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Performance assessment of residential mechanical exhaust ventilation systems dimensioned in accordance with Belgian, British, Dutch, French and ASHRAE standards

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ABSTRACT

Sizing rules in residential ventilation standards lack uniformity in both methodology and resulting design flow rates. Additionally, mere comparison of design flow rates is case sensitive and, due to effects of infiltration, adventitious ventilation and occupancy, ill-suited to assess performance of an exhaust ventilation system with regard to the achieved indoor air quality and energy cost in terms of heat loss. This paper presents a multi-zone simulation based performance assessment of residential mechanical exhaust ventilation systems, using five common dwelling typologies and the sizing rules put forward in the Belgian, British, Dutch, French and ASHRAE residential ventilation standards. The performance of the different cases proved to be substantially different, with an occurrence of poor perceived air quality in 5% or less of the occupation time for the Belgian, Dutch and French standard, and about 15% for the British and ASHRAE standard. When the trade-off between indoor air quality and heat loss is considered, the cases with the Dutch and ASHRAE standard did not achieve pareto optimal performance in comparison to the performances achieved by the other standards.

1. Introduction

The 1970's oil crisis caused the first wave of energy conservation campaigns in buildings. Improved airtightness of newly built dwellings and intensive weatherisation actions considerably reduced the amount of fresh air infiltration. As an unintended consequence of this, the incidence of indoor mould problems peaked and reports on high prevalence of occupants complaining of a wide variety of symptoms or physical discomfort, baptised 'sick building syndrome', emerged.

As a reaction to these problems with indoor air quality, ventilation standards were established in most western countries. Unfortunately, this did not happen on an internationally coordinated level, giving way to the introduction of a wide range of sizing rules. As there is no common methodology, like the one that was developed for non-residential buildings by CEN [1], that is used for the different standards, the flow rates proposed in them can't be compared easily. AIVC listed the requirements of 15 standards without attempting to analyse their performance [2]. A similar effort was done in the framework of the EPHECT project [3]. Two reviews, one by Yoshida [4] and another within the HEALTHVENT project [5] applied the sizing rules to a reference dwelling and found that the design air change rate in the majority of standards is around 0.5 ACH.

In the moderate climate region of West-Europe, especially in Belgium, the Netherlands, France and the UK, simple exhaust mechanical ventilation systems dominate the residential ventilation market [6–8], while heat recovery ventilation and natural ventilation are the most common residential ventilation systems in northern and southern Europe respectively. Such simple exhaust systems are composed of a mechanical exhaust fan, ducted to a series of vent holes in the different 'wet' spaces in the dwelling such as kitchens, toilets, bathrooms and service rooms, combined with externally and internally mounted air transfer devices [9]. The externally mounted air transfer devices, also called trickle ventilators, are intentionally made perforations in the building shell that deliver the make-up air for the air extracted from the dwelling by the fan, while their internally mounted counterparts, also called transfer grilles, allow the air to flow from one space to an other. Since the introduction of ASHRAE 62.2, this kind of ventilation system is also rapidly achieving a dominant position in the US residential ventilation market, although the use of trickle ventilators is usually omitted and not treated as such in the standard. The sizing rules for the trickle ventilators in the standards of the 4 European countries also demonstrate little uniformity, requiring

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the design flow rate, which itself is different for all standards, to be achieved at a different design pressure difference across the ventilator, ranging between 1 and 20 Pa.

The total air change rate achieved by simple exhaust ventilation systems can be considerably different from the flow rate of the fan due to adventitious ventilation and infiltration [10]. The importance of the extra flow rate is mainly related to the sizing of the trickle ventilators relative to the flow rate of the fan [11]. Therefore, the ventilation heat loss of exhaust ventilation systems can't be assessed comprehensively by simple comparison of the design flow rates. In addition, the air flow in the system is controlled by the mechanical flow rate only in the 'wet' spaces, whereas the flow rate in the rest of the dwelling, which comprises the main living spaces, is governed by much less stable driving forces such as wind and buoyancy. Since the occupants spent the vast majority of time in the livings spaces [12,13], the indoor air quality (IAQ) achieved in these spaces will be the dominant contributor to perceived air quality [14]. Again, the design flow rates will not be a good metric for assessing the performance of simple mechanical exhaust ventilation systems.

In the EU, space heating accounts for about 26% of all final energy consumption [15,16]. Since energy performance criteria are being tightened and infiltration, adventitious and intended ventilation combined represent about 50% of the total heat loss in well insulated buildings, the 'right' flow rate and the corresponding sizing rules are at sixes and sevens. Keeping the problems that surfaced after the reductions in flow rate made during the 1970's energy crisis in mind, this debate should be based on a comprehensive analysis of the performance of the ventilation systems proposed in the standards.

Presenting the results from a multi-zone simulation based performance assessment of simple mechanical ventilation systems sized in accordance with the Belgian [17], British [18], Dutch [19], French [20,21], and ASHRAE [22] residential ventilation standards, this paper aims to contribute to this debate. The 4 European countries are chosen because of the dominance of exhaust ventilation in their ventilation market and their geographical clustering. Although exhaust ventilation historically also represents a large part of the residential ventilation market in the Nordic countries, their cold climate [10] and recent market evolutions favour heat recovery ventilation. Therefore they were not included. The ASHRAE standard was chosen for its large geographical applicability and its authority in HVAC design. Additional motives include the fact that its promotion of exhaust ventilation is novel in the US and its recent publication. The sizing rules of each standard are applied to 5 common dwelling typologies and Monte-Carlo analysis is used to consider the sensitivity of the results to the boundary conditions used.

2. Sizing in the standards

As was explained in the introduction, the sizing rules for simple exhaust residential ventilation systems put forward are different in the Belgian, Dutch, French, UK and ASHRAE standards. In this section, the specific rules found in each of the standards are summarized. If different sizing rules are provided for continuous and demand controlled systems, only those for continuous systems are considered.

2.1. Belgium

The Belgian standard requires a design flow rate of 1 l/s m^2 for each occupied space. For the main living space, this design flow rate should be at least 21 l/s and can be limited to 42 l/s, while for bedrooms, studies… the minimum value is 7 l/s and the design flow rate can be limited to 20 l/s. For kitchens, bathrooms and service rooms, a minimum design flow rate of 14 l/s should be taken into account, while it can be limited to 21 l/s. The design flow rate for a toilet is 7 l/s. Table 1 provides a summary of the design flow rates.

Table 1
Design flow rates in the Belgian standard.

Space	Design flow rate	Minimum, l/s	Maximum, l/s
Living room	1 l/s m^2	21	42
Bedroom/study/…	1 l/s m^2	7	20
Kitchen/Bathroom/ Service room	1 l/s m^2	14	21
Toilet	7 l/s	–	–
Hall/stairwell	1 l/s m^2	–	–

The occupied spaces and the wet spaces should be connected to each other or via circulation spaces by transfer grilles sized at 7 l/s at 2 Pa pressure difference, which corresponds to 70 cm^2, except for the kitchen, in which the transfer grille should be sized twice as large. Each living space, bedroom, study… should be connected to the outdoor environment by a trickle ventilator sized at the design flow rate for that space at 2 Pa pressure difference.

2.2. The Netherlands

With a design flow rate of 0.9 l/s m^2 for each occupied space and minimum design flow rates of 7 l/s in bedrooms, studies and toilets and 14 l/s in bathrooms and service rooms, the Dutch standard's sizing rules are quite similar to those in the Belgian standard. The minimum design flow rates for the kitchen, however, is set at 21 l/s instead of 14 l/s, while in the main living space, only 7 l/s is required as opposed to 21 l/s in the Belgian standard. Furthermore, trickle ventilators should be sized at the design flow rate at 1 Pa pressure difference and transfer grilles should have a free face area of 12 cm^2 multiplied by the design flow rate for that space. As a consequence, the size of the trickle ventilators and transfer grilles is larger compared to the Belgian standard's sizing rules.

2.3. France

The design flow rate for each of the 'wet' spaces in the French standard depends on the number of 'main' spaces in the dwelling, e.g. living spaces, bedrooms, studies…. These flow rates have been tabulated in Table 2. The design flow rates of the trickle ventilators in the remaining spaces are also defined as a function of the number of 'main' spaces. For dwellings with only 1 or 2 'main' spaces, the design flow rate is increased for higher total design flow rates in the 'wet' spaces (Table 3).

The trickle ventilators should be sized to the design flow rate at 20 Pa pressure difference, while the transfer grilles should be sized to the design flow rate at 5 Pa and 2.5 Pa for 'wet' and 'main' space grilles respectively. As a consequence, the size of components is typically smaller compared to the Dutch and Belgian standard's sizing rules.

Table 2
Exhaust flow rates in the French standard.

No of main spaces	Kitchen, l/s	Bathroom, l/s	Service, l/s	Toilet, l/s
1	21	5	5	5
2	25	5	5	5
3	30	9	5	5
4	34	9	5	5 or 9[a]
≥5	38	9	5	5 or 9[a]

[a] 5 l/s if multiple toilets are present, 9 l/s if only one.