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Indoor Air Quality Certification Tool for Ventilation Systems

Single-Family Home Reference System

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1 PURPOSE

The work presented in this report formalizes the assumptions and parameters used for the random generation of case simulations in the Single-Family Home reference system using MATHIS computer code [1] as part of the indoor air quality (IAQ) certification project for ventilation systems.

These parameters and assumptions concern:

- the climatic conditions (type of climate, period of the year)
- the environment of the house (terrain roughness, mask of surrounding buildings, orientation, heating)
- the organization of the house (dwelling typology, organization of rooms, air permeability, ventilation system)
- the occupancy and activities (number of occupants, location of occupants, domestic activities).

2 CLIMATE DATA

2.1 Town

Town is an input value entered by the user. The calculation of indicators is performed for a town and repeated for every other town based on the area of application defined by the requester.

The town is chosen as follows to represent a type of climate:

- Temperate: Strasbourg
- Hot: Athens
- Cold: Helsinki

Typical years provided by Meteonorm [2] are used to set the reference wind speed at 10 m, wind direction, outside temperature and outdoor humidity.

The outside volume fraction for CO_2 is set at 400 ppmv. [3]

The outside formaldehyde concentration is set at 1.9 µg/m^3, corresponding to the median value of the measurements obtained as part of the 2003–2005 French national survey on air quality in dwellings and outdoors. [4]

2.2 Calculation period (yearday)

The calculations are performed over 1 week preceded by 2 weeks of setup to establish the inertias (hygroscopic inertia and diffusion of chemical species in the building).

The **yearday** corresponding to the start of the week is chosen based on a uniform law, such as an integer in the interval [1; 365].

2.3 Wind profile linked to remote environment (roughness)

At this stage, the height Hvref used to define the wind speed used for nondimensionalization of pressure coefficients in facades is set at 10 m.

The **roughness** (**rugo)** of the site can have four values (categories II, IIIa, IIIb and IV for respectively open country, discontinuous suburban, dense suburban area and urban center, see example in appendix 6.1), defined within the meaning of the Eurocode on wind actions. [5] Roughness connects the reference speed in the meteorological data file (by agreement, 10 m for a roughness category II) to the speed on the building site.

Table 1 provides the frequency of random generation of the various roughness levels. They were determined from the INSEE data on the distribution of single-family homes in France based on type of municipality. Details about the approach are provided in an appendix to this report. General data on urbanization in Europe are given in section 4.3 of the EN-CAPE 19-006 development-method-QAI-ventilation report.

Table 1: Frequency of occurrence of roughness category on the site (see section 6 of the appendix: ***Distribution of homes based on terrain roughness category)***

Environment	Roughness category	Frequency
Open country	II	36%
Discontinuous suburban	IIIa	22%
Dense suburban area	IIIb	35%
Urban center	IV	7%

2.4 Mask linked to immediate vicinity (cpmask)

Pressure coefficients on the facade, varying between +0.9 and −0.9, depending on the wind incidence angle on the facade, (Figure 1) are used. This data is representative of the immediate vicinity free of obstacles and was generated from measurements of low-rise buildings (1 to 4 floors) in a wind tunnel and the rectangular footprint. [6] [7]

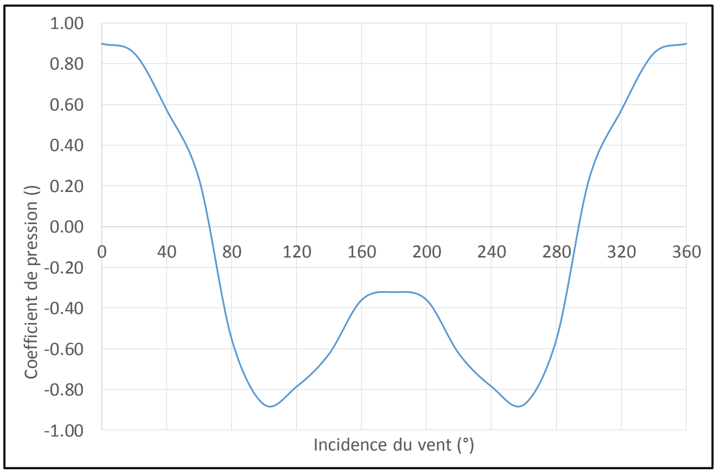

Figure 1: Change in the pressure coefficient on building facade depending on wind incidence in immediate vicinity (Cpmask = 1)

A multiplier **Cpmask** is chosen based on a uniform distribution in the interval [0.25; 1] to represent the mask effects of the wind related to the various levels of obstacle presence in the immediate vicinity of the dwelling. This multiplier is applied to the pressure coefficient in Figure 1.

2.5 Building orientation (orientation)

At the start of simulation, a rotation is applied to the input data to represent the building **orientation**. Orientation is chosen based on a uniform distribution, such as an integer in the interval [0; 350] in steps of 10°.

2.6 Set temperature (Theat)

During the calculation, the internal temperature is set at a given time as the maximum between the outside temperature and the set temperature **Theat**. Theat is chosen based on a uniform distribution, such as an integer in the interval [19°C; 21°C].

Note: The feasibility of setting a lower indoor temperature compared with outside temperature for hot climates because of the use of air conditioning requires additional study. It is necessary to incorporate the impact of air conditioning on the amount of water in the air from condensation on the cold component of the air-conditioning system.

3 DWELLING CHARACTERISTICS

To characterize dwellings and their occupancy (section 4), detailed short-term data is required. **No European study with the data required for these analyses (dwelling typology and occupancy) was found**. **The French data from National Dwellings Survey No. 1 (CNL1) conducted by the Indoor Air Quality Observatory (OQAI), which involved 337 single-family homes, and the INSEE National Housing Survey (ENL 2013), which involved 15,133 dwellings, were included.**

3.1 Dwelling typology (dclass, dwelling, W, B, BW)

The dwelling typology proposed in the NF 205 standard [8] and calculation rules for the examination of Technical Appraisals [9] were crossed-referenced with information from CNL1 and ENL 2013. The presence and number of wet rooms are indicated by a number and a letter. “iB” means I bathroom, “jW” means that there is j toilet and “kBW” indicates the number of bathrooms with toilet.

Table 2: Typology selected and frequency of occurrence for small dwellings

dclass		dwelling		W-B-BW	
Petit	2.8%	F1	0.3%	0W-0B-1BW	0.1%
				1W-1B-0BW	0.2%
		F2	2.4%	0W-0B-1BW	0.5%
				1W-1B-0BW	1.6%
				2W-1B-0BW	0.1%
				1W-0B-1BW	0.2%

Table 3: Typology selected and frequency of occurrence for medium-size dwellings

dclass		dwelling		W-B-BW	
Moyen	42.6%	F3	12.4%	0W-0B-1BW	2.0%
				1W-1B-0BW	8.0%
				1W-2B-0BW	0.4%
				2W-1B-0BW	0.8%
				1W-1B-1BW	0.4%
				1W-0B-1BW	0.9%
		F4	30.2%	0W-0B-1BW	3.1%
				1W-1B-0BW	16.5%
				2W-1B-0BW	1.9%
				1W-2B-0BW	1.0%
				1W-0B-1BW	4.7%
				2W-2B-0BW	1.0%
				1W-1B-1BW	2.2%

Table 4: Typology selected and frequency of occurrence for large dwellings

dclass		dwelling		W-B-BW	
Grand	54.6%	F5	27.7%	0W-0B-1BW	2.1%
				1W-1B-0BW	11.4%
				2W-1B-0BW	4.2%
				1W-0B-1BW	3.3%
				2W-2B-0BW	1.8%
				1W-2B-0BW	2.1%
				1W-1B-1BW	2.7%
		F6	18.3%	0W-0B-1BW	1.1%
				1W-1B-0BW	4.5%
				2W-1B-0BW	2.3%
				1W-0B-1BW	2.3%
				2W-2B-0BW	2.1%
				1W-2B-0BW	1.5%
				2W-1B-1BW	0.7%
				0W-0B-2BW	0.6%
				1W-1B-1BW	2.8%
				1W-0B-2BW	0.4%
		F7	8.6%	0W-0B-1BW	0.6%
				1W-1B-0BW	0.7%
				2W-1B-0BW	1.3%
				1W-0B-1BW	0.9%
				2W-2B-0BW	1.0%
				1W-2B-0BW	1.0%
				2W-1B-1BW	0.6%
				3W-1B-0BW	0.3%
				0W-0B-2BW	0.5%
				1W-1B-1BW	1.4%
				1W-0B-2BW	0.4%

Based on this study, a frequency of occurrence is associated with each typology (see Table 2, Table 3 and Table 4). The dwelling typology is chosen at random from those in the areas of application selected by the requester, taking into account their frequency of occurrence. The area of application is the list of the dwelling types covered, with their configuration (number of bathrooms without toilet, number of separate toilets and number of bathrooms with toilets) or the maximum number of toilets.

This typology determines the following:

- Dwelling class (**dclass**): [small (F1/F2); medium (F3/F4); large (F5+)]
- Dwelling type (**dwelling**): [F1; F2; F3; F4; F5; F6; F7]
- Number of separate toilets (**W**)
- Number of bathrooms (**B**)
- Number of bathrooms with toilets (**BW**)

3.2 Interior architecture

3.2.1 Number and types of rooms

Dwellings are composed based on the selected typology by assembling rooms identified by their use and having characteristics based on that use.

Dwellings consist of the following rooms:

- F1: [‘hall1’; ‘Kitchen1’; ‘Bathroom(i)’; ‘WC(j)’; ‘Bathroom-WC(k)’; ‘Living1_Bedroom1’]
- F2 and more: [‘hall1’; ‘Kitchen1’; ‘Bathroom(i)’; ‘WC(j)’; ‘Bathroom-WC(k)’; ‘Living1’; ‘Bedroom1’]

Where i varies from 0 to B, j varies from 0 to W, k varies from 0 to BW (0 meaning that no room of this type is in the dwelling) and l varies from 1 to the number of bedrooms corresponding to the **dwelling** type.

The interior arrangement consists of a central area (‘hall1’) to which other rooms are connected in terms of airflow.

Each room, including the central area, has specific orientation with respect to the outside (see section 3.3). For open-plan arrangements, the Kitchen1 and Living1 rooms are combined to form a single Living1_Kitchen1 (see section 3.2.4).

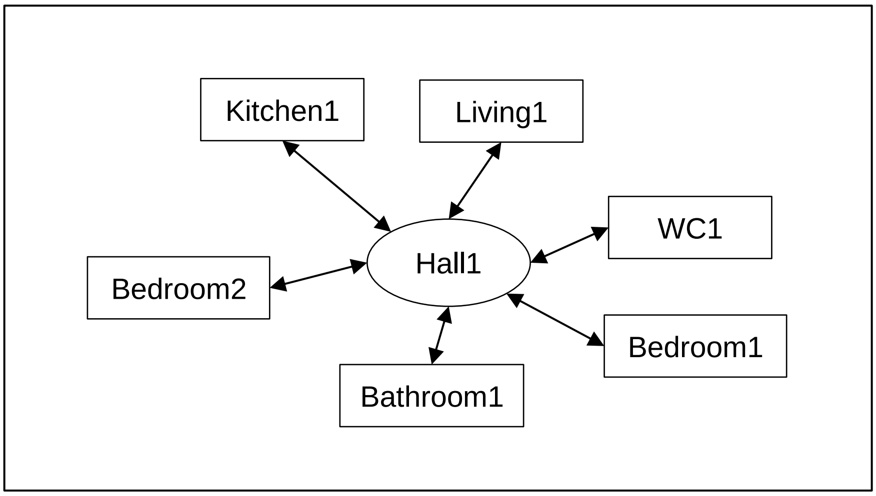

Figure 2: Example of interior design corresponding to F3-1W-1B-0BW with a kitchen separated from the living room

3.2.2 Total floor area of dwelling

The total floor area of the dwelling is derived randomly based on its type.

For each dwelling type, the ENL 2013 campaign provides a minimum and maximum floor area. To perform the analysis by dwelling type, we chose to use a distribution area by 10-m^2 steps. Data analysis of European dwelling floor areas (see section 4.1 of the EN-CAPE 19-006 development-method-QAI-ventilation report) shows that the French building stock is close to the European mean. The floor areas used are therefore representative.

Table 5 below shows the likelihood of floor areas selected by dwelling type. Figure 3 shows the distribution selected for F4 dwellings.

Table 5: Likelihood of occurrence of floor areas based on type

Floor area (m^2)	Dwelling type					
	F1	F2	F3	F4	F5	F6+
20	24%	3%	0%	0%	0%	0%
30	39%	11%	0%	0%	0%	0%
40	22%	24%	4%	0%	0%	0%
50	6%	26%	9%	1%	0%	0%
60	4%	17%	20%	4%	1%	0%
70	2%	10%	22%	11%	3%	1%
80	2%	6%	22%	24%	10%	3%
90	0%	2%	11%	24%	16%	5%
100	2%	1%	7%	16%	20%	9%
110	0%	0%	2%	7%	14%	9%
120	0%	0%	2%	7%	15%	17%
130	0%	0%	0%	2%	6%	8%
140	0%	0%	0%	1%	4%	9%
150	0%	0%	0%	1%	4%	10%
160	0%	0%	0%	0%	2%	8%
170	0%	0%	0%	0%	1%	4%
180	0%	0%	0%	0%	1%	6%
190	0%	0%	0%	0%	0%	2%
200	0%	0%	0%	0%	1%	5%
210	0%	0%	0%	0%	0%	1%
220	0%	0%	0%	0%	0%	2%
230	0%	0%	0%	0%	0%	2%

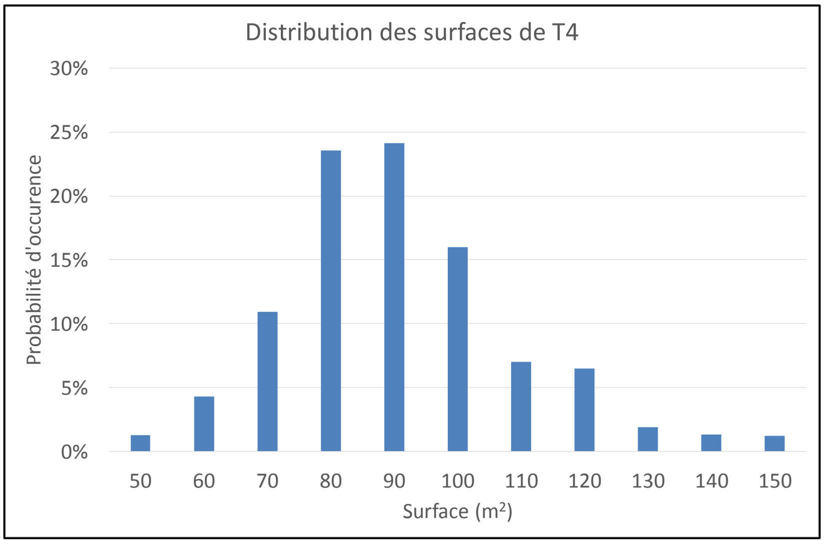

Figure 3: Distribution of floor areas obtained for F4 dwellings

3.2.3 Room floor area

The ENL 2013 campaign provides the distribution of kitchen floor areas based on dwelling type (see Table 6). **We propose limiting the maximum floor area of the kitchen to 16 m².**

Table 6: Likelihood of occurrence of kitchen floor areas based on dwelling type

	F1	F2	F3	F4	F5	F6+
Less than 4 m²	25%	12%	6%	3%	1%	1%
4 m² to less than 7 m²	32%	39%	31%	22%	15%	7%
7 m² to less than 12 m²	39%	45%	55%	63%	50%	30%
12 m² and larger	4%	3%	8%	12%	33%	62%

- Kitchen: $area = \mathcal{U}[4\,;16[$ m²

The floor areas of bathrooms, separate toilets (WC) and bedrooms are then derived randomly according to a uniform distribution between the following bounds:

- Bathroom(i) and Bathroom-WC(k): $area = \mathcal{U}[4\,;8[$ m²
- WC(j): $area = \mathcal{U}[1\,;2[$ m²
- Bedroom1: $area = \mathcal{U}[9\,;15[$ m²
- Bedroom(l>1): $area = \mathcal{U}[9\,;12[$ m²

Living room and hall floor areas are calculated using the areas for the previous rooms. The living room does not exceed 60 m². The larger the remaining area is, the wider the living room and hall are. The hall is then larger than its minimum area of 2 m². On the other hand, the floor area of the living room cannot be less than 15 m², which, in some cases, leads to an increase of the total area of the dwelling (Kitchen, Bathroom, WC, and Bedroom floor areas pushed to toward the upper end of the range).

The floor area of the living room is included based on a uniform distribution between the maximum 15 m² and half of the remaining area (total area minus the sum of the areas of the rooms already defined, i.e. bedrooms and technical rooms, minus the minimum area of the hall) and the minimum between 60 m^2 and the total remaining area. If the remaining floor area is less than 15 m², that of the living room is 15 m²:

– Living 1: $area = \mathcal{U}[\max(15; (\text{Stot} - 2 - \sum Sroom)/2)\,; \min(60; \text{Stot} - 2 - \sum Sroom)[$ m^2

The floor area of the hall is defined as the maximum between 2 m^2 and the remaining floor area.

– Hall1: $area = \max(2\,; \text{Stot} - \text{Sliv} - \sum Sroom)$ m^2

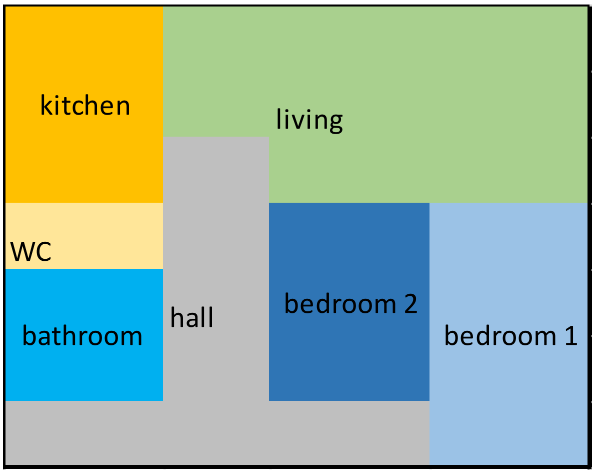

Figure 4: Example of F3 1W-1B dwelling

As an example, for this F3, considering a total area of 60 m² (random generation between 40 and 120 m²), random generation of floor areas for the rooms can be as follows:

- Kitchen: 4 to 16 m²
- Bathroom: 4 to 8 m²
- WC: 1 to 2 m²
- Bedroom 1: 9 to 15 m²
- Bedroom 2: 9 to 12 m²

If all the rooms above are at their minimum areas, there remains 33 m² and the living room is 30 m² and hall 3 m².

If all the rooms above are at their maximum areas, there remains 7 m². The living room is therefore 15 m² and the hall 2 m². The total dwelling floor area is then 70 m².

3.2.4 Open-plan kitchen (openkitchen)

The information from the CNL1 campaign exclusively for single-family homes show that the proportion of separate kitchens and open-plan kitchens is identical regardless of dwelling type.

The Table 7 below give for the likelihood of occurrence for all dwellings in the campaign.

Table 7: Likelihood of occurrence of separate and open-plan kitchen configurations for CNL1 campaign

	Likelihood of occurrence
Separate kitchen (**openkitchen**=.False.)	73%
Open-plan kitchen (**openkitchen**=.True.)	27%

According to information given by the manufacturers present at the certification committee, the probability for European countries is rather 80%. The reference system therefore considers a 80% likelihood of occurrence of having an open-plan kitchen.

3.2.5 Ceiling height (Hceiling)

Ceiling height **Hceiling** is common to all rooms (except the hall, which extends through the entire height of the dwelling when it has multiple levels). It is selected as being included in the interval [2.2; 3] m (in 10-cm steps) from the following table taken from the ENL 2013 campaign.

Table 8: Likelihood of occurrence used to determine ceiling height

Ceiling height	**Likelihood of occurrence**
Less than 2.20 m	1%
2.20 m to less than 2.50 m	62%
2.50 m to less than 3 m	32%
3 m and over	5%

3.2.6 Number of levels (Nlevel)

The CNL1 campaign breaks down the number of levels based on dwelling class as presented in Table 9 below.

Table 9: Likelihood of occurrence of number of floors based on dwelling class

	Dwelling class		
Number of levels	**Small**	**Medium**	**Large**
One-level house	57%	28%	11%
Two-level house	43%	56%	46%
Three-level house	0%	13%	37%
Four-level house	0%	3%	7%

F1 dwellings are one level. For other dwellings, once the number of levels is determined, the bedrooms and bathrooms are broken down on each level, starting with the second level with one bedroom present on the ground floor in the case of a house with several levels. The toilets are broken down starting on the ground floor. The living room, kitchen and hall are on the ground floor.

The initially set ceiling height of the hall is multiplied by the number of levels.

3.3 Orientation of rooms (ior)

Depending on construction, dwellings potentially have four facades (North, East, South and West).

Each room faces only one facade. Its orientation **ior** is chosen according to a uniform distribution (and independently of other rooms) as being included between:

$$ior = \mathcal{U}[\text{'}EXT1\text{'}, \text{'}EXT2\text{'}, \text{'}EXT3\text{'}, \text{'}EXT4\text{'}]$$

where ‘EXT1’ corresponds to North before application of building rotation (see section 2.5).

3.4 Envelope air permeability (Q50Pa and hperm)

Using the certificates issued at the completion of new buildings in France, we can obtain the distribution of air permeability index declarations for all new single-family homes (RT2012[1]). The air permeability index corresponds to the leakage rate at 4 Pa divided by the cold wall surfaces (off low floor) of the heated area (walls and ceiling). It is noted as Q4Pa and is expressed in $m^3/h/m^2$. The values from the French building stock are representative of recent dwellings in Europe (see section 4.2 of the EN-CAPE 19-006 report).

Table 10: Likelihood of occurrence of specific air permeability levels for dwelling envelope in France

Q4Pa ($m^3/h/m^2$)	Likelihood of occurrence
0.1	1%
0.2	3%
0.3	4%
0.4	12%
0.5	17%
0.6	63%

In European countries, permeability of the building envelope is often characterized by the air leakage under 50 Pa. For the reference system, 5 classes are used with the likelihood occurrence of table 11 (grouping of the two lowest levels).

Table 11: Likelihood of occurrence of specific air permeability

Q50Pa ($m^3/h/m^2$)	Likelihood of occurrence
0.71	3.6%
1.06	4.5%
1.41	12.3%
1.77	17%
2.12	62.6%

[1] RT2012 – Réglementation Thermique 2012 [French Thermal Regulation 2012]

Each room is linked to its façade by a leakage ('PERMEABILITY' type within the meaning of the MATHIS software; see [10]) of module QV0 equal to:

$$QV0 = Q50Pa.Hceiling.\sqrt{area} \qquad \text{(m}^3\text{/h under 50 Pa)}$$

where *Hceiling* is the ceiling height of the room and *area* its floor area (see sections 3.2.3 and 0).

This leakage is placed at a variable height **hperm** measured from the elevation of the ground of the room. It is determined for each room using the equation $\mathcal{U}[0.5\,;2[$ m.

For the hall and each room on the last level of the dwelling, an additional leakage at ceiling height is created between the room in question and an outside area at zero pressure. The QV0 module of this duct is determined as follows:

$$QV0 = Q50Pa.(area) \qquad \text{(m}^3\text{/h under 50 Pa)}$$

3.5 Ventilation system

Modeling of the ventilation system includes consideration of friction loss in the system (see appendix 6.1). Depending on size and dwelling arrangement, the system can be shorter or longer and have varying numbers of irregularities (elbow type). The larger the type of dwelling, the longer the network and the number of singularity (elbow type) important. The presence of plenums can be considered.

Once the dwelling type is determined, the system characteristics are randomly generated from the following intervals:

Extraction system

- T1/T2, duct length between 3 and 6 m / 1 irregularity elbow type
- T3/T4, duct length between 3 and 9 m / 1 or 2 irregularity elbow type
- T5 and more, duct length between 3 and 12 m / 1 or 2 irregularity elbow type.

Air supply ductwork:

- T1/T2, duct length between 4 and 6 m / 2 irregularity elbow type
- T3/T4, duct length between 4 and 9 m / 2 or 3 irregularities elbow type
- T5 and more, duct length between 4 and 12 m/2 or 3 irregularities elbow type

3.6 Hygroscopic inertia (hygroarea)

We use the Kusuda model [11] to represent hygroscopic inertia related to furniture in the room.

Its configuration consists in determining for each room an equivalent furniture floor area **hygroarea** using the equation $\mathcal{U}[0.5.area\,;1.area[$ m^2 by extrapolation of the rules for submission of Technical Appraisals [9].

3.7 Formaldehyde emissions (QForm)

Formaldehyde emissions in each room are represented by a constant flow related to the SERaForm surface emission factors for finishing work materials and the number of furniture units [12].

All materials used are category A+ (situation observed on the French market for which labeling exists). The upper limit of the emission factor for this category is SERaForm = 12.5 µg/h/m^2 for floor and ceiling applications and SERaForm = 5 µg/h/m^2 for wall applications.

The lower limit of the emission factor is the median of the measurements made by the CSTB laboratory in Grenoble on real materials sampled on the French market, 1.7 µg/h/m^2 regardless of the application. As a result of the circulation of construction products at European level, this finding on the French market is considered to be representative for Europe.

For a given dwelling, three SERaForm coefficients are selected (floor, ceiling and walls) using a uniform distribution between the high and low values of the emission factor.

The contribution of furniture units to formaldehyde emissions is included by considering the median value of measurements made by CSTB Grenoble for complete furniture units, a SERuForm coefficient of 39 g/h per furniture unit. The furniture unit takes into account such different objects as chair, table, bed, dresser or wardrobe.

To ensure consistency between the number of furniture units per room and the random selection of the equivalent furniture floor hygroarea (see section 3.6), one furniture unit is associated with 4 m^2 of equivalent floor area of furniture considering the average surface of its faces. For example, in a 12 m^2 room, the number of furniture units is between 2 and 3. In a 40-m^2 living room, this number is between 5 and 10.

The total flow of formaldehyde emission by floor area of a room **QForm** is then calculated as follows:

$$QForm = \frac{1}{area}\left[(\mathrm{SERaForm}(1) + \mathrm{SERaForm}(2)).area + \mathrm{SERaForm}(3).\left(4.Hceiling.\sqrt{area}\right) + \mathrm{SERuForm}\ \times \mathrm{round}\left(\frac{\mathrm{hygroarea}}{4}\right)\right]\ \mu g/h/m^2$$

4 OCCUPANCY

4.1 Number of occupants (nbOcc)

The CNL1 and ENL 2013 campaigns make it possible to determine a likelihood of occurrence of a specific number of occupants per dwelling class (see Table 12).

Table 12: Likelihood of occurrence of a specific number of occupants based on dwelling class

	Dwelling class		
Number of occupants	**Small**	**Medium**	**Large**
1	67%	27%	14%
2	27%	39%	37%
3	4%	17%	15%
4	2%	12%	21%
5	0%	4%	10%
6	0%	1%	3%

4.2 Occupancy time

Determination of the occupancy time of each occupant consists in defining for one week and with a time step of 10 minutes their location in the dwelling.

Each occupant can be found over time in the following rooms:

['Living1'; BedroomOcc; 'Kitchen1'; BathroomOcc; WCOcc; 'Outdoor']

At a given moment, we determine the location of the occupant from the presence likelihoods obtained in CNL1 (only study available with this degree of detail of information) based on day of the week (Monday to Friday or Weekend) and occupant type (adult or child).

Occupants 1 and 2 are adults. Occupants 3 and above are children.

The figures below show the presence likelihoods used.

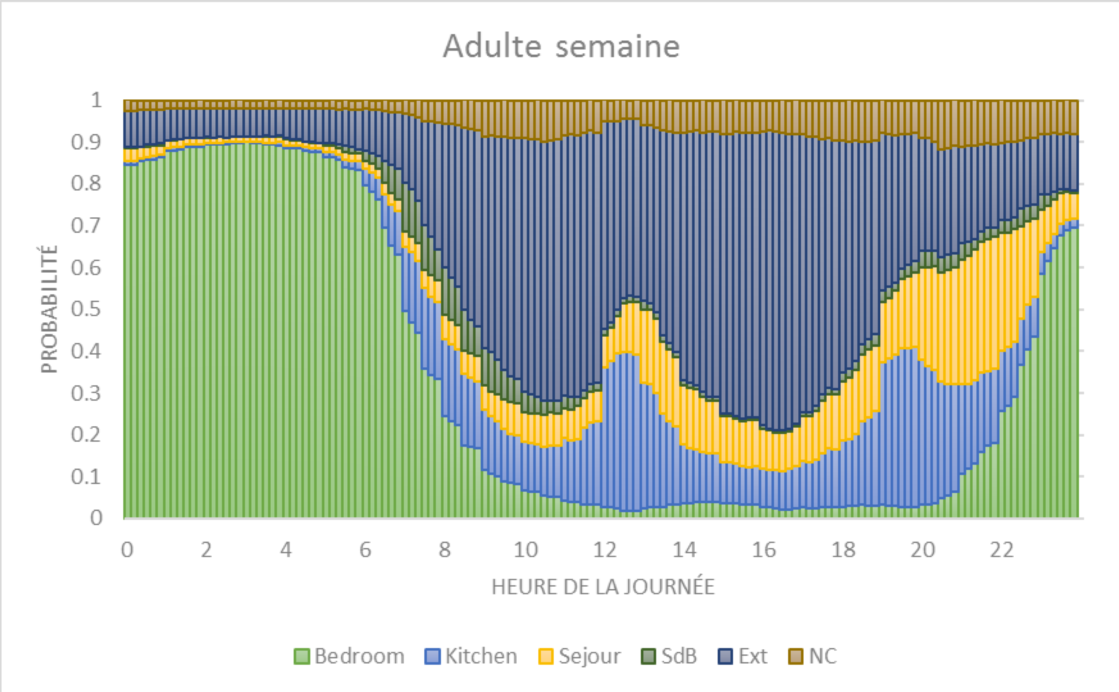

Figure 5: Likelihood of the presence of an adult during the week based on time of day. NC means that the occupant is in the dwelling, but their precise location is unknown. In this situation, we place the occupant in the room used in the previous time step to be prudent as pertains to CO_2 levels.

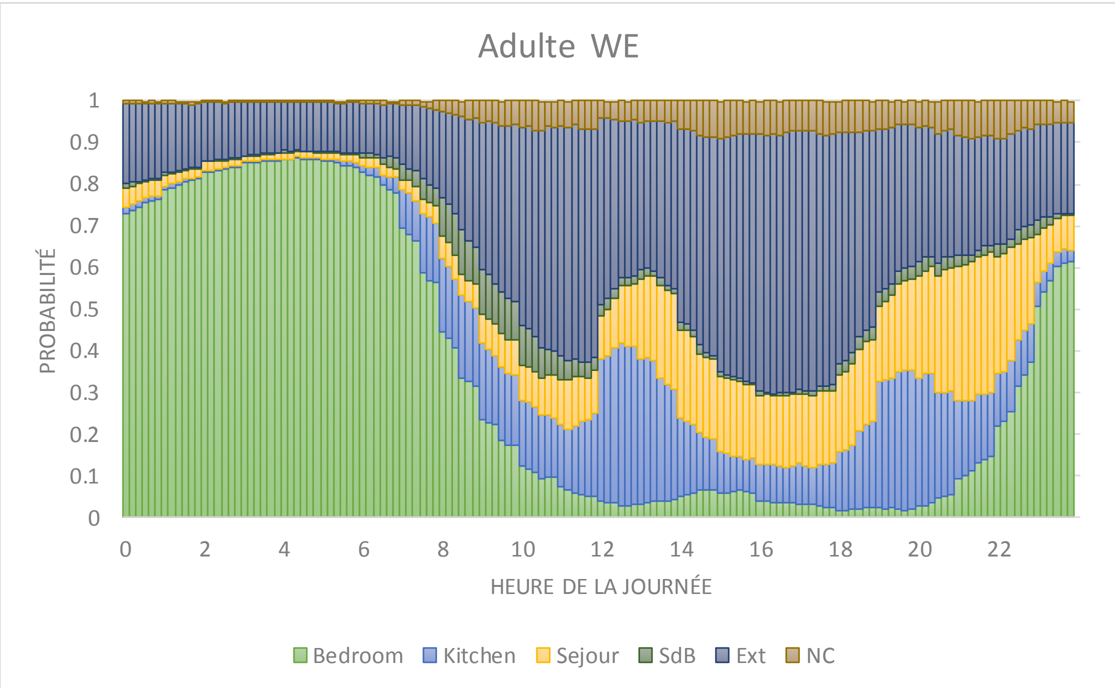

Figure 6: Likelihood of the presence of an adult during the weekend based on time of day.

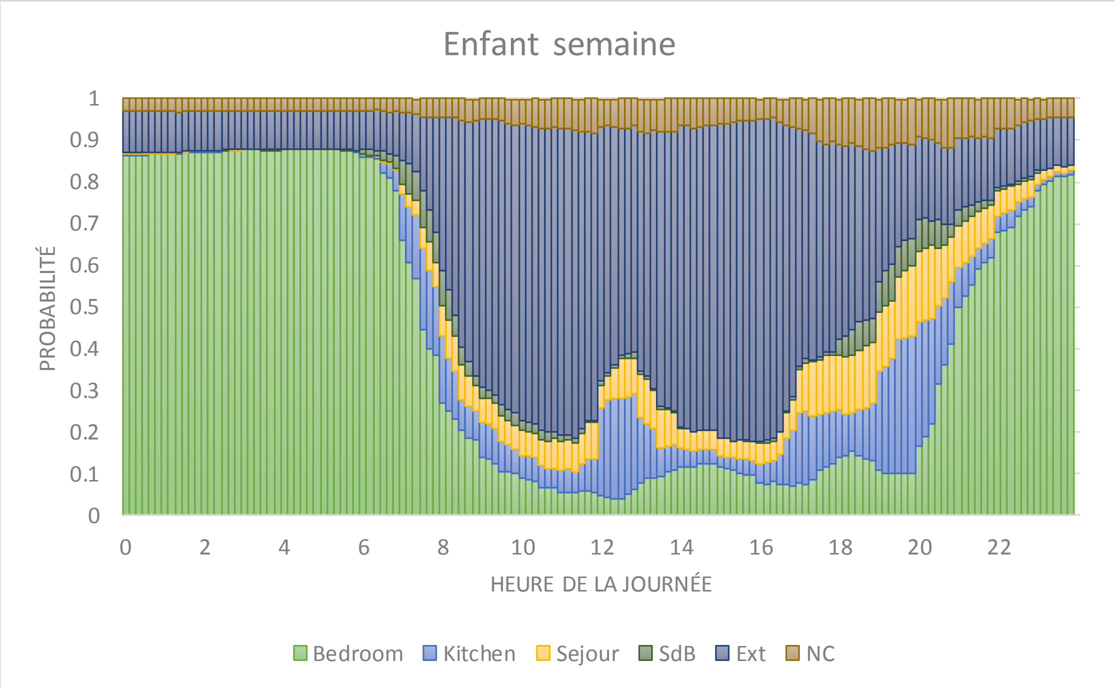

Figure 7: Likelihood of the presence of a child during the week based on time of day.

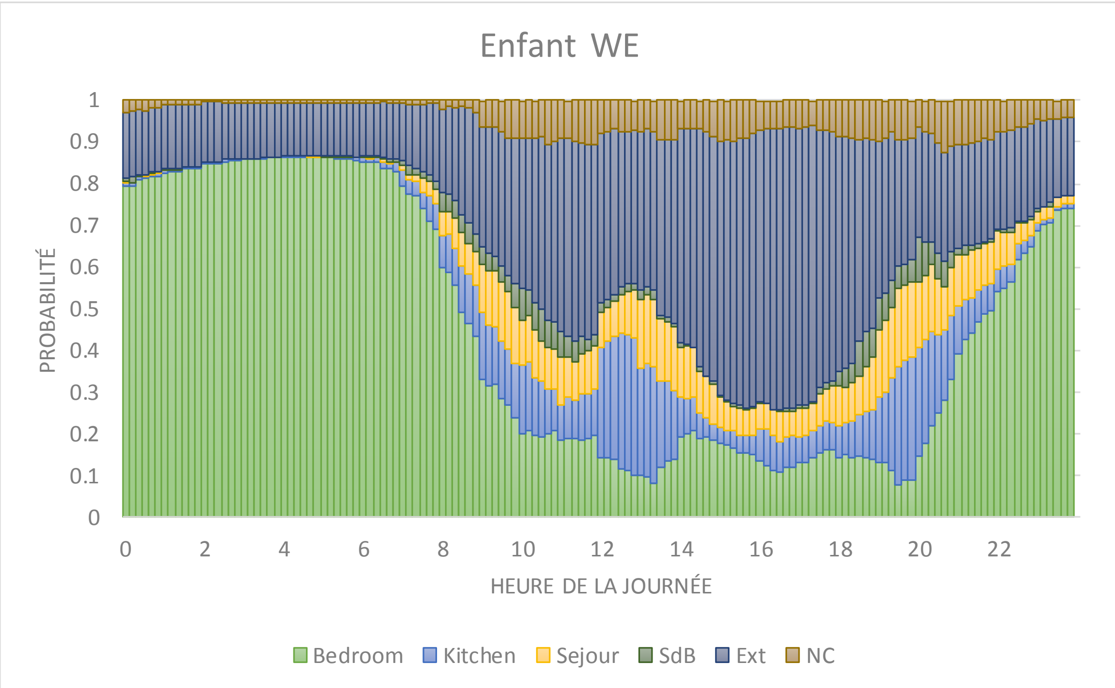

Figure 8: Likelihood of the presence of a child during the weekend based on time of day.

Each occupant uses the same bedroom over time. Occupants 1 and 2 use bedroom 1 (i.e. BedroomOcc = 'Bedroom1'). The other occupants are distributed in the available bedrooms to use them as much as possible.

Each occupant uses the same bathroom and WC over time. At the start of simulation, we randomly select the technical room used by each occupant from those available.

The CNL1 does not provide information on the use of toilets. Because of the lack of data and not to complicate the approach, we did not distinguish between weekdays and weekends for the use of toilets. Each occupant can use the toilets twice a day during the periods [06:00–9:00] and [19:00–22:00]. The exact time is selected as the first of each period satisfying the following conditions:

- The toilet used is not occupied by another occupant.
- The occupant's localization places them in the dwelling.

4.3 Metabolism – CO_2 emission and water vapor

Occupant metabolism is represented by associating with each occupant source terms for CO_2 and water vapor in the volumes of the rooms they occupy. CO_2 and water vapor emissions related to the metabolism of a person depends on age, weight, size, state (awake or asleep), activity, ambient temperature, and other factors.

As concerns the production of water vapor, TenWolde and Pilon [13] found in the literature values that vary from 30 to 90 g/h and chose 50 g/h as representative of an average adult awake at rest. Hite and Bray [16] indicate that four people produce 5 Kg of water vapor per day, which corresponds to an average production of 52 g/h.

Concerning the production of CO_2, Persily and de Jonge [14] present values ranging from 2.9 L/h to 57.6 L/h depending on age (1 to 80 years), sex and activity (physical activity index varying from 1 to 4). For an adult male age 21 to 30, the release of CO_2 is 14 L/h to 17.3 L/h with light activity (index varies from 1 to 1.2).

These values are of the same order of magnitude as those used by GS14.5 [9] for the Technical Appraisal Procedure in France. We therefore use, for all occupant types, the values in Table 13 below.

Table 13: Source terms used to represent the metabolism of an occupant

	Awake	Asleep
CO_2 production	16 L/h	10 L/h
H_2O production	55 g/h	38.5 g/h

Occupant metabolism is represented by associating with each occupant source terms for CO_2 and water vapor in the volumes of the rooms they occupy (see table 12). These source terms are based on their state (awake or asleep). An occupant is asleep when they are in their room and the time of day is between 21:00 and 07:00 for a child and 23:00 and 07:00 for an adult.

4.4 Domestic activities – Water vapor emission

For a time step of 10 minutes, we define water vapor production related to occupant showering, cooking food in the kitchen and washing and drying laundry.
Domestic activities in terms of total production of associated water vapor are defined from crossing the orders of magnitude provided by the Technical Appraisal Procedure [9] and the literature [13], 15] and [16].

4.4.1 Showers

As mentioned by Hite and Bray [16], a bath produces approximatively half less water vapor than a shower. In a conservative way, only showers are considered

According to the IEA [15], a 3-minute shower delivers about 200 g of water vapor and a 15-minute shower 800 g. TenWolde and Pilon [13] use a flow of 2.6 kg/h, or 130 g for 3 minutes and 650 g for 15 minutes. The Technical Appraisal Procedure [9] uses a production of 300 g per shower.

For us, each occupant takes one shower a day for a time step of 10 minutes. The exact time is selected as the first satisfying the following conditions:

- Occupant is in a bathroom.
- Bathroom is not being used by another occupant to take a shower.

For each shower, we randomly select the amount of total water vapor produced according to the equation $\mathcal{U}[200\,;800[$ g over 10 minutes.

4.4.2 Meals

This represents the water vapor produced by cooking food and washing the associated dishes. This water production is strongly related to the type of meal and number of people.

The Technical Appraisal Procedure [9] uses total production of 50 g per person for breakfast, 150 g per person for lunch and 300 g for dinner.

TenWolde and Pilon [13] reviewed some values in the literature and use production of 250 g per dish and 240 g per meal (here, representative of a plate of rice, vegetables and fried chicken for 4 people) which corresponds to 122.5 g per person per meal.

Hite and Bray [16] mentioned that for 4 people, coking and washing for 3 meals represent between 1,5 and 2.8 kg water function of the use of a gas cooker. This gives between 375 and 700 g per person to spread over the 3 meals.

4.4.2.1 Breakfast in the kitchen

The production of water vapor in the kitchen linked to having breakfast is defined by occupant. It is distributed over half hours from the first moment when the occupant is in the kitchen over the period 06:00 to 10:00.

We choose at random a total production of water vapor based on the equation $\mathcal{U}[50\,;100[$ g per person.

4.4.2.2 Shared meals

We consider that occupants may eat two meals together a day.

The production of water related to shared meals is distributed over one hour for the period 12:00–13:00 for lunch and 19:00–20:00 for dinner. It is a function of the number of people N_p participating in the meal. The number of people is defined as the maximum number of people simultaneously in the dwelling during the period.

We randomly select a water vapor flow using the equation $\mathcal{U}[100\,;200[\, * Np$ g/h for both lunch and dinner.

The production of water vapor related to meals is therefore between 250 and 500 g/day/person in accordance with the values mentioned in the literature.

4.4.3 Washing and drying laundry

We use the same scenario used for Technical Appraisals [9] given the lack of relevant information in the literature. Due to the relatively low emission of water vapor during washing in relation to drying (200 versus 1000g), we do not consider any other location than the bathroom for the washing machine. The number of loads per week is based on the number of occupants (see Table 14).

Table 14: Laundry days based on number of occupants

Number of occupants	Laundry days
1 person	Saturday
2 people	Saturday/Sunday
3 people	Wednesday/Saturday/Sunday
4 or more people	Monday/Wednesday/Saturday/Sunday

A laundry load releases 200 g of water vapor over two hours (a flow of 100 g/h) from 8:00 to 10:00. It is followed by a drying time of over 20 hours, releasing 1000 g (a flow of 50 g/h) from 10:00 to 06:00.

The source terms associated with laundry loads are placed in a bathroom selected randomly from those in the dwelling at the start of the simulation.

When there are several bathrooms, the source terms associated with drying times are placed randomly in one of the bathrooms or in the living room. If there is only one bathroom in the dwelling, drying source terms are placed in the living room.

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6 APPENDICES

6.1 Distribution of homes based on terrain roughness categories

Environment types (terrain roughness)

To assess the effects of wind on the dwelling ventilation system, it is necessary to define the local wind characteristics, which depend on the environment. The reference wind provided by Meteonorm corresponding to meteorological wind (terrain roughness category II) must be readjusted based on the roughness of the site.

The environment is characterized by terrain roughness category. The standard Eurocode 1: Actions on structures – Part 1–4: General actions – Wind actions (EN 1991-1-4 (2005)) defines five terrain categories:

- 0: Sea or coastal area exposed to the open sea
- I: Lakes or flat and horizontal area with little vegetation and without obstacles
- II: Area with low vegetation, such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights
- III: Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)
- IV: Area in which at least 15% of the surface is covered with buildings and their average height exceeds 15 m

The France National Annex to NF EN 1991-1-4/NA (2008) uses the following five categories:

- 0: Sea or coastal area exposed to the open sea, lakes and water bodies with wind over a distance of at least 5 km
- II: Open country, with or without some isolated obstacles (trees, buildings, etc.) with separations of more than 40 obstacle heights
- IIIa: Country with hedges; vineyards; wooded country; scattered populations
- IIIb: Urban and industrial areas; dense wooded country; orchards
- IV: Urban areas in which at least 15% of the surface is covered with buildings and their average height exceeds 15 m, forests

The photographs below show the various terrain roughnesses.

Illustration of roughness’s 0, IV (left) and II (right)

Illustration of roughnesses IIIa (left) and IIIb (right)

<u>Placement of dwellings</u>

For France, we found INSEE statistics for the building stock in 2016.

In metropolitan France on January 1, 2016, 82% of dwellings were main residences and **56% were individual homes**. Individual homes prevail over main residences, second homes and occasional housing. The Paris area has 16% of main residences and rural areas 22%.

Second homes or occasional housing are far more often in rural or small urban units (less than 100,000 inhabitants): four out of five compared with only half of main residences. Furthermore, rural areas have 43% of second homes and small urban units 39%.

Individual homes are more common the smaller the town for all housing categories (main residence and others).

INSEE provides a breakdown of dwellings by category and by urban unit (see table).

Distribution of individual and collective housing according to the size of urban unit at 1st January 2016 in France

	en milliers			
	Ensemble des logements	Résidences principales	Résidences secondaires et logements occasionnels	Logements vacants
Ensemble des logements	**34 537**	**28 430**	**3 281**	**2 825**
Individuel	19 325	16 088	1 883	1 354
Collectif	15 212	12 343	1 399	1 471
Communes rurales	**8 341**	**6 227**	**1 405**	**709**
Individuel	7 473	5 768	1 093	613
Collectif	867	460	312	96
Agglomérations de moins de 100 000 habitants	**11 114**	**8 834**	**1 264**	**1 016**
Individuel	6 956	5 798	664	493
Collectif	4 158	3 035	600	523
Agglomérations de 100 000 habitants ou plus	**10 038**	**8 793**	**443**	**801**
Individuel	3 827	3 512	112	202
Collectif	6 211	5 281	331	599
Agglomération Parisienne	**5 045**	**4 576**	**169**	**299**
Individuel	1 069	1 009	13	46
Collectif	3 976	3 567	156	253

Champ : France métropolitaine.

Sources : Insee, SOeS, estimations annuelles du parc de logements au 1er janvier.

From this table and considering all dwellings, we can deduce a distribution of collective and individual housing based on location.

Distribution of single-family homes by type of environment

In considering urbanization in the various situations listed by INSEE, especially from an aerial view, we sought to establish a distribution of homes by terrain roughness category. We used the French National Annex categories.

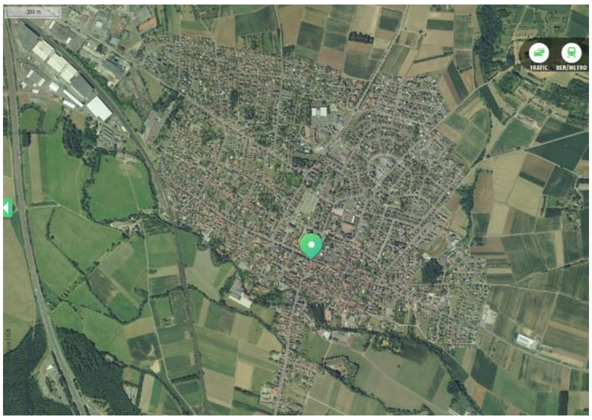
Category 0 representing a small coastal area was not considered. We distributed homes in accordance with categories II, IIIa, IIIb and IV.

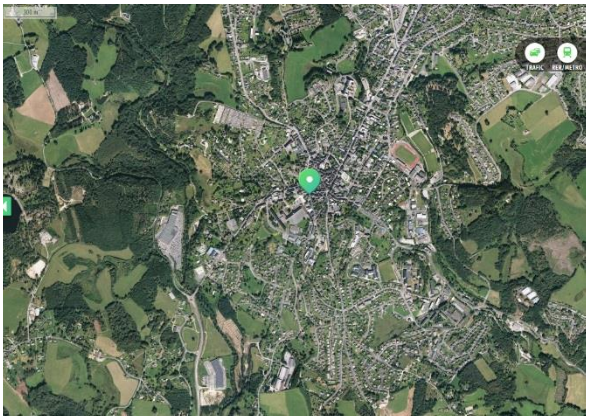
Rural areas consist of scattered populations and small built-up stretches that do not impact the wind. They therefore consist of categories II and IIIa, respectively, 80 and 20%.

Towns with fewer than 100,000 inhabitants correspond to diverse situations, such as remote towns of various sizes, like Lescar, Ussel and Brumath (10,000 inhabitants), Agde and Alençon (25,000 inhabitants) and urban peripheries like Chantepie, Marquette-lez-Lille and Pierre-Bénite (10,000 inhabitants). Towns with 50,000 inhabitants, such as Belfort, Evreux, Laval, and Sevran, have wider urbanized areas. The presence of buildings is quite low in small remote towns. There are more in towns with 25,000 to 50,000 inhabitants and in urban peripheries.

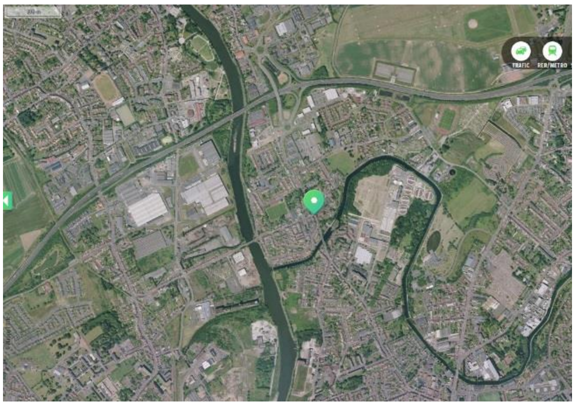
Cities with more than 100,000 inhabitants, from Aix-en-Provence to La Rochelle for the smallest to Lille, Lyon and Marseille for largest, and including Brest, Nantes and Grenoble, cover a larger area and have dense urbanization.

Finally, the Paris area is a continuous urban fabric over several tens of kilometers, with a predominance of buildings.

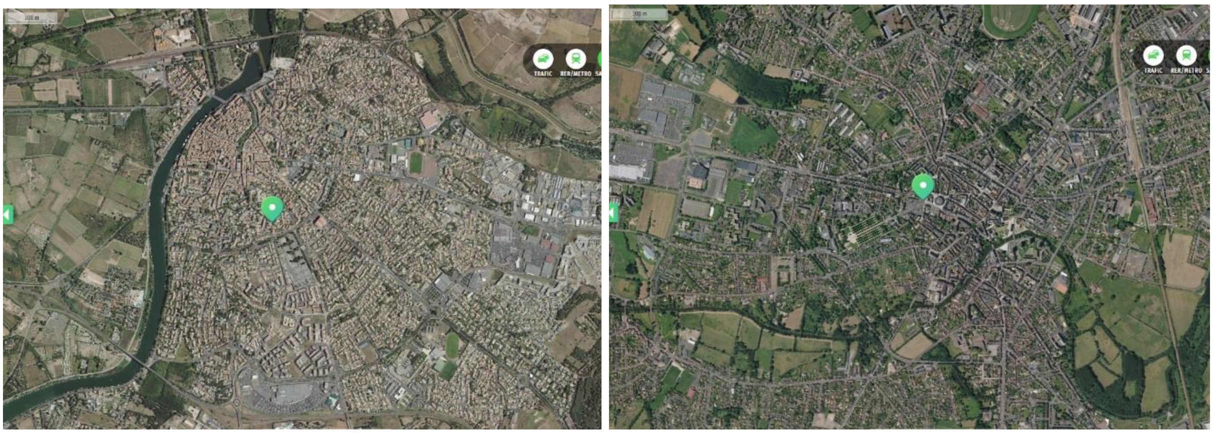




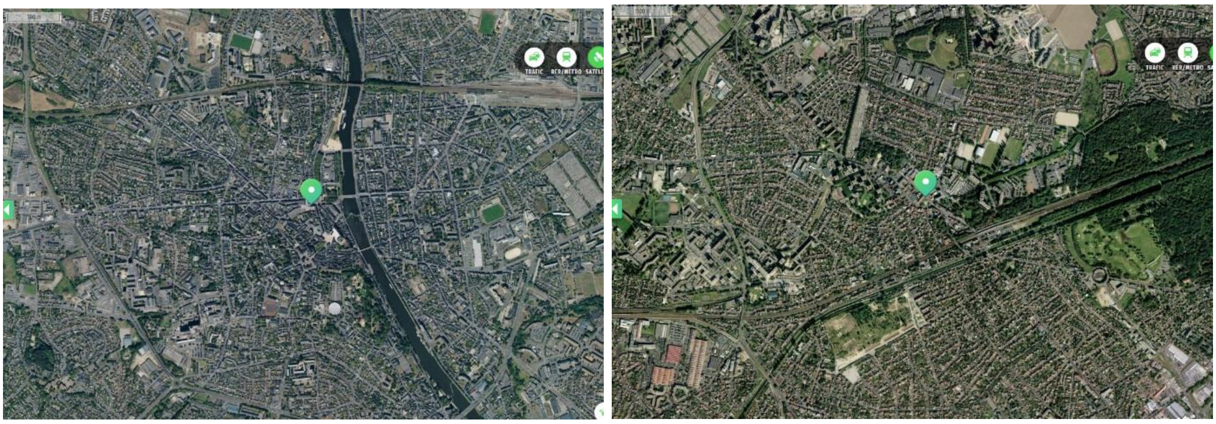
Aerial view of remote towns with 10,000 inhabitants: Brumath and Ussel



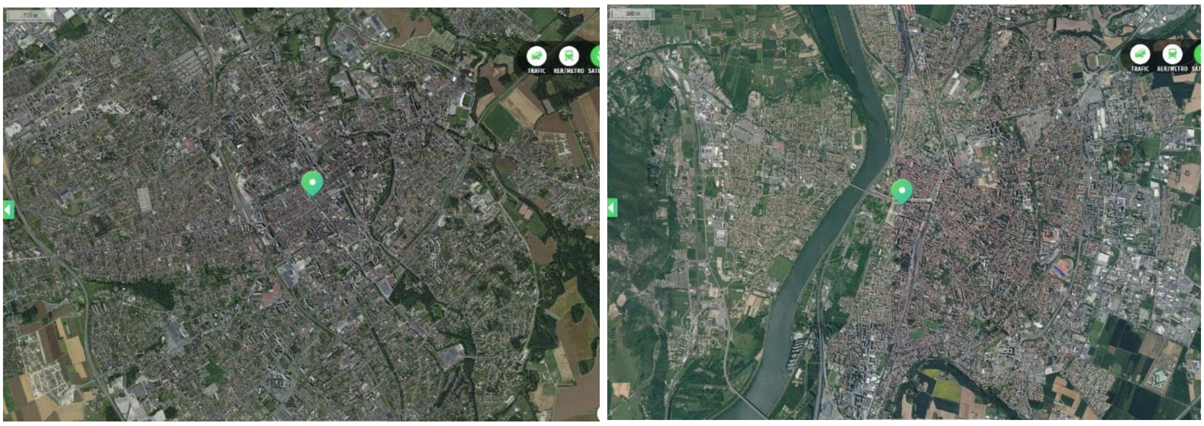
Aerial view of towns with 10,000 inhabitants in the periphery: Chantepie and Marquette-lez-Lille



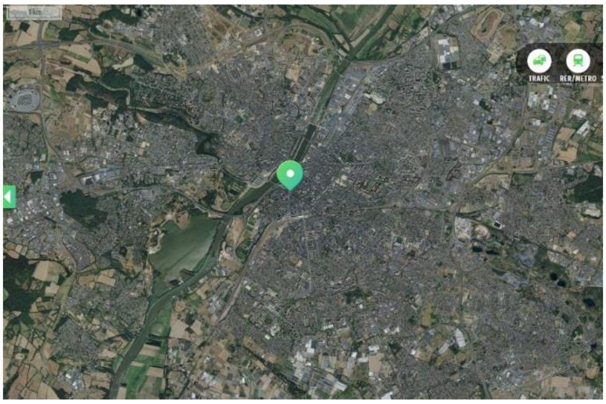
Aerial view of towns with 25,000 inhabitants: Agde and Alençon

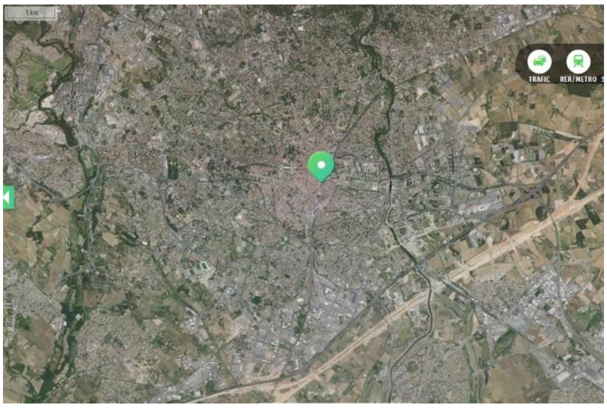


Aerial view of towns with 50,000 inhabitants: Evreux and Sevran

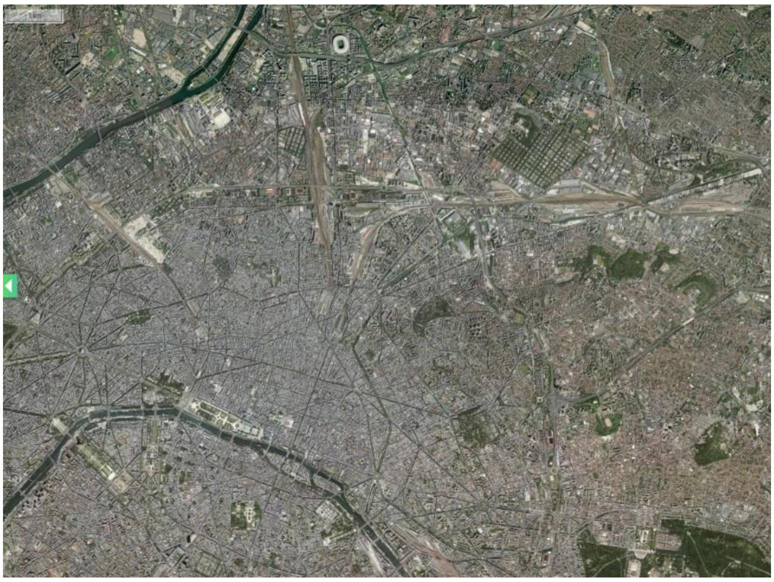


Aerial view of towns with 100,000 inhabitants: Troyes and Valence



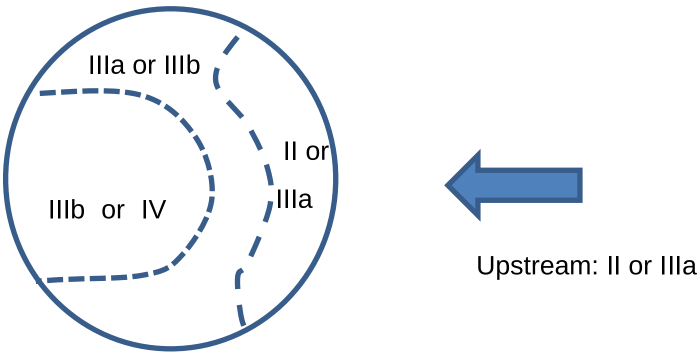


Aerial view of towns with more than 100,000 inhabitants: Angers and Montpellier



Aerial view of the northeast of the Paris area

For towns with fewer than 100,000 inhabitants, we considered an urban area of 1 to 4 km with an insertion of countryside or urban fabric and absence of a densely built-up center. The parts of urban peripheries (500-m stretch) can be in roughness category II, intermediate areas in roughness category IIIa and city centers in roughness category IIIb. We estimate that this corresponds to 10% of houses in category II, 30% in IIIa and 60% in category IIIb.



Schematic view of the organization of urban roughness

For towns with more than100,000 inhabitants, we considered an urban area of 3 to 7 km with an insertion of countryside or urban fabric and the presence of a periphery and densely built-up center. This leads us to estimate that 5% of houses are in terrain category II, 15% in category IIIa, 60% in category IIIb and 20% in category IV.

In the Paris area, we considered a dense urban fabric and the presence of a built-up center, with 30% of houses in category IIIb and 70% in category IV.

			roughness			
Individual housing breakdown	**Number**	**Share of total**	II	IIIa	IIIb	IV
Rural	7473	**22%**				
Share of individual housing		39%	80%	20%	0%	0%
			5978	1495	0	0
Towns <100000 inhabitants	6956	**20%**				
Share of individual housing		36%	10%	30%	60%	0%
			696	2087	4174	0
Towns >100000 inhabiatnts	3827	**11%**				
Share of individual housing		20%	5%	15%	60%	20%
			191	574	2296	765
Paris cities	1069	**3%**				
Share of individual housing		6%	0%	0%	30%	70%
			0	0	321	748
Total	19325		6865	4155	6791	1514
Probability			36%	22%	35%	8%

Table of distribution of individual dwellings (homes) by type of environment (terrain roughness)

The analysis of distribution of dwellings enabled us to estimate the proportions of houses by type of environment, specifically, 36% in roughness category II, 22% in category IIIa, 35% in category IIIb and 8% in category IV. This distribution is used in random generation of cases.

6.2 Friction losses in ventilation systems

General information on friction losses in ventilation systems

Friction losses depend on the section of the duct (shape: circular/rectangular and size), its surface roughness, its length, the presence of irregularities (elbow joints/section changes, etc.) and flow rate through the system.

Friction loss in a straight pipe

Friction losses increase proportionally to the system length and decrease with diameter and increased flow rate.

Darcy equation $\Delta P = \lambda \frac{L}{D} \frac{\rho}{2} V^2$ where ΔP is friction loss (Pa), λ friction factor, L duct length (m), D hydraulic diameter of duct (m), ρ air density (kg/m^3) and V air velocity (m/s).

The friction factor depends on the roughness of the duct wall, which is determined with various equations: Colebrook-White, Swamee-Jain, Moody diagram, Blench equation $\lambda = 0.79\sqrt{\frac{\varepsilon}{D}}$, approximate building code (DTU) calculation.

Local friction losses (elbows, roof outlet, etc.)

General equation: $\Delta P = \zeta \frac{\rho}{2} V^2$ where the ζ factor is tabulated in function of irregularities

DTU calculation (regular + irregular)

A duct is characterized by its length L, its hydraulic diameter D, its section S, a local friction loss coefficient ζ and its friction loss per unit length (gradual loss) k. The friction loss generated by the duct is:

$$\Delta P_{loss}(\rho^*, \dot{m}) = -sgn(\dot{m}) \left[\frac{k.L.\left(\frac{3600.\dot{m}}{\rho^*}\right)^{1.9}}{(1000.D)^5} + \zeta \frac{\dot{m}^2}{2\rho^* S^2} \right] + \Delta P_j$$

Where Δ is the friction loss related to the joint type appearing at the ends of the duct.

The recommended values for *k* in accordance with the NF DTU 68.3 P1-1-1 standard are as follows:

- k=3.10^6 for spiral sheet metal, stapled and other smooth ducts, all materials
- k=5.10^6 for concrete ducts
- k=9.10^6 for flexible ducts

Simplification is possible by using an exponent 2 instead of 1.9 to have a single factor for expression in the interval [] resulting in an expression of the following form: $\boldsymbol{\Delta P_{loss}(\rho^*, \dot{m}) = -sgn(\dot{m}) \left[\frac{a.k.l}{\rho^*.D} + \frac{\zeta}{2} \right] \frac{\dot{m}^2}{\rho^*.S^2}}$

<u>Assumptions for modeling systems</u>

The pressure loss related to friction are given in the table below for some characteristiczl configurations.

Dwelling	Room	Flow rate	Diameter	Losses for 6 m of duct
T2	WC	15 m^3/h	80 mm	1.18 Pa
	Bathroom	15 m^3/h	80 mm	1.18 Pa

	Kitchen	90 m³/h	125 mm	3.17 Pa
T4	WC	30 m³/h	80 mm	3.88 Pa
	Bathroom	30 m³/h	80 mm	3.88 Pa
	Kitchen	105 m³/h	125 mm	4.15 Pa

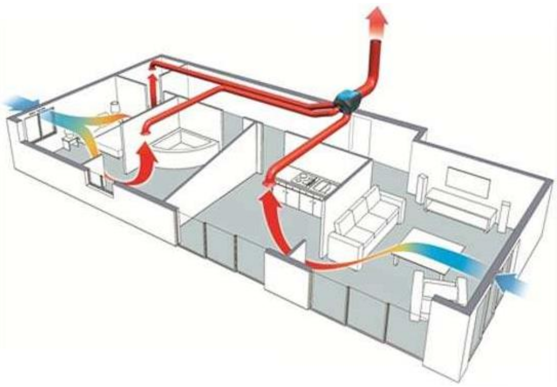
System losses are calculated for various lengths and a number of representative irregularities in the dwelling (increase with dwelling size).

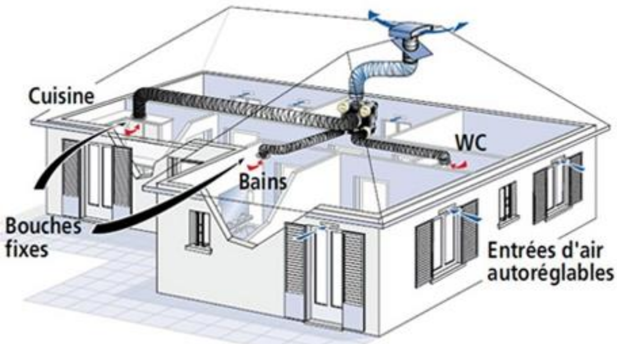
System organization is generically as follows:

- Single flow by extraction: 1 extraction system with terminals connected directly to nozzles of the unit. Same friction losses for all terminals.
- simple flow by insufflation: 1 insufflation system (air supply) with terminals connected directly to nozzles of the unit. Same friction losses for all terminals.
- Central dual flow: 1 extraction system + 1 air supply ductwork, direct connection or distribution plenum

<u>Extraction system</u>

The diagrams below show the organization of single flow extraction systems.



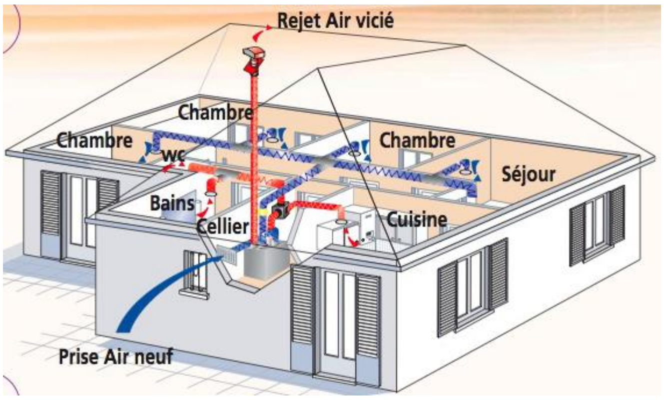


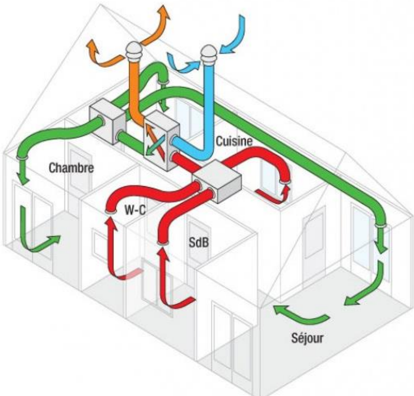
Composition of extraction systems:
- T1/T2 between 3 and 6 m from duct + 1 elbow + with or without plenum
- T3/T4 between 3 and 9 m from duct + 1 or 2 elbows + with or without plenum
- T5 and over between 3 and 12 m from duct + 1 or 2 elbows + with or without plenum

<u>Air supply ductwork</u>

The figure below shows the organization of air supply ductwork for simple flow insufflation system.

The diagrams below show the organization of air supply ductwork associated with extraction systems (dual flow).





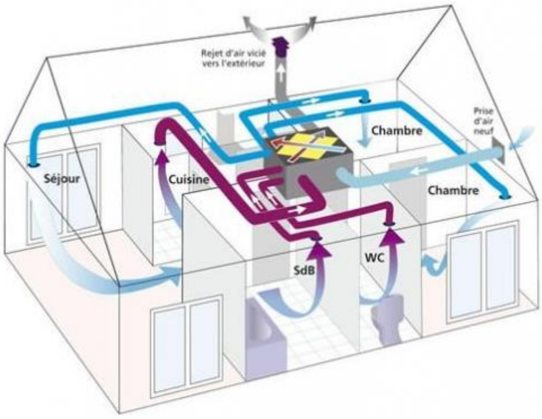
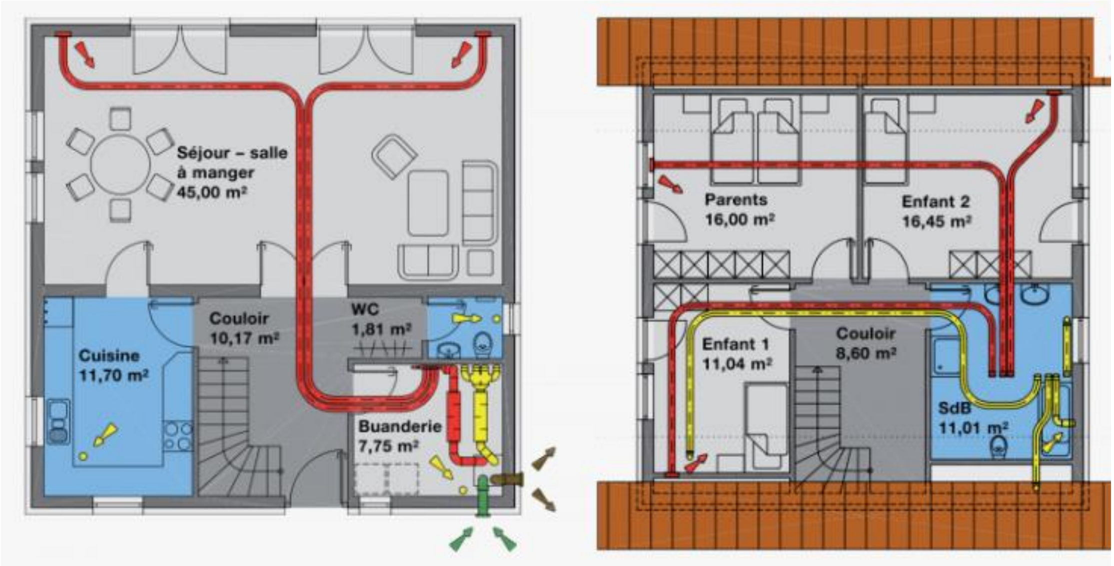


Diagram for one-level house



Two-level house

Composition of air supply ductwork: We propose that air supply ductwork has 30 to 50% greater length and 1 elbow more than those for extraction:

- T1/T2 between 4 and 6 m from duct + 2 elbows + with or without plenum
- T3/T4 between 4 and 9 m from duct + 2 or 3 elbows + with or without plenum
- T5 and over between 4 and 12 m from duct + 2 or 3 elbows + with or without plenum