A simple airflow path approach to sizing natural ventilation systems in a code context

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ABSTRACT

Most of the existing ventilation standards are drafted in a rather prescriptive way. Growing focus on the implementation of rational energy use however, introduces an urgent need for more performance-based criteria. Optimization of energy consumption obviously encompasses minimization of ventilation airflow rates. Comfort, on the other hand, should not be reduced because of these actions. To implement this in a legal figure, one can appeal to the principle of equivalence. This principle states that all systems achieving equivalent performance to that of the systems described in the standard are acceptable. Better yet, a new standard can be devised, imposing a reference performance rather than a reference system. This avoids all discussion about the way the reference system's performance should be interpreted. Nevertheless, practical implementation of a standard will require the definition of sizing guidelines for design purposes. The method presented in this paper is a simplified approximation of the airflow network in a building. It is conceived as a sizing guideline for natural ventilation systems in the context of a national ventilation standard. Supply, internal and exhaust resistances are the main parameters, next to overall building airtightness. These parameters are system independent and allow to describe a large scale of possible buildings. Five different dwellings, with different typologies, representative for the Flemish building stock, were evaluated for this purpose. The predicted airflow and indoor air quality are compared to that predicted by a detailed multi-zone model and acceptable agreement is found. This yields the conclusion that, for the implementation of a performance-based ventilation standard, straight forward calculation methods for sizing guidelines can be incorporated in the standard.

INTRODUCTION

Because of the ever growing stress on energetic performance of buildings, most of the existing ventilation standards have become impractical. They often propose minimal airflows in a rather prescriptive manner, based on a number of assumptions. Based on these minimal airflows, a series of application guidelines are formulated, often resulting in a 'reference system'. A good example of this type of standard is the Belgian residential ventilation standard from 1991 [1]. These standards' principle objective is to introduce minimal standards for ventilation in buildings, a novel problem introduced by increasing airtightness of buildings at the end of the 20th century.

The European EPB directive [2], introduced in 2003, urged the member states to develop and legally introduce a calculation method to characterize the energetic performance of buildings. One of the major factors in this performance indicator, especially in well insulated buildings, is the heat loss through airflows, both because of infiltration and ventilation.

Optimization of the energy performance indicator in a building design will include minimization of both airflow paths. Wherever standards exist concerning building airtightness, they impose minimal airtightness. Doing better is thus never a problem. With ventilation standards however, the opposite situation occurs. Minimizing ventilation losses will result in exploring the limits of the allowable. Therefore, the ventilation standards are the references for these calculation methods.

To evaluate the acceptability of a proposed system, it is proposed to compare its performance to that of the 'reference system' described in the standard. The results of this procedure of equivalence [3], very common in The Netherlands, however, are very sensitive to the interpretation both systems and the assumptions made in the process. As the reference systems put forward in the current standards often only include guidelines for supply, transfer and exhaust openings, the performance of the whole system is largely geometry dependant. This introduces further interpretation difficulties. The introduction of a new standard, not based on one or more reference system(s) but rather proposing a reference performance indicator is to be preferred, especially for more advanced, demand controlled systems often involved in stated energetic optimization process.

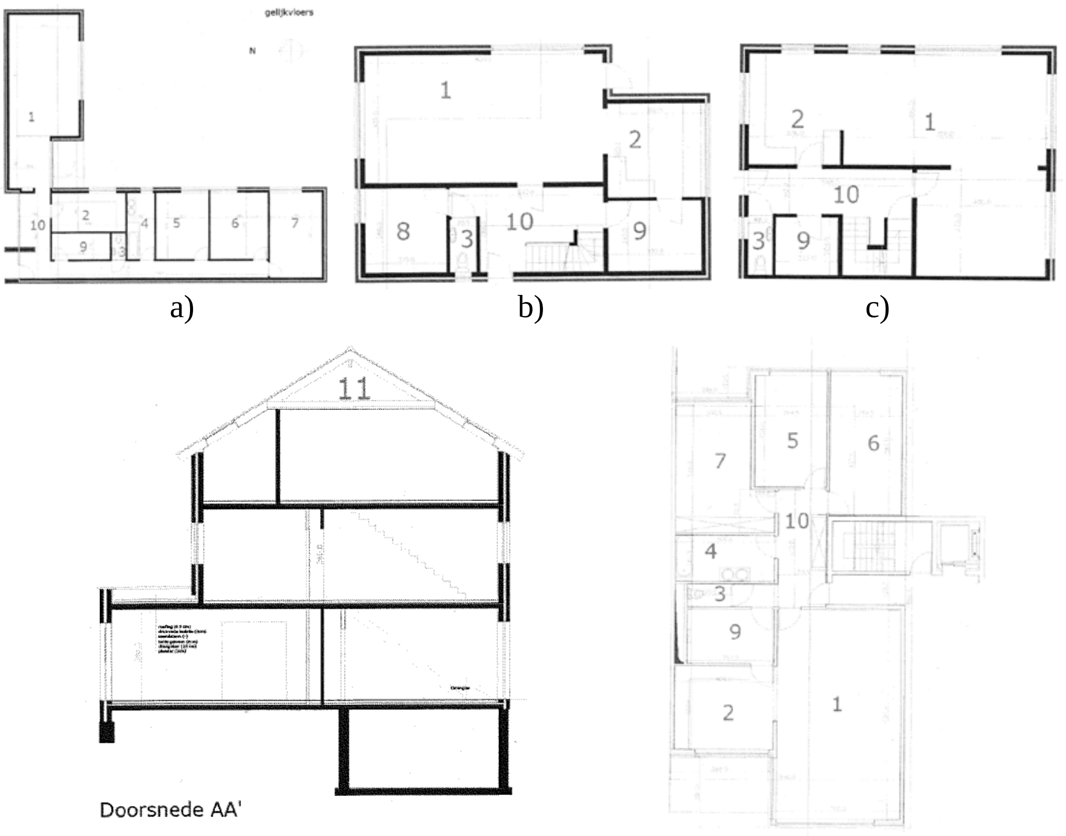
European committee for standardization recently proposed several methods to defined such a reference performance [4] , largely based on the conclusions of Fangers perceived air quality theorem [5]. Nevertheless, once this performance has been introduced, implementation of the standard in building practice will require the definition of sizing guidelines. These should enable all parties of the building process to easily define and verify the acceptability of a proposed system, without extensive simulation.

In this paper, a straightforward and compact calculation method is introduced, applicable in the approximation of the performance of a natural ventilation system. This allows to initially characterize both the energetic and the indoor air quality performance of such a system.

METHODS

Test typologies

The calculus scheme proposed in this paper will be tested on a series of 5 typologies, typical for the Belgian residential building stock [6]. They include a detached, a semi-detached and a terraced dwelling, an apartment and an architectural villa. They were modeled in the commercial multi-zone energy/airflow simulation package TRNFLOW [7]. The ventilation systems in them were sized according to the Belgian residential ventilation standard. In previous presentations [8][9], the assumptions made in these models were discussed more elaborately. The most imported of these in the context of this paper are constant temperature in all zones and consistently negative windpressure-coefficients for the exhaust openings. The exhaust openings are situated 7 meter above the supply openings of the ground floor and 4.5 meter above those of the second floor is one is present.



a) b) c)

d) e)

Figure 1. Used typologies: a) architectural villa, b) detached house, c) semi-detached house (plan), d) terraced house (section) and e) apartment (plan)

Building model schematization

The scheme involves 2 main assumptions. The first is that buildings are more and more airtight (especially in the colder climate regions) and that sizing guidelines should therefore be presented for the ideally airtight building. The second one is the representation of the building in a number of serial resistances in one single airflow path.

The graph in figure 2 shows the impact of airtightness on the average performance of a natural ventilation system in 5 different building typologies in Belgium. The graph depicts the mean CO_2 concentration an occupant is exposed over the course of a whole year in the 5 different typologies proposed, in function of the general airtightness of the buildings. Airtightness is expressed in n_{50}, the air change rate at 50 Pa pressure difference.
This clearly demonstrates that, although unrealistic, the ideally airtight building is the under limit for performance. Performance is only dependent on the implemented ventilation system in this case. It is therefore a very useful approximation in a code context.

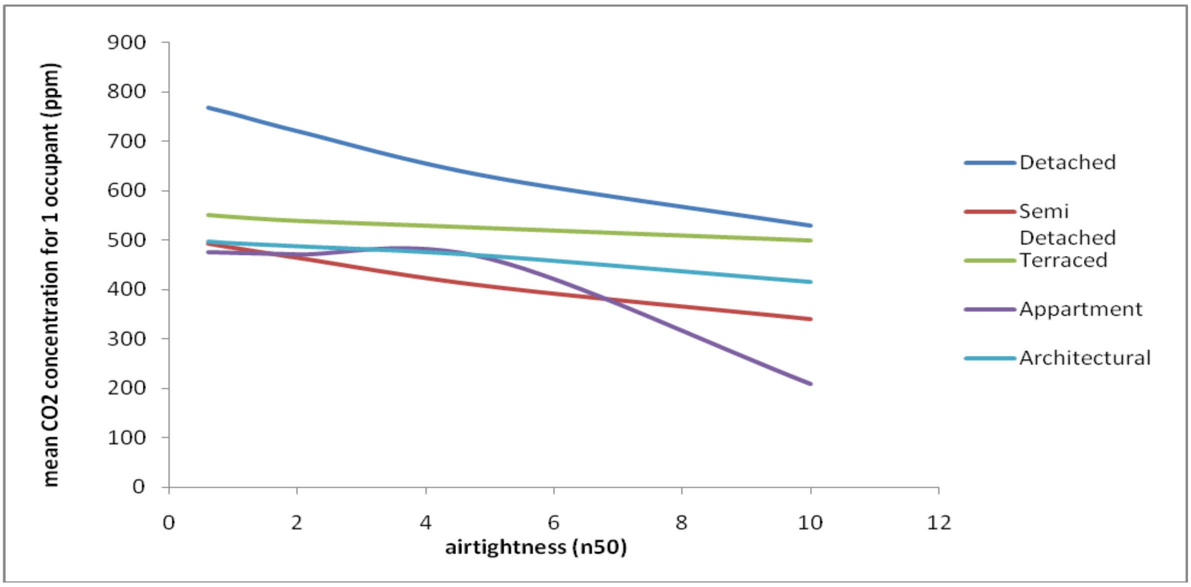


Figure 2. Performance of the natural ventilation system (mean ppm) afo. airtightness (n50, lower number is more airtight)

In general, a house can be seen as a very complex resistance scheme, often modeled in special simulation packages such as COMIS [10]. A simple approximation is proposed that bundles all resistances in one ‘plane’ and ultimately consists of a string of n serial resistances where n is the number of planes. The planes are defined as the consecutive transfer devices in the ventilation system, eg. supply, transfer 1, transfer 2 and exhaust. Figure 3. depicts this simplification.

The left picture is a geometric representation of the ground floor of a detached house. In the rooms to the right, supply openings are present, the ones to the left and in the toilet, contain extraction points. The hall is a transfer room. In the right picture the same ground floor is depicted in a resistance scheme. Some of the interconnections between the rooms have been omitted for the sake of clarity. The 4 panes are clearly marked. The first one comprises all connections of the rooms with the outdoor environment, the second one all transfer openings from supply rooms to the transfer zone (hall), the third one all transfer openings from the transfer zone to the exhaust rooms and at last the fourth one all exhaust openings.

Within one plane, all openings are summed as if they were parallel. For this summation, only the resistances of the system openings are taken into account. All resistances due to building air leakages are neglected, as discussed above. Whenever transfer openings span 2 planes, they should be counted in both with a value 2^n times the original value, thus simulating 2 serial resistances with a summed resistance equal to the original resistance. This way, the ratio of the total resistances in all panes is respected.

Finally, the n resistances thus calculated are serially connected. Mono directional flow through an opening (crack) can be approximated by a simple power law function:

$$Q = C \Delta p^n \quad . \qquad (1)$$

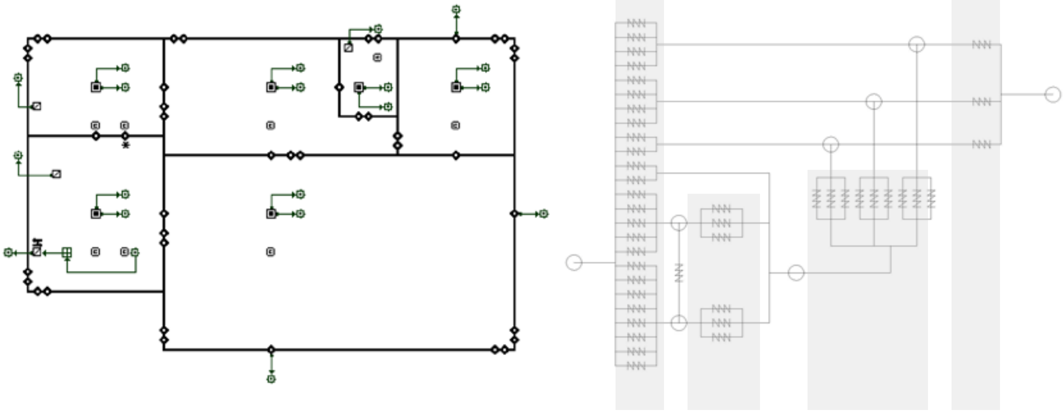


Figure 3. Building approximation. a) geometric, b) resistance scheme with indication of planes

If n is considered equal for all resistances, flow through a serial connection of C then equals:

$$Q = \frac{\Delta p^n}{\left(\sum \frac{1}{C^{1/n}}\right)^n} \quad . \qquad (2)$$

This single second equation can now be used to calculate the airflow through the natural ventilation system in a very straightforward manner.

Environmental schematization

To be able to evaluate equation (2), the pressure difference is needed. Since the systems under consideration are natural ventilation systems, this pressure difference will be caused by two separate mechanisms: wind and thermal buoyancy.

For thermal buoyancy, pressure difference is generated by the different density of air at different temperatures:

$$\Delta p = \Delta \rho g h \quad , \qquad (3)$$

with g the local gravitational constant and h the height difference between supply and exhaust openings. Whenever supply openings in are situated at different levels, a C weighted average of the calculated values should be taken into account.

Wind effects are governed by the difference in wind pressure coefficients:

$$\Delta p = 0.5 \Delta C_p \rho VEM^2 \left(\frac{Z_{ref}}{Z_{bound}}\right)^{2\alpha} \left(\frac{Z_{bound}}{Z_{met}}\right)^{2\alpha_{met}} \quad , \qquad (4)$$

where *Cp*, the wind pressure coefficient, is the ratio of the pressure difference to the local wind speed. Z_{ref} is the height of the eaves, Z_{bound} is 60 if $\alpha < 0.34$ and else 60 + (α - 0.34)*(10800*(α - 0.34)+440), Z_{met} is the height of the meteostation, α is the wind profile of the terrain, α_{met} is the wind profile at the meteostation and *VEM* is the wind speed at the meteostation. Note that wind pressure is dependant on the location of the opening since wind pressure coefficients differ for every location on the building envelope. These can be found in literature [11], measured in wind tunnel tests or calculated with CFD or other adequate software.

With the data from a standard local weather file, both pressure differences can easily be calculated over the year. As they act largely independently, they can be summed. To achieve a realistic estimate for the mean pressure difference, the mean value of Δp^n has to be calculated. To take the different orientations of the supply openings into account, a C weighted average of the pressure differences for these orientations can be introduced.

RESULTS

The application of the proposed calculus scheme to the test buildings renders the following resulting resistances.

Table 1. Resulting resistances of the test buildings (kg/h*pa^n)

Typology	Supply openings	Transfer openings 1	Transfer openings 2	Exhaust openings	Total C
Detached	259	76	96	134	45
Semi-Detached	267	96	96	134	49
Terraced	273	76	96	134	45
Appartment	264	96	96	134	49
Architectural	220	76	96	134	44

Based on a standard climate data for Belgium [12], a heating season mean pressure difference of about 3 – 4 pa can be calculated, depending on the used wind pressure coefficients and the distribution of the supply openings. The pressure difference is calculated for heating season conditions because the impact of the ventilation system is mainly situated in the winter. Occupants tend shut all additional ventilation such as windows and doors when its cold, thus reducing airflows in the buildings to those introduced by the ventilation system itself. Moreover, the energetic impact of ventilation is only important when a considerable temperature difference between in- and outdoors is present.

Figure 4 compares the results of the proposed calculus scheme to airflow predicted with TRNFLOW. The TRNFLOW simulations were carried out with ‘perfect’ airtightness. Fairly good agreement can be seen. Because of the simplifications, always taken to the save side, the method systematically underestimates the airflow.

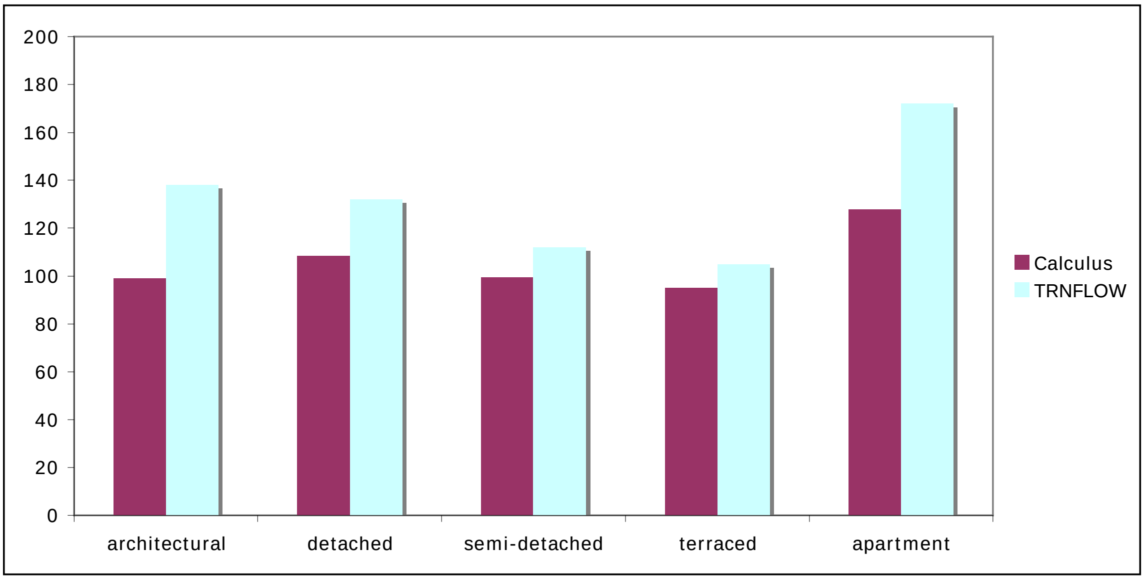


Figure 4. Annual mean airflow results of the proposed calculus scheme to TRNFLOW simulations

CONCLUSIONS

From the results that were presented in this paper, it is shown that a very straight forward method can be devised to estimate the airflow through a natural ventilation system. Such a calculus scheme could be introduced in sizing guidelines in ventilation standards. By doing so, these standards could be made both more flexible for designers and more robust in predicting the performance of the systems. Moreover, because of their robustness, they would be better suited as a criterion to evaluate the acceptability of systems in energy performance regulations and thus be more appropriate for optimization within this context.

DISCUSSION

The method proposed in this paper is, compared to the state of the art of the prediction of airflow through buildings (eg. CFD), extremely rough. However, through its straightforward nature and the conservative assumptions made, it is well suited to assess acceptability in a robust way. It allows designers and other parties within the building process, without extensive physical background, to assess a proposed system with very little effort.

The definition of the pressure difference that has to be taken in to account is however less straightforward and should be tabulated in order to allow for efficient use for this method.

To evaluate the performance of the system in more detail, pressure differences associated to high and low percentile fractions of climate data can be calculated. These provide information about the variance of the airflow that can be expected.

Because of the high level of simplification that is introduced, the scheme is not suited for use in very complex flow schemes. Most of the traditional building stock however adheres to its assumptions.

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