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A review of performance-based approaches to residential smart ventilation

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1 Introduction

In order to conciliate energy saving and indoor air quality issues, interest in a new generation of smart ventilation systems has been growing for 25 years.

In the European Union it is generally understood that buildings account for 40% of final energy consumption and for 36% of the carbon dioxide emissions. Therefore, the reduction of energy consumption related to buildings is an important issue to be achieved in order to reach a reduction of emissions of greenhouse gases.
The use of smart ventilation systems does not only provide better IAQ, more adjusted to real pollutants production and concentration, but also facilitates the reduction of energy consumption.

In March 2017, AIVC identified smart ventilation for buildings as a new and important topic to be addressed.
Several actions were defined by AIVC Board about this topic in order to exchange and disseminate information on this topic. A working group of AIVC experts from several countries was created. One of its tasks was to agree on a definition of smart ventilation. This definition is presented in the VIP n°38 "What is smart ventilation?" (Durier et al., 2018): *"Smart ventilation is 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). (...)"*. Then, the 2018 AIVC conference was held under the main theme "Smart ventilation for buildings".

This paper provides a review of performance-based approaches used around the world for the assessment of ventilation strategies, mainly smart ventilation strategies.

2 Context on smart ventilation

A number of ventilation standards and national regulations have progressively integrated an allowance for smart ventilation strategies, including demand-control ventilation (DCV) systems in residential buildings. At the same time, energy performance regulations have also gradually included the opportunity to claim credit in energy calculations for savings from such systems.

Already in 2004 in the United States a federal technology alert concluded that the HVAC systems in buildings should use DCV to tailor the amount of ventilation air to the occupancy level, for energy and IAQ reasons (Federal Technology Alert, 2004). Some years later, an update to the ventilation standard ASHRAE 62.2 (ANSI/ASHRAE, 2013) allowed the use of smart ventilation technologies. To the best of our knowledge, at the moment in the U.S smart ventilation systems cannot get an energy credit in calculations specific to each state.

In Europe, several countries enable the use of DCV systems in ventilation codes, including Belgium, France, Spain, Poland, Switzerland, Denmark, Sweden, the Netherlands, Germany (Savin and Laverge, 2011; Kunkel et al., 2015; Borsboom, 2015, Linares et al, 2018). The corresponding energy regulations are more or less recent.

Smart ventilation systems must generally prove their IAQ performance through performance-based approaches, in order to comply with the ventilation regulation and/or get a credit in the energy-performance regulatory calculation.

Pushed by the international movement toward nearly-zero energy buildings, smart ventilation system success is not about to end. In Europe, two recently published directives n°1253/2014 regarding the eco-design requirements for ventilation units and n°1254/2014 regarding the energy labelling of residential ventilation units (European Parliament and the Council, 2014) are moving towards a generalization of low-pressure systems, DCV systems and balanced heat recovery systems at the 2020 horizon. According to this second directive, for central- and local-DCV systems, it should be possible to use a correction factor of 0.85 and 0.65, respectively, in the energy consumption calculation performed specifically for this labelling.

In the European Standard EN 16798-7:2017 (CEN, 2017), smart ventilation can also now be considered using a control parameter f_{ctrl}, even if there is no standard to characterize the f_{ctrl} parameter for such systems.

Given these opportunities, DCV strategies have been used at massive scale for more than 30 years, notably in France and in Belgium. On January 1st 2019, 33 DCV systems in France, 35 in Belgium, 22 in Spain and more than 37 in the Netherlands have received an agreement. Most of them use CO_2 or humidity-based strategies.

3 The need of performance-based approaches for residential ventilation

Performance-based regulations were first discussed internationally in 1998 in the Guidelines for the Introduction of Performance-Based Building Regulations by the Inter-Jurisdictional Regulatory Collaboration Committee (IRCC). Performance-based regulations foment innovation and flexibility, promoting the use of new techniques and building practices that conduce to increasing energy efficiency.

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 still mainly based on ***prescriptive approaches***, such as airflows or air change rates requirements (Dimitroulopoulou, 2012). Against such prescriptive approaches, studying the smart ventilation field shows that 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, at the building design stage. 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)

4 Overview of performance-based approaches

Smart ventilation systems energy and/or IAQ performance often have to be assessed with "performance-based approaches", which could be used in many ways.

Such approaches could be required at different scales:

1. **At the ventilation system scale**: for allowing the use of an innovative smart ventilation system instead of "reference" systems, usually defined as the widely used systems, or the systems directly providing the constant airflows required by the regulation. In this case, standardized input data and scenarios (occupation and emissions) should be used;
2. **At the building scale**: at the design stage of a building, input data from the given building (geometry, weather, etc.) should also be used.

As described in Tables 1 to 5 and further developed in (Guyot et al., 2018), each country uses different indicators, calculated with different methodologies at different scales and compared to different thresholds. The common thread in all of these methods is the use at a minimum, of the exposure to a pollutant generated indoors (very often the CO_2), often combined with a humidity related risk. A minimum airflow rate for unoccupied periods is also often required when smart ventilation strategies are used, in order to secure an acceptable IAQ when occupants come back into residences and avoid humidity related risk.

The calculated indicators can be compared either to absolute given thresholds (as in France, Spain and the Netherlands), or to values obtained with "reference" ventilation systems, called "equivalence approaches" (in the ASHRAE 62.2 and in Belgium), to be sure they are at least "equivalent", i.e. they provide at least the same IAQ and/or energy performance. An important issue in this case is that the reference systems themselves are not equivalent, because the calculated indicators are not equal for all the references systems, as shown in Belgium (Caillou et al., 2014b).

We would like to clarify that in 2014, the Belgian regions considered DCV systems mature enough to be directly integrated in the EP-calculation method, without going through the former agreement procedure. A study (Caillou et al., 2014b) evaluated the 35 agreed (ATG-E agreement) systems. The initial method was improved by taking into account its limitations. Authors proposed classifying DCV systems according to the sensing type: type of sensor, type of spaces, local or centralized and the ventilation type: exhaust only, supply only, balanced and regulation type: local, zonal or centralized. For each class of DCV systems, they proposed standard values for the energy saving coefficient. As a result, as of January 1st 2016, only the energy saving coefficient given in the tables of a Ministerial Order (Moniteur Belge, 2015) can be used directly in the EP-calculation. This Order requires sensors to conform to the stipulations on accuracy and a minimum airflow over 10% of the minimum constant airflow for each room. Intermittent ventilation is allowed if the 15-minute average airflows is equal to this 10% requirement. As a result, Table 5 only describes the former agreement procedure which has been used for a while until 2014, and which illustrates a performance-based approach.

For the Spanish case, IAQ regulation was improved in 2017 in a performance-based approach. Before, once a DCV system received an agreement, called "Documento de Idoneidad Técnica" (DIT), it could be used in new dwellings according to its specifications. The DIT is a document of about 30 pages that specifies how the system must be designed, how components of the system such as inlets, outlets and ducts, must be installed, and precisely how the system must be commissioned and maintained. For each type of dwelling and climate, the DIT gives the product number of air inlets and outlets, and the input data for energy calculations in the form of an equivalent reduction of constant ventilation flow rates specified in the current regulations. The DIT is adopted for a 5-year period and is subject to yearly reviews. The compliance assessment involves reference scenarios: each room of the dwelling is modelled as single-zone with the multizone software CONTAM, with a time-step of 40 seconds. Standardized input data are given which include: external data (outdoor CO_2 concentration, weather), the dwellings (14 standard dwellings), the occupancy scenario and associated emission rates, the ventilation components (trickle ventilators positioning, airflow characteristics of humidity sensitive air inlets and outlets, schedules for toilets exhaust…).

The objective of the new 2017 regulation was to make it more flexible and adjusted to real needs, which can reduce energy needs (Linares et al. 2015). Now, designers can either use ventilation systems with DIT-agreements or calculate the whole system based on a real dwelling. In this new regulation, the mandatory minimum flows were reduced, and a performance methodology was introduced based on the average and accumulated CO_2 concentration in each room of each dwelling. CONTAM was used for determining the constant ventilation flows that are provided in the regulations and fulfil the performance approach. In the current government's EP-calculation method, the ventilation system is assessed as function of the annual average flow derived from the IAQ requirements. If the DCV can offer a reduced average flow, then the EP-calculation will consider lower energy consumption.

5 Conclusions

This paper shows that a favorable context exists in many countries for the development of smart ventilation strategies. The paper gives an overview of the regulations and standards proposing "performance-based approaches" in five countries to promote the use of smart ventilation strategies. The common thread in all of these methods is the use, at a minimum, of the exposure to a pollutant generated indoors (very often the CO_2) and humidity related risk. As a result, more than 20 agreed DCV systems are available in countries such as Belgium, France, the Netherlands and Spain.

With this review, we could put into perspective the need for "performance-based approaches" ventilation. It would secure ventilation IAQ performance from the design stage using performance requirements for ventilation.

Some challenges could already be listed for such performance-based methods:

- Could we define a reasonable set of IAQ performance indicators, not only based on humidity and CO_2, to be calculated at the design stage of a building?
- Would it be possible in the coming years to propose the corresponding pollutants emission rates at the building scale as input data?
- How to secure, with such approaches, that ventilation systems are not only designed to fulfill the determined IAQ requirements at the design stage, without considering other issues as durability and resilience once they are installed?
- For such systems, would it be interesting to consider ventilation airflows, once they have been designed through a performance-based approach, as intermediate IAQ performance indicators, with the advantage that they are *in situ* measurable, at the commissioning stage for instance?

Table 1

ASHRAE 62.2 2016				
Person in charge of the calculation (scale)	***Performance-based approach***	***Calculated IAQ indicators***	***Credit in EP-calculation***	***Minimum airflow***
The manufacturer, specifier or designer (ventilation system scale or the building scale)	**Equivalence method** Single zone modelling $\Delta t<1h$ constant fictive pollutant emission rate	Yearly average relative exposure R, fictive pollutant concentration normalized to the one obtained with the equivalent constant-airflow system: $R<1$ At each time-step $R_i<5$	No	Can be null if the total airflow rate equivalence is required over any 3-hour periods

Table 2

The Netherlands				
Person in charge of the calculation (scale)	***Performance-based approach***	***Calculated IAQ indicators***	***Credit in EP-calculation***	***Minimum airflow***
The manufacturer for each DCV system (ventilation system scale)	Correction factors are given in the standard for DCV, but a complementary performance-based approach can be performed, using the multizone pressure code COMIS, in a semi-probabilistic approach	**Per person, over the heating period:** Cumulative CO_2 exposure over 1200 ppm: LKI_{1200} < 30,000 ppm.h	Correction factors can be used	A function of the number and type of occupants

Table 3

France				
Person in charge of the calculation (scale)	***Performance-based approach***	***Calculated IAQ indicators***	***Credit in EP-calculation***	***Minimum airflow***
The manufacturer of each (humidity) DCV system (ventilation system scale)	Multizone modelling with MATHIS software Δt =15 min Conventional input data	**Per room, over the heating period:** 1/CO_2 cumulative exposure indicator E_{2000} < 400,000 ppm.h 2/Number of hours $T_{RH>75\%}$ <600 h in kitchen, 1000 h in bathrooms, 100 h in other rooms	Average equivalent exhausted airflow (m^3/h) can be implemented in the EP-calculation	Switch off not allowed, minimum airflow is 10-35 m^3/h according to the number of rooms in the building

Table 4

Spain (since 2017)				
Person in charge of the calculation (scale)	***Performance-based approach***	***Calculated IAQ indicators***	***Credit in EP-calculation***	***Minimum airflow***
The designer of the building, based on information given by the manufacturer (ventilation system scale or building scale)	Since 2017, at the design stage of each building, **not only for smart systems** Multizone modelling, e.g. with CONTAM $\Delta t = 40$ s Conventional entry data	**Per room, over the year:** 1/ Yearly average CO_2 concentration < 900 ppm 2/ Yearly cumulative CO_2 exposure over 1600 ppm E_{1600} < 500,000 ppm.h	Yearly average ventilation airflow could be implemented in the EP-calculation	1.5 $l.s^{-1}$ in each room during unoccupied periods

Table 5

Belgium (before 2015)				
Person in charge of the calculation (scale)	***Performance-based approach***	***Calculated IAQ indicators***	***Credit in EP-calculation***	***Minimum airflow***
The manufacturer of each DCV system shall pass through an agreement procedure (ventilation system scale)	**Equivalence method (with non-equivalent reference systems)** Multizone modelling with CONTAM $\Delta t = 5$ min, conventional entry data both deterministic and stochastic	**Per room, over the heating period:** 1/CO_2 cumulative exposure indicator E'_{1000} 2/Monthly average RH> 80% on critic thermal bridges from December 1st to March 1st 3/Exposure to a tracer gas emitted in toilets and in bathrooms They must be at least equal that the worst performing reference system.	An energy saving coefficient f_{reduc} is extrapolated and can be implemented in the EP-calculation	10% of the nominal flow rate

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