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CONTROLLED NATURAL VENTILATION

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SUMMARY

Natural ventilation of dwellings is commonly applied, especially in mild and moderate climates.The disadvantage of natural ventilation is the poor control of both flow directions and flow rates within the ventilated building. To improve control, the use of mechanical exhaust is often recommended.Though this may improve total ventilation, the ventilation of separate rooms often is insufficient still.

Our approach was to try and find a highly controlled natural ventilation system, whose control is highly independent of weather changes and dwelling properties, just like in thermostatic temperature control. Therefore a study has been carried out, using a ventilation calculation model.

The results show that controlled natural ventilation is possible and very advantageous. What's more, the principle is also applicable to improve mechanical exhaust systems.
In both cases, for a good controllability and maximum energy saving, a high air-tightness is recommended, though the control in the mechanical exhaust option is more sensitive to air-tightness.
The main conditions for controllability appear to be over dimensioned vertical exhaust ducts to the pitch of the roof and special, self-regulating supply provisions in habitable rooms.
With this system, ventilation flow rates of separate rooms may be kept constant, without occurrence of flow reversion, during over 90 % of time. Hence, the air quality will be highly improved to almost optimum. On the other hand, the occurrence of draughts, due to unheated air supply, will be highly reduced. Also, total ventilation energy consumption will reduce up to about 20 %, compared to a good manual control.

CONTENTS

1. INTRODUCTION

To get both an acceptable indoor air quality and a reduction of energy consumption in dwellings the control of ventilation flows per room is necessary. The present natural ventilation systems do not allow a proper control. This is illustrated by figure 1, showing the results of in-situ ventilation measurements for an airtight dwelling with natural exhaust duct, when ventilated respectively by cracks-only and by opening vent-lights [ref. 1].

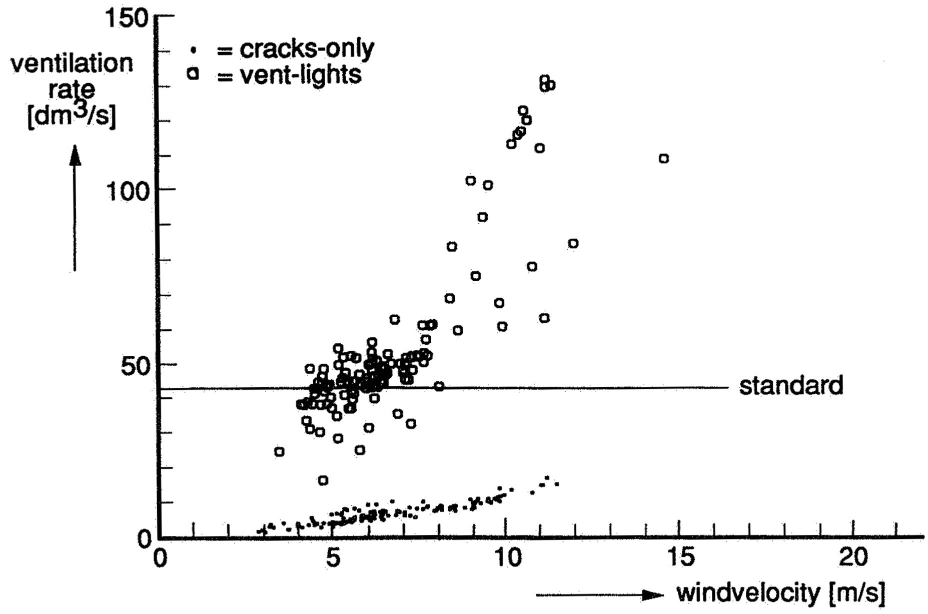


Figure 1: Measured natural ventilation rates in an air-tight dwelling by cracks only and by vent lights

The reason for the variation of ventilation flows is obvious; the setting of natural ventilation openings by the inhabitants has to depend on :

- -the wind-velocity and -direction,
- -the shape of the building,
- -surrounding obstacles,
- -temperature-differences between in- and outside,
- -the building lay-out,
- -the air-tightness of the building,
- -the use of internal doors,
- -location and size of ventilation ducts,
- -the use of ventilation provisions in other rooms.

The complexity of the ventilation process, combined with the lack of accurate signals to sense the ventilation level or even the ventilation effect, is obstructing a good manual control of natural ventilation devices.

As a solution for this problem the use of mechanical exhaust systems is often suggested. Though research has shown an improvement of the total ventilation control by the use of mechanical exhaust (see figure 2), still the control of separate rooms ventilation appears to be insufficient (see figure 3) [ref. 1].

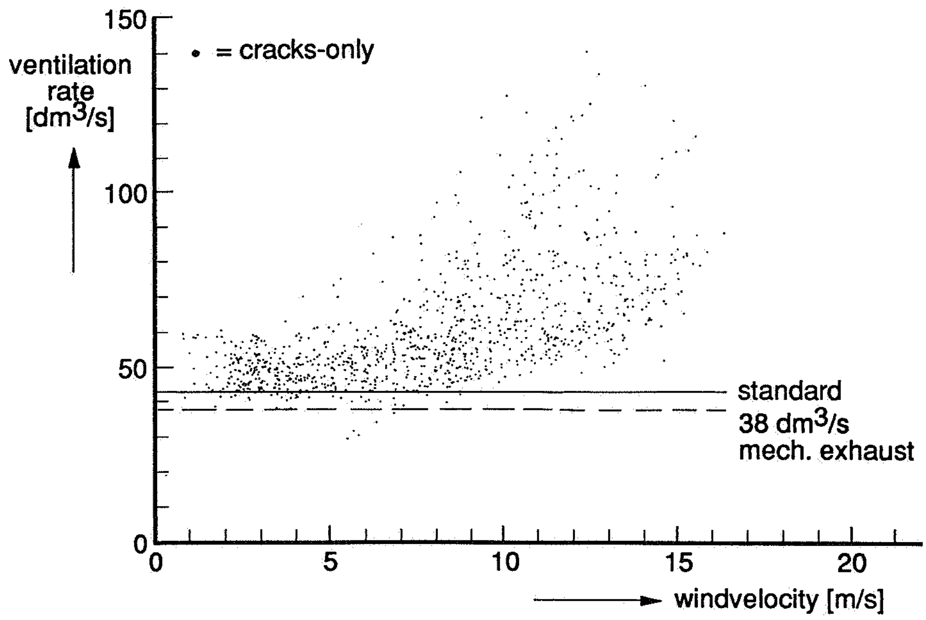


Figure 2: Measured ventilation rates in an air tight dwelling with mechanical exhaust

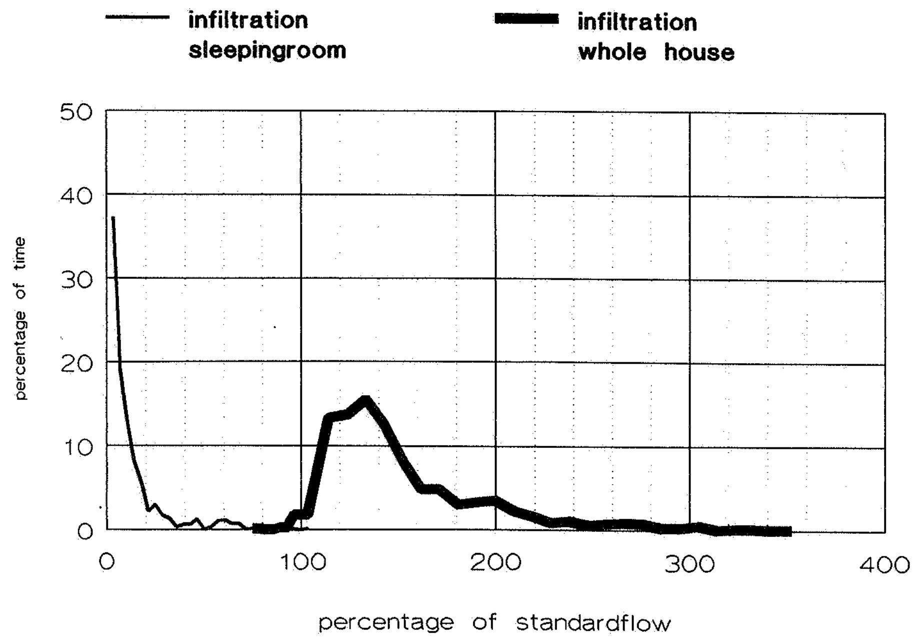


Figure 3: Ventilation distributions related to the standard flows for the whole house and a separate bed room of the air-tight dwelling with mechanical exhaust

This may be solved by the use of mechanical supply and exhaust systems. However, this type of system needs a high air-tightness of the building, to prevent extra ventilation losses by infiltration. Moreover, the costs of these systems are high, especially when installed within existing buildings.

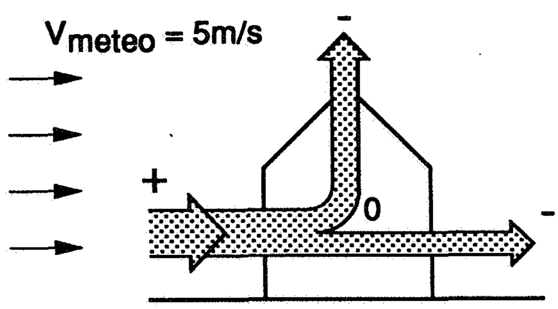
To deal with the disadvantages mentioned before, our approach was to try and find an improved, low-cost control of natural ventilation systems or mechanical exhaust ventilation systems. A parallel may be made with thermostatic temperature control. In this system the temperature has been kept constant to a set level, independent of weather changes, dwelling properties (e.g. insulation level) or fluctuations of the internal heat load.
The aim was to develop a comparable ventilation control, which automatically compensates the effects of weather changes in combination with the air-tightness and the use of internal doors within a high range, thus maintaining a pre-set ventilation level.

This publication deals with the generation of the new control principle, the determination of important system dimensions and control features by model calculations and the advantages compared to other systems. Finally, the requirements for the development of system components are summarized.

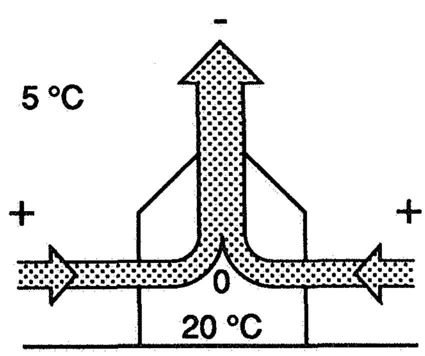
2.PRINCIPLE

Natural ventilation is mainly generated by wind forces and thermal buoyancy. These forces create pressure differences over all kinds of openings and leakages, thus causing ventilation flows through these openings. Both, the pressure differences and ventilation flows are depending on the distribution of openings over and within the building and on the parameters mentioned in chapter 1.

The main flow directions through dwellings, due to wind and thermal buoyancy, are shown in figure 4. Also shown are simplified, related pressure distributions [Note: in fact, due to thermal buoyancy, not the outside pressure but the inside pressure is varying with the height]. The actual flow directions and pressure differences under different circumstances may be all kinds of combinations of these shown in figure 4. Hence, the flow rates may differ accordingly. An often occurring pressure distribution, with related flow directions and flow rates, is presented in figure 5. The often almost zero pressure difference on the leeward side explains the under ventilation of the bed room presented in figure 3.



due to wind



due to thermal buoyancy

Figure 4: Pressure distribution over a dwelling and related flow directions and flow rates

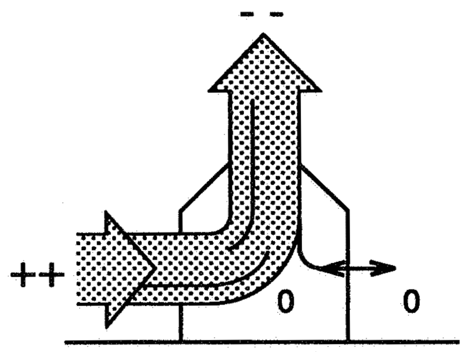


Figure 5: Often occurring pressure distribution and related flows

<u>The first step in controlling natural ventilation is to control the flow directions.</u>
It may be noticed from figures 4 and 5 that, during heating season conditions, near the pitch or the middle of the roof always extraction of air will occur. This general occurrence of exhaust in the pitch or the middle of the roof plays a significant part in controlling the flow directions. It means within this zone the lowest pressure levels will occur. By installing over dimensioned, vertical exhaust ducts into the dwelling, with outflow within this zone, the dwelling will be depressurized. This allows supply of air onto each facade, even on the leeward side (figure 6). These flow conditions will especially occur at:

-general occurring wind velocities,
-outdoor temperatures below inside temperatures.

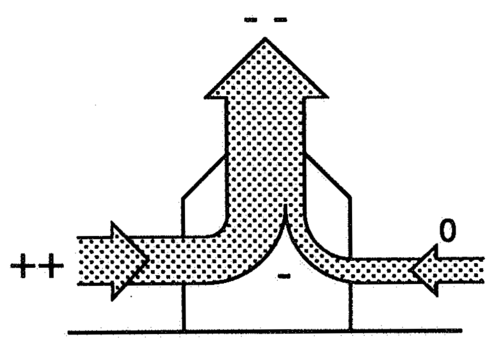


Figure 6: Depressurizing the dwelling by over dimensioned vertical exhaust ducts will improve control of flow directions.

<u>The second step is to control the supply flow rates</u> through the openings into the facade.
Without this control high differences between the flow rates of the windward and the leeward side may occur, or even flow reversion at leeward side will occur at high wind velocities, due to cross ventilation. This means ventilation openings into the facades have to be reduced with increasing positive pressure differences. While the pressure differences may differ on varying locations, decentral control of the various ventilation openings is recommended. Because of the difficulties in manually controlling ventilation openings properly, as mentioned before, automatic flow rate control is considered to be necessary. This may be fulfilled by self-regulating vents. The principle of a self-regulating vent is illustrated by figure 7.

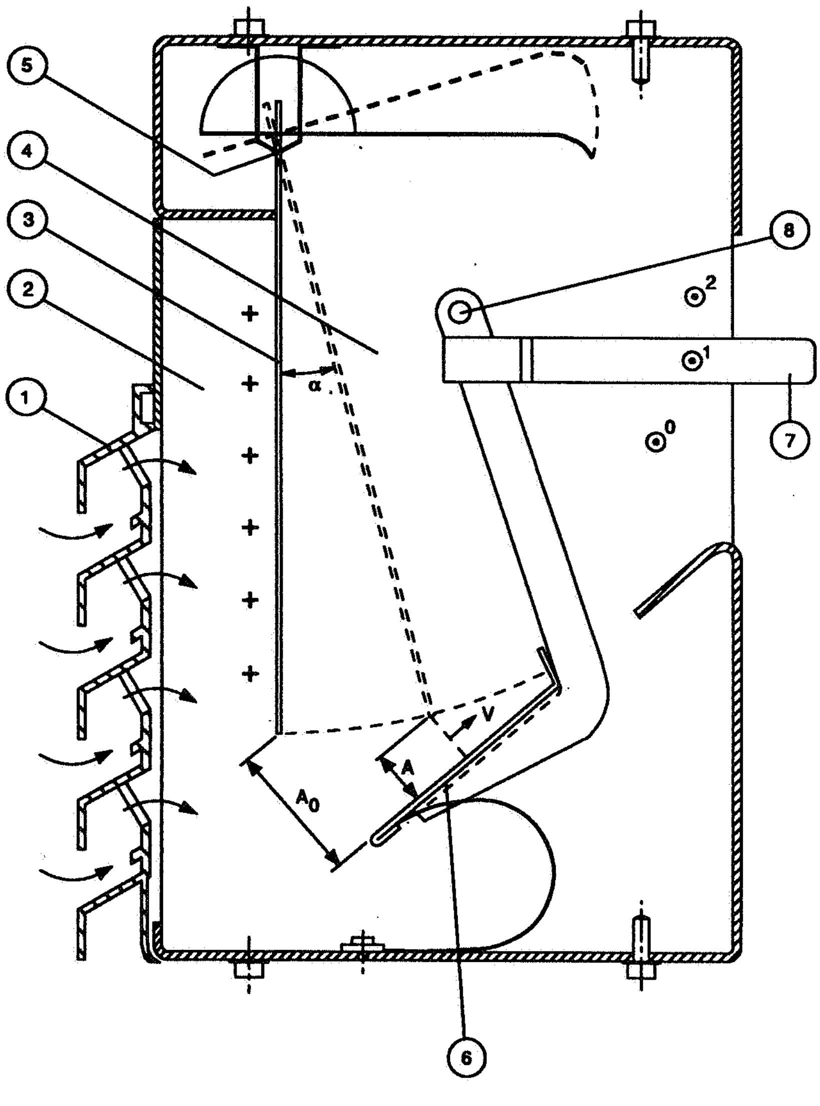


Figure 7: Example of a self-regulating vent

Influenced by over-pressure on the facade, ventilation air enters through the outside grid (1) into the front chamber (2)

of the self-regulating vent. By this, pressure is built up on the entrance side of the valve (3), compared to the chamber (4) behind the valve. The pressure difference between chambers (2) and (4) causes a deflection (α) of valve (3), which is suspended from blade hinges. The flow-through area between valve (3) and bottom plate (6) hereby contracts from A_0 to A. Also the pressure difference causes a flow velocity (v) in the area (A). As the pressure difference over the grid and thus over the valve increases, the flow-through area (A) decreases and the flow velocity (v) increases. The product A*v, multiplied by a contraction factor, depending on its design, is the flow rate (q_v). The aim is to create a relation between the deflection of the valve and the pressure difference, which results in a set, constant ventilation flow at all pressure differences.
To set the required flow level, the bottom plate (6) can be adjusted, using the adjustment arm (7), hinging at point (8). This will cause a proportional increase or decrease of the flow-through area (A) at every position of the valve.

A proper control may be impaired by the presence of non-controllable leakage openings into the building shell. Their contribution to the ventilation will increase at increasing pressure difference. This may be compensated by reducing the flow rate, let through by the self-regulating vent, at increasing pressure difference. While this possibility is restricted, also certain demands are expected on the air-tightness of the dwelling.

3. CALCULATION MODELS

To find out wether the principle of controlled natural ventilation can be worked out within realistic system-dimensions, calculations have been made using the TNO ventilation model [ref.2].
The second aim of the model calculations was to establish the requirements for optimal self-regulating vents.
Finally, the ventilation properties compared to other systems are established.

The calculations have been performed on a typical dutch dwelling. The lay-out of this dwelling is shown in figure 8.

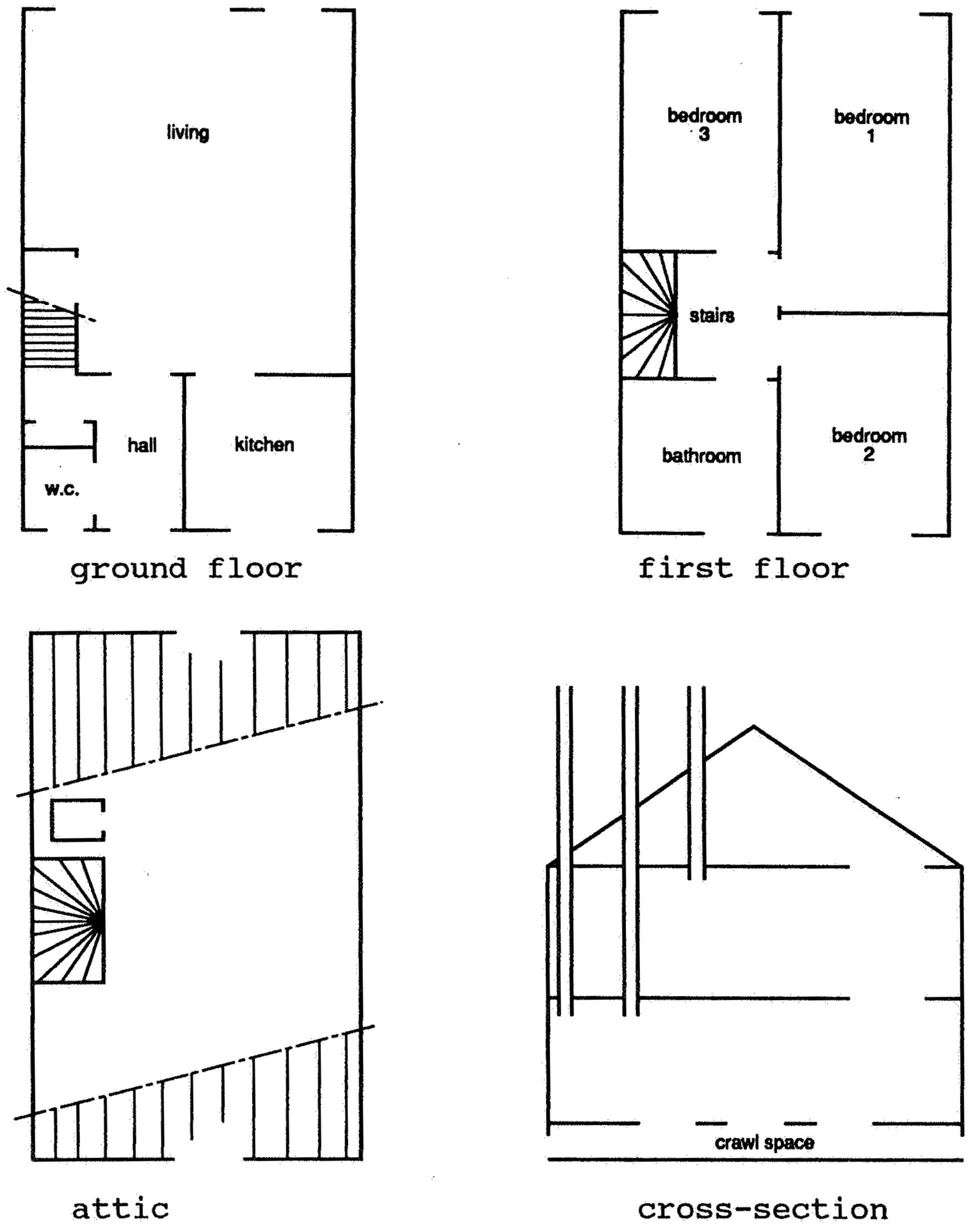


Figure 8: Lay-out of the dwelling, used for model calculations.

The calculations have been made for three levels of air-tightness:

1. Average dutch dwelling, air-leakage 9 ach at 50 Pa, distribution: roof 73%, facades 22% and ground floor 5%.
2. Dwelling with standard air-leakage of 6 ach at 50 Pa, distribution: roof 71%, facades 21% and ground floor 8%.
3. Airtight dwelling, air-leakage 2 ach at 50 Pa, distribution: roof 62%, facades 30% and ground floor 8%.

The inner doors are closed, however, each door has a leakage-opening of 160 cm^2 (2 cm gap beneath it).
The vertical exhaust ducts are situated in the service rooms (kitchen, bathroom and W.C.). The self-regulating vents are situated in the facades of the bed rooms only. This is because dutch standards demand fresh air supply within these rooms, but they allow air to overflow to the living room, to be exhausted from the service rooms, thus creating an optimum use of the ventilation air.
The dimensions of the vertical exhaust ducts are:

- kitchen 84 cm^2,
- bathroom 60 cm^2,
- W.C. 30 cm^2.

Originally the self-regulating vents are dimensioned to supply standard flows at a wind velocity of 2 m/s, which means 39 cm^2 and 77 cm^2 net opening area for respectively 7 dm^3/s and 14 dm^3/s flow rate. Later on, the opening areas are enlarged to 80 cm^2 and 155 cm^2, allowing standard flows even at a very low wind velocity of 0.5 m/s. Correspondingly, each self-regulating vent is tuned to supply the standard flow minus the actual crack flow of the particular room at each pressure difference above 0.5 Pa. Under 0.5 Pa the vent is fully opened.

The dwelling is situated in a low-rise urban area, which is representative for most dutch dwellings. The corresponding wind pressure coefficients (C_p-values) are drawn from a data-base. All calculations are made at an outside temperature of 5°C , representative for average heating season conditions.

To enable a comparison, apart from the controllable natural ventilation system, calculations have been made on a mechanical exhaust system with the next options for supply:

- cracks only,
- manual controlled vent-lights or -windows,
- self-regulating vents.

In these cases the mechanical exhaust flows are:

- kitchen 21 dm^3/s,
- bathroom 14 dm^3/s,
- W.C. 7 dm^3/s.

For supply through manual controlled vent-lights or -windows the next control behaviour for the bed rooms is suggested, depending on the wind conditions:

wind velocity	0	2	5	10	15 m/s
leeward side	300	300	150	65	65 cm^2
windward side	300	300	150	65	0 cm^2

The windows in the other rooms are closed, just as in the option with the self-regulating vents.
The control behaviour mentioned is proved to be one of the best possible types of manual control. In practice bed room windows often are opened much wider during about 4 to 8 hours a day.

4. CALCULATION RESULTS

The results of the model calculations are given in ref. 2 and 3. The most important results will be dealt with in this publication.

Figure 9 presents the ventilation levels in different rooms of the air-tight dwelling (2 ach at 50 Pa), in case of the mechanical exhaust system, for three types of supply:

- -cracks only,
- -self-regulating vents,
- -optimum use of window-vents.

The ventilation is an average over all wind velocities for wind directed to the front facade.
To enable a check of the ventilation levels the standard values are also given in figure 9.

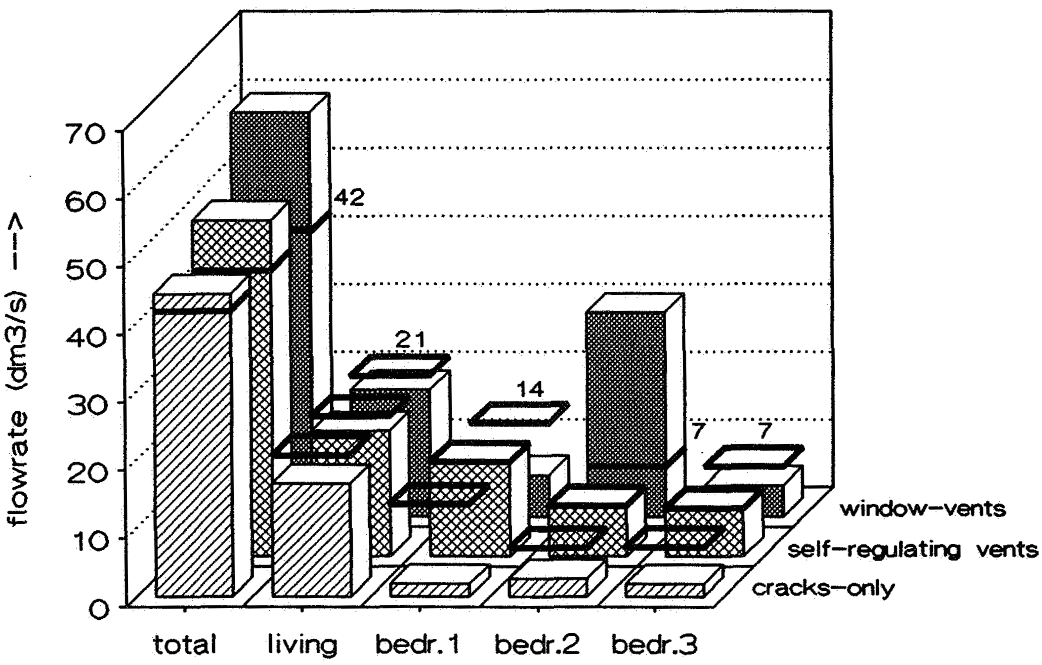


Figure 9: Ventilation for an air-tight dwelling (2 ach at 50 Pa) with mechanical exhaust (42 dm³/s) and different types of supply, related to standard flow rates. Average of all wind velocities. Wind directed to the front facade.

Figure 9 shows the effect already mentioned in chapter 1, concerning sufficient total ventilation, but very insufficient bed room ventilation, in case of mechanical exhaust and supply through cracks. The average bed room ventilation on the leeward side is just 26 % of standard value and on the windward side 37 %
By opening window-vents or vent-lights the ventilation of leeward side bed rooms is still insufficient (66 % of standard value), while the windward side bed room is over ventilated (430 % of standard value), with a high risk of draughts. Also,

the total ventilation shows an overshoot of 42 %, resulting in comparable ventilation energy losses.
The application of self-regulating vents for air supply appears to be a good solution. The flows of all rooms are controlled very well, diminishing draught risks (average bed room ventilation 94 and 100 % of standard value, respectively on leeward and windward side). The overshoot of total ventilation is reduced from 42 to 18 %.

From figure 9 one could suggest that the proper supply through cracks to the bed rooms is impaired by the high level of air-tightness of the dwelling. However, the results in figure 10, referring to a dwelling with standard air-leakage (6 ach at 50 Pa), show this assumption is not right.
Mechanical exhaust, with supply through cracks only, still leads to insufficient ventilation of bed rooms (average ventilation 17 % of standard value on the leeward side and 56 % on the windward side). On the other hand, the increase of air-permeability with a factor 3 does create a 40 % overshoot of total ventilation, resulting in a comparable increase of ventilation energy consumption.
Despite the increase of air-permeability, leading to less authority of the controllable openings, still the standard ventilation rates of separate rooms are approached, using self-regulating vents (average bed room ventilation on the leeward side 76 % of standard value and on the windward side 100 %). Just like in the air-tight dwelling a slight increase of total ventilation occurs, compared to supply through cracks only (total ventilation increased from 140 to 154 %).

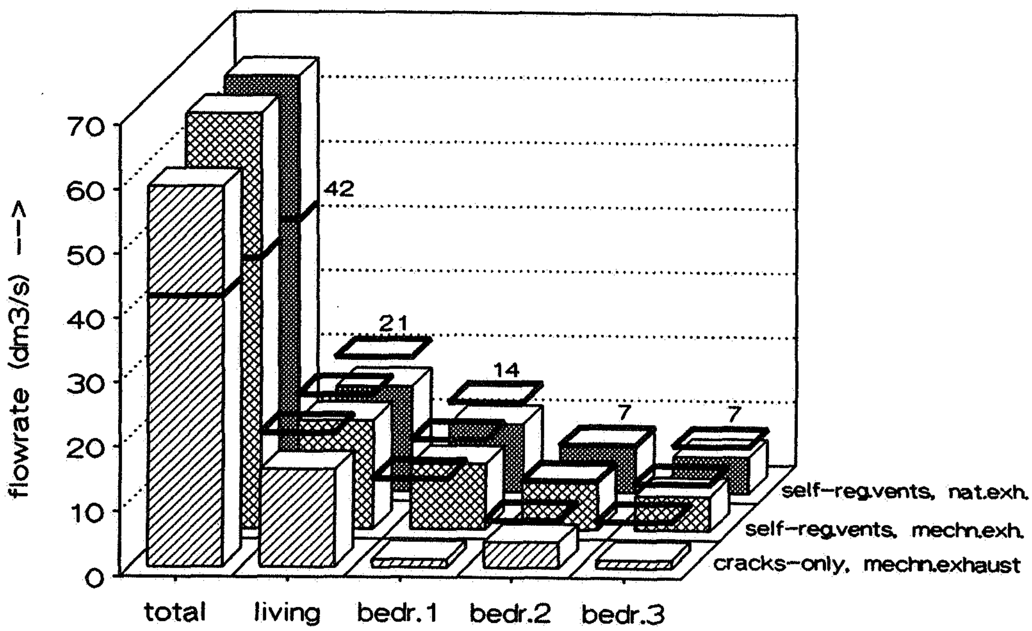


Figure 10: Ventilation of a dwelling with standard air-leakage (6 ach at 50 Pa) and different types of supply and exhaust, related to standard flow rates.
Average of all wind velocities.
Wind directed to the front facade.

Figure 10 also shows the ventilation in case of self-regulating supply vents combined with natural exhaust ducts. There appears to be hardly any difference with mechanical exhaust.
One should notice that average ventilation rates over all wind velocities are concerned. A differentiation to wind velocities for bed room 2 (windward side) and 3 (leeward side) is presented in figure 11.

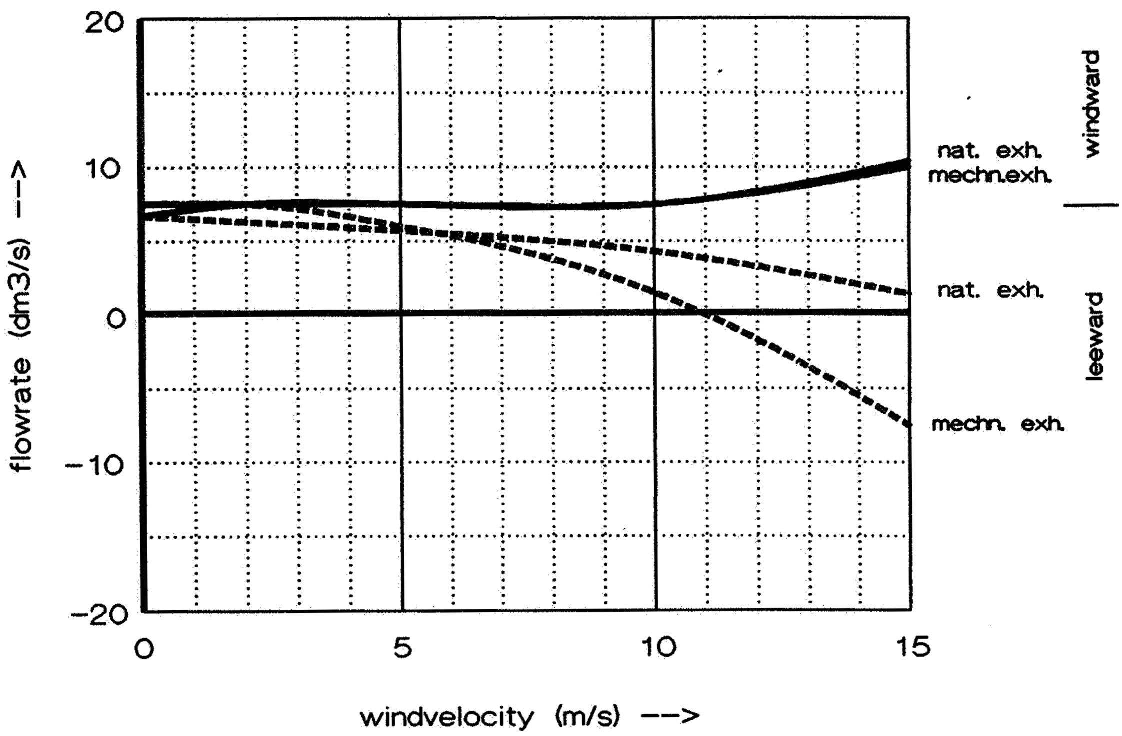


Figure 11: Ventilation flow related to wind velocity for a leeward and a windward bed room. Comparison between self-regulating vents with natural or mechanical exhaust.

Figure 11 still shows no difference between self-regulating vents with natural or mechanical exhaust, as far as the windward room is concerned. In both cases some increase of ventilation occurs at rare wind velocities above 10 m/s. However, the leeward room ventilation shows some remarkable differences. The ventilation with natural exhaust appears to be less variable than with mechanical exhaust. Also, flow reversion does not occur with natural exhaust, contrariness to mechanical exhaust. This could be explained by the pressure stabilizing effect of an exhaust fan, which does not allow the inside pressure to lower with increasing wind velocity, as much as it does with natural exhaust. Consequently, the pressure difference over the leeward facade will decrease more rapidly in case of mechanical exhaust. This effect is confirmed by figure 12, presenting the calculated pressure differences over the leeward facade.
The surprising conclusion may be that the application of self-

regulating vents is preferred in combination with natural ventilation, rather than with mechanical exhaust.
Apart from the improvement on ventilation of separate rooms, this will save installation costs of the exhaust fan, as well as auxiliary energy of about 500 kWh a year [ref. 4].
An exception to this conclusion have to be made for sheltered houses with exceptional wind pressure distributions.

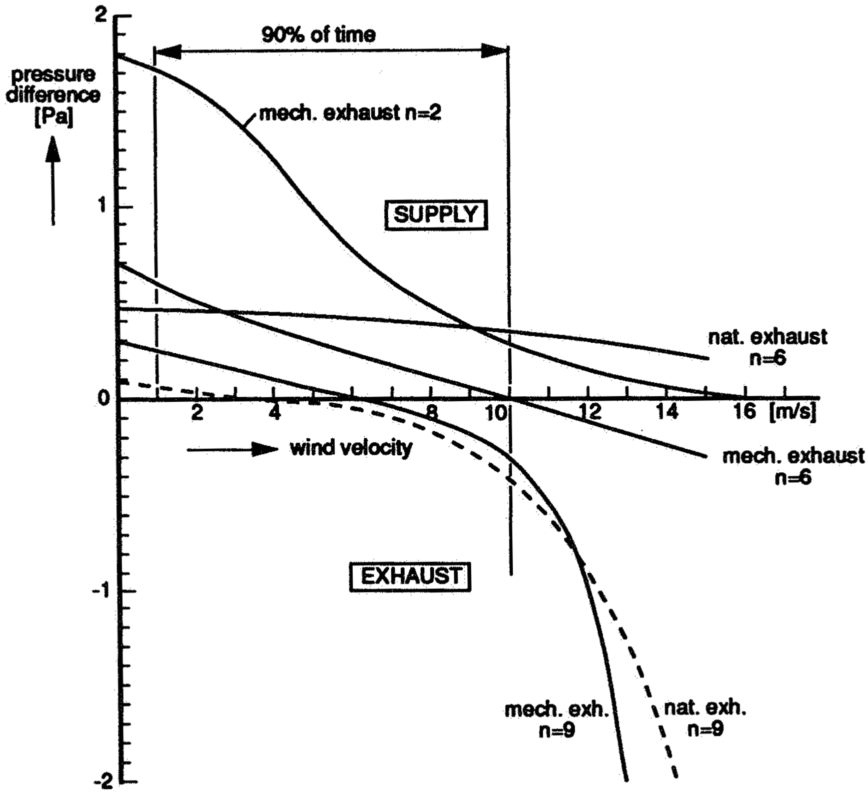


Figure 12: Calculated pressure differences over the leeward facades of dwellings with self-regulating supply vents.
Natural or mechanical exhaust.
Air-leakage n=2, 6 or 9 ach at 50 Pa.

Figure 12 shows that leeward pressure differences are relatively small, compared to the windward pressure differences, as presented in figure 13. Nevertheless, due to the self-regulating vents, leeward pressure differences are positive over 90 % of time, if the air-leakage is not over the standard value. This means supply will occur under this conditions. The importance of the air-tightness is evident.

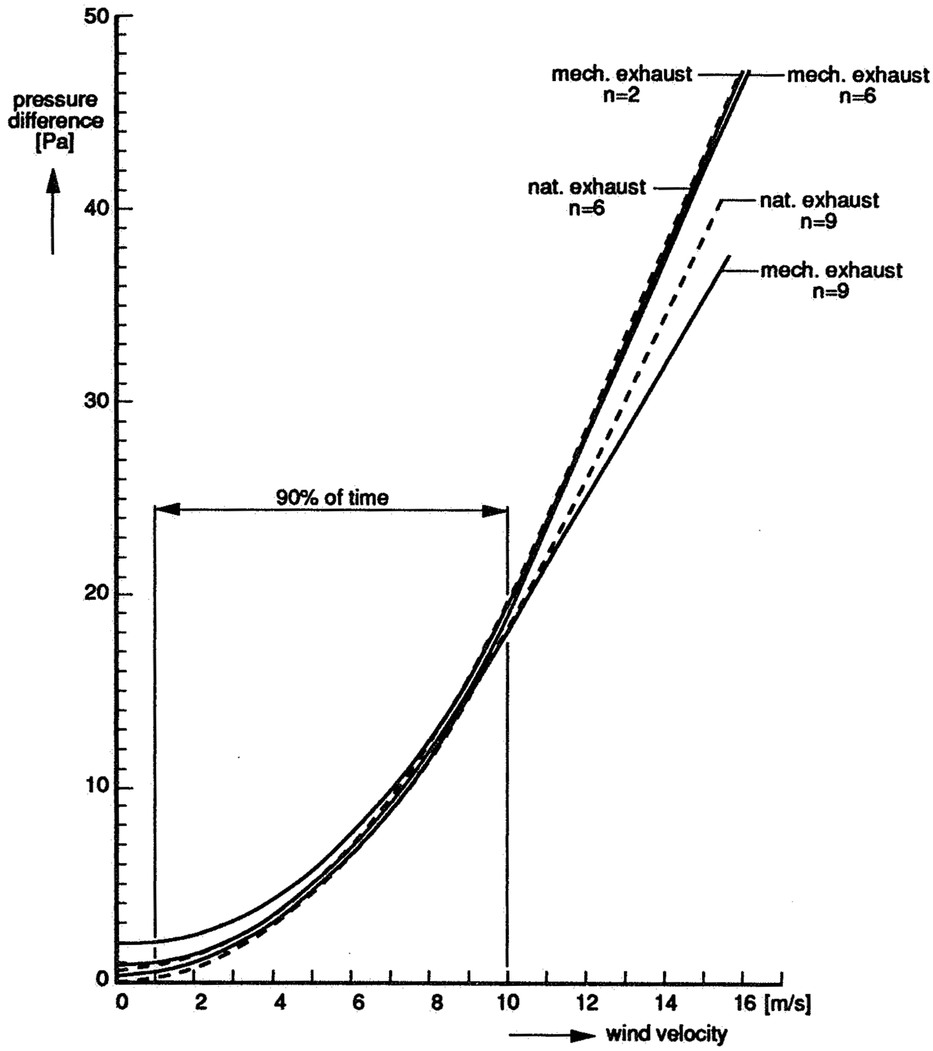


Figure 13: Calculated pressure differences over the windward facades of dwellings with self-regulating supply vents.
Natural or mechanical exhaust.
Air-leakage n=2, 6 or 9 ach at 50 Pa.

To enable the self-regulating vents to control on standard flows for about 90 % of time, control have to start at about 0.5 Pa and the air-tightness have to be at least 6 ach at 50 Pa in case of natural exhaust and 2 ach at 50 Pa for mechanical exhaust.
This is another advantage of the natural ventilation option over the mechanical exhaust option.
The total control range have to be from 0.5 to about 20 Pa, as can be derived from figure 13. Only control of supply flows is considered to be necessary.
This range of pressure differences is considered to be realistic, compared to on-site measurements [ref. 5].

The control requirements of the self-regulating vents are high. Especially control at 0.5 Pa may be hard to fulfil technically. One could wonder if a compromise is possible. Some self-regulating vents, already for sale, are intended to peak shave at high wind velocities, thus reducing draught risks. In this case control starts at about 20 Pa. Another option may be control starting at about 5 Pa, being the windward pressure difference under average conditions. The effect of both options on ventilation control of a windward and a leeward bed room is presented in figure 14. The options "control starting at 0.5 Pa" and "no control" (not even a manual control) are presented too, to enable a comparison. The 5 Pa and 20 Pa control option, as well as the no control option are dimensioned to enable standard flows at a wind velocity of 2 m/s and 5 °C temperature difference, according to the dutch standard.

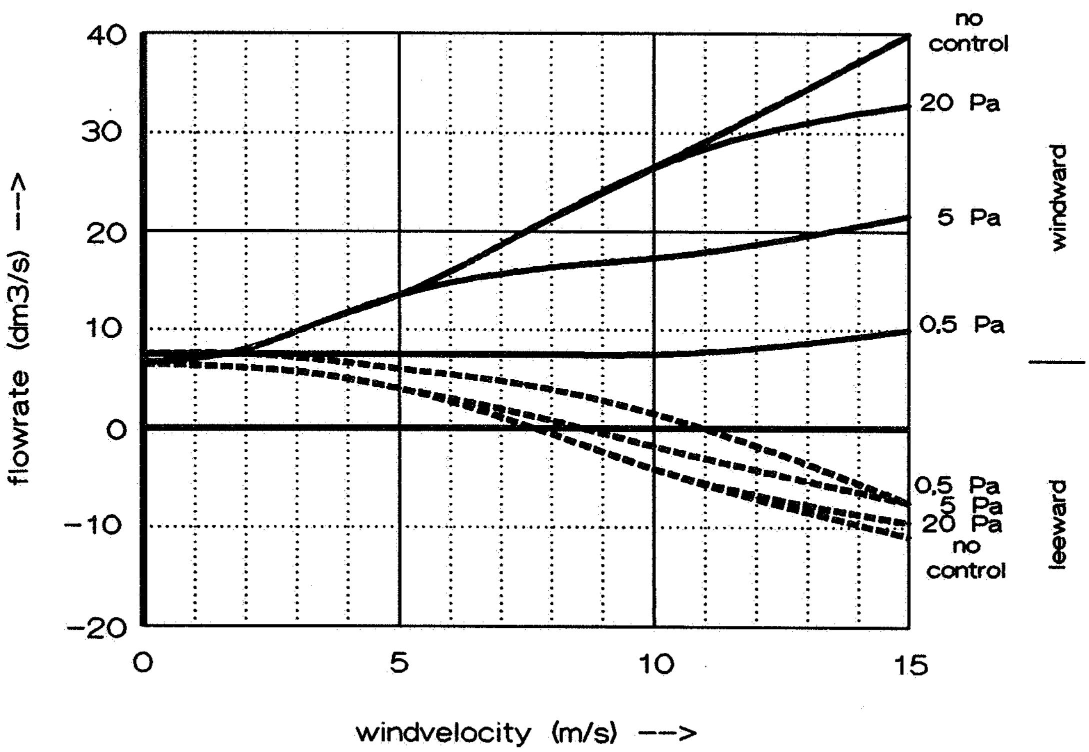


Figure 14: Windward and leeward bed room ventilation in an air-tight dwelling (2 ach at 50 Pa) with mechanical exhaust and self-regulating supply vents with:
-control starting at 0.5 Pa,
-control starting at 5 Pa,
-control starting at 20 Pa,
-no control.

Figure 14 shows that the 20 Pa control option only has a difference to the no control option at wind velocities above 11 m/s. These wind velocities will occur just 3.4 % of time. Hence, the effect of 20 Pa control on ventilation is negligible. The mean total ventilation and ventilation energy

consumption shows an overshoot of 60 % in stat of the 18 % with 0.5 Pa control (percentages related to an ideal standard ventilation). The leeward rooms remain under ventilated. The main aim, draught reduction, is not reached, while windward flows get up to 450 % of standard flows.
The image of the 5 Pa control option is just slightly better. Total ventilation and ventilation energy consumption still have an overshoot of 56 %. The average leeward bed room ventilation is about 47 % of standard values, which still means considerable under ventilation. Draughts at windward side are very likely, while flows get up to 300 % of standard value. Research in our climatic test chamber showed that a draught-less supply to a room, up to the standard flow of 2 persons, is possible, down to an outside temperature of -10°C, without pre-heating the air [ref. 6].

Another feature of the self-regulating vents, to be discussed, is the compensation of air leakage through the facades. The idea is to reduce the controlled flow with increasing pressure difference in the same amount the leakage flow of the same room is increased.

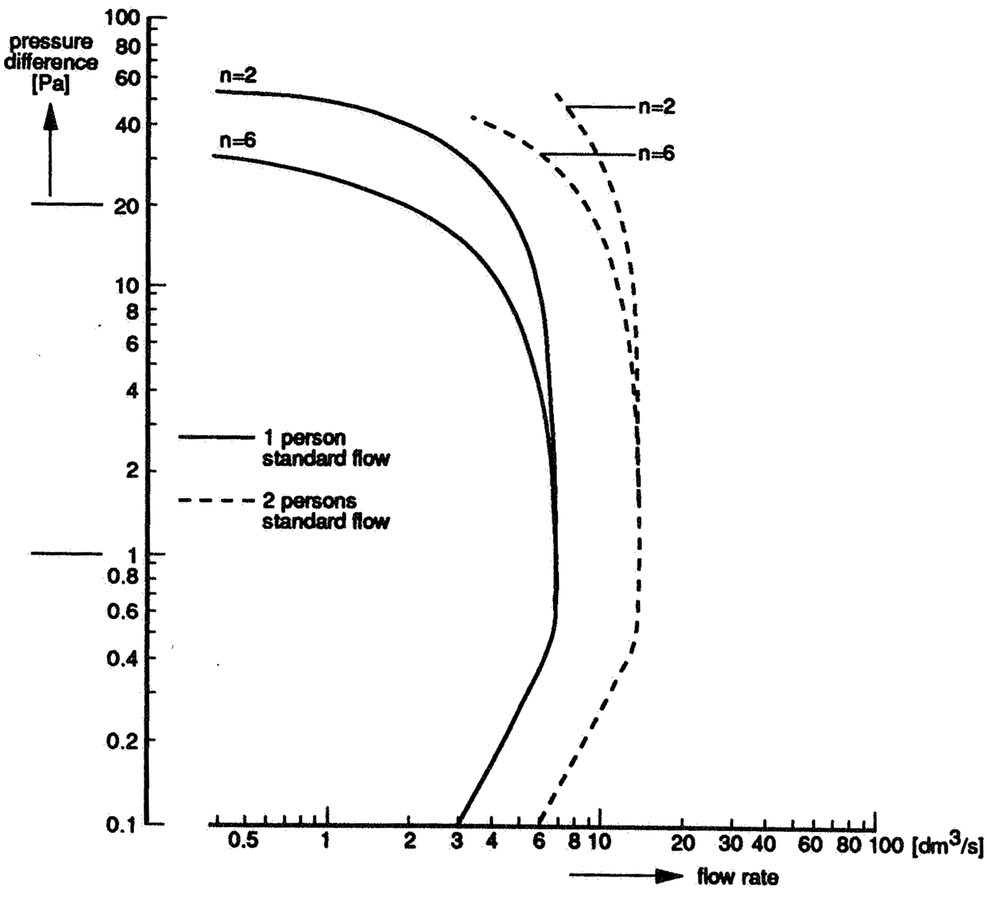


Figure 15: Ideal control characteristics of self-regulating vents with leakage compensation for two levels of air-tightness (n=2 and n=6 ach at 50 Pa).

For the case of leakage compensation the resulting control characteristics of the self-regulating vents are presented in figure 15, both, for 1 and 2 person(s) standard flows and air-tight and standard air leakage dwellings.
Calculations with and without leakage compensation show a minor effect on total ventilation, due to the minor contribution of the facades to total air leakage.
Nevertheless leakage compensation is recommended, because of its positive effect on leeward pressure differences, improving leeward rooms ventilation. It is also recommended because its reduction of draught risks. At increased pressure differences, namely, despite the flow rate control, the entrance velocity through a self-regulating vent is likely to increase. Hence, the impulse increases and with it the draught risk. Reducing the flow rate, because of leakage compensation, however, reduces the impulse and the draught risk again.

5. SUMMARIZED REQUIREMENTS

The calculation results show that controllable natural ventilation or controllable mechanical exhaust ventilation is possible.
The requirements to get an optimum control are mentioned in ref. 7. The main requirements are summarized here.

DWELLING REQUIREMENTS

* Preferred air leakage for optimum control:
  - 2 ach at 50 Pa in case of mechanical exhaust,
  - 6 ach at 50 Pa in case of natural exhaust.

However, to reduce energy consumption the highest air-tightness possible is recommended. Especially air tightening of the ground floor and other lower parts (supply openings) will improve control features.

* Overflow openings in internal walls of at least 10 cm^2 per dm^3/s, to allow the supply into bed rooms to overflow via hall and living room to service rooms, to be exhausted (in special cases silencers on these openings may be preferred).

The ventilation of the living room may be improved by creating an overflow preference to e.g. the kitchen via the living room in the dwelling lay-out.

* The vertical exhaust ducts of the ventilation system have to discharge in or near the pitch of the roof.

Self-regulating vents at least have to be installed into the facades of the bed rooms. Additional installation in the living room may be considered.

VENTILATION SYSTEM REQUIREMENTS

* Minimum dimensions of natural vertical exhaust ducts:
  - kitchen net 84 cm^2 (diameter approximately 16 cm),
  - bath room net 60 cm^2 (diameter approximately 14 cm),
  - W.C. net 30 cm^2 (diameter approximately 10 cm).
* Requirements for self-regulating vents:
  - control ratio 0.5 to 20 Pa, only functioning as supply control;
  - set point equals the standard flow for the number of inhabitants of the particular bed room (usually 1 or 2 persons = 7 or 14 dm^3/s);
  - supplied flow decreased at increasing pressure difference, to compensate air leakage of the facade;
  - set point manual adjustable by inhabitants to their individual ventilation needs, in an easy way and in steps of at least a one person ventilation need;
  - possibility to totally close each vent;
  - good dynamic behaviour at pressure fluctuations up to 60 % of the dynamic wind pressure, within frequencies of 0.3 to 7 Hz (to prevent effects like noise- generation, accelerated wearing and draught aggravation, due to fluctuations of incoming air).

  A time constance of 0.3 s is recommended;

- good design of the inside grid, to get a quick mixing of incoming air (to minimize the draught risk);
- durable, long life construction, insensitive for improper use and disturbances;
- operation preferably without auxiliary energy;
- to be built-in in common facade types;
- rain, insect and burglary protected on the outside;
- insensitive for pollution, combined with good cleaning possibilities;
- insensitive for temperature and humidity variations of the outside climate;
- preferably also available in a noise reducing variety;
- competitive sales price.

6. CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

A highly controllable natural ventilation system for permanent ventilation of dwellings appears to be possible. The main conditions for controllability are:

- over dimensioned vertical exhaust ducts with outflow near the pitch of the roof;
- self-regulating supply vents in the facades of habitable rooms.

The principle of controllable natural ventilation is also applicable on mechanical exhaust systems.
In that case, a higher air-tightness of the dwelling is recommended.
Also, the ventilation of separate rooms shows a slightly stronger relation to wind velocity.

The controllable natural ventilation system allows almost optimal air quality levels in all rooms.
The distribution of ventilation air to separate rooms is highly improved, preventing:

- under ventilation of especially leeward bed rooms (which is about 20 % of room ventilation standards for crack-supply and 65 % for supply through vent-lights),
- over ventilation of windward rooms (up to 400 % of ventilation standards in traditional natural and mechanical exhaust systems).

The ventilation energy consumption in an air-tight dwelling (2 ach at 50 Pa) with mechanical exhaust reduces from 142 % in case of good manual control, to 118 % in case of self-regulating vents (100 % is ideal standard ventilation).
With supply through cracks-only total ventilation is 106 %, however, as mentioned, air quality in bed rooms becomes very poor.
In the natural ventilation option, even an additional yearly reduction of about 500 kWh on auxiliary energy will occur, due to the absence of an exhaust fan.

In moderate climates, the occurrence of draughts, due to supply of unheated ventilation air, will be highly reduced by using self-regulating vents.
Consequently, the features of the highly controllable system will not be impaired by the interaction of the users.

RECOMMENDATIONS

The self-regulating vent is a vital component in the control system. A further product development is recommended.

The model calculations show some clear benefits of the proposed control system. An evaluation in practice is recommended.

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