THREE INVESTIGATIONS OF THE BEHAVIOUR OF DUCTS FOR NATURAL VENTILATION, IN WHICH AN EXAMINATION IS MADE OF THE INFLUENCE OF LOCATION AND HEIGHT OF THE OUTLET, OF THE BUILT-UP NATURE OF THE SURROUNDINGS AND OF THE FORM OF THE OUTLET

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1. INTRODUCTION

Changing the air in dwellings is necessary from the point of view of both health and comfort.

The removal of combustion gases from eg central heating boilers, geysers and gas-operated cooking appliances is similarly necessary. In dwellings, the air changes are effected without mechanical ventilation, since air enters via openings in the facades (eg windows or associated cracks) under the influence of natural forces. Removal of air takes place:

- either partly through the facade and partly through ducts (Fig 1a)
- or entirely through the ducts (Fig 1b).

As regards ventilation ducts and ducts for removing combustion gas installed in dwellings, it is presumed that these remove air and combustion gas respectively from the dwelling to the outside.

The reverse, ie flow-back from the outside to the inside of the dwelling through these ducts, must be regarded as a series defect, and indeed in the case of combustion gases as a danger.

Flow-back in ventilation ducts involves

- spreading odours from eg kitchens and toilets inside a dwelling (Fig 2) in multi-family houses with combined ventilation ducts, moreover;
- spreading odours from dwelling to dwelling (Fig 3) with single-family houses it involves moreover:
- the possibility of draughts due to cold outside air flowing in without being warmed, and concentrated in one location, eg the toilet, the bathroom or the shower. These phenomena, which occur very frequently, are undesirable. With a well designed mechanical extraction with a

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ventilator/fan providing the driving force, back-flow will be cut right out.

2. OPERATION OF EXTRACTION DUCTS

With natural ventilation, pressure differences caused by the wind and by the difference in temperature between inside and outside constitute a pre-requisite in order that transport shall take place through ducts to the outside.

This applies also to combustion gas extraction ducts.

Although the temperature difference between inside and outside usually contributes positively to the ventilation, the reverse is sometimes the case with ventilation ducts in the summer. In the winter the temperature inside the house will always be higher than outside. The warmer - and hence lighter - inside air will then try to escape upwards via the ducts. As the temperature difference increases the ventilation will increase. Up to a certain value, the ventilation also increases as the length of the duct increases.

However, there may be a time in the summer when the air indoors is colder than outdoors; low down in the dwelling (eg on the ground floor) cold, heavier air will tend to flow from the inside to the outside while the warmer outside air will flow into the house high up (eg via the ducts). As regards the ducts of gas-fired installations, a much greater temperature difference is involved. However, the pressure difference due to this temperature difference is proportional to the length of the extraction duct. With central-heating boilers located in the loft this length is not much more than 2 m. The pressure difference is then relatively small, in spite of the larger temperature difference.

If we assume that in the absence of wind the thermal draught must be able to overcome the frictional resistance in the duct, then in the presence of wind the pressure due to it at the outlet of the duct will have to be lower than that at the inlet in order that flow-back may occur.

The lowest possible pressure at the inlet occurs when the duct starts in a room situated at the leeward side, eg the kitchens, where there is an open window, while there are no windows open at the other side (Fig 4). This is a situation that is very common in practice; windows on the windward side are generally kept closed for longer periods. In order that there may always be satisfactory operation as regards flow from locations with a higher pressure to locations with a lower pressure, the pressure P_u at the outlet of the duct must be lower than the pressure P_i at the inlet.

3. OBJECT OF THE INVESTIGATION

A knowledge of the pressure distribution around dwellings is necessary in order to be able to indicate the desirable location and height of duct outlets above the roof.

Existing specifications relating to outlets often appear to aim too short.

Both nationally and internationally, practically nothing is known about pressures at a given distance above buildings at the location of the outlets.

The literature does indeed contain many results of measurements regarding the pressures on the facade and in the roof-level of a building. These studies were mostly aimed at obtaining data necessary for calculating the mechanical strength of a building.

In order to fill in these gaps, one of the subjects studied was the pressure distribution around dwellings. The investigation is in three parts:

- Investigation of the pressure distribution around dwellings located in a non-built-up environment but with some plants, eg hedges etc - Investigation of the influence of surrounding buildings on the build-up of pressure around a dwelling.
- Investigation of the influence of a chimney-cowl or ventilation cowl on the pressure at the outlet of ducts.

These three parts of the investigation are discussed in the following chapter in separate sections.

4. INVESTIGATION AND RESULTS

4.1 INFLUENCE OF THE LOCATION AND HEIGHT OF THE OUTLET ABOVE THE ROOF

4.1.1 MEASUREMENT ARRANGEMENTS

This investigation was conducted by measurements of the pressure distribution around dwellings located in surroundings with hardly any plants. In the wind-tunnel of the TNO Institute for Environmental Hygiene and Health Engineering tests were made on a wooden model of a block of four single-family dwellings; the scale of the model was 1:40. The situation corresponding to the above environment was moreover simulated in the wind-tunnel.

The wooden model of the block of dwellings had the following dimensions:

length of model 630 mm (actual size 25.2 m)
height of model 135 mm (actual size 5.4 m)
width of model 185 mm (actual size 7.4 m)

Symmetrical roofs were arranged on this model, with slopes respectively of:

0° - 13° - 20° - 22°30' - 25° - 30° - 45°

For obtaining an idea of the pressure at the ventilation duct outlets above the roof, what is involved is not the static pressure in the flow in the immediate vicinity of the outlet, but the pressure which develops in the outlet which is determined <u>also</u> by the flow-arrival direction of the air. In these measurements the output from the ventilation duct is maintained at zero.

The pressure at the outlet could be measured up to a height corresponding to 8 m above the roof level of the model. The pressures on the facade are also measured (see Fig 5).

In the investigation the velocity in the wind-tunnel was maintained at a constant value of 8 m/s. This gives a velocity-pressure of

$$\frac{1}{2} \rho V^2 = \frac{1.25 . 8^2}{2} = 40 \ P_a$$

(1 P_a = 1 N/m^2 = approx 0.1 mm WK)

The velocity of 8 m/s does not correspond with the model rule according to Reynolds. In order to obtain the same flow distribution the Reynolds number would have to be kept the same in the model and in actuality

$$Re = \frac{v.D}{U}$$

where V = velocity (m/s)

D = a characteristic length dimension (m)

U = the kinematic viscosity (m^2/s)

This cannot be realised in the model, because it would make very high velocities necessary.

In reality, with a building height of 5.4 m and a wind velocity of 8 m/s

$$R_{eW} = \frac{8 \times 5.4}{15 \times 10^{-6}} = 2.9 \times 10^6 = 2900 \times 10^3$$

whereas in the wind-tunnel at 8 m/s and a model height of 135 mm

$$R_{eM} = \frac{8 \times 135 \times 10^{-3}}{15 \times 10^{-6}} = 72 \times 10^{3}$$

This difference is however tolerable with sharp edged models.

4.1.2 RESULTS

The results are presented in Figs 6 and 7. The pressure in the opening - which, as previously noted, is not the same as the static pressure in the flow - is measured as the excess pressure P with respect to the static pressure in the undisturbed flow.

This excess pressure is then converted to a dimension-less quantity by means of the relation:

relative excess pressure $\Delta\Psi = \frac{P}{\frac{1}{2}\rho (V_{wind})^2}$

Points having the same relative pressure in the opening are joined by curves; the corresponding $\Delta\Psi$ values are indicated. The curve which has the same $\Delta\Psi$ as the measured relative under-pressure at the leeward side is as indicated by '$\Delta\Psi_{\ell}$'.

The region above roof level in which the prevailing pressure is higher than at the leeward side of the dwelling is shown hatched. If a window is opened at the leeward side of the dwelling, then a higher pressure will occur in a duct that opens out in the hatched area than at the leeward side of the dwelling. Thus in a duct that opens out into the hatched area back-flow may occur, at least if there is no thermal draught.

The results give rise to the following important conclusions as regards the requirements to be satisfied by the location of the outlet in order to obtain satisfactory extraction.

- With a roof slope less than 22°30' it is sufficient for the height of the duct above the roof to be 0.5 m, regardless of location in the roof level.
- With a roof slope greater than 22°30', the distance from the outlet to the ridge must be limited if it is desired to restrict the height of the duct above roof level to 0.5 m. The tolerable distance to the ridge diminishes as the roof slope increases.

With an arbitrary location in the roof level the height must increase with increasing distance to the ridge and/or with increasing roof slope.

- If the outlet is at the highest point of the roof (the ridge), then a height of 0.5 m for the duct is always sufficient.

The influence of wind direction was investigated for a number of cases. This was in order to establish what pressure distribution around the dwellings was most unfavourable for the behaviour of the ducts.

From the point of view of back-flow, the most critical factor generally appeared to be the situation with the wind incident normally on the block (see Fig 8). Only with a roof slope of 45° did this appear to be not entirely the case. The difference with normal incidence was however so small that, bearing in mind the behaviour of the natural wind, with its continual changes of speed and direction, this has only a negligible influence on the definite requirement to be imposed on the height of the duct.

NOTE: Locations of the outlets very close to gables (' ') of buildings were not investigated.

4.2 INFLUENCE OF HIGHER SURROUNDING BUILDINGS ON THE PRESSURE BUILD-UP AROUND A DWELLING

It is generally known that the presence of high buildings often influences the pressure distribution around lower buildings in their vicinity in such a way as to affect extraction via ducts adversely.

The extent of this influence was investigated in relation to the requirements which have to be imposed on the location and height of the outlets above the roof.

An investigation was conducted for this purpose in the IG-TNO wind-tunnel, the distance from the higher buildings to the block of dwellings being varied. In one set of measurements these higher buildings were in front of the block of dwellings being investigated; in a second set of measurements they were behind it (see Figs 9a and 9b).

Sixteen distance ratios were chosen, ranging from $(a/h_2) \simeq 3$ to $\simeq 0.35$. Different height ratios were also used, namely $(h_2/h_1) = 2, 4, 6, 8$.

Roofs were placed on the low building, with slopes of 0°, 30° and 45°.

In 11 cases also the direction of wind incidence was varied over 45°.

To provide a reference basis, measurements were first made without the high building, in which moreover the expected 'roughness' ('ruwheid') of the surroundings was taken into account. This means to indicate that the block of dwellings was located in an environment comparable to the centre of a large town.

Comparison of the results with those of the investigation without built-up surroundings indicated that the ratio of the pressure on the leeward side with respect to the pressure above the roof became somewhat more favourable in the built-up case, and this is of great significance for the value of the results of this investigation.

It was of course only possible to investigate a limited number of combinations of parameters out of the practically unlimited number of possibilities.

The measurements carried out give rise to the following preliminary conclusions:

- If the wind reaches the low building first and then the high building, the situation as regards the pressure distribution around the low building is the same as even more favourable than with the low building in non-built-up surroundings with a few plants (eg hedges).
- For more severe requirements which may have to be imposed on outlets above the roof in the vicinity of higher buildings, of the situations investigated the only ones that seem to be of importance are those in which the high building is located in front of the low building.
- In that case a downward whirlwind is produced behind the (high) building (see Fig 10).
- As regards the behaviour of the whirlwind, three zones are distinguished in the region behind the building:

1. the zone where the whirlwind is indeed descending, but flows through;
2. the zone where the descending whirlwind strikes the roof;
3. the zone where the whirlwind flows back. The location of these zones depends on the ratios (h_2/h_1) and (a/h_2) where

- h_1 is the height of the low building
- h_2 is the height of the high building
- a is the distance from the high building to the low building (see Fig 9).

With roof slopes of 30° or more the second zone did not show up. The location of the different regions is indicated diagrammatically in Fig 11. The distance of the buildings from one another is given here by the (obstruction) ('belemmerings') angles β and γ.

In Fig 11 $\gamma = 35°$ while β depends on the ratio of the heights of the buildings under consideration h_2/h_1 (see Table 1).

Table 1

h_2/h_1,	2	4	6	8	10	12
β	10°	15°	20°	25°	30°	30°

Where the dwellings have roof slopes of 30° or more angle β = γ, hence zone 2 is absent.

4.3 INFLUENCE OF A CHIMNEY COWL OR A VENTILATOR COWL ON THE PRESSURE IN IN THE DUCT OUTLETS

When the extraction via ducts is unsatisfactory, it is generally expected to improve matters by the introduction of a cowl. Various investigators have in the past studied many cowls (see also Bibliography). In the meantime many new cowls have arrived on the market.

The present study investigates in which cases a cowl produces an improvement compared with an open pipe and also the question of stability of pressure level. Thirteen actual-size cowls were investigated in the IG-TNO wind-tunnel under the following conditions:

3 wind velocities (0, 4 and 8 m/s);
4 velocities in the extraction duet (0, 1, 2 and 3 m/s);
13 states as regards the wind from perpendicular descending to perpendicular ascending wind, in steps of 15° (see Fig 12).

The results of the measurements are given in Figs 13, 14, 15 and 16. The thin dashed lines in the figures represent the characteristics for the open pipe. The differences in the behaviour of the cowls can be seen clearly. Whereas eg the 'Giveg' cowl produces a more stable and higher draught practically overall compared with the open pipe, the 'Greskap' produces a considerable worsening of the pressure, even with low transport. The stability of the 'Giveg' is also better than that of the 'Greskap'.

As regards the effect they produce, the cowls can be separated into three groups:

- Cowls which produce an improvement of the pressure and the stability compared with an open pipe. The cowls based on an investigation conducted by the Gas Institute (GIVEG), which are marketed ie under the brand names 'Trega' cowl and 'Amgas' cowl, belong to this group, as does the 'gek'.
- Cowls which work worse than an open pipe in the presence of wind. The 'greskap' (so-called 'theepot'(?) and the rotating cowl belong to this group.
- Cowls which have a positive influence in certain circumstances and in other cases have a negative effect compared to the open pipe.

These cowls generally have a favourable effect in the presence of descending winds but an unfavourable effect with rising winds.

The general conclusion from this investigation is:

The cowl developed by the Gas Institute (GIVEG) works best with both descending and rising winds.

The so-called 'gek' is also satisfactory. The presence of rotating parts constitutes a serious difficulty (as regards reliability in service) for satisfactory operation in the longer term.

5. APPLICATION OF THE RESULTS

The three investigations described have given rise to a Section in Draft NPR 1088, explanation of Draft Standard NEN 1087 'Ventilation of dwellings'. The gist of this Section is represented by Fig 17, in which:

h is the height above the highest intersection point of the duct and the rooflevel, in m;
a is the horizontal distance from the centre of the outlet to the highest point of the rooflevel, in m;
γ is the slope of the (part of the) roof which is intersected by the relevant duct, in degrees.

Moreover, in relation to the surrounding buildings, Fig 11 and Table 1 discussed in Section 4.2 are applicable; in zone 3 a Giveg cowl is always required. Figs 18 and 19 illustrate how, following these instructions, the required outlet heights are positioned in view of the erratic course of the measurement results.

6. SUMMARY

The three investigations have given rise to a better basis for the requirements as regards location and height of the outlets above the roof.

In addition, much new information has been obtained regarding the distribution of pressure around buildings and the operation of chimney and ventilation cowls.

Further research is necessary particularly as regards the influence of high buildings on the pressure distribution around low buildings, as well as information regarding boundary effects, in order to obtain a better idea of the requirements to be imposed.

7. ACKNOWLEDGEMENTS

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9. COMPARISON OF THE REQUIREMENTS AS REGARDS OUTLETS ABOVE THE ROOF IN THE DRAFT NPR 1088 AND IN NEN 1078 (GAVO)

It must be noted at the start that the requirements for the extraction of combustion gases are different from those for the extraction of air.

In the case of ventilation ducts the decisive factor is the removal of air to the outside. A lower pressure at the outflow opening above the roof than at the inflow opening in the interior is in itself sufficient to serve the purpose at the outflow point.

In the case of ducts for the extraction of combustion gases it is necessary not only to deal with the asphalt of extraction but also to take account of the nuisance of the smoke in the environment. Moreover, there is a larger temperature difference involved in this case, giving rise to a greater thermal pressure difference, which has a favourable effect on the extraction.

The GAVO requirements are given in one Figure (illustration 1 in the GAVO Annex P).

In Draft NPR 1088 the detrimental influence which the surroundings may exert on the extraction are separated from the requirements that may be imposed on an isolated house. For comparing the requirements in the GAVO for smoke extraction and in the Draft NPR 1088 for ventilation outlets we make just one choice out of the many possibilities. The requirements compared are those that may be imposed on above-roof outlets for isolated and non-isolated dwellings with roof slopes of 0° and 45°. In the case of the non-isolated dwellings there is assumed to be a block of flats nearby which is about six times as high as the dwelling.

EXAMPLE 1

An isolated house with flat roof (roof slope 0°). The various requirements are indicated diagrammatically in Fig 20. The GAVO requires an outlet height of 1.0 m for an outlet without a cowl and 0.5 m for an outlet with a cowl. The Draft-NPR states that 0.5 m is satisfacory. The difference is thus 0.5 m for an outlet without a cowl.

EXAMPLE 2

An isolated house with a roof slope of 45°. Fig 21 indicates the various requirements, and it is seen that in this case the differences are absent or small close to the ridge but become very large at even a relatively short distance from the ridge.

EXAMPLE 3

Houses with a flat roof at various distances behind a building six times as high.

Fig 22 shows the different regions in which an ordinary outlet, an outlet with a cowl, or no outlet may be used according to GAVO or Draft NPR 1088.

In a part of the region where GAVO permits an outlet with a cowl, Draft NPR 1088 prohibits the use of an outlet of a duct for natural ventilation. Where GAVO permits no outlet, Draft NPR 1088 permits an outlet with cowl. The specified requirements are thus clearly different here.

EXAMPLE 4

Houses with a roof slope of 45° at different distances behind a building six times as high.

In the region where GAVO does not permit any outlet, an outlet with cowl can be permitted according to Draft NPR 1088. In this case Draft NPR 1088 does not recognise any prohibited region. See Fig 23.

CONCLUSION

From these examples, it appears that further study and modification of the regulations must be considered desirable.

FIGURES

Note: In Draft NPR 1088, 'free outlet' means 'without cowl'. Height of outlet, with or without cowl, to be obtained from Fig 17

Fig 23 — Comparison of the requirements specified in GAVO and in Draft NPR 1088 for dwellings with a roof slope of 45° situated in the vicinity of a building six times as high. See Note to Fig 22

Fig 21 — Comparison of the requirements specified in GAVO and in Draft NPR 1088 for an isolated dwelling with a roof slope of 45°