Introduction: Why performance-based assessment methods? Overview of the needs and the possibilities.

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SUMMARY

In future building regulations 2020, building performance is going to be extended to global performance, including indoor air quality (IAQ). In the energy performance (EP) field, successive regulations pushed for a "performance-based" approach, based on an energy consumption requirement at the design stage. Nevertheless, ventilation regulations throughout the world are still mostly based on prescriptive approaches, setting airflows requirements. A performance-based approach for ventilation would insure that ventilation is designed to avoid risks for occupant's health.
Given the European context with the generalization of nearly zero energy buildings, envelope airtightness is often included in EP-calculations, frequently through single-zone models with uniform air leakage. Because more consideration is often given to EP than to IAQ, impact of several zones interconnected by unevenly distributed leaks, on the envelope and on internal partition walls, is a rarely investigated issue, which is investigated in this work.
Faced with this issue, we conducted an experimental study on multizone air leakages of 23 detached houses and developed an innovative database. The analysis of this database reveals that internal air leakage can become significant at door undercuts and that the type of building structure has a great influence. We propose airleakage values and dispersion input data for multizone IAQ models. Then, through a multizone modelling of a low energy house case study, we quantify impacts of these airleakage distribution data on IAQ. We model CO_2, humidity and formaldehyde with two type of ventilation (exhaust-only or balanced). We highlight strong impacts and conclude that detailed airleakage distributions should be used in IAQ performance assessment methods.
An extensive review work combined with complementary analysis allows us to come up with the development of a performance-based approach for house ventilation to be used at the design stage in a regulatory calculation. We select the use of five relevant IAQ performance indicators, based on CO_2, formaldehyde and $PM_{2.5}$ exposures, and RH-based indicators assessing both condensation and health risks. We propose also pollutant emission data and occupancy schedules to be used. Lastly, we describe the multizone modelling laws, the physical models and associated assumptions, and the boundary conditions.
Importantly, we demonstrate that our proposed performance-based method was applicable, applying it to a low-energy house case study. We assume being at the design stage of a house which should comply with a hypothetical regulation, requiring IAQ performance indicators and associated thresholds. We also demonstrate how such an approach could help at the design stage in key choices as the type of structure (regarding its impact on airleakage distributions), the type of ventilation system, the level of pollutant emissions. Indeed, in the case study, only the balanced ventilation combined with low or medium-emission class of formaldehyde emissions allow to fulfil the IAQ requirements. We show also that such an approach could help in the ventilation design, notably the distribution of the air inlets and/or outlets, or even the airflows, in order to secure the fulfilment of IAQ requirements.
At the end of this work, we highlight the needs for such performance-based approaches, from the robustness of performance indicators which should also be based on acute exposures, to the lack of data to be used to assess the pollutants emissions at the dwelling scale.

KEYWORDS

Ventilation, performance, design, indoor air quality

1 INTRODUCTION

In new labels and future building regulations, building performance should be extended to indoor environment quality, beyond energy performance. In the energy performance field, successive regulations pushed to a ***"performance-based" approach***, based at least on an energy consumption requirement for heating and/or cooling at the design stage (Spekkink 2005).

Nevertheless, in the building ventilation field, regulations throughout the world are mainly still based on ***"prescriptive" approaches***, such as airflows or air change rates requirements (Dimitroulopoulou 2012). As the list of identified indoor pollutants is long and may still increase, it has been impossible to create definitive IAQ indicators for standards and regulations governing residential buildings (Borsboom et al. 2016). As a result, standards and regulations generally set ventilation rates based on comfort considerations and not on health criteria as suggested in the Healthvent project (Seppanen and et. al. 2012; Wargocki 2012). The trouble with this approach is that it assumes that in addition to displacing human bio-effluents including odors, ventilation is a sufficient mean of controlling other contaminants (Matson and Sherman, 2004 and Persily, 2006). Against such prescriptive approaches, it is possible to develop **performance-based approaches** for residential building ventilation. Regarding the fact that prescribed ventilation rates are only an (unperfected) way to achieve a given IAQ, it could be imagined to require IAQ performance indicators instead of ventilation rates. The performance-based approach concept is illustrated on Figure 1.

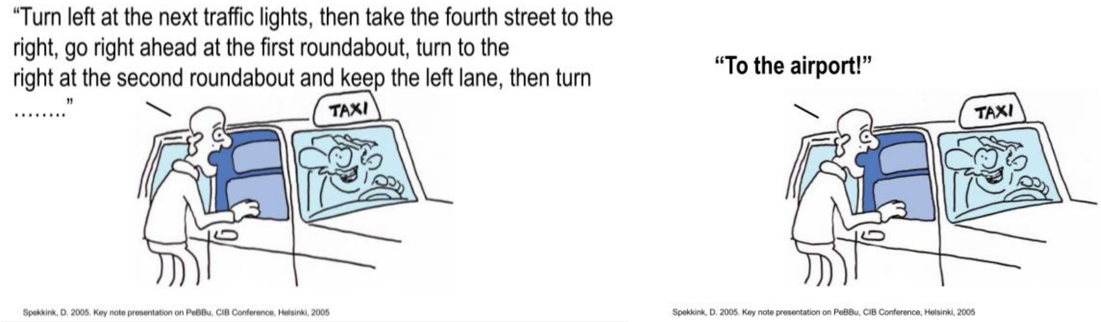


Figure 1. Illustration of (a) a prescriptive approach; (b) a performance-based approach. Source : (Spekkink 2005)

"Performance-based" approaches for ventilation would insure that it is designed to avoid risks for occupant's health and building damages. Such an approach could be required at different scales:

1. At the ventilation system scale: for allowing the use of an innovative ventilation system instead of "reference" systems. "Reference" ventilation systems are usually defined as the widely used ventilation systems, or the ventilation systems directly providing the constant airflows required by the regulation. In this case, standardized input data and scenarii should be used,
2. **At the building scale: at the design stage of a building, input data from the given building should also be used.**

Such approaches could also be used at different stages of the building's construction:

1. At the design stage, as a design method;
2. **Later at the end of design stage, during the regulatory compliance stage, to assess the design. It could be called a design assessment method;**
3. At initial commissioning, or later once the building is occupied, as an in-situ performance assessment method.

If we compare to the energy performance field, the design method is the detailed energy simulation performed to optimize the energy consumption of the building, the design assessment method is the regulatory energy performance calculation based on simplified assumptions and a limited number of performance indicators, complete in-situ performance assessment methods are rare but could be based on several measurements (airleakage test, wall thermal conductivity, energy consumption, …).
Facing a lack of data about the relevant method for ventilation, we propose in this work to develop a performance-based approach for assessing ventilation performance at the building

scale and at the end of the design stage, as does an energy performance regulatory calculation. We propose also to be at the regulatory compliance stage (number 2) as developed just above.

2 A PERFORMANCE-BASED APPROACH IN THREE STEPS

In order to develop such a performance-based approach, we need to address the following topics:

1. What are the relevant pollutants and/or parameters to use for calculating performance indicators and what indicators should be used?
2. What are the relevant input data to use regarding the occupancy and pollutant emission scenarii?
3. Lastly, what level of detail should we use for modelling airflows and pollutants throughout the house, concerning general modelling assumptions (multizone, weather data, …), the airleakage distributions, the moisture buffering effect?

It is important to divide the inputs in two categories:

1. The ones which correspond to "standard" data, called "Standard conditions and scenarii",
2. The ones which are data from a given building due to design choices on this building, called "Building design data".

Each of these three steps constitutes a scientific barrier that we propose to come down in this work.

2.1 Review of existing performance-based approaches and ventilation performance indicators in residential smart ventilation strategies

Because this specific field has been shown as worthwhile for identifying both existing performance-based approaches for ventilation and performance indicators, the "smart ventilation" concept has been investigated. Smart ventilation has been defined as "*a process to continually adjust the ventilation system in time, and optionally by location, to provide the desired IAQ benefits while minimizing energy consumption, utility bills and other non-IAQ costs (such as thermal discomfort or noise)*"(Durier, Carrié, and Sherman 2018). The demand-controlled ventilation (DCV) concept is a specific subset of smart ventilation.
Analysis of performance-based approaches that both enable and reward smart ventilation used in five countries (France, Belgium, The Netherlands, USA, Spain) revels emission scenarii, often multizone modelling levels and indicators taken into account (Guyot et al., 2018b).
Through our meta-analysis on the performance reported in 38 studies of various residential smart ventilation systems since 1983 (Guyot et al., 2017), we very clearly identified a scientific problem due to the lack of ventilation performance indicators, most of them being only CO_2 and humidity based indicators.

From these both reviews, we showed the need of robust performance-based approaches for ventilation, using notably better IAQ performance assessment calculation and better IAQ indicators. Moreover, their applicability to all types of ventilation, and not only to smart ventilation is an issue of concern. Indeed, with CO_2-based DCV ventilation for instance, it is easy to obtain a good IAQ performance indicator based on CO_2 cumulative exposure over a threshold, if the switching value of the ventilation system is set just below this threshold. Consequently, the proposed method should allow to obtain a more robust IAQ assessment, based on several IAQ performance indicators using several indoor pollutants, to avoid such pitfalls.

2.2 First proposition of an applicable method

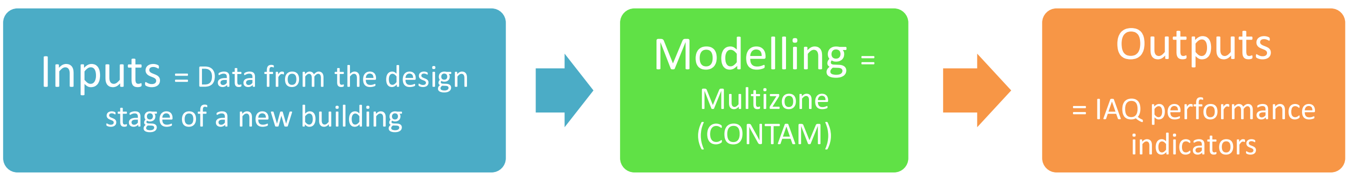
We described and proposed the method with three steps (Figure 2).

In the first step, we identified from a literature review five relevant IAQ performance indicators to be used as output data of such an approach:

- the maximum cumulative exceeding CO_2 exposure over 1000 ppm in the bedrooms,
- the maximum cumulative occupant formaldehyde exposure,
- the maximum cumulative occupant $PM_{2.5}$ exposure,
- the maximum of the percentage of time with RH higher than 70% in all rooms (condensation risk),
- the maximum of the percentage of time with RH outside of the range [30%–70%] in the bedrooms (health risk).

In the second step, we proposed pollutant emission data and occupancy schedules to be used, from an extensive review. Face to the lack of data, we focus on chronic exposure and gave up at the moment $PM_{2.5}$. We proposed a method to calculate average constant formaldehyde emission rates and applied it on a sample of ten low-energy houses. As a result, we proposed to use three levels of formaldehyde emissions: the low-emission class: 4.5 $\mu g.h^{-1}.m^{-2}$, the medium-emission class: 12.0 $\mu g.h^{-1}.m^{-2}$, the high-emission class: 23.6 $\mu g.h^{-1}.m^{-2}$. We also proposed emission data and associated schedules for relative humidity and CO_2.
In the third step, we described the modelling laws and assumptions to be used. We showed notably that it was essential to use multizone modelling, with detailed airleakage distributions on internal partition and external walls (Guyot et al. 2019). Then, we describe the physical model and its resolution, the building modelling, and the boundary conditions to be used in such an approach.
Then, we showed that this method was applicable. Indeed, we applied the proposed performance-based approach on a case study, a low-energy house. We assumed being at the design stage of this house which must comply with a hypothetical regulation, code or label, requiring to calculate the proposed IAQ ventilation performance indicators according to the proposed method. We showed that the method allows to assess the IAQ performance through a radar scheme. We also demonstrated how such an approach could help at the design stage in key choices as the type of structure (regarding its impact on airleakage distributions), the type of ventilation system, the level of pollutant emissions. Indeed, in the studied case, only the balanced ventilation combined with low or medium-emission class of formaldehyde emissions allow to fulfil the IAQ requirements.
We showed also that such an approach could help in the ventilation design, notably the distribution of the air inlets and/or outlets. We showed that with the same total exhaust airflow it was possible to adjust these distributions to fulfil the IAQ requirements.

Lastly, we proposed also a complementary discussion about the non-equivalence of "reference" ventilation systems. "Reference" ventilation systems being usually defined as the widely used ventilation systems, or the ventilation systems directly providing the constant airflows required by the regulation. We showed also that both studied reference ventilation systems: balanced and exhaust-only ventilation system, were not IAQ equivalent with relative gaps between 26 and 70% depending the indicators.



Building design data

- Geometry data for each of the room (multizone approach)
- Envelope airleakage value
- Type of structure: heavy/wooden (regarding the impact of envelope and internal partitions wall airleakage distributions)
- Ventilation system (exhaust-only, balanced, ...) and associated airflows at each of the air inlets and outlets
- Doors (location, size and undercut)
- IAQ labelling of material and products => level of emission (high/middle/low)

Standard conditions and scenarios

1-Standard boundary conditions (as representative as possible):

- Weather : wind speed and direction, temperature, atmospheric pressure, relative humidity,
- Pollutants concentration profiles

2-Standard occupancy scenario

- Number of occupants = f(number of bedrooms), only adults
- At each time-step, how many occupants in each room + activities, for France (see):
- A unique schedule,
- Time spent for each occupant: 9h20 in its bedroom, 2h50 in the living room, 2h40 in the kitchen in 3 periods for breakfast, lunch and dinner, 40 minutes in the bathroom.
- A ventilation high-speed in the kitchen switched-on for 1 hour twice a day.

3-Standard pollutant emissions scenario

- At least: CO_2, humidity, formaldehyde, $PM_{2.5}$
- See Table 14.

Physical model

- Need of multizone (CONTAM, COMIS, ...)
- stack effect model and assumptions,
- wind model and pressure coefficients c_p distribution,
- moisture buffering effect model and assumptions,
- calculation period adapted to the climate and habits of the country,
- time-step > 10 minutes,

Buildings model

- Closed doors,
- Uneven distributions of envelope and internal partition walls airleakage with data proposed in Part 3,
- Models used for airflow calculation at each of the ventilation components,
- Ducts and ventilators could also be modelled in a more detailed approach.

IAQ performance indicators

- At least 5 indicators: see Table 6 with associated thresholds

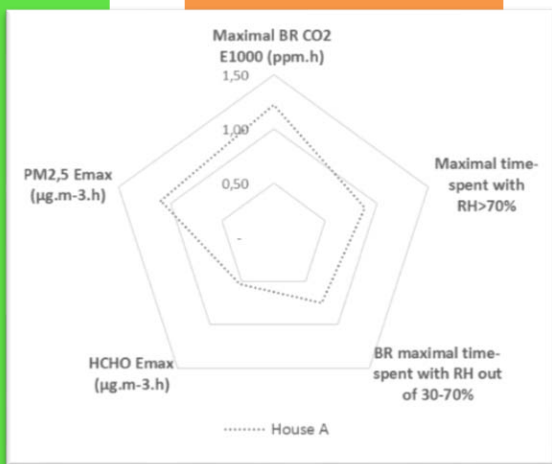
1.Maximum cumulative exceeding CO_2 exposure (for instance: over 1000 ppm) in the bedrooms,

2.Maximum cumulative occupant formaldehyde exposure,

3.Maximum cumulative occupant $PM_{2.5}$ exposure,

4.Maximum of the percentage of time with RH higher than 70% in all rooms (condensation risk),

5.Maximum of the percentage of time with RH outside of the range [30%–70%] in the bedrooms (health risk).



- Rooms ACR also usefull as intermediate metrics

Figure 2. Overview scheme illustrating the proposed performance-based approach for ventilation.

3 CONCLUSIONS AND PERSPECTIVES ABOUT THE REMAINING SCIENTIFIC BARRIERS

At the end of this work, several limitations and perspectives could be highlighted.
Facing a lack of data on pollutant emissions rates at the building scale, it was not possible to include peak exposure and $PM_{2.5}$ in our approach, but it should definitively be completed later as soon as additional data are published.
We showed that the proposed performance-based approach for ventilation was already applicable on houses equipped with constant-airflow reference ventilation systems. We should now check the applicability of our method when applied to smart ventilation systems, as the humidity-based one being also a reference system for France.
From a general perspective, this would be now suitable to study how such a performance-based method at the design stage of a building, could be combined with IAQ or airflows in-situ measurements, to secure the performance at initial commissioning and its sustainably for the whole residential building life.
Lastly, ventilation performance has been restricted to IAQ performance in this work. It is absolutely necessary to extend our method to the global performance of a building, including the energy performance issue, the indoor environment quality (not only IAQ but also comfort …), life-cycle and environmental performance…

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