**	**4.43**	**1.63**	**1.70**	**1.05**	**4.46**	**1.31**	**2.35**	**1.17**
P75	4.45	7.47	2.24	6.20	6.18	3.37	4.41	5.51	6.04	3.44	5.53	2.85
Max	15.56	92.70	10.44	27.70	13.36	10.95	20.14	7.96	13.20	20.21	13.11	17.72

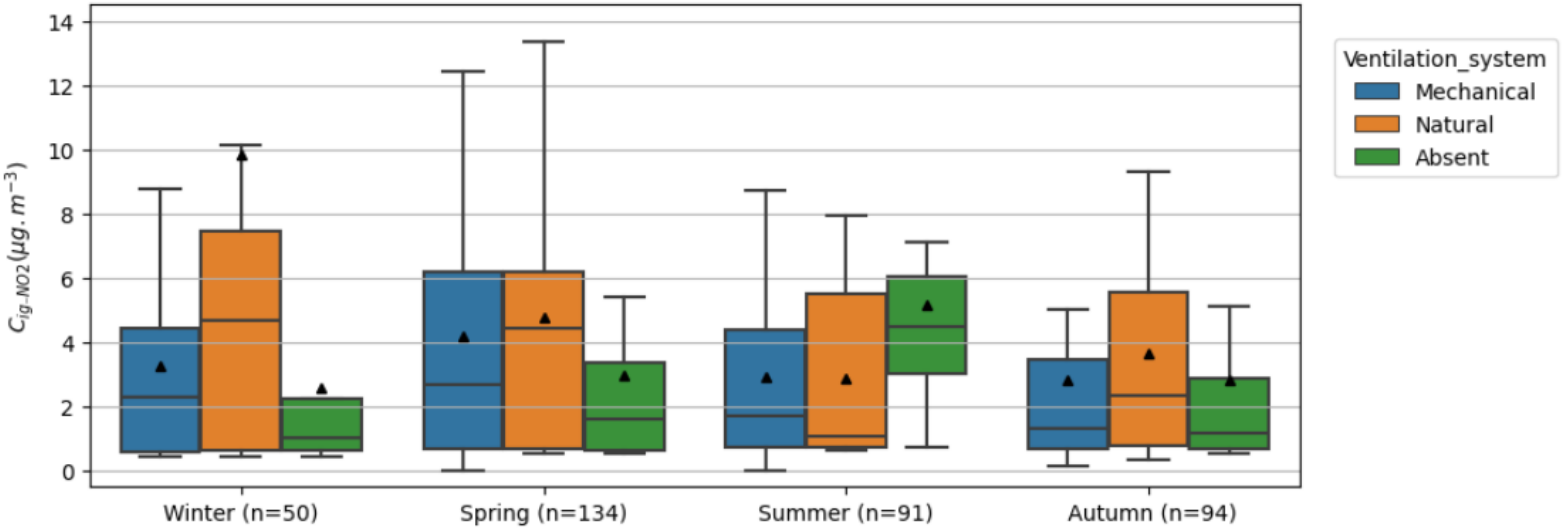


Figure 26. Distribution of estimated C_{ig_NO2} considering F_{inf_NO2} equal to 0.65.

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Table 32. Distribution of estimated C_{ig_NO2} considering F_{inf_NO2} equal to 0.75.

	$C_{ig_NO2_WINTER}$ (µg.m^{-3})			$C_{ig_NO2_SPRING}$ (µg.m^{-3})			$C_{ig_NO2_SUMMER}$ (µg.m^{-3})			$C_{ig_NO2_AUTUMN}$ (µg.m^{-3})		
Ventilation system	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent	Mechanical	Natural	Absent
N	27	14	6	87	19	20	58	12	14	46	20	17
Mean	**2.51**	**9.77**	**2.29**	**3.89**	**4.06**	**2.56**	**2.58**	**2.38**	**4.86**	**2.70**	**3.27**	**2.36**
Std	3.27	23.60	3.01	4.90	3.96	3.22	3.24	2.52	3.26	3.78	3.61	3.94
Min	0.17	0.25	0.21	0.22	0.31	0.14	0.11	0.42	0.50	0.23	0.14	0.21
P25	0.36	0.48	0.37	0.48	0.46	0.39	0.51	0.51	2.80	0.47	0.42	0.46
P50	**1.55**	**3.21**	**0.53**	**2.71**	**2.76**	**0.48**	**0.64**	**0.58**	**4.42**	**0.87**	**1.35**	**0.58**
P75	3.31	6.94	3.85	5.87	5.60	3.17	4.22	4.14	5.83	3.60	5.24	1.69
Max	13.24	91.03	7.20	27.46	12.71	10.02	19.30	7.03	12.23	19.97	11.95	16.09

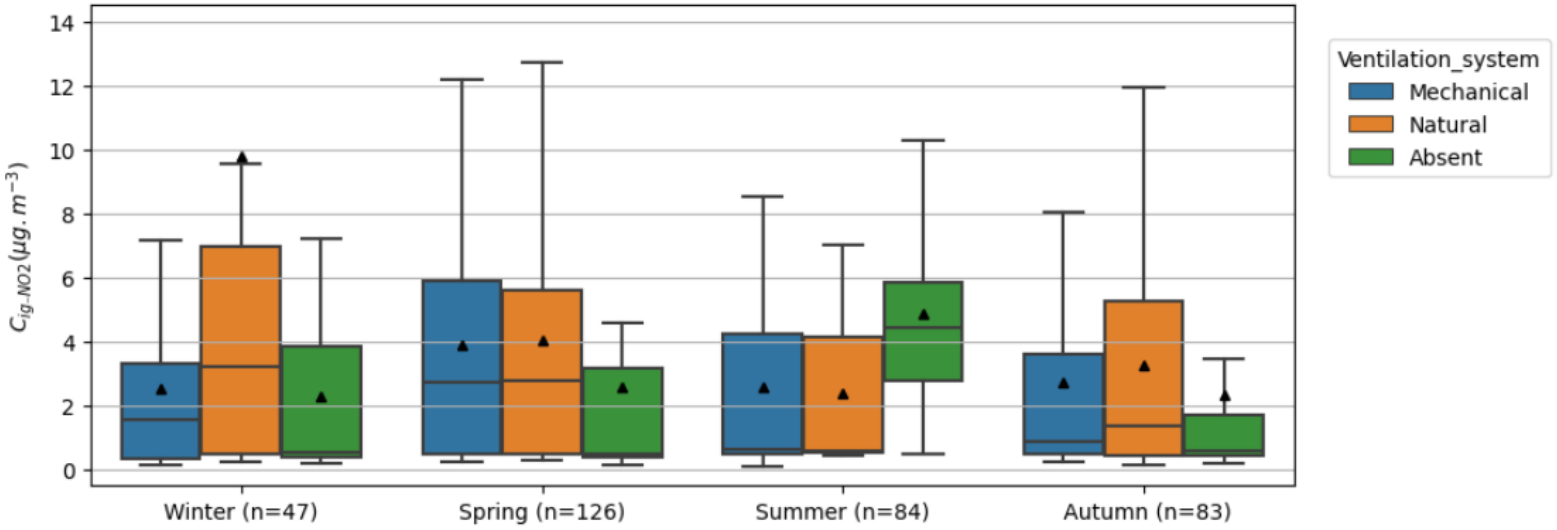


Figure 27. Distribution of estimated C_{ig_NO2} considering F_{inf_NO2} equal to 0.75.

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Table 33. Ratio between the median and the mean estimated C_{ig_NO2} winter values (P50/mean) using different F_{inf_NO2} values.

	WINTER		
F_{inf_NO2}	Mechanical	Natural	Absent
According ventilation system installed in the dwellings (0.56 for mechanical, 0.53 for natura land 0.50 for absent)	0.29	0.33	0.59
0.65	0.71	0.47	0.39
0.75	0.62	0.33	0.23

Percentage of occupancy by season

Figure 28 presents the percentage of dwellings occupied during the measurement week by season. People tend to spend longer periods indoors in winter than in the other seasons. However, the profile of the four seasons is similar, showing that during workdays, people are usually at home between mid-night and 7:00 a.m. They leave at 7:00 a.m. and return around 11:30 a.m. and then leave around 1:00 p.m. The curves increase from 4:30 pm onwards indicating that the occupants are returning home definitively. These occupancy periods are similar to those found using the CNL1 database which contains information of 567 dwellings measured during one week between 2003 and 2005 (Zeghnoun et al. 2010).

The biggest difference between the occupancy periods of the four seasons is observed on weekends: from Saturday at 16:30 to Sunday at 2h00 and Sunday from 12:00 to 18h00. The percentage of occupied dwellings is the lowest on Saturday night in all seasons. None of the four curves reach 100% of occupancy at any time of the week, even during the workweek nights when occupants are supposed to return home to sleep. This may be due to some of the occupants working away from home at night (the database does not contain information on the occupants' working hours) or to occasional travel (work or non-work related).

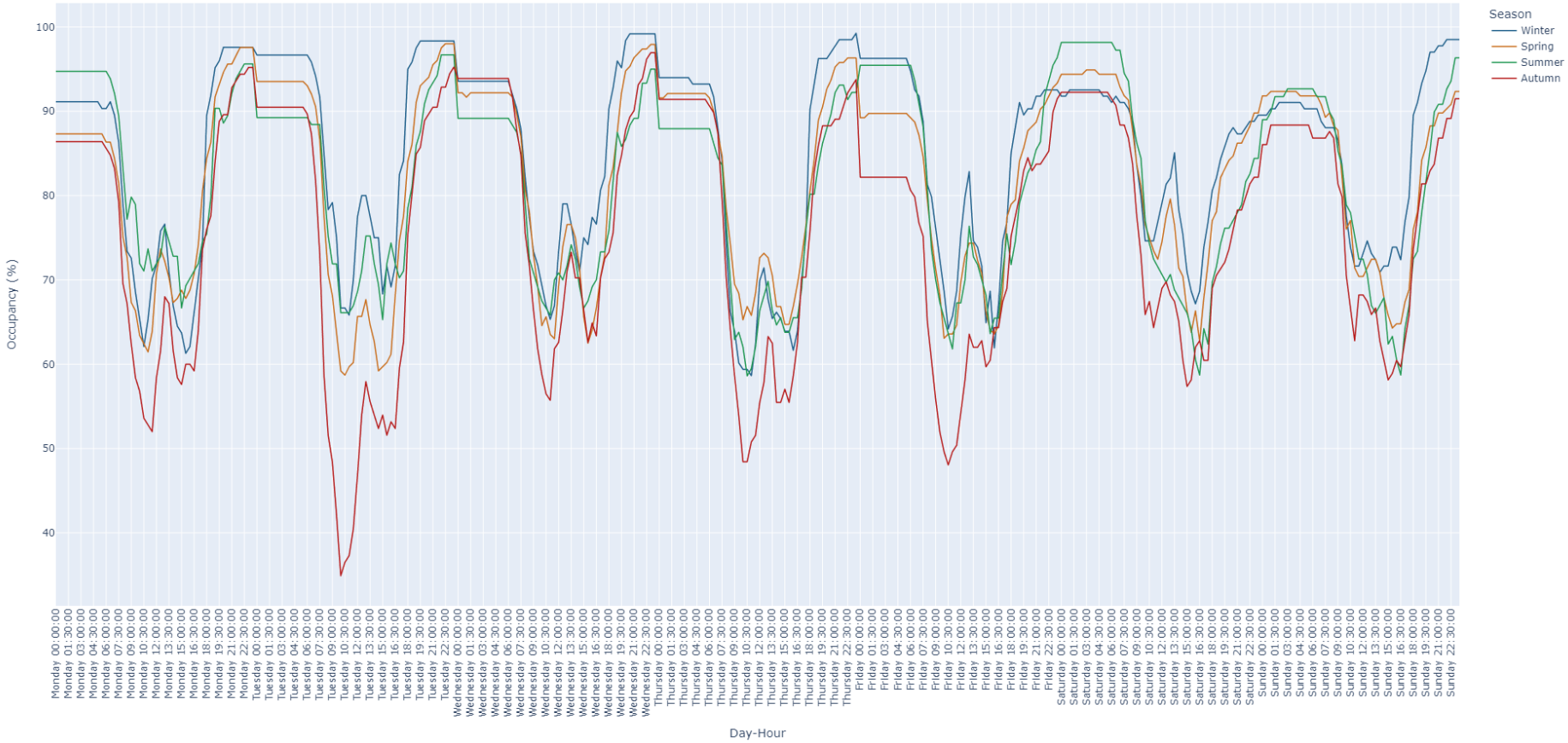


Figure 28. Percentage of dwellings occupied during the measurement week.

Conclusion

The CNL2 French database containing information on 571 dwellings measured over one week between 2020 and 2023 in various regions of France allow us to estimate some of the mass-balance model (Healthvent approach) parameters for $PM_{2.5}$ and NO_2: a, F_{inf} and C_{ig}. The considerable size of the sample and the variability in the characteristics of each of the dwellings (location, year of construction, construction materials, etc.) that compose the sample, allow us to have a broad view of the French housing stock and of the values of the parameters evoked before.

The conclusions obtained from this study are presented by parameter in the following paragraphs.

Air exchange rate (a)

a is higher in summer than in the other seasons, regardless of the type of ventilation system installed in the dwelling. In contrast, the lowest a tend to be in winter regardless of the type of ventilation system installed in the dwelling. Median values are inferior to mean values (the ratio between the median and the mean ranges between 0.62 and 0.91).

Since the mean is easily affected by outliers, it is preferable to use the median values as representative values. In fact, the median represents the exact midpoint when a dataset is arranged in order. It serves as a measure of central tendency, dividing the dataset into two equal halves: the lower 50% and the upper 50% of values.

The median a values estimated by season and by ventilation system may be used as standard values in the mass-balance model when the actual values are not available and when the conditions of the dwelling and its surroundings are similar to those of the CNL2 dwellings.

Infiltration factor (F_{inf})

$F_{inf_PM2.5}$

The infiltration factor depends on three parameters: a, P and k. The mean and median $F_{inf_PM2.5}$ values obtained for each combination and for each season and ventilation system are very close. Using the a of each dwelling, setting $P_{PM2.5}$ equal to 0.85 (ANSES value) and varying exclusively $k_{PM2.5}$ from 0.1 to 0.4 h^{-1}, we found that an increase of 0.1 h^{-1} in $k_{PM2.5}$ leads to a decrease of up to 0.1 in the mean and median $F_{inf_PM2.5}$ values for all seasons and ventilation systems. Similarly, using the a of each dwelling, setting $k_{PM2.5}$ equal to 0.2 h^{-1} (k value recommended in typical conditions with secondary inorganic and organic aerosols dominating) and varying exclusively $P_{PM2.5}$ from 0.85 to 0.95, we found that an increase of 0.05 in $P_{PM2.5}$ leads to an increase of up to 0.05 in the mean and median $F_{inf_PM2.5}$ values for all seasons and ventilation systems.

The dispersion of $F_{inf_PM2.5}$ values is also affected by the variation of $P_{PM2.5}$ and $k_{PM2.5}$ values. The interquartile range (P75-P25) of $F_{inf_PM2.5}$ increases when the $k_{PM2.5}$ increases.

Since the ANSES $F_{inf_PM2.5}$ values for French and worldwide dwellings are included in the $F_{inf_PM2.5}$ ranges calculated using the six combinations of $P_{PM2.5}$ and $k_{PM2.5}$ values, we conclude that a $k_{PM2.5}$ between 0.1 and 0.4 h^{-1} coupled with $P_{PM2.5}$ between 0.85 and 0.95 are appropriate for the calculation of $F_{inf_PM2.5}$ when the actual values are not available and when the conditions of the dwelling and its surroundings are similar to those of the CNL2 dwellings.

F_{inf_NO2}

F_{inf_NO2} was calculated as the ratio between the indoor and outdoor concentrations exclusively in the dwellings considered free of indoor sources of NO_2. Median and mean values are relatively close for all seasons and ventilation systems (the ratio between the median and the mean ranges between 0.79 and 1.21)

Since winter use to be the season with least contribution of contaminants from the outside, it is preferable to use the median winter F_{inf_NO2} as reference values of the sample according to the ventilation system installed in the dwelling: 0.44 with mechanical ventilation system, 0.50 with natural ventilation system and 0.42 without a ventilation system. However, these values are lower than the ANSES values for worldwide and French dwellings, 0.65 and 0.75 respectively.

Given that the F_{inf_NO2} was calculated in a simplified way (without the use of a, P and k and without taking into account photochemical reactions), it is preferable to inject the ANSES values in the mass-balance model equation. The use of a higher F_{inf_NO2} value results in a higher indoor concentration and thus avoids an underestimation of the indoor exposition to NO_2.

Indoor generated concentration (C_{ig})

$C_{ig_PM2.5}$

$C_{ig_PM2.5}$ was estimated considering different values of $F_{inf_PM2.5}$:

- $F_{inf_PM2.5}$ calculated using a of each dwelling, $P_{PM2.5}$ equal to 0.85 and four $k_{PM2.5}$ values
- $F_{inf_PM2.5}$ calculated using a of each dwelling, $k_{PM2.5}$ equal to 0.20 and two $P_{PM2.5}$ values
- $F_{inf_PM2.5}$ equal to 0.60 and 0.70

Since in reality it is not possible to have negative concentrations, the negative $C_{ig_PM2.5}$ were removed from the eight samples.

In the cases where $F_{inf_PM2.5}$ was calculated using different $k_{PM2.5}$ values, we observed that the number of removed dwellings decreases when the $k_{PM2.5}$ value increases. Therefore, the lowest number of dwellings removed due to a negative $C_{ig_PM2.5}$ value was found with $k_{PM2.5}$ equal to 0.4 h^{-1}. In the three samples using $k_{PM2.5}$ equal to 0.2 h^{-1}, the number of removed dwellings increases when the $P_{PM2.5}$ value increases. In the cases where $F_{inf_PM2.5}$ was fixed, the number of removed dwellings was fewer for $F_{inf_PM2.5}$ equal to 0.6.

The median $C_{ig_PM2.5}$ values are inferior or equal to the mean $C_{ig_PM2.5}$ values for all seasons and ventilation systems for all $F_{inf_PM2.5}$ values.

The median $C_{ig_PM2.5}$ presents a systematic increase in almost all seasons and ventilation systems when $k_{PM2.5}$ increase. The median $C_{ig_PM2.5}$ tends to decrease when $P_{PM2.5}$ increase. The comparison of median $C_{ig_PM2.5}$ values obtained using $F_{inf_PM2.5}$ equal to 0.6 and 0.7 shows that an increase of 0.1 in the $F_{inf_PM2.5}$ leads to a decrease of up to 14% in the median $C_{ig_PM2.5}$.

To avoid the underestimation of the $C_{ig_PM2.5}$ and due to the lower quantity of negative values, the $C_{ig_PM2.5}$ proposed for been used in the mass-balance model when the actual values are not available and when the conditions of the dwelling and its surroundings are similar to those of

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the CNL2 dwellings are the Winter $C_{ig_PM2.5}$ estimated considering a of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.4 h^{-1}.

C_{ig_NO2}

C_{ig_NO2} was estimated considering different values of F_{inf_NO2}:

- F_{inf_NO2} calculated for the dwellings considered free of indoor sources of NO_2
- F_{inf_NO2} equal to 0.65 and 0.75.

The negative C_{ig_NO2} were removed from the three samples.

The lowest number of dwellings removed due to a negative C_{ig_NO2} value was found using F_{inf_NO2} equal to 0.65. The comparison of median winter C_{ig_NO2} values obtained using F_{inf_NO2} equal to 0.65 and 0.75 shows that an increase of 0.1 in the F_{inf_NO2} leads to a decrease of up to 1.47 µg.m^{-3} in the median C_{ig_NO2} (a decrease between 31 et 47%).

To avoid the underestimation of the C_{ig_NO2} and due to the lower quantity of negative values, the C_{ig_NO2} proposed for been used in the mass-balance model when the actual values are not available and when the conditions of the dwelling and its surroundings are similar to those of the CNL2 dwellings are the Winter C_{ig_NO2} estimated using F_{inf_NO2} equal to 0.65.

In the future, indoor concentrations of $PM_{2.5}$ and NO_2 estimated from outdoor concentrations can be calculated for other countries using the mass balance model (Healthvent approach) and the standard a, P and k values presented in this report. In addition, the estimated indoor concentrations can be used to estimate the relative risk associated with different causes of mortality.

Limits of the study

The fact that the concentration of CO_2 and $PM_{2.5}$ outside of dwellings has been estimated rather than directly measured can cause a, F_{inf} and C_{ig} values to differ from reality. On one hand, the overestimation of the outdoor CO_2 concentration leads to an overestimation of a, which leads to an overestimation of F_{inf} and to an underestimation of $C_{ig.}$ On the other hand, the overestimation of the outdoor $PM_{2.5}$ concentration leads to an underestimation of $C_{ig.}$

F_{inf_NO2} was calculated as the ratio between the indoor and outdoor NO_2 concentrations in the dwellings considered free of indoor sources of NO_2 without the use of the actual a, P and k values. If the dwelling has an unidentified source of NO_2, F_{inf_NO2} will be overestimated.

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Annex - Histograms of calculated F_{inf}

The histograms below show the distribution of the calculated values of $F_{inf_PM2.5}$ and F_{inf_NO2}. These histograms were created using the Sturges' rule to determine the optimal number of bins.

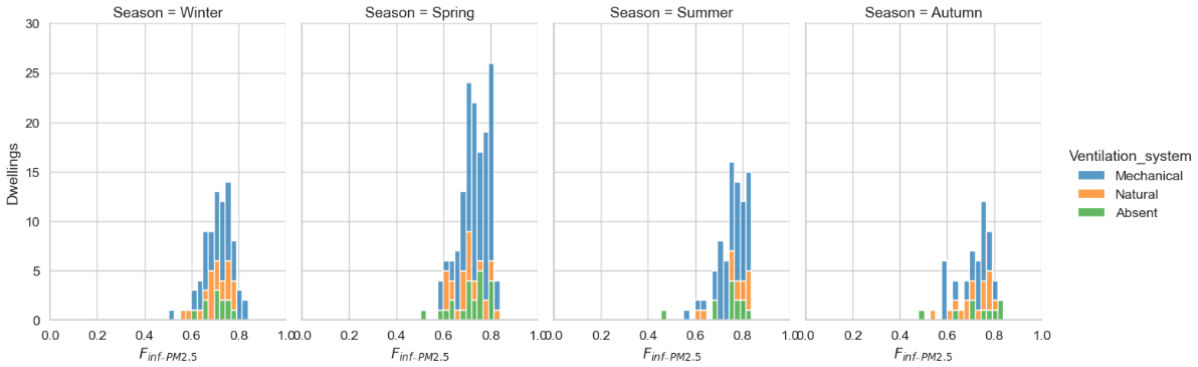


***Figure 29*. Histograms of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.1 h^{-1}.**

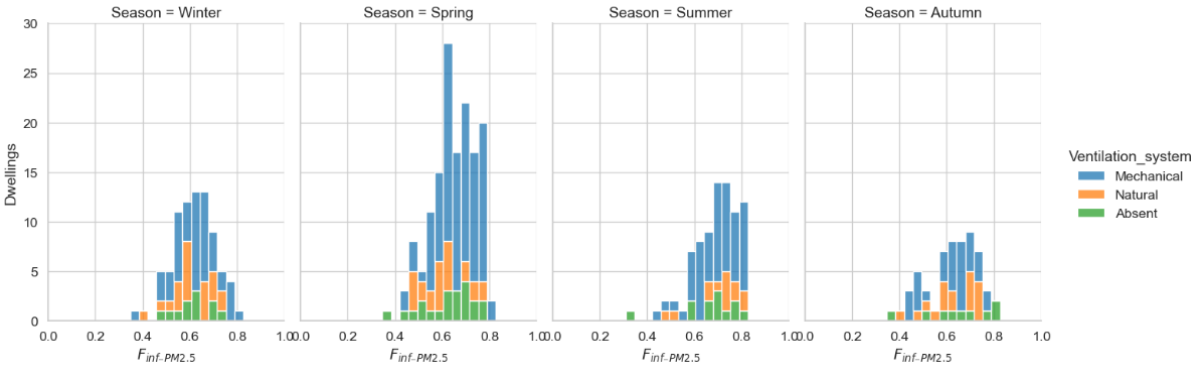
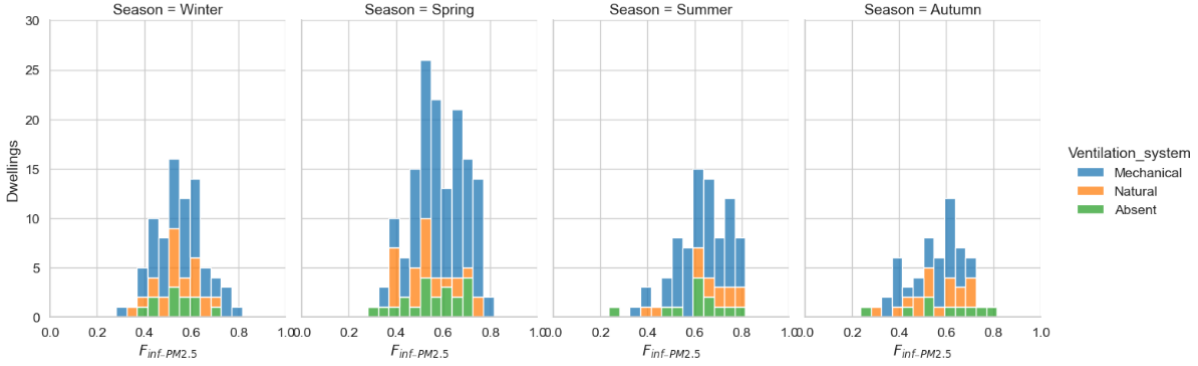


***Figure 30*. Histograms of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.2 h^{-1}.**



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Figure 31. **Histograms of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.3 h^{-1}.**

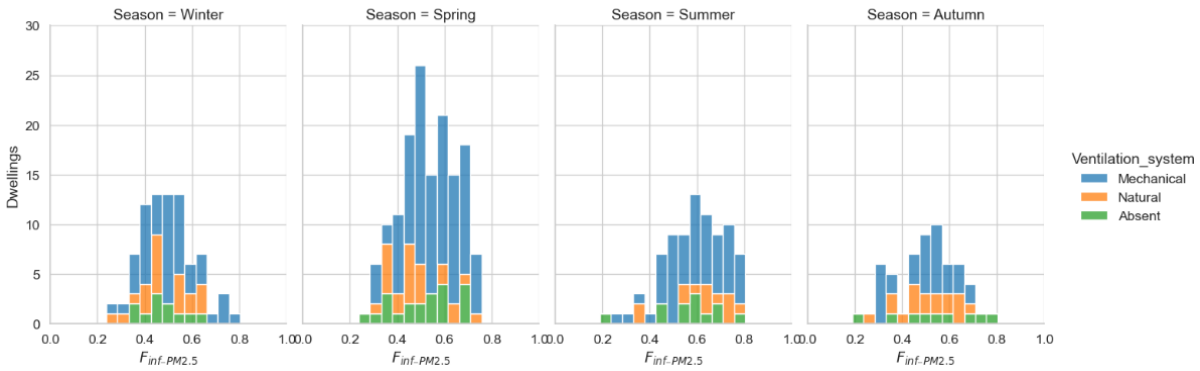


Figure 32. **Histograms of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.85 and $k_{PM2.5}$ equal to 0.4 h^{-1}.**

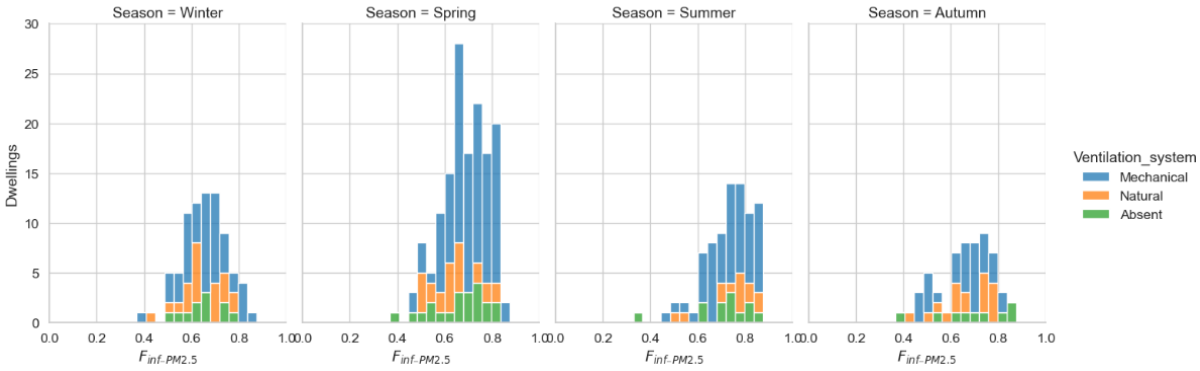


Figure 33. **Histograms of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.90 and $k_{PM2.5}$ equal to 0.2 h^{-1}.**

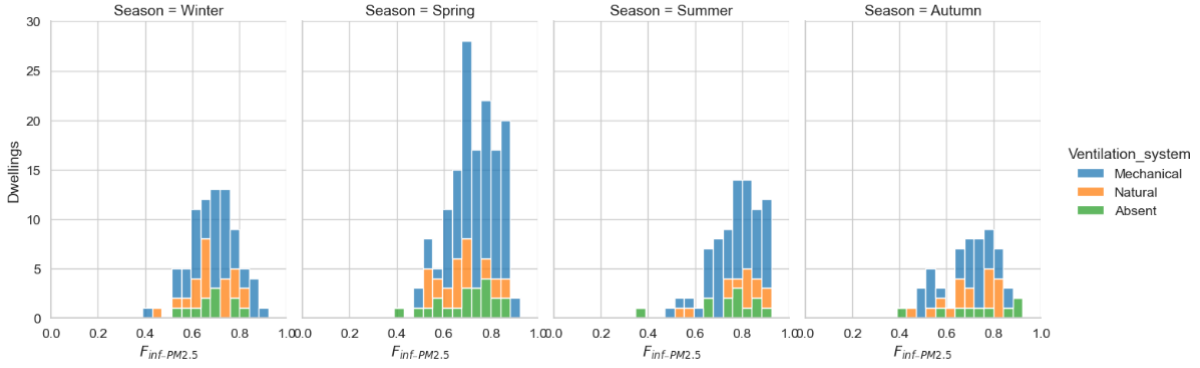


Figure 34. **Histograms of $F_{inf_PM2.5}$ calculated using the air exchange rate of each dwelling, $P_{PM2.5}$ equal to 0.95 and $k_{PM2.5}$ equal to 0.2 h^{-1}.**

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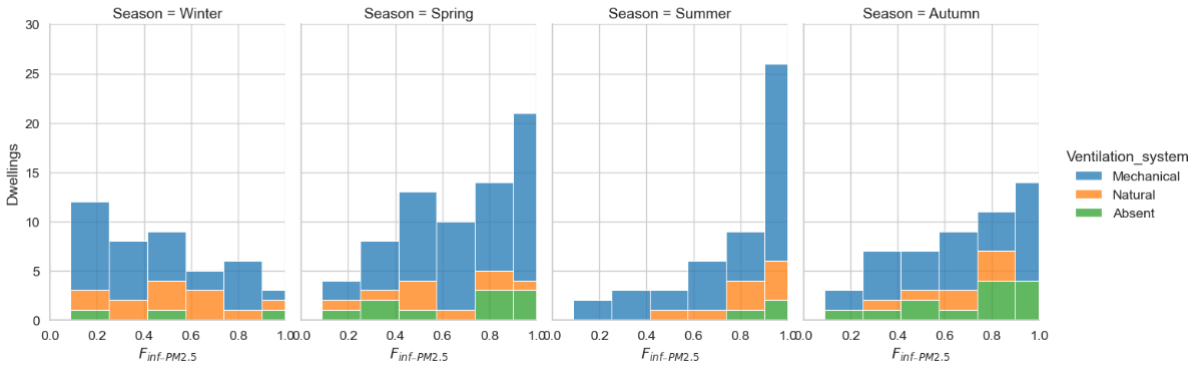


Figure 35. **Distribution of F_{inf_NO2} of the CNL2 dwellings considered free of indoor sources of NO_2.**

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