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EN-CAPE 19.006 C – V2

Development of a Method of Characterizing Ventilation System Performance

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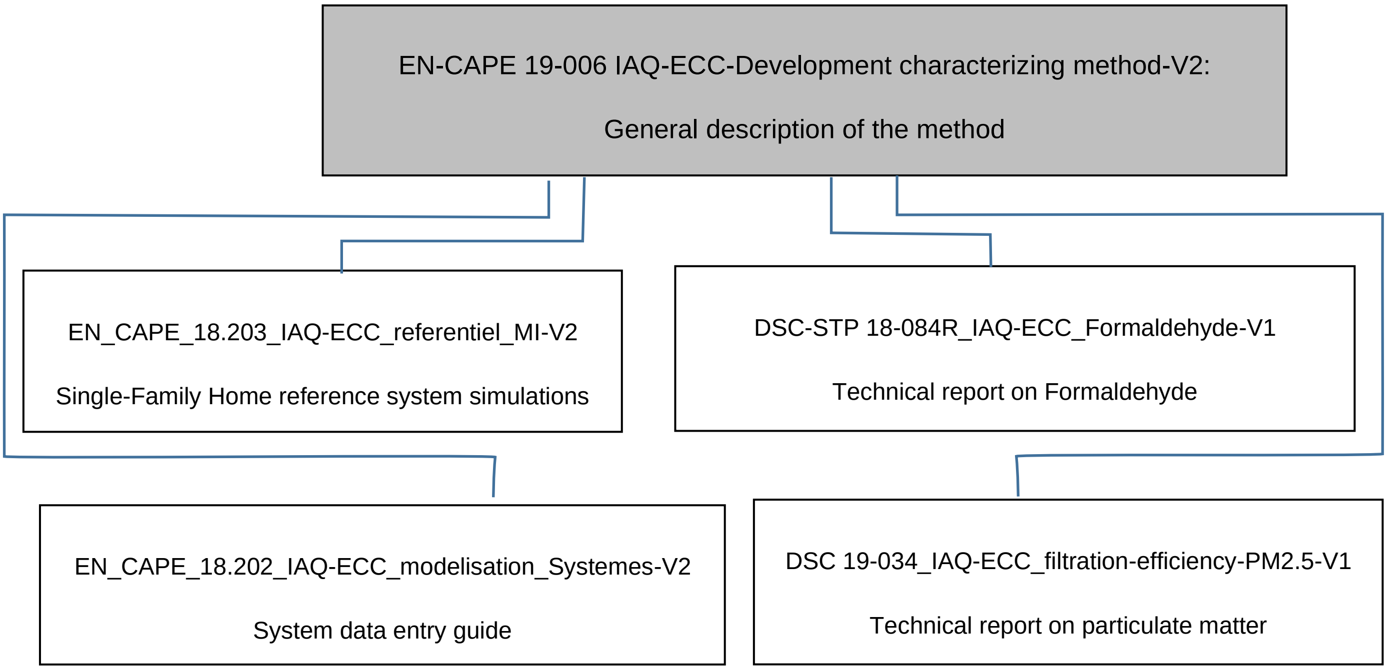
1. INTRODUCTION

At the request of the company ECC, the CSTB, through its CAPE (Climatology, Aerodynamics, Pollution and Purification), Health & Comfort and Energy & Environment operational departments, has developed a method of certifying the performance of ventilation systems.

This method includes performance regarding indoor air quality (IAQ) and energy in connection with ventilation (direct consumption and induced by air renewal). It will be used to implement IAQ/energy certification for ventilation systems with maximum flow rates of 1000 m^3/h.

This report presents the entire method, providing explanations of the choices made, and introduces various technical reports that address specific points.

The reports are organized as follows:



2. DESCRIPTION OF APPROACH

The proposed approach aims to enhance indoor air quality (IAQ) related to energy consumption. This should enable a ranking of mechanical ventilation systems based on criteria beyond the scope of energy consumption. We therefore use the following indicators to characterize the performance of ventilation systems:

- CO_2 concentration (see section 3.1)
- Formaldehyde concentration (see section 3.2)
- Relative humidity (see section 3.3)

- Outside air filtration levels (see section 3.4)
- Intrinsic consumption of fans (see section 3.5)
- Consumption induced by air renewal (see section 3.5).

The method must take into consideration the various possibilities of current and future regulations.

The method applies to the following buildings: single-family homes, apartment buildings and office buildings up to a flow rate of 1000 m^3/h.

Given the limitations of deterministic approaches using a limited number of specific cases, and therefore the risk of a "dependent" approach with biases linked to existing systems, partially taking into account product usage conditions, and the risk of product adjustment/optimization for high performance for specific configurations and analysis criteria, we propose determining performance using a stochastic approach. This involves generating a large number of simulations (several hundred to several thousand to converge indicators) over a period of one week as determined by randomization of parameters for each simulation. The distribution of values for each indicator obtained for each configuration determines system performance.

The simulations are generated by the MATHIS nodal airflow code developed by the CSTB since 2011.

There are two kinds of input data for the simulations:

- Data for stochastic modeling: dwelling type, usage scenario, formaldehyde emission levels, climate region, type of environment.
- Ventilation system characteristics: components and control.

For stochastic modeling, the method defines ranges for parameters and random generation laws for the ranges. The EN_CAPE_18.203_IAQ-ECC_referentiel_MI_V2 report describes the parameters for application to single-family homes.

Ventilation system characteristics are entered from the manufacturer's data using an Excel file. The input mode for this data is described in the EN_CAPE_18.202_IAQ-ECC_modelisation_Systemes_V2 report.

3. IAQ INDICATORS

3.1 CO_2 concentration

CO_2 concentration relates to occupancy and comes from human respiration.
For this indicator, we use the ICONE index based on CO_2 concentration within the concept of indoor air stuffiness. The ICONE index is derived from work in schools (OQAI, 2011;

Dassonville et al., 2013; Ramalho et al., 2013). Its equation is designed to provide a rating on a scale of 0 to 5 depending on the frequency of occurrence and CO_2 concentration. A rating of 0 corresponds to no stuffiness (CO_2 concentration always less than 1000 ppmv), the most favorable situation; 5 corresponds to extreme stuffiness (CO_2 concentration always greater than 1700 ppmv), the most unfavorable situation. The proposed thresholds of 1000 and 1700 ppmv are intended to fit within the limits set out in French county health regulations (RSDT) of 1300 ppmv and the standard thresholds in other countries.[1]

The equation is as follows: **ICONE = 8.3 log(1+f1+3f2)**
where f1 is the proportion of CO_2 concentrations between 1000 and 1700 ppmv and f2 the proportion of values greater than 1700 ppmv.

<u>Note</u>: With this equation, a control system ensuring a constant level of 1699 ppmv of CO_2 obtains a rating of 2.5.

Work by the CSTB for the French Ministry of Housing and the Environment and Energy Management Agency (ADEME) show that the index can be transposed for dwellings (Ribéron et al., 2011). The 1000 and 1700 ppmv thresholds also appear relevant to dwellings.

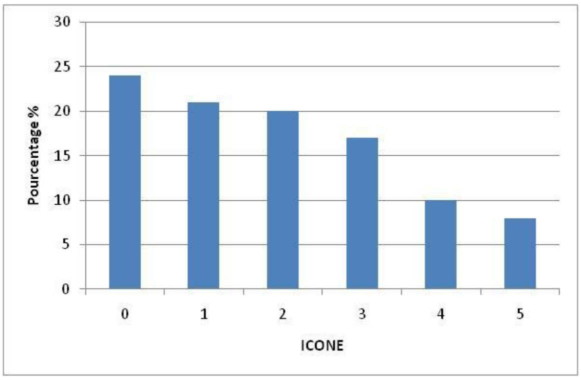
Calculations of the ICONE index over a heating season were made by a GS14 working group using the MATHIS software for 39 cases of T2 to T4 dwellings with different ventilation systems. Results are analyzed up to a single decimal. This work, although limited (dwelling type, type system and control), provides a first indication of the index levels. For the living room, the ICONE values are between 0.8 and 3.1, with a median of 1.9, and for the main bedroom (CH1) between 1.5 and 3.3, with a median of 2.7.

In the absence of more specific information on CO_2 thresholds in dwellings, we propose maintaining the thresholds 1000 and 1700 ppmv for calculating ICONE indexes for dwellings.

In addition, the figure below shows the distribution of ICONE ratings calculated for the sample of dwellings in the National Dwellings Survey (2003–2005) conducted by the Indoor Air Quality Observatory (OQAI, 2011). ICONE ratings are calculated from CO_2 values measured in the main bedroom during the night from 01:00 to 05:10 during one week of measurement (7 days) and only when occupants are present. ICONE ratings were calculated for 450 dwellings.

Although it is not symmetrical, the distribution of ICONE ratings covers the entire scale from 0 to 5. The analysis confirms the value of the index, its scale from 0 to 5 and the thresholds initially proposed for schools.

[1] Report of the French Agency for Food, Environmental and Occupational Health and Safety (ANSES) "Carbon dioxide (CO_2) in indoor air: concentration and health effects." 2013. https://www.anses.fr/fr/content/dioxyde-de-carbone-co2-dans-l%E2%80%99air-int%C3%A9rieur



Distribution of weekly stuffiness ratings in bedrooms at night (n=450)

In the proposed approach, the ICONE index of each bedroom is calculated for each simulation (the calculation is done when there is an occupant in the bedroom) and the maximum value is used for configuration (the week). The final value of the ICONE index characteristic of the system corresponds to the median of indices used for each simulation.

3.2 Formaldehyde concentration

Formaldehyde is a substance emitted by many domestic sources, mainly coverings (floor, walls, ceiling) and furniture. It can also be emitted from combustion processes, such as tobacco smoke, cooking, candles and incense. It is also formed by chemical reactions involving ozone and volatile organic compounds in indoor air. For this project, we consider only materials for finishing works, decoration and furniture for which emission factors are available.

Formaldehyde has a regulatory guideline value for indoor air quality (Decree No. 2011-1727 of December 2, 2011). Characterization of emissions from decoration materials and furniture in dwellings and development of an index (rating from 0 to 5) of formaldehyde concentrations is described in the DSC-STP 18-084R IAQ ECC Formaldehyde-V1 report. This report also analyzes the potential of formaldehyde sources in ventilation systems. The data available in the literature does not mention formaldehyde emission by the system itself; only leakage from heat exchangers can pollute the intake air.

The work leads us to consider a short-term formaldehyde index, I_{ST}, based on the occurrences of concentrations exceeding 100 $\mu g/m^3$ for all simulations and a long-term index, I_{LT}, based on the mean concentrations obtained for all weeks simulated.

These indices are calculated in living rooms and bedrooms and their average value is considered.

The two indices are given by the tool, we propose to use the worst of the two indices to characterize the system's performance for formaldehyde with only one index.

3.3 Relative humidity

Humidity relates to human activities (breathing, shower, kitchen, laundry, etc.). Relative humidity affects the feeling of comfort of users and can have an impact on the quality of a building through condensation on walls, which promotes the development of mold and mites.

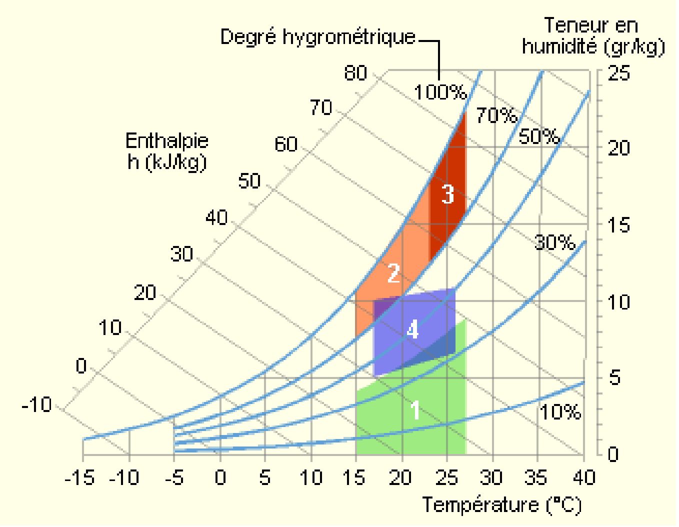
Humidity has relatively little impact on the feeling of comfort of individuals in a building normally heated (20°C). Discomfort only appears in extreme situations, regardless of the temperature:

- Relative humidity below 40%
- Relative humidity above 70%

Low levels of relative humidity (below 40%) cause problems such as increase in static electricity and dry mucous membranes (Wolkoff, 2008).

High levels of relative humidity (above 70%) can give rise to substantial microbial growth and condensation on cold surfaces.

Fauconnier (1992) defines a hygrothermal comfort range in the following diagram:



1: Range to avoid because of dryness problems.

2 and ***3***: Ranges to avoid because of bacterial and mold growth.

3: Range to avoid because of mite development.

4: *Hygrothermal comfort polygon*

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (2013) recommends humidity lower than 65%.

The calculation rules for examination of Technical Appraisals, CCFAT (2016), consider the number of hours for which humidity exceeds 75%.

Due to the fact that, in some climates (cold and dry climates), low air humidity depends on weather conditions and not ventilation systems, CSTB propose an index with two thresholds limits, like the ICONE index, with values of 65 and 75% relative humidly.

Following the certification committee exchanges, at the request of the manufacturers, an index with a low threshold of 40% and a high threshold and 70% is retained.

The equation is as follows: $\mathbf{I_{H2O} = 12 \log(2.61(f0+f2)+f1)}$

where f0 is the proportion of humidity values lower than 40%, f2 the proportion of values greater than 70% and f1 the proportion of humidity values between 40 and 70%.

The index is calculated for each humid room of each simulation. The final I_{H2O} index characteristic of the system corresponds to the median of maximum indices calculated for each simulation.

3.4 Filtration and particulates

With the tools and knowledge now available, it is not possible to model indoor particulate matter (PM) concentrations using the same principle as that for formaldehyde. Nevertheless, given the impact of particulates on human health and the ability of some ventilation systems to filter particulate air pollution entering buildings, we propose specific consideration of particulates. The particulate indicator chosen is the $PM_{2.5}$ fraction because it is a regulated parameter in ambient air for which there is ample measurement data and the health effects have been widely demonstrated in the short and long terms.

Four annual profiles of outdoor $PM_{2.5}$ concentrations on an hourly basis were constructed from data from Official Air Quality Monitoring Associations (AASQA): countryside, discontinuous suburban, dense suburban and urban center. These profiles were compared with European data and their representativeness was verified. With each iteration of the calculation, a roughness value is chosen at random and outdoor $PM_{2,5}$ concentrations for the corresponding profile is determined. Using these concentrations, we first calculate an annual outdoor mean and apply the reduction by the filter in the system under study to calculate the annual indoor mean concentration, and then we calculate the running 24-hour means of outdoor concentration and apply the reduction by the filter to obtain a 24-hour running mean indoor distribution. The rating expressing filter performance for outdoor particulate pollution is derived with respect to annual running 24-hour means with the reference values available.

The approach is detailed in the DSC_2019-034_IAQ-ECC_PM-V1 report.

3.5 Energy consumption

Intrinsic consumption

Studying the intrinsic consumption of the fan makes it possible to enhance the design of the entire system and consider the friction losses caused by the presence of filters or heat exchangers. The calculation is performed for each time step of 10 minutes for each simulation, using the characteristic consumption curves based on the flow rate of mechanical ventilation units (data provided by the manufacturer). Consumption calculations over 10 minutes are cumulated to obtain the total consumption over a week, and every week is extrapolated to the year by multiplying by 52. The annual consumption of all simulated cases is averaged to provide an annual mean consumption per dwelling in kWh. This gives a picture of the mean consumption for the entire area of application.

Induced consumption

By taking into account consumption induced by air renewal, systems can be differentiated based on the presence and performance of a heat exchanger. The calculation is based on the intake airflows in rooms through ventilation components and envelope permeability and temperature differences between the incoming air and the set temperature of the dwelling. The heating power required to compensate for losses is calculated each time step and included if the outside temperature is below 16° (temperature above which the inertia and occupancy of the building does not require heating). The power multiplied by the duration of the time step gives the energy that is weighted by the (Text -16°) difference for the given time step. This intermediate result is in kWh/°C for the week.

For each meteorological data file, the annual heating time (Text below 16°C) and the mean outdoor temperature over this time are known.

The weekly intermediate result is extended to the year by multiplying by the ratio of the annual heating time to the weekly heating time and the difference between 20°C (mean set temperature) and Text. The mean of all cases gives the mean annual consumption induced by the dwelling for the entire area of application in kWh.

4. SIMULATION PARAMETERS

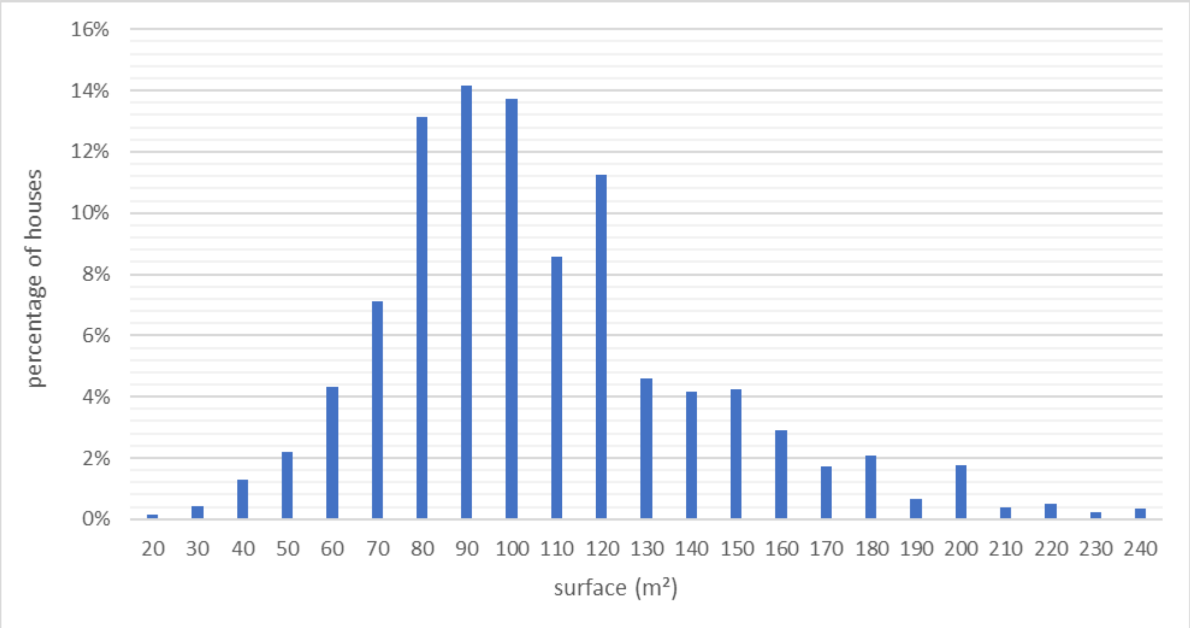
Because of the lack of specific data on a European scale, the parameters for the simulations (see EN_CAPE_18.203_IAQ-ECC_referentiel_MI_V2 were mostly constructed from French data from National Dwellings Survey No. 1 (CHL1) conducted by the Indoor Air Quality

Observatory (OQAI) and the INSEE National Housing Survey (ENL 2013). The results of OQAI campaign was the only sufficiently detailed data found for this work.

The use of **EU Building Stock Observatory** data, created to document the energy performance of the building stock in Europe, provided information on floor areas and permeability of dwellings, which we can compare with selected values. Thus, we can estimate the representativeness of the selected values from the French data.

4.1 Total floor area of dwelling

To configure the method, the mean floor area of the sample used (ENL 2013) is 106.8 m². The distribution of the home floor areas is shown below.



Distribution of floor areas of single-family homes in France

The mean area of dwellings in Europe varies as shown in the table below. The mean value for Europe (EU28) is 90.17 m², which is close to the value for France, 91.91 m², Germany, 91.92 m², and Spain, 91.61 m². These values are similar to those chosen from the French data. In these results, the distinction between "single family" and "multi-family" does not exist, this can explain the slight mean floor area difference for France.

Country	Average floor area (m²)	Country	Average floor area (m²)
Austria	100.19	Italy	93.44
Belgium	81.26	Latvia	65.43
Bulgaria	74.13	Lithuania	67.47
Croatia	82.99	Luxembourg	128.87

Cyprus	145.9	Malta	106.4
Czech Republic	78.69	Netherlands	119.33
Denmark	118.74	Poland	73.55
Estonia	62.18	Portugal	111.33
Finland	62.18	Romania	40.59
France	91.91	Slovakia	85.75
Germany	91.92	Slovenia	82.56
Greece	85	Spain	91.61
Hungary	101.62	Sweden	93.33
Ireland	120.81	UK	96.07

Mean values for residential dwellings from 2014 EU Building Stock Observatory data

4.2 Envelope air tightness

We used certificate data at the end of work on new buildings in France to establish our envelope permeability distributions (see section 3.4 of the EN_CAPE_18.203_IAQ-ECC_referentiel_MI_V2) report. Permeability is characterized using the Q50Pa value, which corresponds to the leakage rate at 50 Pa in $m^3/h/m^2$.

In Europe, the data was presented at the 37th AIVC conference in September 2018.

Bassam Moujalled (2018), using the same certificate database at the end of work on 215,000 dwellings between 2007 and 2016, shows that the mean Q50Pa value varies from 5.73 before 2006 to 1.41 in 2016 for single-family homes and 4.88 to 2.47 for multi-family buildings. For single-family homes, in 93% of cases, the Q50Pa is less than 2.12 $m^3/h/m^2$.

De Strycker (2018) shows, from a little over 20,000 tests in the Flemish region of Belgium, between 2015 and 2017, that Q50 values are between 0 and 12, with a mean of 3.36 $m^3/h/m^2$, and a mean Q50Pa equal to 3.39 $m^3/h/m^2$.

Irene Poza-Casado (2018), using an analysis of 401 dwellings in Spain, mostly built between 1960 and 2006, mentions Q50 values ($m^3/h/m^2$) between 0.96 and 29.92, with a mean of 5.91 and a median of 5.

The Passivhaus label requires envelope tightness of homes to be **$n50 \leq 0.6\ h^{-1}$.** Considering a rectangular parallelepiped with a height of 2.5 m, this corresponds to a Q50Pa of 1.48 $m^3/h/m^2$.

The EU Building Stock Observatory database has little information on permeability.

Source	**Unit**	**2013**	**2015**

Finland	**Ministry of Environment**	**$dm^3/s/m^2$**	**4.00**	**-**
Ireland	**BRT:** http://www.seai.ie/Your_Building/BER/National_BER_Research_Tool/	**$dm^3/s/m^2$**	**-**	**4.16**
Latvia	**PAIC measurements database: http://www.paic.lv/en/**	**$dm^3/s/m^2$**	**-**	**3.79**

Air tightness of residential buildings (Q50) from EU Building Stock Observatory

The selected values are low for Europe but correspond to the tendency for buildings. Because the objective is to certify new ventilation systems that are usually installed in new or substantially renovated dwellings and whose air tightness is well managed, this choice of tightness levels is consistent.

4.3 Environment

We established the following distribution for four terrain roughness categories: II, IIIa, IIIb and IV (see EN_CAPE_18.203_ECC_referentiel_MI_V1 appendix).

Environment	Roughness	Proportion of houses
Open country	II	36%
Discontinuous suburban	IIIa	22%
Dense suburban area	IIIb	37%
Urban center	IV	7%

Distribution of homes by type of environment

Analyses of the EU Building Stock Observatory database show that 28% of dwellings are in rural areas, 30% in intermediate urban areas and 42% in urban centers. This data does not distinguish between single- and multi-family housing. These types of dwellings represent 51% and 49% of the European building stock, respectively. A higher distribution of homes in less urbanized areas seems logical. The proposed values do not contradict this information for Europe.

Degree of urbanisation differs a lot between Member States

The degree of urbanisation is a classification based on a combination of geographical contiguity and minimum population thresholds applied to a 1 km² population grid cells. This indicator reflects the number of residential buildings/dwellings per location:

- High-density cluster/urban centre: contiguous grid cells of 1 km² with a density of at least 1 500 inhabitants per km² and a minimum population of 50 000;
- Urban cluster: cluster of contiguous grid cells of 1 km² with a density of at least 300 inhabitants per km² and a minimum population of 5 000;
- Rural grid cell: grid cell outside high-density clusters and urban clusters.

The average distribution of residential buildings is 42% in the urban centre, 30% in intermediate urban areas, and the remaining 28% in rural areas. Of course, this distribution differs among countries. While Germany, Sweden and Italy the degree of urbanisation is aligned with the EU average distribution, in Malta the population is mainly concentrated to the urban centre.

Sources: Eurostat Notes

Level of urbanization according to EU Building Stock Observatory studies

4.4 Number of simulations and convergence criterion

To be representative of ventilation system behavior for its area of application, we recommend performing at least 500 simulations. Convergence of results is better with approximately 2000 iterations, but it depends on the system.

Convergence criteria are calculated for all the indicators by calculating statistical values, average and standard deviation, over the last 100 iterations. The absolute and relative level of standard deviation allow users to assess the convergence of the simulation but does not automatically stop iterations. The user remains responsible for stopping the simulations.

TECHNICAL REPORTS

- DSC-STP 18-084R IAQ ECC Formaldehyde-V1: Consideration of formaldehyde and analysis of pollution by the system itself.

- DSC 19-034R IAQ ECC filtration-efficiency-PM2.5-V1: Consideration of filter performance for fresh air.

- EN_CAPE_18.203_IAQ-ECC_referentiel_MI_V2: Description of parameters considered for the characterization method for systems dedicated to single-family homes.

- EN_CAPE_18.202_IAQ-ECC_modelisation_Systemes_V2: Modeling ventilation systems and entering input data.

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EU Building Stock Observatory : https://ec.europa.eu/energy/en/eubuildings / https://ec.europa.eu/energy/en/eu-buildings-database