EVALUATION OF A PRESCRIPTIVE VENTILATION STANDARD WITH REGARD TO 3 DIFFERENT PERFORMANCE INDICATORS

Jelle Laverge[1], Arnold Janssens[1]
[1]Building Physics Research Group, Ghent University, Ghent, Belgium

ABSTRACT

In this paper, the performance of Belgian building code compliant residential ventilation systems is evaluated on multiple performance indicators: occupant exposure to bio-effluents, occupant exposure to other use-related pollutants (odours) and occupant exposure to building material emissions.

The fitness of the proposed criteria in this context is then discussed in a broader context and this information is then used to interpret the fitness of the code prescriptions as design criteria for performant ventilation systems.

INTRODUCTION

Context

The correlation of IAQ and health, mental performance and comfort has been elaborately discussed in literature (eg. Fanger, 1988 and Seppänen 2004). Moreover, ventilation and infiltration losses represent an ever more significant part of the total energy demand of well insulated buildings, stressing the importance of efficient ventilation even more.

Ventilation standards and codes however, are often drafted in a prescriptive way, demanding a fixed airflow rate for a certain type of space . An overview has been published by the AIVC (2008).

In an international context of growing public attention to air pollution/quality, rising energy prices and political intention to minimize fossil fuel depletion; owners, building professionals, technical engineers as well as researchers ask for a more open standard that will allow for innovative ventilation concepts that combine reduced airflow rates and high IAQ.

The Belgian Standard

This paper will present an analysis of the performance of a prescriptively drafted standard, namely the one included in the Belgian residential building code (NBN, 1991). Therefore, this standard is presented more elaborately in the following section.

As stated above, it proposes a fixed flow rate per room, depending on the use of the space. These are summarized in Table 1.

Table 1
'Nominal flow rates' in the Belgian residential ventilation standard

ROOM TYPE	FLOW RATE	MIN / MAX
Living room	1 l/(s*m²)	21 / 42 l/s
Bedroom / Study	1 l/(s*m²)	7 / 20 l/s
Kitchen/ Bath	1 l/(s*m²)	14 / 21 l/s
Toilet	7 l/s	-/-
Hallway	1 l/(s*m²)	-/-

To achieve these flow rates, the standard proposes 4 systems. These range from natural ventilation (A), over mechanical supply (B) and mechanical exhaust (C), to a fully mechanical system (D). All of these systems supply fresh air to the living areas of the building, transfer it through the circulation areas and extract the air in the 'wet' rooms, such as kitchen and bathroom. The setup of these systems is based on the 'nominal airflows' mentioned above. Supply and extraction devices of all systems should be sized according to these flows.

Non-mechanical components, such as all openings for system A, the extract ducts for system B and the supply vents for system C, should be sized to the nominal air flow at a pressure difference of 2 Pa. Mechanical components should be able to realize the indicated flow rates at all normal weather conditions. The standard also includes a table for the sizing of transfer openings.

Although no performance for airtightness is mandatory in the standard, it recommends a maximum leakage at 50 Pa (n_{50}) of 3 ACH for the implementation of a fully mechanical system (D) and 1 ACH for such systems with heat recovery.

Other European Standards

In other European countries (AIVC, 2008), similar standards exist. Most of them however, are only guidelines and are not included in the building code. In contrast to this, Norway is one of the first to have a stringent code with associated inspection.

In many countries, such as Portugal and Germany, operable windows are accepted as a ventilation strategy. Proper guidelines for the sizing of these windows are then included in the standard. Note that this kind of ‘peak ventilation’ is not accepted to achieve IAQ in the Belgian standard. Furthermore, in Europe, only Poland implemented a list of maximum concentrations for a series of substances in its building code. Finland adopted another strategy and introduced a standard for material emissions. The Netherlands have, due to their equivalence approach, a very flexible standard that is fully performance based, but only evaluates a single criterion, the Low Ventilation Index or LVI. Only a few standards, eg. Finland and Germany, impose maximum leakage rates..

Selected Criteria

As stated above, the performance of the Belgian code is analyzed with respect to 3 indicators proposed in the European EN 15665 standard (CEN 2007): occupant exposure to bio effluents, occupant exposure to odours and occupant exposure to material emissions.

The occupant’s exposure to bio-effluents is based on Fangers Perceived Air Quality approach (Fanger, 1988). It is evaluated through occupant exposure to CO_2 and the correlation found between this concentration and the predicted percentage of dissatisfied users (CEN, 1998). Evidently, this correlation is only valid for situations where humans are the main source of CO_2.

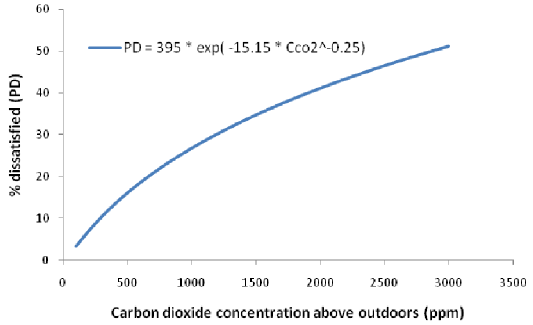

Figure 1. Fangers correlation CO_2 and perceived air quality

Occupant exposure to specific odours is especially related to the use of certain spaces, such as the kitchen and the toilet. Odours are produced in large quantities in these spaces. Nuisance occurs when concentrations are high in the spaces where these odours are produced and when they spread through the residence. A simple example is the smell of cooking fish. The amount of back-draft - air flows from ‘wet’ spaces to living spaces - is therefore a useful performance criterion for a ventilation system.

Occupants are often exposed to emissions from building materials. Since this exposure is often directly related to health, dose limits have been proposed in literature. The WHO gives a comprehensive overview (2008).

Finally, relative humidity relates both to user discomfort and mould problems. It is also frequently used as a control value for demand controlled ventilation. The interpretation of humidity effects however, is strongly dependant on buffering. This is not dealt with in this paper, but has been thoroughly addressed in literature (eg. Steeman and Laverge 2009).

SIMULATIONS

Reference dwellings

To evaluate the performance of the Belgian standard, 5 different residence typologies (terraced, semi-detached, detached, apartment and bungalow) were modelled in the multi-zone ventilation model TRNFLOW. The geometry of these buildings is based on statistical data from the National Institute for Statistics for the residential building stock in Belgian. Their designs have been developed in the framework of a research project on the optimisation of building envelope and services for low-energy residential buildings (Hens, 2006).

All of the houses have 3 bedrooms, a living area, kitchen, serviceroom, bathroom and toilet. The detached house and the terraced house also include a study. Compactness - the ratio of building volume to transmission surface - ranges from 3.8 m for the apartment to 0.9 for the bungalow. Nominal supply flow rates, according to table 1, are about 90-100 l/s for each of them and nominal extraction flow rates about half of that. Note the large unbalance. These dwellings have also been used in a CONTAM model by Vandenbossche (2007).

Airflow model

The airflow in these dwellings has been modelled through the introduction of system components and leakage.

According to observations by Bossaer (1998), the specific leakage rate through roof and walls has a 2/3 ratio. Overall airtightness, characterized by the n_{50} value, is distributed over the roof and wall surface according to this ratio by means of cracks. Each wall is fitted with two cracks, one at 1/3 of its height and the second one at 2/3. The interior floors are modelled with 1 crack and the doors are represented with additional cracks in the walls where they appear. For the indoor walls and ceilings, a fixed specific leakage value is assumed.

For each of the reference buildings, a model for all 4 of the system setups proposed in the standard is implemented. The mechanical components are modelled as ‘perfect fans’, delivering the nominal airflow at any pressure difference. The non-mechanical components are modelled to adhere to a simple power-law function with a flow exponent of 2/3. They are sized according to the standard, delivering the nominal flow rate at 2 Pa. In Table 2., an overview of the nominal airflows per space is given for the detached house.

Table 2

'Nominal' air flows for the detached house

ROOM	FLOW RATE
Living room	36 l/s (Supply)
Bedroom 1	17 l/s (Supply)
Bedroom 2	18 l/s (Supply)
Bedroom 3	18 l/s (Supply)
Study	8 l/s (Supply)
Kitchen	14 l/s (Extract)
Service room	14 l/s (Extract)
Bathroom	14 l/s (Extract)
Toilet	7 l/s (Extract)

None of the standard system components are in any way demand controlled. In accordance to the standard, fresh air is supplied in the living room, the bedrooms and the study and polluted air is extracted in the kitchen, service room, bathroom and toilet. Due to the space-based approach of the standard, flow rates for mechanical supply systems (B) and mechanical extraction systems (C) are very different. Indeed, as can be seen above, the total supply rate is twice the extraction rate.

Occupancy

For all simulations presented in this paper, a fixed occupancy schedule is used. It represents a 4 person family, comprising 2 adults of which one stays at home and 2 school going children. The occupancy sequence is randomly chosen according to a 'normal' living pattern. Figure 2. depicts the resulting occupancy for the different rooms during a weekday.

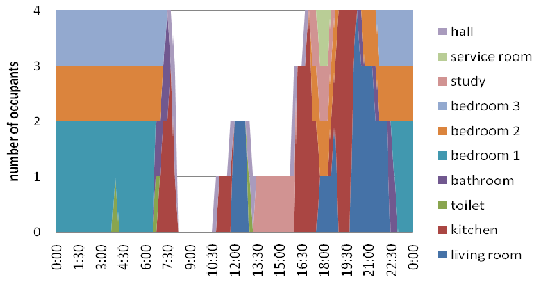

Figure 2. Occupancy during a weekday

Pollutants

For the evaluation of the 4 performance indicators mentioned above, 3 pollutants are introduced in the model. They do not interact with each other, since in reality they represent different aspects of air quality that are independent.

CO_2 is introduced as a measure for human bio-effluents, with a correlation to nuisance as was discussed above. Note that for this correlation, only the excess concentration with regard to the outdoor concentration is relevant. The occupants are the only CO_2 source in the model, at 19 l/h. This is based on the EN 15251 standard (CEN, 2005).

To quantify the nuisance from odours, a second, fictional gas was introduced. In the rest of this paper, this gas will be referred to as 'tracer'. The tracer is released in the 'wet' spaces of the dwellings (kitchen, bathroom and toilet) whenever they are occupied, at a fixed generation rate.

A third, equally fictional, gas is released in all rooms to quantify the exposure to substances emitted by building materials. This 'emission substance' is released at a fixed generation rate per square meter of wall and floor area in a room. This represents eg. VOC emissions of finishing materials. Comparable emissions by furniture etc. are not taken into account separately. It is assumed that the amount of furniture is more or less related to the amount of wall and floor area. Time dependent effects of these emissions are not taken into account.

Boundary conditions

Weather data from the Meteonorm-weatherfile for Uccle, at the centre of Belgium, were used to carry out the simulations. Windpressure coefficients, that represent the ratio of the pressure on an exterior wall and the wind velocity, from the AIVC handbook were used. The windpressure at the exhaust ducts was assumed to always be negative, regardless the wind direction.

All simulations are ran over a typical winter period , since the performance of a ventilation system is only relevant when it is the main source of fresh air in a building. The Belgian climate is very moderate in summer, causing most people to open windows and doors over long periods of time (Erhorn, 1986). Thus airflows in the dwellings are no longer controlled by the ventilation system and irrelevant for the assessment of its performance.

Outdoor concentrations for CO_2, the tracer and the emission substance were assumed to be 0. Since CO_2 is only an indicator for human bio-effluents and therefore only the excess concentration is relevant, this does not affect the results. For the tracer and the emission substance a similar rationale is followed. Both are fictional indicators for nuisance and health problems respectively. Since the goal of this paper is to evaluate the performance of the ventilation system, the effectiveness of the removal of these indicator gasses will not be affected by the outdoor concentration. Only the absolute value of the indoor concentration will be offset.

Evaluation parameters

With regard to the 3 indicators discussed in the introduction of this paper, numerical parameters are introduced to evaluate the performance of the systems.

For human bio-effluents, the mean percentage of dissatisfied per occupant μ_{PD} or mean exposure to CO_2 over the total simulation period and its standard deviation σ_{PD} are used.

For exposure to odours, the mean exposure to the tracer μ_{tot} and the total dose of the tracer in rooms where it is not released TRC are used. Since the amount of tracer that is released in the buildings is the same (fixed occupant schedule and occupant related release) for all simulations, these values are representative for the effectiveness of removal of odours from the dwelling and for the back-draft effects (spread of odour) in the building respectively.

For the exposure to emissions from building materials, the mean exposure to the emission substance μ_{voc} is used. This value is only relevant for relative comparison. It can only be used to compare different systems under the same conditions (eg. the 4 standard systems in 1 typology).

Exposure to bio-effluents

First, the results for occupant exposure to bio-effluents is presented. In Figure 3. and 4. the mean CO_2 concentration, used by Laverge (2008), and the μ_{PD} to which 1 occupant is exposed over the simulation period is shown in relation to the leakage-level in the detached house. Figure. 5. shows the standard deviation on the CO_2 concentration.

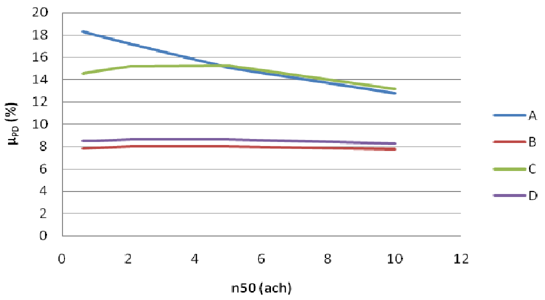

Figure 3. μ_{PD}, results for the detached house

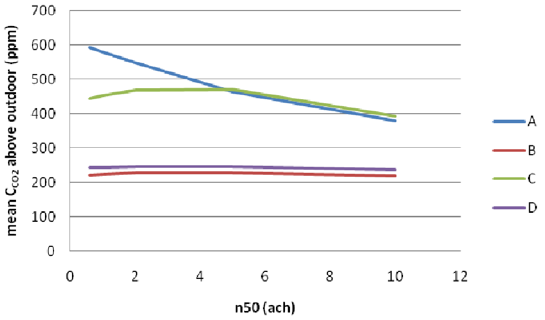

Figure 4. Mean CO_2 concentration, results for the detached house (DH)

As is to be expected, mean concentration and μ_{PD} predict equal trends since μ_{PD} is directly calculated form C_{co2}.

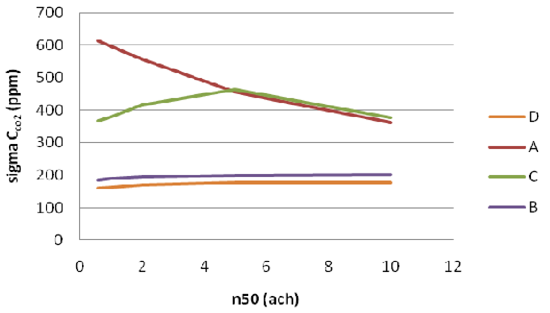

Figure 5. Standard deviation CO_2 concentration DH

For system A, increasing PD is reported for increasing airtightness. With system C, a maximum occurs at the 2-5 ACH n_{50} interval. This is due to pressurization effects, as was reported by Laverge (2008). System B and D produce relatively airtightness independent results because they supply fresh air at a constant rate to the rooms where the occupants are in a relatively large portion of the day.

Note the correlation between the mean performance (μ_{PD}) and the standard deviation of the different systems. This is due to the setup of the different systems.

The performance of non-mechanical system components is far less robust than that of mechanical components. The variance-coefficient δ (the ratio of standard deviation and mean), is a good indicator for system robustness. In Figure 6. this can clearly be observed. In the 10 – 5 ACH n50 range, system C, which has far smaller flow rates than system B is not able to generate enough pressure and the whole system acts as a natural system. As pressurization builds up with increasing airthightness and the performance of the system is thus more influenced by the mechanically controlled airflow, the robustness increases (smaller δ), arriving at virtually the same level as the other two mechanical systems for extreme airtightness levels.

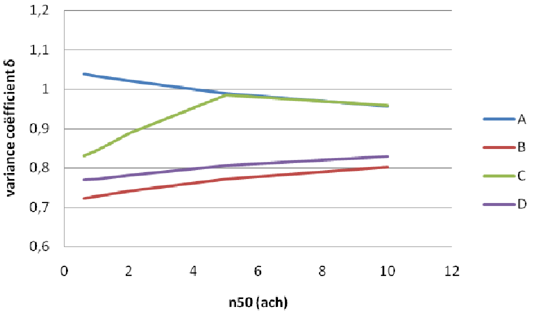

Figure 6. variance coefficient δ (dimensionless) DH

When the performance of a system is compared in different dwellings, 2 observations can be made. On the one hand, the correlation between the systems performance and increasing airtightness is similar for all dwellings. On the other hand, the absolute performance level and the strength of the influence of airtightness are very different for system A. This to, as is the large difference in performance of system B and C, is mainly due to the room-based approach of the standard, instead of a system based approach.

This is depicted in Figure 7., where the performance of system A is shown for all of the 5 reference dwellings. The apartment and bungalow have the worst performance since they are only 1 story high and therefore do not profit from thermal buoyancy effects.

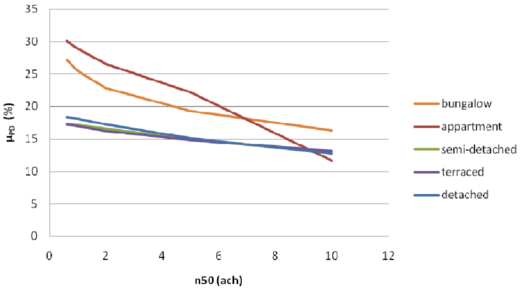

Figure 7. System A in all reference dwellings

This thermal buoyancy also produces other effects. In the terraced house, the parent’s bedroom is situated along the neutral pressure plane (the middle floor in a three storey house). Therefore, fresh air supply to this room by a natural ventilation system is minimal and indoor air quality subsequently lower. This can be seen in figure 8., where the μ_{PD} for a parent and for the two children is depicted. Note that due to this effect the indoor air quality in the parent’s bedroom is also far less dependent on the airtightness. Difference in occupancy schedules thus renders significantly different performance of the system for each individual occupant.

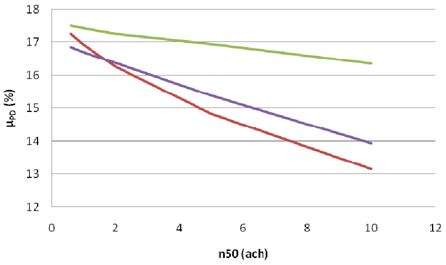

Figure 8. parent (green) and children in the terraced house with system A

Exposure to odours

When exposure to odours is then considered, all of the observations made above can mutatis mutandis be applied. Note, however, that the absolute values do not represent any physical reality since a fictional tracer gas is used.

As can be deduced from the graph in figure 9., pressurization effects enable system B to perform more effectively at odour removal from the ‘wet’ rooms with increasing airtightness, whereas the performance of system C is virtually independent of airtightness since it extracts a constant flow rate from the spaces where the odours are produced. Due to its significantly smaller flow rate however, its absolute performance is worse than that of system B. The performance of system D is somewhere in between that of these system C and system B since the mechanical controlled extraction has a constant flow rate and the pressurization this induces diminishes transfer flows.

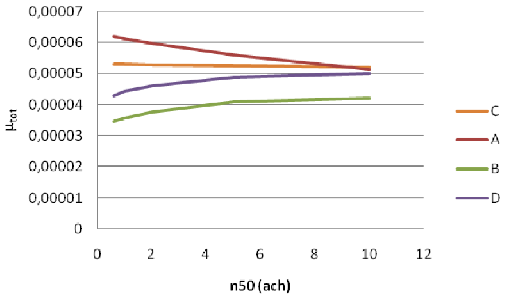

Figure 9. total exposure of an occupant to tracer in terraced house

Figure 10. parallels with figure 7: the trend seen is the same for all reference buildings, but due to differences in thermal buoyancy, the strength of this effect is different. Because of the fact that the extraction area’s have very little or no outer wall area, the effect of increasing airtightness on a natural system for the buildings without sufficient height is even more dramatic. The previous observations with regard to robustness also apply.

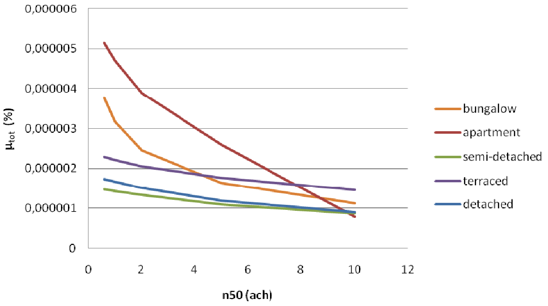

Figure 10. System A in all reference dwellings

With regard to spread of the odours, Figure 11. again demonstrates the importance of pressurization. System C, which is ideally conceived to extract all odours, only reaches good control of the spread of odours when sufficient pressurization is reached. Again the possible instability of flow orientation in system D can be noted. Note that while the robustness of system A decreases with increasing airthightness when μ_{tot} is concerned, the stability of flow direction improves.

Exposure to material emissions

Once again, the phenomena observed in the previous two chapters can mutatis mutandis be found for the exposure of the occupants to material emissions.

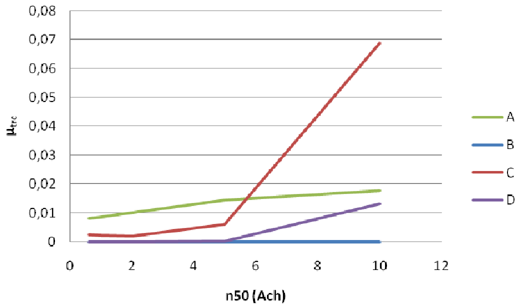

Figure 11. TRC in the detached house

Here again, system B is more robust and system C is more airtightness dependent because of the difference in design air flow rate. Pollutants are generated in both living and 'wet' aeras. Therefore the performance of a system for this criterion is a combination of its performance for the above mentioned two. Note again that the absolute value indicated is not a physical property nor does it represent a specific material. It is merely an indicator for this kind of pollutants. Moreover, as was mentioned above, it is only relevant for comparison of systems within the same dwelling.

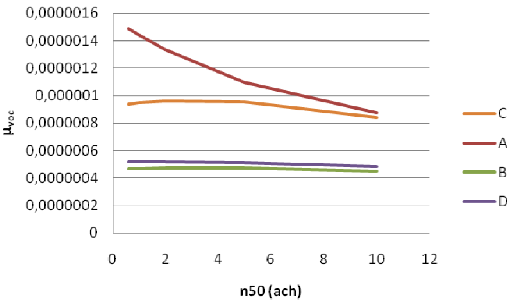

Figure 12. exposure to building material emissions in the semi-detached house.

DISCUSSION AND RESULT ANALYSIS

The analysis above proves that the ability of the current Belgian standard to assure good performance of the ventilation system is rather dubious. From the results presented above, at least large differences in performance for the different systems and in different reference buildings can be observed. Due to this, the only criterion that is currently used to assess the acceptability of a new system is a comparison to the worst of the systems that are described in the standard (Wouters, 2008), by lack of a better legal argument.

It would of course be more preferable to have a more abstract criterion to assess acceptability, if only to avoid tedious calculus and endless discussion on how the reference system should be simulated. The implementation of such a criterion in a standard is what could be called a 'performance based' ventilation standard and is described in EN 15665. This standard proposes several methodologies for the definition of a reference critierion. In the simulations presented here, the exposure of the occupants to three kinds of pollutants was addressed. These types were chosen because they are specific to the indoor environment. However, other possible parameters were not taken into account, such as pollution introduced by the mechanical and ducted ventilation components (mould growth in filters, dust accumulation, chemical desorption etc.). It is evident that only systems with mechanical supply components will pose a threat with regard to this type of pollution. Quality management and maintenance are the best countermeasures.

Comments on numerical parameters

With regard to bio-effluents, Fanger (1988) established a broadly accepted framework to assess quality of indoor air. Eg. The European standard for non-residential ventilation (CEN, 2004) is based on it. This framework however is oriented toward design air flow rates, in steady state situations. The quality of a ventilation system, especially in the residential context, lays in its ability to provide good comfort over a broad range of occupancy situations.

The parameters introduced here (μ_{PD}, σ_{PD} and δ) have proven adequate for relative comparison of simulation results, but as can be seen in Figure 13., the distribution of the air quality to which an occupant is exposed does not adhere to a specific distribution and thus μ and σ are not fit to assess the performance of the system in an abstract way.

The Dutch ventilation standard introduced a methodology to address this time-based component by means of the Low Ventilation Index (Lvi). This criterion is dose based, normalised to a reference CO_2 concentration. It can easily be read from by integrating (1 - cumulative distribution of the air quality). Vandenbossche (2007) introduced a similar dose based criterion.

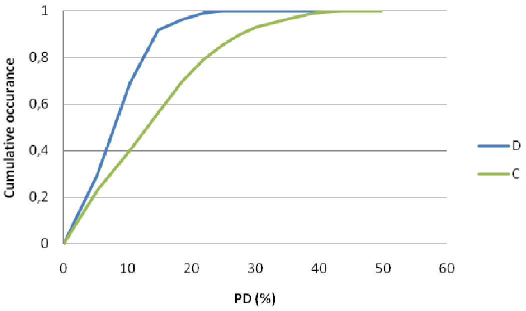

Figure 13. Cumulative occurrence of dissatisfaction for system D and system C in a detached house.

In the European standard EN 13779 (CEN, 2004), different indoor air quality classes are defined, the second best class (IDA II - medium IAQ) allows a maximum PD of 20%. If a dose of 1 is allowed, this means that PD 30 % (IDA IV - bad IAQ) occurs for maximum 10% of the time. For the two systems seen depicted in Figure 12. this dose is 0.15 and 1.39. With this criterion, system C can't be allowed.

The Dutch standard is far more sever and allows 30 % dissatisfied for maximum 1.5 % of the time. Note again that system C is not acceptable when this criterion is applied. (Lvi of 0.0009 for system D and 0.07 for system C, with a maximum of 0.005 allowed, but window use is taken into account in the calculation procedure for the Dutch standard)

These numerical criteria were not used in the analysis of the systems because of the fact that, although they are better suited for the assessment of acceptability of the systems, they fail to render a good impression of the general, 'mean' air quality provided by a system.

Comments on occupancy schedules

The assessment of a ventilation system is, with regard to human generated pollutants, heavily dependent on the occupancy schedule used. The importance of source definition is also stressed in the EN 15665 standard. While the Dutch standard applies a single reference family, Vandenbossche (2007) applied a Monte Carlo analysis, based on occupancy schedules for 100 families developed by the BBRI.

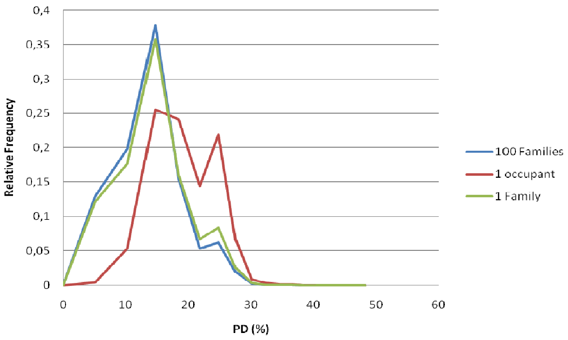

Figure 14. Relative occurrence of indoor air quality for different occupancy references.

Figure 14. depicts the relative occurrence of different indoor air quality levels in the simulation period for 1 occupant, 1 family and finally the total of all 100 families for system C in the detached house. It is clear that there is a large difference between the distribution of air quality to which one individual occupant is exposed and the distribution of air quality to which larger groups are exposed. The larger the group is, the smaller the weight of a single occupant and thus the greater the risk of non detection of his ill-adapted situation.

To counter this risk, one could simulate a large number of equally possible occupancy schedules, as is done in the Monte Carlo approach, and then interpret the air quality of a high-end percentile of the distributions per occupant. It is evident that a large amount of calculus will be necessary with this approach. One could also apply only one simulation and interpret the distribution of the occupant in this simulation with the worst indoor air quality. This nonetheless does not provide any information about the relevance of this single occupant. A simplified approach could be to try and achieve something similar as the Monte Carlo in a single simulation.

When assessing the acceptability of a system, the focus should be on the minimization or containment of risk involved. This principle is currently broadly accepted, eg. the Eurocodes for structural design. If statistical information about the occupancy of dwellings is available, a X % percentile occupancy schedule can be produced from this data. The graph in Figure 15. for example, depicts the 90 % percentile occupancy schedule deduced from the 100 families mentioned above. When this occupancy/source schedule is implemented, it represents 90% of the situations deemed to occur in each of the rooms of this dwelling.

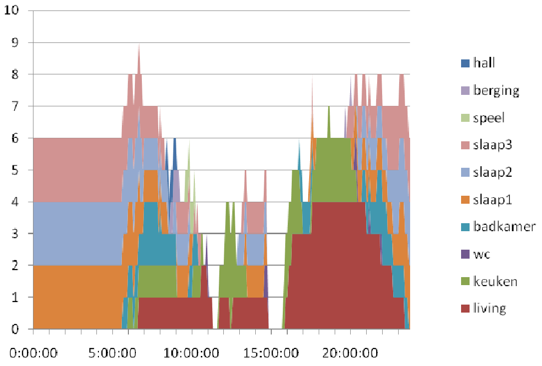

Figure 15. 90 % percentile occupancy schedule for a weekday

Note that while the more than 90% of the families in Belgium have 4 members or less (ADSEI, 2005), up to 9 occupants occur in this schedule due to uncertainty about the location of the family members. Hence they appear at several locations simultaneously. This schedule is thus a very severe one. The effects of ill-adapted situations will accumulate and the distribution of the air quality to which occupants are exposed will reflect a high percentage of possible situations as well.

Concerning the exposure of occupants to odours, a similar methodology can be used. A quantative criterion nevertheless is very hard to conceive, since, although Fangers olf and decipol can easily be applied, data on the typical strength of odour sources is not available.

For material emissions, which are health related, dose based criteria are generally applied in literature (WHO, 2006; CEN, 1998). Again, the selection of source strength is rather challenging, since these are subject to large variations in time and considerable uncertainty due to the change of furniture finishing materials. Conversely to the removal of occupancy related pollutants, which can't be avoided, building material emissions should be controlled at the source rather than with ventilation. Since ventilation has a large impact on the heating load of a building, it should be kept minimal at all times. The use of adequate materials should be enough to avoid transgression of the acceptable dose of emissions at all times without raising ventilation rates. The Finish M1-standard is an example of the implementation of such an approach.

To establish the maximum emission rates per room for a given system, the methodology described above can be applied. In literature (eg. WHO), dose limits for dozens of substances can be found. By calculating the maximum emission rates allowable to achieve a dose of “1” for the fictional emission substance introduced above and assuming that this is the allowable dose, these rates can be scaled to the maximum emission rates for any of the aforementioned substances. This way, calculus can be limited. The translation of these rates to a rate per unit of material (finishing, furniture) is rather difficult, because of the uncertainty of the quantity of material in the room. This can be addressed by applying large safety coefficients.

Comments on the code prescriptions

The performance of ventilation systems sized to the prescriptions in the Belgian building code is shown to vary significantly depending on the building typology in which the system is implemented, on the building airtightness and on the type of system implemented. This is mainly due to 2 clear problems in the prescriptions. While the concept of sizing the system components to the size of the room is a valid assumption, the omission of a clause that states that the flow rates of mechanical components must be determined to the maximum of required supply or exhaust rate gravely hypothecates the systems efficiency, as was demonstrated for system C. In the example standard given in EN 15665 such a clause is integrated. Related to this is the lack of attention to pressurization. If a single sided mechanical system is used (eg. system B and C), it will only function properly if it generates sufficient pressure to control the airflow in the entire building. This is related to the flow rate, the airtightness of the envelope in the mechanically ventilated rooms and the sizing of transfer devices inside the building. As long as the resistance of the transfer devices equals that of the envelope, no efficient transfer is realized. The introduction of airtightness limits is thus crucial.

CONCLUSION

The systems described in the Belgian residential ventilation standard were tested with 3 different performance indicators: exposure to human bio-effluents, odours and material emissions. Large differences in performance for the different systems were found. This is mainly caused by the lack of a system-oriented layer in the sizing guidelines. Overall, system B and D, which do not suffer from ‘bottleneck’ components, perform very well, while system A and C should be revised. These trends have been found for all 3 of the considered indicators.

REFERENCES

ADSEI. 2005. bevolking en huishoudens, S220.A3N/2005

AIVC. 2008. Trends in building ventilation market and drivers for change, VIP, 17-26

BIN. 1991. Ventilatievoorzieningen in woongebouwen, NBN D 50-001, Brussel.

Bossaer, A., Demeester J., Wouters P., Vandermarcke B, Vangroenweghe W. 1998. Airtightness performances in new Belgian dwellings. Proceedings 19th AIVC-conference, Oslo, 77-84

CEN. 1998. Ventilation for buildings – design criteria for the indoor environment, CR 1752, Brussel

CEN. 2004. Ventilation for non-residential buildings – Performance requirements for ventialtion and room-conditioning systems, EN 13779, Brussel

CEN. 2005. Criteria for the indoor environment, including thermal, indoor air quality, light and noise, EN 15251, Brussel

CEN. 2007. Ventilation for buildings – Determining performance criteria for design of residential ventilation systems, EN 15665, Brussel

Erhorn E. 1986. Influence of the meteorological conditions on the inhabittants’ behaviour in dwellings with mechanical ventilation. 7th AIC Conference, UK, 11

Fanger P. O. 1988. Introduction of the Olf and Decipol units to Qualify Air Pollution perceived by humans indoors and outdoors, Energy and Buildings (1-6), 1988(12).

Hens H., d’ Haeseleer W. 2006. EL²EP final report, Leuven

Laverge J. and Janssens A. 2008. Comparison of code-compliant residential ventilation systems on a performance basis, BPS2008, Leuven

Säteri J., Hahkala H. 2001. Classification of Indoor Climate 2000., FiSIAQ, ISBN 952-5236-14-5

Seppänen O. A., Fisk W. J. 2004. Summary of human responses to ventilation, Indoor Air, (102-118)2004(7)

Steeman M., Laverge J. and Janssens A. 2009. On including moisture buffering in the performance evaluation of humidity controlled ventilation systems. Cold Climate 2009

Van Den Bossche, N., Janssens A., Heijmans N., Wouters P. 2007. Performance evaluation of humidity controlled ventilation strategies in residential buildings. Thermal performance of the exterior envelopes of whole buildings X, ISBN 978-1-933742-28-1. ASHRAE special publications,

Wouters P., Heijmans N., Erhorn-Kluttig H., Erhorn H., Lahmidi H., Spiekman M., van Dijk D. 2008. Assessment of innovative systems in the context of EPBD regulations, Information paper P063 of EPBD Buildings Platform, ASIEPI WP6 report

WHO. 2006. Air Quality Guidelines, global update