REVIEWING LEGAL FRAMEWORK AND PERFORMANCE ASSESSMENT TOOLS FOR RESIDENTIAL VENTILATION SYSTEMS

Rob C.A. van Holsteijn[1], Bas Knoll[*2], Harm J.J. Valk[3],
and Marco C. Hofman[4]

1 VHK BV
Project manager MONICAIR
Elektronicaweg 14
2628 XG Delft, Netherlands
e-mail address: r.van.holsteijn@vhk.nl

2 TNO Delft
Researcher Energy, Comfort & IAQ
van Mourik Broekmanweg 6,
2628 XE Delft, Netherlands

3 Nieman Raadgevende Ingenieurs
Senior Consultant
Atoomweg 400
3542 AB Utrecht, Netherlands

4 ISSO, Dutch Buildings Services Institute
Chair National Standard Committee on Ventilation
Kruisplein 25
3014 DB Rotterdam, Netherlands

ABSTRACT

The field research project MONICAIR indicates that ventilation systems that fully comply with Dutch building codes show large differences in their IAQ-performance in habitable rooms during heating season and do not always achieve acceptable IAQ-levels [lit.1]. The results indicate that there are considerable differences in the actually achieved air-exchange rates per person during presence in habitable rooms. System averages on CO2-excess doses per heating season (an indicator for the duration and the amount of the excess above 1200 ppm CO2) vary from 68 to 349 kppmh per person. This roughly corresponds to situations in which either 7% or 35% of the time spent at home ventilation rates per person are insufficient. Variations between individual dwellings are even bigger with values ranging from 0 to 853 kppmh per person per heating season. These differences in habitable rooms occur despite the fact that the overall ventilation rates for all dwellings investigated are well above 10 l/s per person.

Concerning the RH-levels, only limited exceedance of threshold values were monitored. Generally these levels are well below 70% in all rooms, and only in bathrooms RH-values may rise above 70% for a period off - on average - less than two hours per day. Periods with RH-values less than 30% occur in all rooms of all dwellings and last on average 4 to 6 hours per day.

Other recently concluded monitoring studies further substantiate the results from the MONICAIR field research [lit.2,3]. These results point to the conclusion that the assumption that all code compliant ventilation systems perform comparable on IAQ, is clearly not justified. In consequence, the declaration of the Energy performance of ventilation systems has limited meaning as long as a direct link to a properly assessed IAQ-performance is lacking.

Current building codes, test standards and determination methods apparently are not sufficient to ensure the required air exchange rates in habitable rooms and consequently reduce the exposure to human odours (hygienic threshold values) and all other indoor pollutants.

In respect to these findings the MONICAIR consortium reviewed the existing Dutch building codes and related test- and determination method to determine if and where the legal framework and related guidelines can be further refined to ensure a minimal IAQ-performance of ventilation systems.

On several topics the legal framework and related assessment and test tools can be further expanded and refined. But the key item here is the fact that an actual performance requirement is missing, as well as a proper test protocol for assessing the performance of a ventilation system on its primary function “diluting concentrations of indoor pollutants by exchanging air and thus reducing exposure”.

KEYWORDS

IAQ-aspects in ventilation regulation, controls and user interaction

1 INTRODUCTION

In the developed countries people spend around 80 to 90% of their time indoors, of which approximately 60% in their own houses [lit.4]. Although some pollutants might originate outdoors, most pollutants that affect Indoor Air Quality (IAQ) come from sources inside the dwelling. Building materials, interior- and decorative products as well as humans and their activities cause emissions, resulting in concentrations of pollutants that are generally considerably higher than the concentrations outside [lit.5]. Exposure to these higher concentrations of indoor pollutants has an effect on people's health. The WHO Guidelines for Indoor Air Quality [lit.6] present guidelines for the protection of public health from risks due to a number of chemicals commonly present in indoor air.

The first and most important step towards the improvement of the IAQ is the reduction of source emissions from building materials, interior products and people's activities. Various guidelines and regulations related to source emissions of building materials and interior products are already in place and regularly revised. The second important mechanism for reducing concentrations of indoor pollutants is *ventilation*, or, the removal and/or dilution of indoor pollutants by replacing polluted indoor air (preferably where is it highly concentrated) with cleaner outdoor air. This not only implies that all in home combustion systems – as far as they don't operate independently from the indoor atmosphere – are effectively vented. It also means that kitchen hoods must comply to minimum pollutants capture efficiencies and bathrooms and utility rooms need to be properly vented to remove moisture. And finally it implies that built-up concentrations of indoor pollutants in habitable rooms are effectively diluted, particularly during presence when exposure occurs.

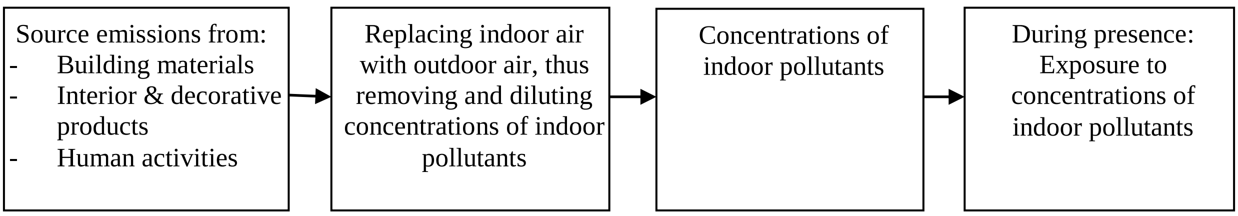


Figure 1. Factors that determine the concentration of and the exposure to indoor pollutants

If we want to determine the IAQ-performance of a ventilation system, we need to assess the performance on its primary function: 'the ability to remove and/or dilute concentrations of indoor pollutants to an acceptable level, by replacing indoor air with cleaner outdoor air, not only in wet rooms, but also in habitable rooms where people spent most of the time en where there is long-term exposure'.

Only by fulfilling this primary function, exposure to concentrations of indoor pollutants can be reduced. Depending on the type of indoor pollutant and the rate of indoor source emissions, air exchange rates of ventilation systems can be further increased to achieve acceptable concentration levels. The prEN 16798-1:2015 [lit.7] lists the following air exchange rates for ventilation systems in residential buildings.

Table 1. Air-exchange rates ventilation systems in residential dwellings

Category	**Air-exchange rates**		
	Ventilation per person	**Air change rate dwelling**	
	l/s/pp	l/s/m2	ach
I	10	0.49	0,7
II	7	0.42	0,6
III	4	0.35	0,5
IV		0.23	0,4

To assess the performance of a ventilation system on its primary function, the MONICAIR consortium – a broad consortium of Dutch ventilation unit manufacturers and research institutes supported by the Dutch government – monitored the real life performance of ten code-compliant ventilation systems in 62 dwellings for over a year. The project not only monitored the relative humidity (RH-) levels in all rooms, but also the CO_2-levels in all habitable rooms. Relative humidity is a valid indicator for the ventilation performance in wet rooms. CO_2-concentrations are generally considered a good indicator for the ventilation performance in habitable rooms. It does not only point out whether hygienic limit values are exceeded or not, it also indicates the actual occurring air exchange rates in relation to the number of people present [lit.8,9].

2 RESULTS MONICAIR FIELD RESEARCH PROJECT

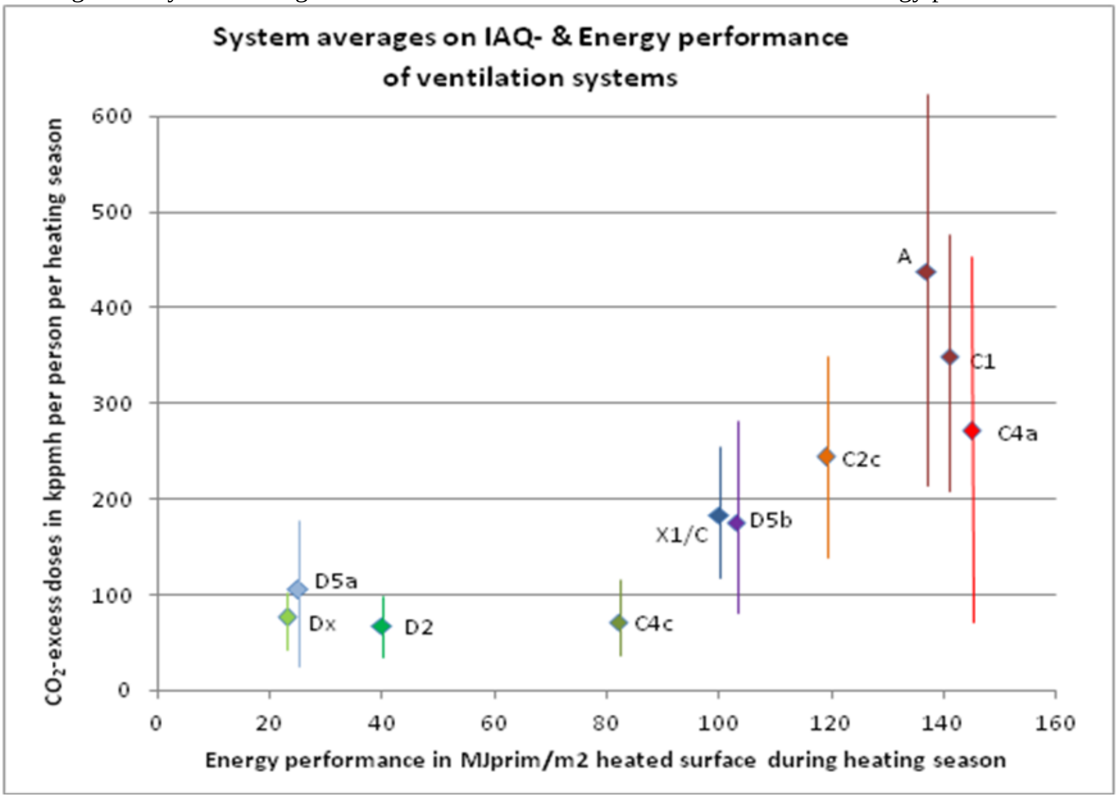
Because the results of the MONCAIR field research were already discussed in lit.1 and lit.10, only a summary is presented here. The code compliant ventilations systems investigated are C-type (or MEV-) systems that apply mechanical extraction in wet rooms and natural supply in habitable rooms, except for system type C.4c which applies mechanical extraction in all rooms. The D-type (or MVHR-) systems are ventilation systems with heat recovery that use both mechanical extraction from wet rooms en mechanical supply for the habitable rooms. X1-type systems use local MVHR in the living section and MEV or fully natural systems in the sleeping section (see also lit.1 for further explanation of ventilation system types). The results on RH-levels are presented in table 2. With the exception of a few houses were the natural exhaust provision in the bathroom is inadequate, all systems in all dwellings show fairly good results on achieved RH-levels, indicating a sufficient ventilation performance in the wet rooms (please note that most of the kitchens in the monitored dwellings have dedicated cooker hoods). Occupant behaviour like leaving the bathroom door open or opening a window after showering may have contributed to these results.

Table 2. System averages on hours per day RH-limits are exceeded during heating season

ventilation system type		**average No. of hours per day RH> 70%**				**average No. of hours per day RH< 30%**			
		Total of all rooms	**bathroom**	**kitchen**	**per indiv. hab.room**	**Total of all rooms**	**bathroom**	**kitchen**	**per indiv. hab.room**
		[h/day]	[h/day]	[h/day]	[h/day]	[h/day]	[h/day]	[h/day]	[h/day]
	A	1.47	1.46	0.01	0.00	27.26	5.02	5.44	4.42
MEV-systems	C1	1.31	1.31	0.00	0.00	49.53	10.10	7.77	8.56
	C.2c	1.09	0.60	0.00	0.11	20.03	10.37	n.a.	2.25
	C.4a	0.29	0.29	0.00	0.00	29.70	10.48	2.73	4.34
	C.4c	1.32	1.32	0.00	0.00	17.13	2.80	n.a.	4.09
MVHR systems	D.2	1.52	0.88	0.00	0.16	23.02	5.18	n.a.	4.46
	D.5a	0.54	0.54	0.00	0.00	47.69	10.09	n.a.	8.55
	D.x	2.78	2.78	0.00	0.00	18.33	5.33	n.a.	3.25
	D.5b	0.35	0.35	0.00	0.00	33.15	7.68	9.23	5.41
Comb.	X1/C	1.53	1.52	0.01	0.00	25.80	3.20	5.00	4.40
	X1/A	7.35	7.35	0.00	0.00	26.60	5.90	2.70	6.00

The results on CO_2-concentrations in habitable rooms and on energy consumption are presented in figure 2. In the graph the diamond markers represent system averages on CO_2-excess dose per person (product of duration and amount of excess above 1200 ppm during heating season). The vertical lines represent the standard deviation of a group of ventilation systems (both refer to the vertical axis of the graph). On the horizontal axis the system averages for energy consumption of ventilation systems in total primary energy per m^2 heated surface during heating season is indicated. The standard deviation on energy consumption is limited and therefore not displayed in the graph (see lit.1 for further explanation of ventilation system types).

Figure 2. System averages and standard deviation on CO_2 excess dose and Energy performance



Apart from ventilation system A (which was added at the request of housing associations because they represent a significant share of the housing stock) all other ventilation systems are code compliant. The large differences both in CO_2 excess dose per person and in the standard deviation illustrates that there are considerable variations in the IAQ-performance of the code compliant ventilations systems in habitable rooms. The data illustrates whether the ventilation systems were capable of achieving the requested air exchange rates per person in the various habitable rooms and consequently dilute all concentrations of indoor pollutants. Although periods of insufficient air exchange were observed in all habitable rooms, main problems occur in the bedrooms. The large extent of these differences in achieved air exchange rates were not fully anticipated, especially given the fact that all ventilation systems achieved overall air exchange rates well above 10 l/s per person, which complies with the highest IAQ category in table 1.

Ventilation systems type D (MVHR-systems) vary in their IAQ-performance, mainly due to the fact that some units or individual fans are temporary switched off because of noise or draught. Type C (or MEV) systems show large variations due to the fact that some of these systems have insufficient control over the air exchange in the habitable rooms. Some of these MEV systems require frequent interventions from active occupants and the monitoring results show that this type of behaviour was not exhibited. Unlike with temperature, light and noise, people neither possess the requested sensory capacities to perceive the IAQ, nor the expertise to properly control these ventilation system with their complex interactions between window- and door openings, fluctuating natural buoyancy and pressure differences over facades due to varying weather conditions.

Apart from the fact that various indoor pollutants are odourless (radon, CO, various VOC's), people also adapt to their IAQ. Although some large and sudden changes in concentrations of pollutants might be notices, occupants at least need to be awake to observe this which obviously is not always the case. Therefore, the assumption that people are able to judge and manually control the IAQ by correctly operating their ventilation system does not seem appropriate, even if the required operations are easy.

In respect to the energy performance of the investigated ventilation systems, it may be concluded that the real life energy consumption is not in line with the EPBD assessment methods. This is partly caused by differences in the assumed and real life system operation. Apart from that, there are certain types of ventilation systems with CO_2- control, that actually perform considerably worse in real life than according the assessment methods. Overall there are also differences in their relative ranking. And above all the question arises as to what the meaning is of an assessment of the energy performance without a direct link to its IAQ-performance.

Clearly the (implicit) assumption that all code compliant ventilation systems perform comparable cannot be substantiated by these findings. Further refinement of the legal framework and the performance assessment tools is necessary.

3 EXISTING LEGAL FRAMEWORK , ASSESSMENT AND TEST TOOLS

In Work Package WP3a, the MONICAIR consortium reviewed the existing legal framework and performance assessment test tools in the Netherlands, which resulted in the following list of items than can be further improved to ensure a minimal IAQ performance of ventilation systems.

3.1 Actual performance requirement is missing

The leading article in the Dutch building codes related to ventilation systems (article 3.28) states that *"a dwelling must have provisions for air exchange which prevent adverse health impacts".* Section 3.6 of the Dutch building codes further describes that all individual rooms need to have such a provision and indicates what air exchange rates these provisions must be able to achieve (values are based on the advice from the Dutch Health Council, demanding that at least 7 l/s per person can be achieved). For the determination method the building codes refer to NEN1087. This Dutch standard describes the conditions for properly dimensioning and implementing ventilation systems and fulfilling requirements.

Although this legal framework apparently is sufficient to ensure that requested ventilation rates are achieved at total dwelling level and (to a considerable extend) in the wet rooms, it does not suffice to ensure the requested air exchange rates in the distinctive habitable rooms. What is missing, is a clear performance requirement describing where and when these air exchange provisions must (at least) operate properly, not only in wet rooms but also in the habitable rooms, where exposure time is the longest.

3.2 Ventilation requirements based on m^2

To enable different lay-outs within a dwelling, Dutch building codes now specify air exchange rates based on the room surface area. For bedrooms this may not always lead to a correct sizing of the air exchange provisions. Bedrooms for two people are generally (at least in the housing stock of both housing associations and a vast majority of privately owned dwellings in Netherlands) smaller than 16 m2. With the ventilation requirements of 0,7 l/s/m^2 for habitable rooms, this will lead to insufficient minimum ventilation, even if the air exchange rates are actually achieved. For ventilation systems that have limited control over air exchange rates in habitable rooms, the IAQ will be even worse.

3.3 Requirements outdoor air quality

Ventilation systems can only succeed in their final goal if the outdoor air is sufficiently cleaner than the indoor air. Bearing in mind the fact that the limit values on ambient air quality (Directive 2008/50/EC) are not always and everywhere achieved in the Netherlands, it seems only right to add certain requirements related to the cleaning or filtering of the supplied air. Exposure to particulate matter (PM10 and PM2,5) from traffic and industry for instance, has a large impact on people's health. Moreover, there are large groups of the population that have a predisposition for lung diseases and allergies that will largely benefit from targeted cleaning of the outdoor air before is it supplied into the dwelling.

3.4 Ventilation system control based on human intervention

The legal framework and performance assessment procedures are partly based on the assumption that people are capable of assessing the IAQ in their dwellings and act upon it by correctly operating the ventilation provisions. This assumption is questionable to say the least. Various studies have been performed to investigate how people judge their IAQ and their ventilation system. Apart from monitoring the actual IAQ in 62 dwellings, the MONICAIR project also did a survey amongst its inhabitants. And although CO_2-levels in bedrooms and living rooms frequently exceeded the 1200 ppm limit values (sometimes even exceeding the 3500 ppm CO_2), 95% of the interviewees are content or fairly content with their ventilation systems and rate the freshness of their indoor air with a 7 or an 8 out of 10. Combined with the facts that various indoor pollutants are odourless (radon, CO, various VOC's), that people adapt to their IAQ, and that people do not possess the required sensory capacities to perceive the IAQ, this leads to the conclusion that people cannot be held responsible for the correct operation of their ventilation system and the resulting IAQ. Consequently the design paradigm that performance of ventilation systems can be based on human intervention should be abandoned.

3.5 No test procedure for determining the performance of ventilation systems

Apart from the fact that there is no clear legal performance requirement for ventilation systems (see 3.1), a proper test procedure for determining the performance of a ventilation system on its primary function, is also missing. There are several national and European test standards on the individual components of a ventilation system, but so far a validated test procedure for the overall ventilation system is lacking. Simulation programs are now filling this gap, but without ample validation from real life field research, their link with reality is questionable. As illustration: for all ventilation systems that were investigated in the MONICIAR field research project, simulation were done using the software of VLA-method [lit.10] . The result was that all systems complied with the Air Quality Index limit value of 30 kppmh per person per heating season. The MONICAIR field research project supplied data showing that real life values for this Air Quality Index vary from 0 tot 853 kppmh per person per heating season, with system averages way above 30 kppmh/pp per heating season.

As a consequence of the situation described above, the ventilation market and the IAQ-topic is facing difficulties, because:

- Fact and fiction on the performance of ventilation systems cannot be distinguished (claims cannot be verified)
- Product development and design of ventilation systems is focussed on compliance with building codes and not on performance requirements
- Procurement procedures cannot dispose of adequate IAQ and energy performance data
- IAQ is not an issue when selecting ventilation systems

4. CONLUSIONS : PROPOSALS FOR IMPROVEMENT

Over the years the performance of ventilation systems has certainly improved, as well as the legal framework and performance assessment tools for these systems. Recent insights and knowledge however give cause for a next step in refining this framework and related assessment methods, especially with a building stock that is gradually improving in terms of thermal insulation and air tightness.
With the right focus both MEV and MVHR systems can be further improved to ensure that the required air exchange rates can also be achieved in the distinctive habitable rooms, particularly during presence.
Key requisites for achieving these improvements are:

4.1 Drawing up of minimal requirements

Give a stricter and verifiable definition of the primary function of residential ventilation systems and add minimal performance requirements as to when and to what extent air exchange rates must be achieved in both wet rooms and habitable rooms.

4.2 A validated and (internationally) accepted test protocol for complete systems

Develop a test protocol that facilitates the measurement of the real life performance of ventilation systems. This protocol can for instance be based on the methods and indicators used in the MONICAIR field-research project, for which the Air Quality Index of the VLA-method [lit.11] was the underlying principle. Thus acquired results can be used for fine tuning of existing simulation software. The acquired knowledge can also be used for the further characterization of ventilation systems and their relation with its IAQ-performance and the energy performance.

4.3 Design a system for indicating the IAQ-performance of ventilation systems

Obviously there will be ventilation systems that can do more and perform better than the minimal requirements. Examples are ventilation systems that:

- are able to (silently) increase the air exchange rates per person and reduce CO_2-concentrations to long-lasting levels below 1000 or 800 ppm,
- automatically adjust air exchange rates per room to the number of people present or to their (polluting) activities
- have (standards or improved) filter capabilities,

Such differences must become visible to the market. Large quantities of real life performance data (see 4.2) will also facilitate the categorization or labelling of ventilation systems on their IAQ-performance.

4.4 Link the IAQ-performance with the energy performance

Finally a correct link between the IAQ- and the energy performance must be made and communicated. Without such a link, an assessment of the energy performance is without meaning.

The MONICAIR consortium is discussing with the Dutch standardization body NEN, the Ministry of Interior Affaires and research institutes how and to what extend these modification can be implemented. The Consortium is also initiating the process of developing a test protocol with a corresponding ventilation test kit and is looking for international backing and support.

5. ACKNOWLEDGEMENTS

This paper was prepared within the MONICAIR project, part WP3a. The project is financed by the consortium members and by the Dutch Ministry of Economic Affairs within the framework of TKI

(Top consortia for Knowledge & Innovation). Consortium members and their particular representatives involved in this part of the MONICAIR study are: Jelmer de Jong, Peter Schabos, Rutger Vasters, Rolf-Jan Hans, Hans van Klooster, Roelof Ziengs, Leon van Bohemen, Jan Rijnbeek, Harm Valk, Wim Kornaat, Bart Cremers, Rick Bruins, William Li, Bas Knoll and Rob van Holsteijn. The MONICAIR consortium owes thanks to Peter Cool for his support on the data monitoring of the boilers, to Robèrt de Haas for his patience and support in developing the MONICAIR database and queries, to Wilbert van den Eijnde for the face-to-face interviews with all inhabitants and finally to the housing corporations for their support in the selection of dwelling for this part WP1a of the MONICAIR project: Barry Top, Gerben Heering and Winfried van Emmerik.

6. REFERENCES

[1] Van Holsteijn, R.C.A., Li, W.L., Valk, H.J.J., Kornaat, W. (2015), Improving the Energy- & IAQ Performance of Ventilation Systems in Dutch Residential Dwellings, Conference Proceedings Healthy Buildings Europe May 2015, The Netherlands, Paper ID504.

[2] McGill, G.M., Oyedele, L.O., Keeffe, G.K., McAllister, K.M., Sharpe, T. (2015), Bedroom Environmental Conditions in Airtight Mechanically Ventilated Dwellings, Conference Proceedings Healthy Buildings Europe May 2015, The Netherlands, Paper ID548.

[3] Tappler, P., Hutter, H.P., Hengsberger, H., Ringer, W. (2014), Lüftung 3.0 – Bewohnergesundheit und Raumluftqualtität in neu errichteten energieefficienten Wohnhäusern, Österreichisches Institut für Baubiologie und Bauökologie (IBO), Wien, Austria

[4] Klepeis, N.E., Nelson, W.C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P. (2001), The National Human Acitivity Pattern Survey (NHAPS): A Resource for Assessing Exposure to Environmental Pollutants, Lawrence Berkeley National Laboratory, Berkeley, USA.

[5] Logue, J.M., Sherman, M.H., Price, P.N., Singer, B.C. (2011), Why We Ventilate, Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Report Number 5093-E, Berkeley, USA.

[6] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe, (2008), Official Journal of the European Union.

[7] Energy performance of buildings – Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings ddressing indoor air quality, thermal environment, lighting and acoustics – Module M1-6, prEN 16798-1:2015

[8] De Gids, W.F., Wouters, P., (2010). CO_2 as indicator for the indoor air quality, General principles, AIVC Paper N° 33.

[9] Schell, M., Inthout, D. (2001), Demand Control Ventilation Using CO_2, Ashrae Journal, February 2001.

[10] Van Holsteijn, R.C.A., Li, W.L. (2014), Monitoring the energy and IAQ performance of ventilation systems in Dutch residential dwellings, Proceedings of the 35th AIVC conference, Poznan, Poland.

[11] Vereniging Leveranciers Luchttechnische Apparaten, VLA, (2012). VLA methodiek gelijkwaardigheid voor energiebesparende ventilatieoplossingen in woningen.