Natural ventilation of auction halls in bleiswijk, the netherlands*)

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Samenvatting

Voor de hallen van de groenteveiling te Bleiswijk is een onderzoek naar de mogelijkheden van natuurlijke ventilatie verricht. Hiervoor zijn berekeningen uitgevoerd met behulp van een rekenprogramma voor de ventilatie. Als ingangsgegevens zijn onder andere resultaten van een windtunnelonderzoek gebruikt. Door systematisch het ontwerp te wijzigen en het effect ervan op de ventilatie te berekenen, is een gunstige uitvoeringsvorm van het natuurlijke ventilatiesysteem ontwikkeld.
Het blijkt dat met uitsluitend ventilatievoorzieningen in het dak een ventilatiesysteem kan worden gecreeërd dat in de praktijk ruimschoots zal voldoen.

1. Introduction

The choice of the most suitable ventilation system for large, partly open structures such as auction halls, industrial halls or parking garages is often a difficult one in practice. Particularly, the possibilities and optimal design plans for systems for natural ventilation are comparatively undeveloped. In the past, this has led to improperly functioning systems for natural ventilation.

This led many designers to prefer systems with mechanical ventilation. Apart from the fact that the energy consumption costs for mechanical ventilation systems have sharply risen during the last few years, there are sometimes great differences in investment and maintenance costs as compared with a system for natural ventilation. Therefore, it is attractive to weigh types of systems against each other before making a choice. For some time, it has been possible to determine the best ...ice as early as the design stage. For this, an electrical analogue model which was developed by the Sound, Light and Indoor Climate Division of the TNO Research Institute for Environmental Hygiene [1] has been used.

This model has now been replaced by a mathematical one which was developed on the basis of the analogue model and recent knowledge. The mathematical model is not only more convenient in use but it also gives more accurate results.

The principle of the mathematical model was discussed at the 7th TNO-TVVL Seminar in 1977 and described in Publication no. 632 of IMG-TNO [2]. In that paper, the results of calculations are compared with the results of measurements of the ventilation in an existing industrial hall. For both the analogue and the mathematical models, pressures at the side walls and roofs are required as input data. For most building shapes, scale model tests in a wind tunnel are necessary. With the mathematical model, a study of the possibilities for natural ventilation of a large parking garage still in the design stage [3] has been made.

*) the TNO Research Institute for Environmental Hygiene, ...ft, Netherlands. TNO-TVVL dag 1981

In this paper is reported possible ways of improving the natural ventilation of existing auction halls.
The auction association wanted to use the results of this research for making a choice between a system for natural or for mechanical ventilation. (See Figure 1).

2. Description of the auction-halls

The auction complex is situated at Bleiswijk, near Rotterdam, the Netherlands, in a varied polder landscape. In the neighbourhood of the complex, there are greenhouses and a higher situated road with some adjoining buildings. During the investigation, plans were advanced to extend the industrial buildings north of the auction complex. A map of the auction complex is shown in Figure 2. The complex consists of three auction halls.

These are divided in different ways. Along several long margins of the halls, there are separate rooms for use by the exporters. The investigation concerns the remaining parts intended for general use. These have several functions and are divided at some places by so-called fire-walls. The purpose of these is to prevent the spread of fire as long as possible and they must therefore be kept closed.

The dimensions of the halls are also indicated in Figure 2. Here, the so-called shed construction of the roofs is also illustrated. The parts of the halls important for the investigation all have a length of 270 m, a width of 82 m and a mean height of ridge of 12.1 m.

The volume of such a part of a hall is about 200,000 m³.

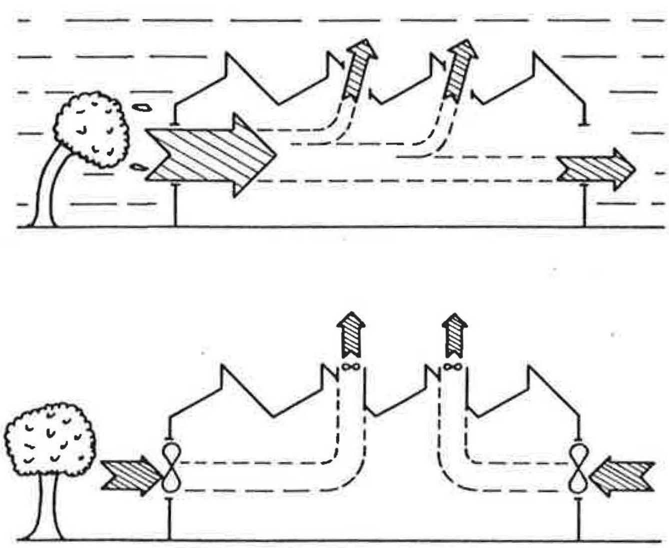


Fig. 1. Natural ventilation or Mechanical ventilation?

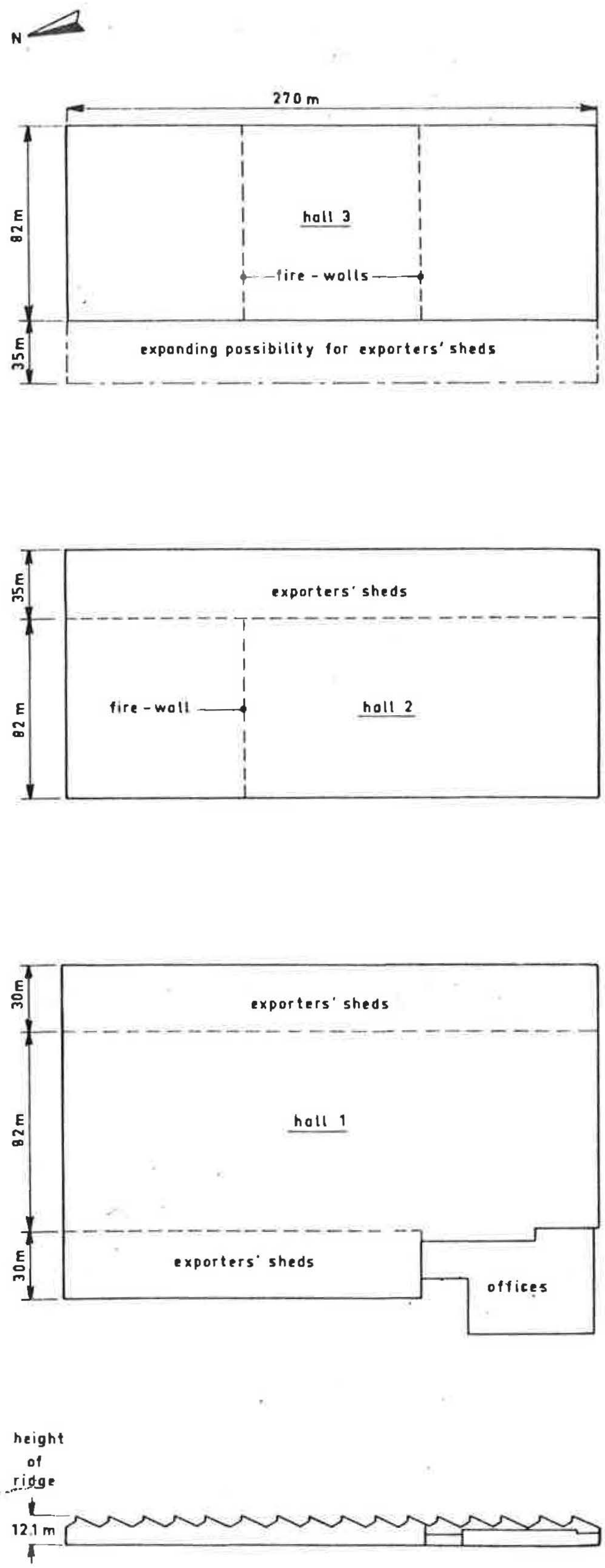
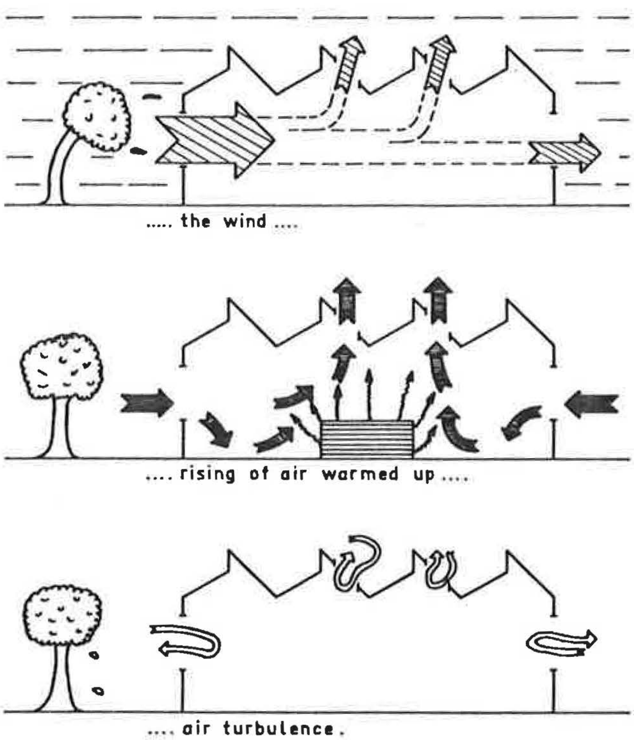


Fig. 2. Floor plan of the auction complex of Bleiswijk.

Figure 4 Natural ventilation by ....



a. during what percentage of the time can low wind velocities and small temperature differences be expected? (unfavourable weather conditions for natural ventilation).
b. during what percentage of the time or in what situation are lower air change rates acceptable?

To answer the first question, statistical meteorological data have been studied [8]. From this, the following conclusions can be drawn:
a. in the neighbourhood of Rotterdam where the auction hall is situated, wind velocities below 2 m/s can be expected during about 7% of the time;
b. wind velocities below 1 m/s can be expected during about 2% of the time;
c. calm weather (wind velocities below 0,5 m/s) occurs in less than 0.5% of the time;
d. as Figure 5 shows [9], the wind velocities in the daytime are about two times as high as at night, owing to atmospheric influences. This is important because entry of solar heat only occurs by day and requires high air change rates;
e. In June, the sky is quite clear (100% sun) during about 38% of the daytime. In this situation, there is a high heat load and there may be large temperature differences;
f. partly clouded days, with the sun shining for 50 to 100% of the time, occur during about 15% of the daytime.

Over long time periods, almost no data exist concerning the simultaneous occurrence of certain weather conditions, for example, a wind velocity <2 m/s and unclouded. From the above-mentioned data, this can only be estimated. Whether lower air change rates than those desired are allowable must be examined separately for each ventilation design.
Whether the desired air change rate for heat discharge (4.5 h) can be attained in the vegetable auction or not may have limited consequences of an economical and possibly also of a climatological nature. The solar heat supplied may cause a rapid decrease in the quality of the vegetables and may lead employees to complain about heat. This holds exclusively when the outdoortemperature is high. In all other cases, airchange rates < 4.5 per hour are also allowable. If the desired air change rate for dilution of the exhaust gases (1 per hour for local differences in air change rate which are not too large) is not reached, this may adversely affect the health of the employees, in particular of those who remain in the halls for the longest time. This applies only during the estimated peak situation in the internal transport. In most situations, lower air change rates are usually sufficient unless large local differences in the air change rate can be expected. Considering this, it was decided to adjust the ventilating devices of the auction halls at an airchange rate of 4.5 per hour, taking into account the following conditions:
a. mean meteorological wind velocity is 2 m/s;
b. difference between the temperature at ground level and the outdoor temperature is 5K;
c. temperature gradient at the top of the halls is 8K.
The chance of air change rates less than 4.5 per hour during the day is then estimated at less than 5%. The chance of temperature differences between outdoors and indoors at ground level greater than 5K, in combination with high outdoor temperatures will be considerably less.

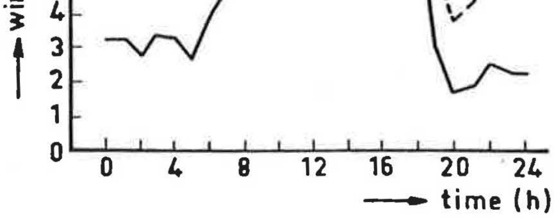


Fig. 5. Daily course of the wind velocity on different heights (ref. [9]).

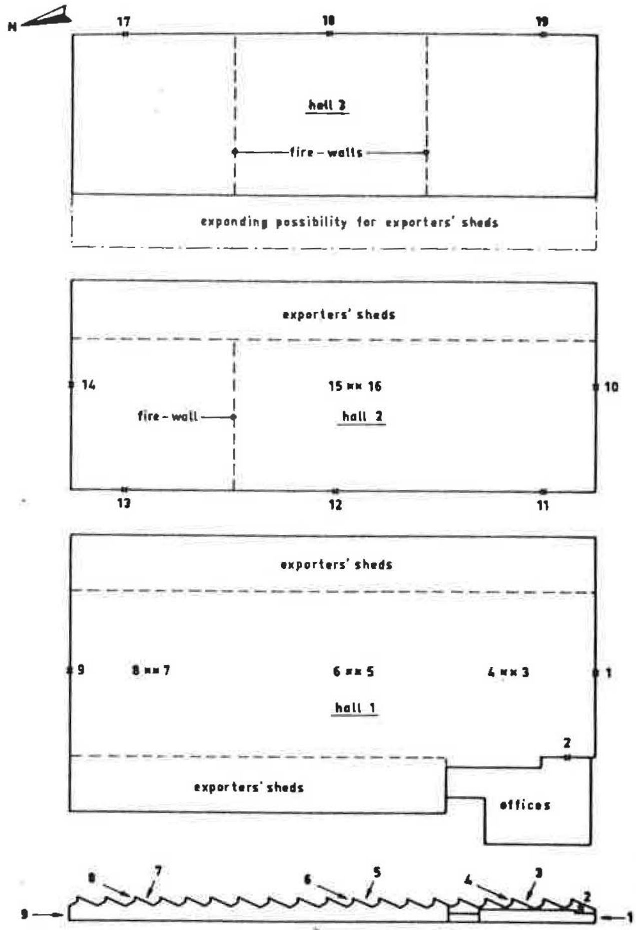


Fig. 9a. Floor plan with pressure measuring points (1 till 19) on model 1:500 of the auction complex.

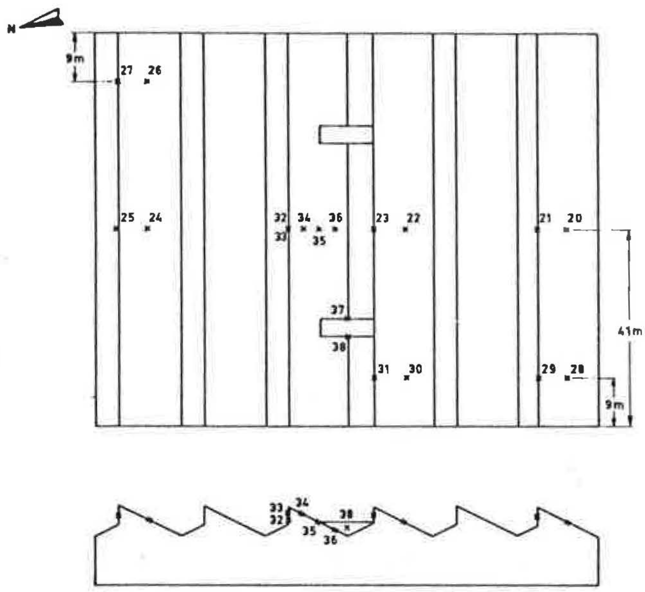


Fig. 9b. Floor plan with pressure measuring pints (20 till 38) on model 1:125 of a part of an auction hall.

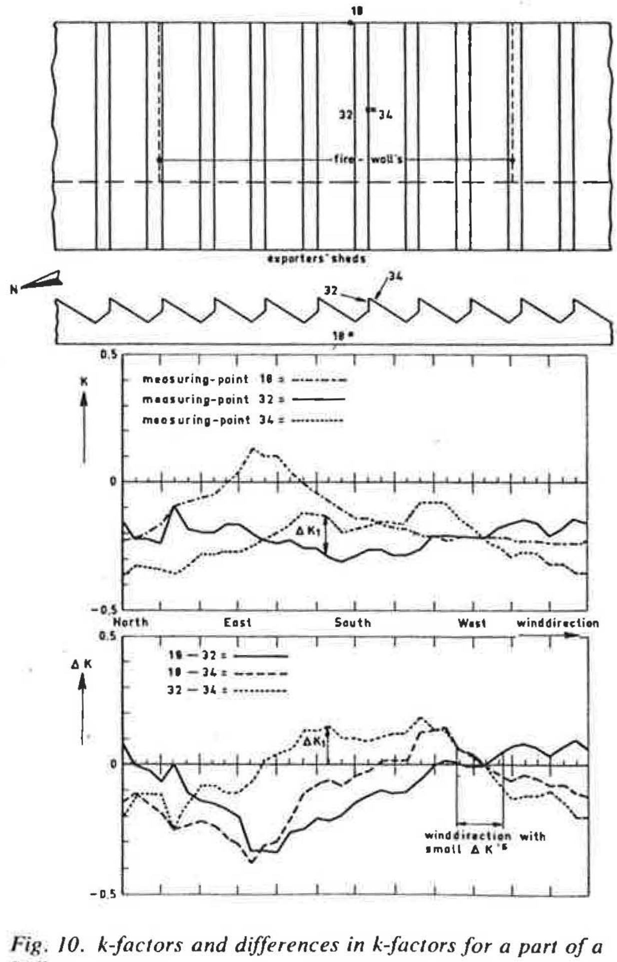


Fig. 10. k-factors and differences in k-factors for a part of a hall.

6. Design

6.1. Choice of the positions of the ventilating devices

The choice of the positions of the ventilating devices depends on the following factors:

a. the possibility of positioning the ventilating devices in view of the geography of the building, etc.;
b. the size of the differences in k-factors, between the various walls such as front walls and roof surfaces. The most favourable sites are the ones between which the greatest wind pressure differences occur;
c. the cost difference between the ventilating devices applicable at the different sites.

To limit complaints about draughts, if front wall openings are applied, they should be made as high as possible above the working level. Because of ventilation due to temperature differences, the difference in height between ventilating devices should be as great as possible. For a reduction of the local differences in air change rates, a good distribution of the ventilating devices over the halls is desirable.

In the auction halls, the possibilities for placing the ventilation devices is restriced by the presence of isolated exporters' sheds and fire walls. Owing to this, the possibilities for placing ventilating devices are limited. Comparing the k-factors for these places, it appears that, in some parts of the halls, not a sufficiently large difference in k-factors (ΔK) can be attained for all wind directions. Figure 10 illustrates this. From this, it appears that, for the part of hall 3 pictured, there is no or only a small difference in k-factors for westerly wind directions.

It appears that the differences in k-factors are mostly much too small in the whole auction hall complex for wind directions along the roofs (easthern and western). In view of this, it has been investigated what supplementary provisions cause considerable differences in k-factors for exactly these wind directions. It appears that this is the case when making a construction across the roofs (measuring points numbers 37 and 38; see differences in k-factors in Figure 11) such as a tunnel construction (Figure 12a) or partitions for propelling the air (Figure 12b).

If such supplementary architectural provisions are included in the design, it must in principle be possible to design a good natural ventilating system. It appears that, in a universally applicable design, the most appropriate places for ventilating devices are (see Figure 12):

a. on both sides of the roof construction mentioned (tunnel or partitions for propelling the air);

b. at the top of the long slanting roof;

c. in the vertical roof surface.

Without ventilation calculation, one cannot say if this is the most suitable design; that is, different combinations of places for ventilating devices are possible for the separate hall parts in which the front walls available are included. Because of the differences in k-factors however, these combinations of places do not always seem to lead to a decrease in the total area for placing ventilating devices. Therefore, only the first-mentioned, universal, combination of places has been worked out.

6.2. Nature of the ventilating devices

To be able to determine the size of the ventilating devices, a selection should be made from the various designs. This is important for the magnitudes of the values for C and n mentioned in [2].
They are a measure for the resistance met by the flow in the ventilating devices. As mentioned earlier, the ventilating devices for the auction halls ought to be controllable. This is desirable not only to prevent draughts but also to prevent the temperature from falling too much in

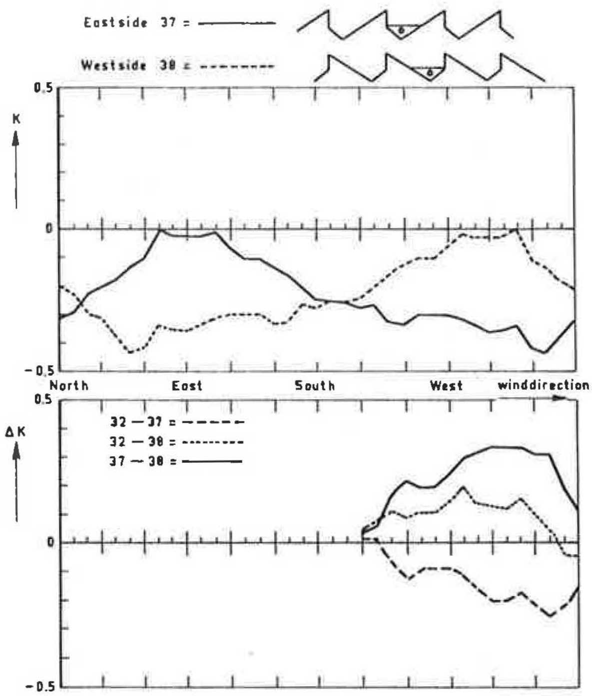


Fig. 11. k-factors for roof constructions and differences in k-factors for wind directions along the roof.

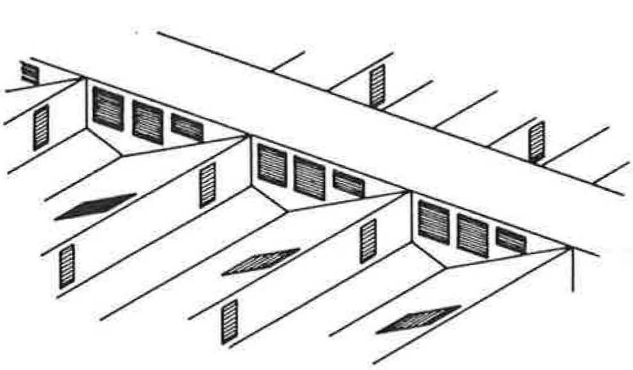


Fig. 12a. Ventilating devices in the roof and in a tunnel construction.

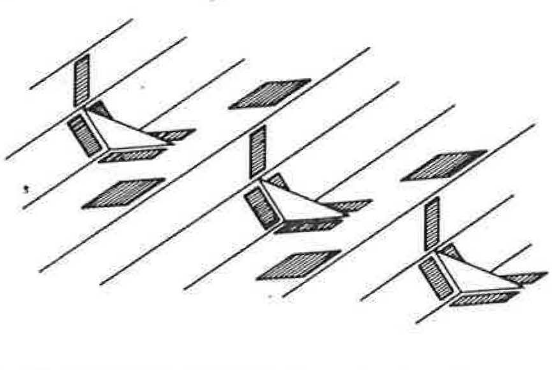


Fig. 12b. Ventilating devices in the roof and partitions for propelling the air.

winter. Besides, the ventilating devices must be free from rain coming in. For both the vertical and the sloping roofs, laminated grates were chosen. Laminated grates for sloping roofs are generally considered to have a limited permeability to air. With respect to prevention of raining in, the laminations may not extend beyond the horizontal positions (Figure 13).

However, in this case, it may be argued that one is concerned with an entirely opened grate for transport of solar heat for which a ventilation rate of 4.5 per hour is required. The simultaneous occurence of rain and sun is a rare event. When the grates are fully open, the entrance of solar heat increases. However, this quantity is negligible as compared with the total solar heat gain.

These grates will always cause a completely turbulent flow, so that one may use a value of n= 2. The values of C for the grates can be derived from [12]. For an completely opened grate, a value of C per m² of gross surface area of 0.77 m³/s is taken at 1 Pa. The specific mass of the air (ϱ) is then taken at 1.2 kg/m³.

6.3. Size of the ventilating devices

In section 6.1, the four roof surfaces for placing the grates are given. From the different k-factors for these roof surfaces, a convenient proportion of the grate surface areas in the four different roof surfaces is estimated. Then, a rather arbitrary estimation of the surface area of the grates in one of the roof surfaces is made.

From the proportion estimated for this, the grate surface areas in the other roof surfaces are determined. The grate surface areas are converted into values of C. By means of the calculation programme for the ventilation, the airchange rates for this situation are calculated for the different wind directions (Figure 14a). Then, all grate surface areas are proportionally enlarged or reduced so that an airchange rate of 4.5 per hour is attained for the unfavourable wind direction(s) (Figure 14b). In this way, the airchange rate desired is attained, but the estimated proportion between the grates in the different roof surfaces need not be the most favourable one.

To gain insight into this, the grate surface area in each of the four roof surfaces is changed succesively, so that other proportions are established between the grate surface areas. The changes which cause a more flat course of the airchange rate with the wind direction (Figure 14c) are revised a few times until the course of the ventilation rate with the wind direction is as flat as possible (Figure 14d).

Finally, the airchange rate for the unfavourable wind direction(s) is restored to the value desired (4.5 per hour) by proportional enlargement or reduction of the grate surface areas (Figure 14e).

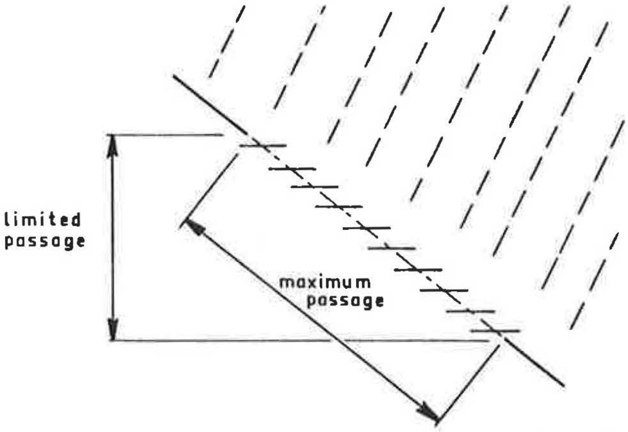


Fig. 13. Consequence of a grate position free from rain coming in for the permeability to air.

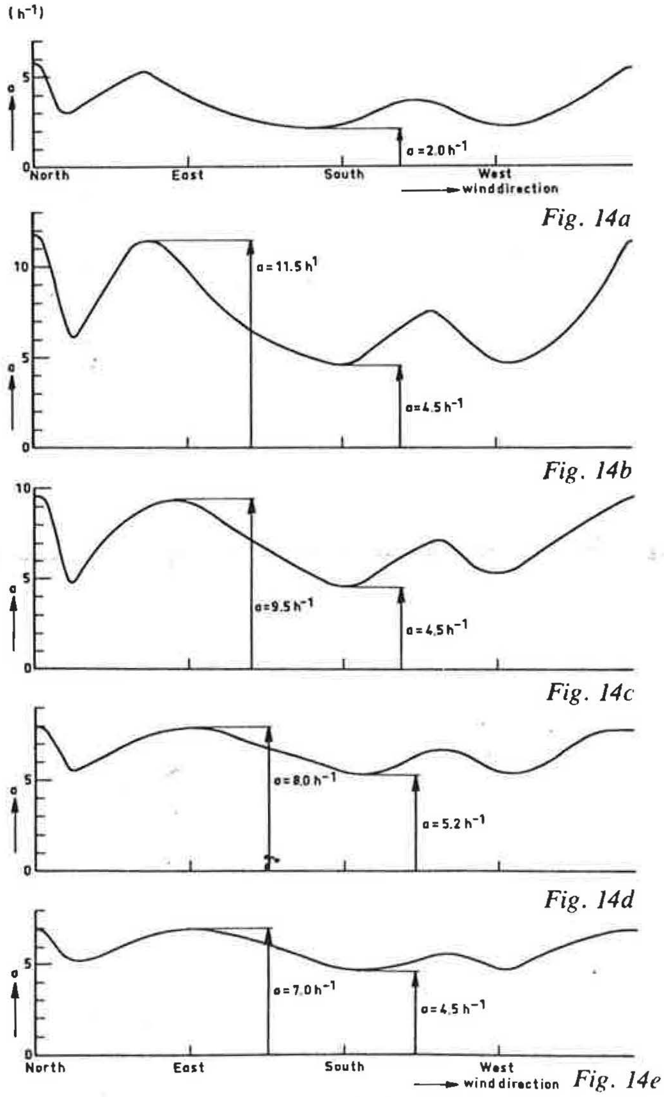


Fig. 14. Optimization of the size of the ventilating devices by means of the calculated course of the air change rate with the wind direction (for explanation, see Section 6.3).

In this way, the following sizes of the grate surface areas have been derived for the auction halls.

a. a gross grate surface area of 28 m² for each roof in the vertical roof surface. This is about 11% of the total area of the vertical roof surface;

b. a gross grate surface area of 53 m² for each roof at the top of the long sloping roof surface. This is about 5.5% of this surface area;

c. a choice for each roof is either grates in the roof on both sides of one or two partititions for propelling the air with a gross surface area of 21 and 11 m², respectively, per side per partition or grates in both vertical sides of a tunnel construction with a gross surface area of 21 m² per side.

The architectural plans should include attention to preventing short circuiting of the air flow (Figure 15).

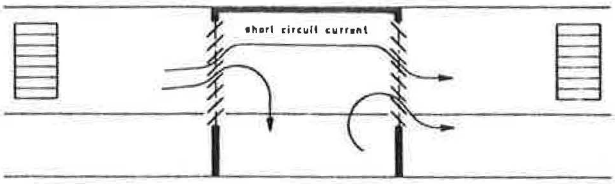


Fig. 15. Short circuit air flow through opposite grates in opened position in a tunnel construction.

6.4. Control of the ventilating devices

In the foregoing, the importance of the possibility for controlling the ventilating devices has been stressed more than once. On the one hand, there is a changing need for ventilation in different situations. This depends on the use (supply or no supply of products, much or little internal transport), the heat load (extent of solar heat entrance, the outdoor temperature) and the possibility of draughts (combination of air temperature and air velocity). On the other hand, the possibilities for ventilation are not always as great. They are dependent on weather conditions such as wind velocity, wind direction and indoor/outdoor temperature differences. By changing the grate positions, the possible ventilation can be influenced in such a way that it meets the requirements for ventilation. So, the employees present might operate certain grates if desired. As a consequence of this, the combined action of different grates can be seriously disarranged, owing to which not only the ventilation can be influenced unfavourably but also the possibility of complaints increases. This argues in favour of using a preliminary scheme by which the grate positions are controlled.

Table 1:
Air change rates for different grate positions; ventilation provided by wind and thermal flow ($\Delta T = 3K$).

Winddirection				North				East				South				West			
Meteorological wind velocity (m/s)				0	2	5	8	0	2	5	8	0	2	5	8	0	2	5	8
Grate positions: vertical roof surface	at top of sloping roof surface	east side of cross construction	west side of cross construction																
1	1	1	1	2.5	7	19	30	2.5	7	18	30	2.5	4.5	13	22	2.5	4.5	12	19
1/2	1/2	1/2	1/2	1.5	4	10	16	1.5	3.5	10	15	1.5	2.5	7	12	1.5	2	6	9.5
1/4	1/4	1/4	1/4	1	2	5.5	9	1	2	5	8	1	1.5	4	6.5	1	1	3	5
1/8	1/8	1/8	1/8	0.5	1	3	5	0.5	1	2.5	4.5	0.5	1	2	3.5	0.5	1	1.5	3
1/2	1	1	1	2	5.5	15	24	2	6	16	26	2	4	12	19	2	3.5	9.5	16
0	1	1	1	2	5	11	18	2	5	12	20	2	3	9.5	16	2	3	7.5	13
1	1/2	1	1	2	5.5	15	24	2	6	15	25	2	4	9.5	16	2	4	11	18
1	0	1	1	1.5	3	7.5	12	1.5	4	9.5	16	1.5	2	5	8.5	1.5	4	9	15
1	1	1/2	1	2	6	16	27	2	6.5	17	27	2	4.5	12	20	2	4	11	17
1	1	0	1	1.5	5.5	14	22	1.5	5.5	14	23	1.5	4	11	19	1.5	3.5	8.5	14
1	1	1	1/2	2	7	18	29	2	5.5	14	24	2	4.5	13	21	2	3.5	8.5	14
1	1	1	0	1.5	6.5	17	28	1.5	4	10	16	1.5	4.5	12	20	1.5	3.5	8	13

In buildings such as auction halls in which the ventilation may vary within ample limits, it is sufficient that the grates be handled manually by a person appointed for this. Generally, it will also then be sufficient to adjust the grates once at the beginning of a work day, unless strong weather changes occur. If it must be possible to control the ventilation within narrower limits, automatic control of the grate positions should be recommended.

For both manual and automatic operation, the grate control should be based upon data on the expected supply of products and the weather conditions. These data can lead to a desired airchange rate and a maximum attainable one. To know at which grate positions the desired air change rate can be realized, data on the air change rates occuring under different weather conditions and at different grate positions are required. These data can be generated with the calculation programme for the ventilation. Table 1 is an example of this. From the data given in Table 1, directives for the control can be drawn up. In this way, a synchronous control of the grates at all orientations seems to be attainable for the auction halls.

7. Conclusions

a. By changing the ventilation design systematically and by determining the relating changes in the degree of ventilation, an optimum ventilating system can be developed.

b. It appears that a natural ventilating system can be realized for the three vegetable auction halls by placing ventilating devices exclusively in the roof. The ventilation is then chiefly provided by the differences in wind pressure caused by the shape of the roof.

8. References

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9. Nomenclature

a	air change rate	h^{-1}
C	air flow coefficient	m^3/s at 1 Pa
k	dimensionless pressure coefficient	–
n	exponent, between 1 and 2, dependent on the nature of the air flow	–
ΔT	indoor/outdoor temperature difference	K
ϱ	specific mass of the air	kg/m^3