OPTIMAL SIZING RULES FOR NATURAL, SIMPLE EXHAUST AND MECHANICAL RESIDENTIAL VENTILATION SYSTEMS

Jelle Laverge* and Arnold Janssens

Ghent University
Jozef Plateaustraat 22
9000 Gent, Belgium
**Corresponding author: jelle.laverge@ugent.be*

ABSTRACT

Sizing rules in residential ventilation standards lack uniformity in both methodology and resulting design flow rates. In order to investigate the best achievable performance of natural ventilation, exhaust and fully mechanical ventilation systems, this paper presents a multi-zone simulation based optimization study for both a detached dwelling.

Total ventilation heat loss, including mechanical ventilation, adventitious ventilation and infiltration as well as occupant exposure to carbon dioxide are used as criteria. The results show that the relative optimal performance of all three system approaches can be very different, when average exposure or peak exposure is considered.

KEYWORDS

Optimization, Exhaust Ventilation, Residential, Simulation, IAQ

INTRODUCTION

The first wave of energy conservation interventions in buildings, ushered into existence by the 1970’s oil crisis, considerably reduced the amount of fresh air infiltration through improved airtightness of newly built dwellings and intensive weatherisation campaigns. 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’[1-5], emerged.

The continued scientific interest in these emerging problems was the basis for the indoor environmental science field, growing fast over the last decades. The state of the art within this field has demonstrated positive correlations between indoor air pollution and human health [6, 7], comfort [8-10] and productivity [11, 12]. As people spend about 90% of the time indoors [13, 14], the minimization of these effects is essential. The issue has been prioritized by WHO [15]. Although source control is the most effective and straightforward way to reduce exposure to harmful pollutants, some emissions are related to the very function of the building, such as housing the occupants in residences. The sources related to these essential functions can’t be eliminated. Therefore, the pollutant concentrations are diluted by ventilation. For occupant health, fresh air flow rates below 25 l/s per person for offices or building air change rates lower than 0.5 are associated with higher prevalence of symptoms of sick building syndrome and allergies respectively [16]. With respect to comfort, flow rates below 7 l/s per person are considered to result in unacceptably poor perceived air quality in European ventilation standards [17, 18].

Political action in the aftermath of the reports on the consequences of poor indoor air quality saw to the introduction of ventilation requirements in building codes all over the western countries. The air flow rates required in these standards, as well as the sizing required for non-mechanical system components such as trickle ventilators and transfer grilles [19], can vary quite considerably, with whole building air change rates ranging from 0.3 to 1 [20] for dwellings.

In addition, due to differences in climate, boundary conditions, occupant behaviour and consumer preference, 3 main types of residential ventilation systems are dominant in the Northern, Western and Southern part of Europe respectively. Heat recovery ventilation is the most common system in Scandinavia [21]. In the moderate climate region, simple exhaust systems are more popular [22], while natural ventilation is widespread in Southern Europe.

The performance of the different systems [23-25] and approaches to sizing of their components that are put forward [26] is the object of relentless debate. Presenting the results from a multi zone simulation based optimization study of residential ventilation design flow rates and sizing of the system components, this paper aims to provide a benchmark for achievable performance for the different systems for moderate climate regions (eg. Western Europe), as well as point to possible sizing strategies for future standards.

SIMULATION MODEL

The results presented in this paper are based on airflow simulations. These were executed in the multi-zone airflow simulation package Contam [27], which takes effects of buoyancy, wind and fan pressure into account and is used in numerous ventilation studies [eg. 28, 29].

Building Model

The geometry used in the model is based on a detached house that is statistically representative for the average Belgian dwelling. It has been designed for and used in several previous research projects [30-34] and is currently used to assess the performance of residential ventilation systems in the EPBD framework in Belgium [35]. Table 1. lists the dimensions (m²) of the spaces in the building model. The airflow in the dwelling has been modelled taking into account both the ventilation system and leakage. Overall leakage, characterized by the v_{50} value, is modelled by means of cracks in the roof and wall surface. The v_{50} value is the ratio of the air leakage rate at 50 Pa pressure difference and the building envelope heat loss area. According to observations by Bossaer [36], the specific leakage rate through roof and walls has a 2/3 ratio, which has been implemented in the model. Each wall is fitted with two cracks, one at 1/4 of its height and the second one at 3/4. The internal doors are simulated with additional cracks in the walls. For the internal walls, a fixed specific leakage value is assumed. This methodology is in agreement with guidelines given in EN 15242 [37]. In the results presented, a specific airleakage (v_{50}) of 1 is used. This represents the 'best practise' for current construction in Belgium and other european countries [38]. This high performance level for building leakage was selected to assess the performance of the ventilation system as such, unbiased by the effect of leakage on both heat loss and indoor air quality.

The production of CO_2 within the model is only related to the occupants' metabolism and corresponds to their whereabouts. A constant outdoor background concentration of 350 ppm is assumed. A different occupancy scheme is used for each day of the simulated week. This makes sure that the reported exposure is insensitive to the specific occupancy schedule and the promotion of 'tailor made' sizing rules is prevented. The mean occupancy for the whole week, 3.4 persons, corresponds to the average occupancy of a 3 bedroom dwelling in

Belgium. Humidity production, like carbon dioxide production, is linked to the metabolism of the occupants with additional production linked to activities such as cooking, bathing and drying clothes. An effective moisture penetration depth model is used to take buffering into account. An odour tracer is produced in sync with the use of the toilets.

Ground Floor	**Area**	**Supply**	**Exhaust**
Living room	35.7	128.4	
Office	8	28.9	
Kitchen	10.2		50
Service room	7.7		50
Toilet	1.7		25
Hallway	28.1		
1st Floor	**Area**	**Supply**	**Exhaust**
Bedroom 1	17	61.1	
Bedroom 2	18.2	65.6	
Bedroom 3	18.3	65.8	
Bathroom	8		50
Hallway	28.1		

Table 1. Geometrical characteristics of reference dwelling.

Ventilation system design and model

The ventilation scheme used in both dwelling geometries is based on the sizing rules put forward in the Belgian residential ventilation standard [39]. This standard is chosen because it contains clear and simple sizing rules for natural, exhaust and mechanical ventilation.

The Belgian standard requires a design flow rate of 1 l/s*m² for each occupied space. For kitchens, bathrooms and service rooms, a minimum design flow rate of 14 l/s should be taken into account. The design flow rate for a toilet is 7 l/s. The design flow rates for the reference dwelling according to these sizing rules are listed in Table 1.

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 cm², except for the kitchen, in which the transfer grille should be sized twice as large. For natural and exhaust ventilation systems, supply trickle ventilators and exhaust grilles should be sized at the design flow rate for that space at 2 Pa pressure difference.

The design flow rates for supply, transfer and exhaust as mentioned above are varied from 10% to 200% in 10% steps in order to assess the optimal performance of 3 ventilation system approaches. Since the flow rates proposed in the Belgian standard are moderate to high in comparison to other residential ventilation standards [19, 20], this covers a broad range of sizing options that are both realistic and within ranges used in existing standards.

All mechanical exhaust vents were modelled as constant volume flow rate components in the respective zone node, while transfer grilles and trickle ventilators were modelled with single direction power law flow components with a flow exponent of 0.5 [40]. All systems were modelled with windows and internal doors closed, in order to simulate the performance of the systems as such, without user interaction.

Assessment parameters

Through the correlation between excess CO_2 concentration and mean percentage of dissatisfied [17] and Fanger's Perceived Air Quality approach [10], excess CO_2 concentration is now widely accepted as a proxy for perceived indoor air quality [18], especially if the main pollution sources are related to the human metabolism. In contrast to the basic model, steady state conditions are rarely applicable to real ventilated environments. CO_2 concentrations are inherently transient, due to changes in environmental boundary conditions. Additionally, the relevant CO_2 sources tend to constantly move around in the multi-spaced dwelling, introducing discontinuous sources and further increasing the transient character of the indoor air quality. There is no consensus in literature about the way transient concentrations have to be interpreted. This lack of agreement is reflected in the disparate list of performance criteria provided in EN 15665 [41]. From the suggested parameters in this standard, 2 were selected for use in this paper, namely the total dose of CO_2 for an occupant over the total heating season and the dose of CO_2 over 1000 ppm excess CO_2. Exposure to concentrations in excess of 1000 excess CO_2 is considered to correspond to poor perceived indoor air quality [18] and is therefore a relevant parameter for peak exposure.

The total, heating season averaged, convective heat loss through the combination of intended ventilation, adventitious ventilation and infiltration is used to assess the energy performance of the different sizing options. Fan power was not taken into account because it is very system specific.

RESULTS AND DISCUSSION

As was discussed above, the sizing of supply, transfer and exhaust components was, each in 20 steps, varied within a realistic range. This amounts to $8*10^3$ cases for every system option. From these sizing options, the achievable performance is assessed based on the proposed criteria. Ventilation is always faced with a trade-off between indoor air quality and associated ventilation heat loss. Therefore, the achievable performance is defined as the set of pareto optimal sizing cases for a specific indoor air quality criterion. Pareto optimal cases are cases where none of the other cases achieve better results on both indoor air quality and heat loss.

Figures 1-2 show the pareto optimal cases for the airtight detached house with natural ventilation, simple exhaust ventilation and mechanical ventilation and using occupant exposure to carbon dioxide as indoor air quality criterion. As was mentioned in the methods section, two separate parameters were initially selected to characterize this exposure: the average concentration to which occupants are exposed and the total dose over 1000 ppm excess carbon dioxide. When the former is considered, the pareto optimal solutions for the different installation concepts are rather similar (figure 1.). Considering the latter, however, two striking aspects are observed: in a large number of cases, the occupants are not exposed to excess carbon dioxide concentrations higher than 1000 ppm, regardless of the system concept while the optimal cases off the different system concepts demonstrate larger discrepancies (Figure 2.). The exposure to high carbon dioxide concentrations for an optimal case of the natural ventilation system is on average 7.5 times higher than that for an optimal case of the mechanical ventilation system at the same level of heat loss, while this increase was only about 50% when considering average exposure. The average heat loss for an optimal case of the natural ventilation system is 16, and 22 % higher than the heat loss for an optimal case of the mechanical ventilation system at equal exposure, considering average exposure and dose over 1000 ppm excess carbon dioxide concentration respectively. The differences between the spread in optimal performance found with the different criteria is readily explained by the higher variability of the air flow in the natural system. This increases the exposure to peak concentrations, while the average is less affected.

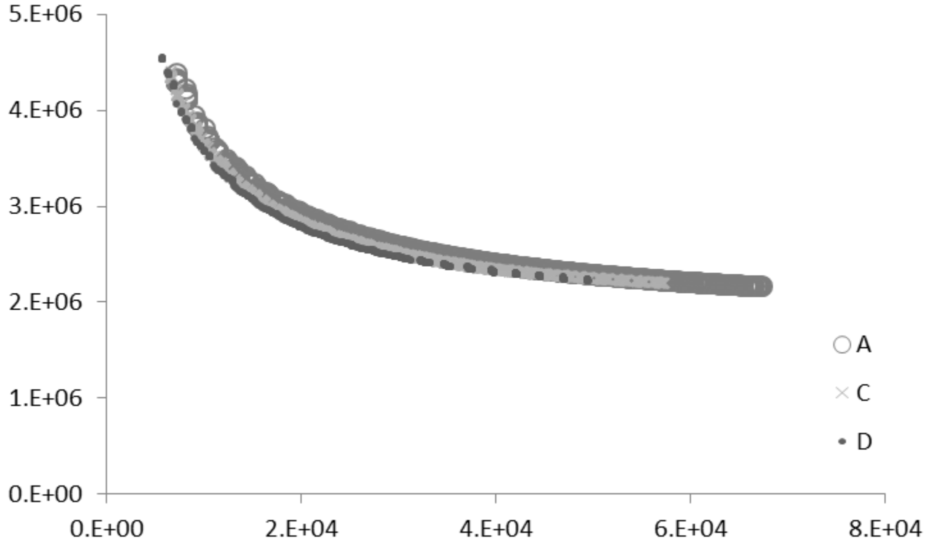

Figure 1. Heating season averaged ventilation heat loss traded-off against total exposure to carbon dioxide concentration to which occupants are exposed during the heating season for all pareto optimal cases for natural (A), simple exhaust (C) and mechanical (D) residential ventilation.

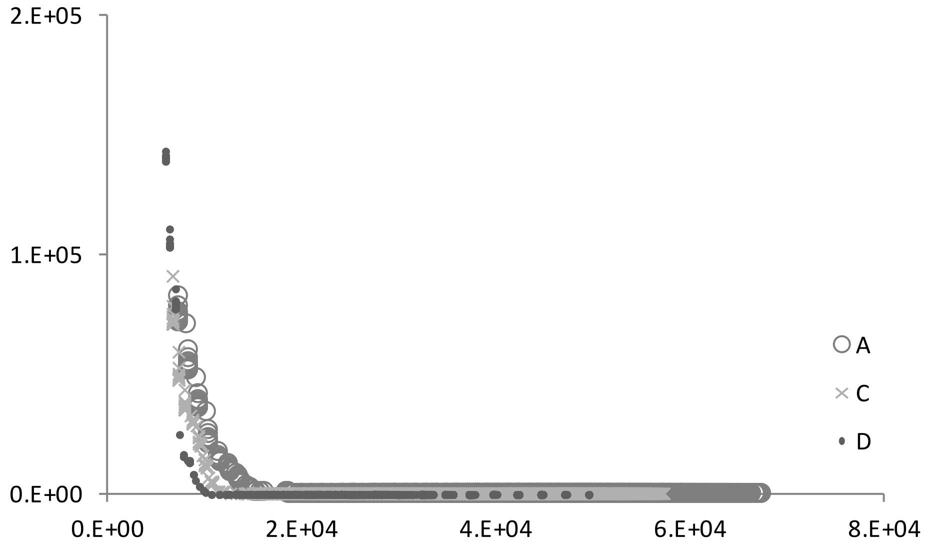

Figure 2. Heating season averaged ventilation heat loss traded-off against exposure to carbon dioxide concentration in excess of 1000 ppm above the outdoor concentration to which occupants are exposed during the heating season for all pareto optimal cases for natural (A), simple exhaust (C) and mechanical (D) residential ventilation.

CONCLUSION

In this paper, the differences in optimal performance of the natural ventilation, the simple exhaust ventilation and the mechanical ventilation concept was assessed with numerical simulations. Optimal performance was defined as the best achievable indoor air quality for a given ventilations heat loss or vice versa. Total and peak exposure to carbon dioxide was used as indoor air quality assessment parameters. Heat loss through mechanical flow rate, adventitious ventilation and infiltration were considered part of the total ventilation heat loss.

Considering total exposure to carbon dioxide, only slightly better performance of the mechanical ventilation concept compared to simple exhaust ventilation was observed, while the latter demonstrated slightly better performance than natural ventilation. The spread in optimal performance increased when exposure to peak concentrations was considered instead of average exposure. Nevertheless, the differences remained moderate.

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