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LUCHTDOORLATENDHEID VAN 21 GEVELS MET GEVELELEMENTEN IN DRIE SEIZOENEN.

(The air permeability of 21 facades with facade elements in three seasons)

Door: Ing. B. Knoll,
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Rapport C 490, november 1981

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THE AIR PERMEABILITY OF 21 FACADES WITH FACADE ELEMENTS IN THREE SEASONS

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Ing. W.F. de Gids

Report C490, November 1981

Department Sound, Light and Indoor Climate
with the assistance of J. de Bakker, J.H.K. Holst, J. Molenaar,
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Project leader: Ing. W. F. de Gids
Client: Department of Housing and the Environment (MVRO) within the
scope of the research programme of the Advisory Group Energy and Buildings. (SEG)

THE AIR PERMEABILITY OF 21 FACADES WITH FACADE ELEMENTS IN THREE SEASONS

In the ventilation of houses the air permeability of the facades with facade elements plays a part. In order to achieve an inventarisation of the air permeability of various types of facades in occupied dwellings, measuring took place at 21 facades. It must also be investigated whether the air permeability changes for each season. This is the reason why measuring at each facade was carried out in three seasons. Additionally, it was investigated at twelve facades which share the various gaps (of movable sections) and joints (between fixed sections) have in the air permeability of the facades.
The entire research had been carried out at the request of the Department of Housing and the Environment (MVRO) within the scope of the research programme of the Advisory Group "Energy and Buildings" (SEG).
The research shows that the share of the joints in the air permeability of the facades is considerably greater than mentioned in the Dutch Standard NEN 3661 (6). This standard stipulates conditions with regard to the manufacture of facade elements. It is apparent that the gaps of five out of the twelve measured facades do not meet the initial points of the standard.
There appear to exist great differences both between the air permeabilities of gaps and of joints in various facades as well as between the air permeabilities of the facades themselves. No clear tendency could be established with regard to the seasonal influence. The most frequently occurring tendency shows an increase of the air permeability during the winter as compared to the summer and the spring or autumn.

Furthermore, there are indications that besides the air humidity also the temperature greatly influences the air permeability.

I ADVICE TO THE READER

The reader who wishes to get a quick impression of the progress of the research, without extensively investigating various issues, is recommended to read the abbreviated version of the report as shown on the coloured pages.

II Abbreviated version of the IMG-TNO report C 490
"THE AIR PERMEABILITY OF 21 FACADES WITH FACADE ELEMENTS, IN THREE SEASONS
by Ing. B. Knoll and Ing. W.F. de Gids

At the connections between frames and walls, glazing and frames and similar joints, openings can be found through which the air can penetrate into the house or escape from it. The same can occur via the connections of windows and other movable parts on the rabbet (gaps). This is shown in Figure I.

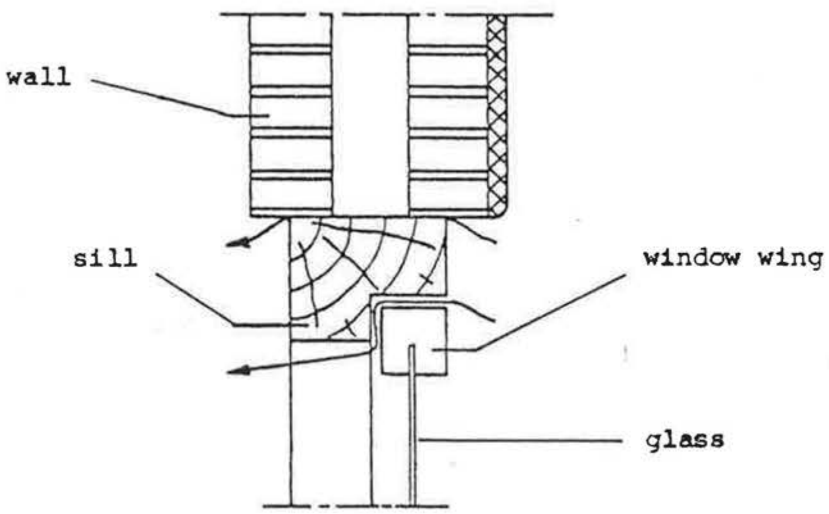


Figure I. Air exchange via gaps and joints in the facade.

Little is known about the total air permeability (degree of leakage) of the various types of facades.

Objective of the research

1. Inventarisation of the total air permeability of various types of facades.
2. Investigation whether there is any seasonal influence.

Arraggement of the research

- 21 different types of facades have been selected in which the variety in the Dutch forms of building is more or less expressed. In the selection additional attention was paid to other, possibly important criteria, such as age and maintenance.
- Under the influence of temperature and humidity of the air and sun radiation deformation of the facade components may occur. By executing the measurements three times at the facades, in the summer, spring or autumn and winter, the possible influence on the air permeability of the facades can be signalled.
- In the Dutch Standard NEN 3661 requirements are laid down for the air permeability of windows (gaps) with regard to the manufacture. The air permeability of joints is here supposed to be negligibly low, namely 1% of the air permeability of gaps. In order to check this, the air permeability of gaps and joints of a number of facades has been determined.

Characterisation of the air permeability

The air permeability of a facade is expressed in the allowed volume flow at a specific difference in pressure for the facade, expressed per unit for the size of the facade or for the size of the air passing parts of the facade.

Measuring principle

A surplus pressure is applied to one side of the facade with the aid of a ventilator (see Figure II).

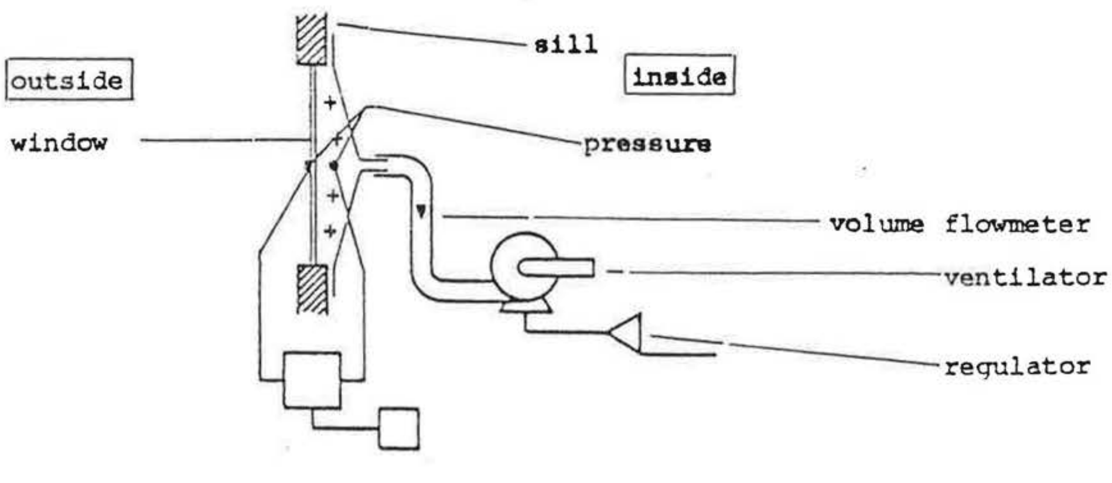


Figure II. Measuring principle in one of the applied measuring arrangements.

The pressure difference across the facade is measured. The ventilator displaces a volume flow, which is also measured. In the arrangement of Figure II this volume flow escapes exclusively through the gaps and joints in the facade. Two other measuring arrangements have been applied, by which also the volume flow through the gaps and the joints could be determined. A passed volume flow at different pressure differences across the facade has been measured at various speeds of the ventilator.

Results

By plotting the measured pressure differences and relating volume flows at the various speeds of the ventilator, the air permeability characteristics obtained as shown in Figure III.

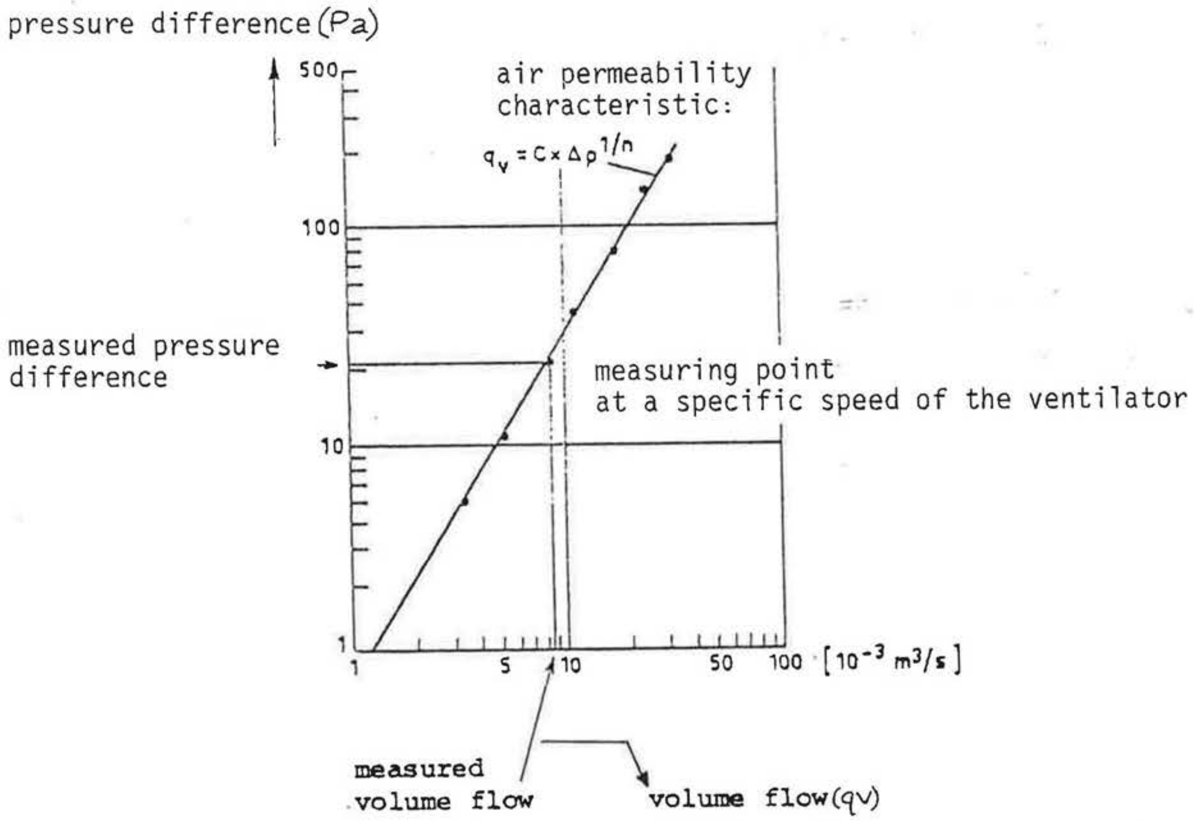


Figure III. Air transport through the facade depending on the pressure difference across the facade (air permeability characteristic).

They are characterized by the general comparison:-

$$q_v = C \times p^{1/n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which q_v = the air volume flow through gaps and joints in the facade (10^{-3} m^3/s)

Δp = the difference in pressure across the facade (Pa)

C = aire permeability coefficient (10^{-3} m^3/s at 1 Pa)

n = flow coefficient (-)

The values C and n for the various facades per season are shown in table 1, following this report.
This also includes the other particulars of the facades. C and n of a facade provide information regarding the air permeability of that facade.
In order to facilitate mutual comparison of facades in various seasons, the report includes a figure, plotting the passed volume flows at one and the same, frequently occurring pressure difference (figure 9 of the report).
As the air permeability must be shown independent from the size of the facade, the air permeability of the facades has been plotted against various magnitudes which are characteristic for the size of the facade.
This is shown in figures 10 to 12 of the report. In the figures 13 and 14 of the report the air permeability of the gaps and joints per metre length has been separately plotted for a number of facades.

Conclusions

1. Measurements investigating the individual contribution of gaps and joints in the air permeability of facades shows that in practice especially the share of the circumferential joints must not be ignored.
This is contrary to the suppositions in the Dutch Standard NEN 8661. The 12 measurings on which this has been based, provide an average air permeability of the circumferential joints per metre length which is approximately 40% of the air permeability of gaps. The standard suggests that this must be less than 1%.

2. The air permeability of the circumferential joints of twelve facades varies from 0.01×10^{-3} m^3/s per metre joint at a pressure difference of 3 Pa for the least leaking joints to $0.65 \times 10^{-3} m^3/s$ for the most leaking joints, consequently a variation with a factor 65. In no case is the air permeability of the joints $<$ 1% of the limiting value for gaps as stated in the standard.

3. The air permeability of the gaps of twelve facades varies from 0.07 x 10^{-3} m^3/s per metre gap at a pressure difference of 3 Pa for the least leaking gaps to 1.52 x $10^{-3} m^3$/s for the most leaking gaps, consequently a variation with a factor of more than 20. The gaps of five of the twelve facades apparently do not meet the initial points of the standard. The maximum transgression of the limiting value set in the standard amounts to a factor three.

4. The total air permeabilities of gaps, joints and other leaks in facades can be expressed in different ways. A fairly good expression is as as passed volume flow at a specific pressure difference per metre of the total gap length increased by 40% of the length of the circumferential joints. If the air permeability of the 21 facades at which measuring took place, is shown in this manner, the air permeability appears to vary from 0.06 to 1.28 x $10^{-3} m^3$/s per metre of the stated length at a pressure difference of 3 Pa. Consequently, the difference is therefore more than a factor 20.

5. At a frequent pressure difference of 3 Pa the least leaking of the 21 facades permits through all gaps and joints an air volume flow of 0.5 x $10^{-3} m^3$/s. The most leaking facade permits at the same pressure difference 18 x $10^{-3} m^3$/s.through.
   If the pressure difference across the facade increases to the little occurring value of 40 Pa, then approximately the sixfold is permitted through. Owing to the fact that both the ventilation requirement as well as the share of the facade in the ventilation per space may vary considerably, one should not decide solely based on these figures regarding the permissibility of the said air transports through the facades.

6. There appears to be no uniform relationship between the air permeability of facades add the season. The most prevailing tendency is the occurrence of the maximum air permeability in the winter.

7. There are indications that the air permeability is not only influenced by the humidity of the air but also to an important degree by the air temperature.

CONTENTS

Appendices

C490

IMG-TNO Dept. GLB

November 1981

BK/dG/ed

FOREWORD

We would like to thank all those who have enabled the execution of this research.

More in particular we would like to express our gratitude to the persons who tried to find the suitable facades and the occupants of the houses concerned. This in particular because the investigation required three times the sealing off of parts of their houses and because in many cases damage to wallpaper and paint could not be avoided.

The authors.

AIR PERMEABILITY OF 21 FACADES WITH FACADE ELEMENTS, IN THREE SEASONS

1. NAMES AND SYMBOLS

In this report the general terminology for building work, technical names, etc. are used as much as possible.
For reasons of clarity a description of some frequently used concept follows below.

Facade : the vertical separation of the dwelling between inside and outside; consequently the outside wall plus possible windows, doors, sills etc.

Facade element: the section of the facade which consists of a sill with windows and/or doors and/or glazing and possibly available panels, plates, etc. (figure 1)

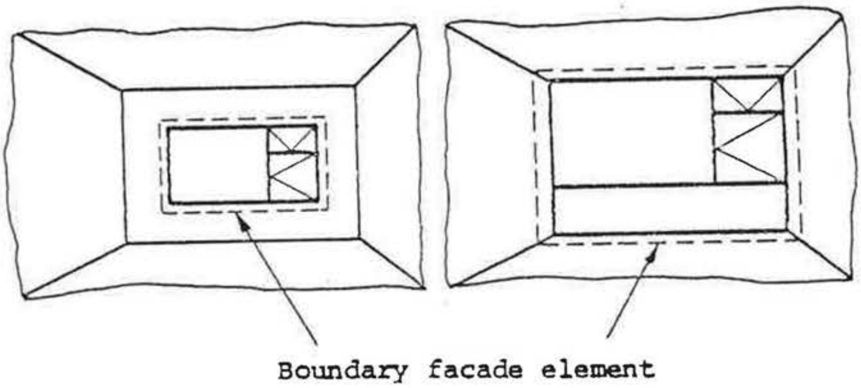


Figure 1: examples of facade elements.

The facade elements is surrounded by building components such as walls, floor, ceiling or other facade elements.

Slit: general name for the opening at the connection of structures or component parts of structures to each other in closed condition.

Joint: The slit between parts which as a rule not move with regard to one another, for example, between sill and wall (figure 2).

Gap: the slit which is not only present owing to non-precision in the manufacture, but is or should be available for a good functioning with regard to one another of moving parts, for example, between window and sill (figure 2)

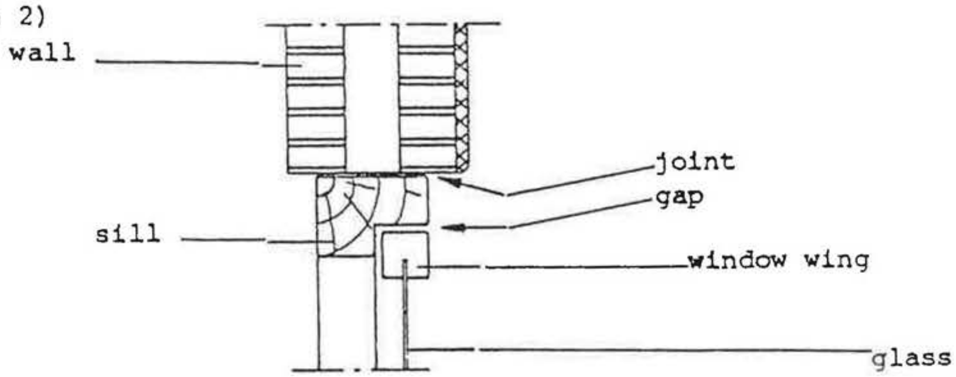


Figure 2. Example of gaps and joints

Names which are also used in the building industry are "grooves" and "rebate".

Slit, joint or gap length: Example, length of the joint between sill and wall is the circumference of the day opening in the wall.

Slit, joint or gap width: Example: the width of the joint between sill and wall is the shortest distance existing between the sill and the wall at the place where these should adjoin.

Slit, joint or gap depth:Example: depth of the joint between sill and wall is the shortest distance which the air mus pass through this opening in order to enter from the inside to the outside.

Untightness:each slit or joint slits through which the air can flow to or from a space.

Air permeability (of a facade): property (of a sealed facade) to allow the air to pass through when subjected to a pressure difference. The air permeability is charracterized by a volume flow and is expressed in $10^{-3} m^3/s$ (l/s) as function of the pressure difference. As concerns, for esample, a facade with facade element, the volume flow is related to the area of the facade element or to another characteristic magnitude for the number of untightnesses, such as the total gap and joint length.

In this report the following symbols are used:-

A	= area	m^2
C	= aire permeability coefficient	m^3/s at 1 Pa
l_k	= gap length	m
l_n	= joint length	m
n	= flow coefficient	-
p	= pressure difference across the facade	Pa
q_v	= air volume flow through the facade	m^3/s
$q_v(3)$	= air volume flow through the facade at a pressure difference of 3 Pa	m^3/s
$q_{v_k}(3)$	= air volume flow through the gaps at a pressure difference of 3 Pa.	m^3/s
$q_{v_n}(3)$	= air volume flow through the joints at a pressure difference of 3 Pa	m^3/s
r	= correlation coefficient	-

2. INTRODUCTION

"Participate in the national gap hunt"

With this and similar slogans the occupant is encouraged to limit the loss in energy by unchecked ventilation. This concerns the air exchange via untightnesses in the outer shell of the house. Especially the untightneses in the exterior walls of heated rooms, such as living rooms, kitchen, bathroom and study and to a lesser degree the bedrooms, appear to be important. These untightnesses will mainly be found where the facade elements adjoin the walls (circumferential joints) and where the movable parts such as windows, doors and grids adjoin the fixed parts of the facade elements (gaps). Figure 3 shows this.

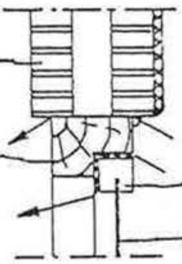


Figure 3. Air exchange via gaps and joints.

However, when sealing these and other leaks, one should be aware of the fact that ventilation is not only undesirable owing to the loss of energy. A limited ventilation is essential. Think, for example, of the supply of fresh air for the available persons, removal of moisture and thinning of harmful substances. This last issue is topical in connection with the formaldehyde and radon problems. The minimum supply of fresh air should be adjusted to these issues. In (1) there is mention, for example, of a desirable supply of fresh air of $8 \times 10^{-3} m^3/s$ ($30\ m^3/h$) per person in connection with the production of CO_2 by persons.

In connection with the above it is important besides having an insight in the required minimum need in fresh air per living room, also to have an insight in the realisation of the required ventilation. For example, a well-sealed facade may necessitate a controlable ventilation provision such as a grid or flap. However, in the event of incorrect use, the ventilation could then increase by this in such a way that ther is more loss in energy than with an identical, less well sealed facade, in which the flap may remain sealed. Another aspect which is important in the sealing of gaps and joints is the efficiency. This depends on the share of the untightnesses in the total ventilation of a room or house.

In order to gain a better understanding of the said and similar issues, a number of ventilation investigations have been carried out in recent years. For example, it has been investigated what is the effect of the opening of a window on the ventilation (2), how the untightnesses and openings are distributed across a house and how large they are (3), the amount of ventilation created by this and the influence of the occupants' behaviour on the ventilation (4).

Already as far back as in 1953 results were published about the untightness of various window structures and the spread thereof (5). However, recent data about the untightness or air permeability of entire facades with window constructions or other facade elements are little known. It is expected that the air permeability per facade may differ considerably by differences in building manner, building materials, form of execution of the facade elements, location, age, etc. In order to gain an impression in the order of magnitude in which the air permeability is placed in practice and the spread thereof, the investigation described in this report has been carried out. To this purpose the total air permeability of all available gaps and joints of 21 different facades with facade elements, in occupied houses has been determined. In order to be able to assess the seasonal dependence of the air permeability by the influence of moisture, temperature differences and sunshine, the measurings were carried out three times in different seasons.

3. ARRANGEMENT OF THE RESEARCH

3.1. Selection of the facades

The measuring programme has been set up in such a way that it is possible to obtain a maximum insight in the air permeability of the facades as used in Dutch houses. Consequently, when selecting the facades a variation has been introduced in the following points:-

- Building manner or material of the walls
  - . traditionally built (brickwork)
  - . cast concrete with sills positioned on site
  - . Concrete skeleton building with prefabricated facades
  - . interior cavity panel gypsum, timber or sandwich panel
- Material of the sills
  - . soft wood varieties
  - . hard wood varieties
  - . steel
  - . aluminium

- Nature and type of a movable part
  - . door, window, ventilation grid
  - . slide, flap, turn or tumble movement
  - . single or multiple point closure
- Insulating measures
  - . cavity filling, flakes, blankets, foam, granules
  - . cemented constructions
  - . draught strips
  - . double glazing
- Size of the facade element
  - . gap and joint length
  - . capability to deform
- Location of the facade
  - . height above the ground
  - . protection against the weather
  - . type of room (heated/ not heated, dry/humid)
- Age of the facade element
  - . old, new, renewed
- Maintenace
  - . shrinkage, subsidence
  - . paint coating, hardened putty, cement, draught strips.

Based on these points some 21 facades have been selected which are further described in appendix 1. It has been endeavoured to select facades which are more or less representative for the Dutch houses. However, it will be obvious that with such a large number of variables it is not possible to acquire a complete survey.
The results of this research must therefore be considered as being a first orientation regarding the air permeability of the facades which have been applied in the Dutch house building.

3.2. Dependence on the season

As we mentioned already in the introduction, the research must also assess a possible seasonal dependency of the air permeability of the facades. Deformations of the facade elements may occur owing to the changing influence of air temperature, air humidity and sun radiation. They change the gap and joint size and consequently also the air permeability of the facade. In order to be able to assess this penomenon, it has been decided to determine the air permeability of each facade in three seasons.
A difference was made between the summer, in between and winter season.

The 'in between' seasons are considered to be the spring and autumn. In order to be able to compare the measurements in each season, measuring was carried out in periods of the same weather type. For the summer season, this meant dry and sunny weather at an average outside temperature between 15°C. and 19° C. The 'in between' seasonal measurings have been carried out with overcast sky and rainy weather and average outside temperatures between 6°C and 10°C.. The winter measurements have been carried out at dry and clear weather with average temperatures of around freezing point. Even though the air permeability in the summer season is of little interest from the point of view of loss in energy, as it is outside the heating period, measurements were carried out during this period. The reason is that the indication of a possible seasonal dependencycan take place most clearly at maximum differences in the type of weather.

3.3. Individual air permeability of gaps and joints

The research has been arranged in order to determine the total air permeability of the gaps and joints in the facade, so that one can assess the share in the ventilation. Additionally, it is recommended to compare the measuring results with the standards in this fields The Dutch Standard NEN 3661 (6) lays down stipulations with regard to the air permeability of gaps. However, the air permeability of the joints in the facade are herein supposed to be negligibly small, namely 1% of the air permeability of gaps. It is desirable to check this under practical circumstances in order to recognize a possible relationship between the air permeability of facades and the toal gap and joint length. It has therefore been decided to separately measure the air permeability of gaps and joints of a number of facades in one season.

3.4. Integration of other research

For some time the window has been a source of study from various points of view. Besides some function for ventilation, the window also serves as light admittance and the admittance of sun warmth. These properties must be set against an increased loss of heat owing to transmission and a reduction of the sound resisting properties as compared to a facade without windows. The physiological and psychological effects of a window with regard to noise pollution, the contact with outside and such issues, must also be considered in the design of windows.

The department Sound, Light and Interior Climate of the Institute for Environmental Hygien and Health Technique TNO endeavours in co-operation with the Section Social Sciences of the Institute to achieve an integrated approach of such multi-disciplinary study objects. Within this framework and besides the investigation of the air permeability of facades, a research was made regarding the daylight admittance through facades (7) and the sound admittance through gaps and joints of a number of facades (8).

4. MEASURING METHODS

4.1. The concept air permeability

The air permeability (measure of leakage) of a facade can be expressed in a volume flow permitted to pass through at the exposure of the facade to a specific pressure difference. The air permeability is expressed per unit of magnitude of the facade or the parts of the facade which allow the air to pass through.

4.2. Measuring principle

A pressure difference is provided across the facade which is being investigated. This causes a volume flow through the untightnesses in the facade. The pressure difference acroos the facade is measured, as well as the relating volume flow through the facade. The dimensions of the facade or the air permeable parts of the facade are determined. A measure for the air permeability of the facade is acquired by/the dividing volume flow which at a specific pressure difference by this.

4.3. Practical executions

The existing or a special created space at the inside of the facade is brought under pressure with the aid of a ventilator. The pressure difference across the facade is measured with an electrical pressure recorder. The air volume flow supplied by the ventilator to the space is determined with a pitot tube or measuring flange. The supplied air volume flow escapes entirely through the facade if there are no other openings available in the space. This can be achieved by sealing these openings beforehand or by providing an airtight space against the facade, for instance with the aid of foil (figure 4). In these cases we speak of the "direct measuring method".

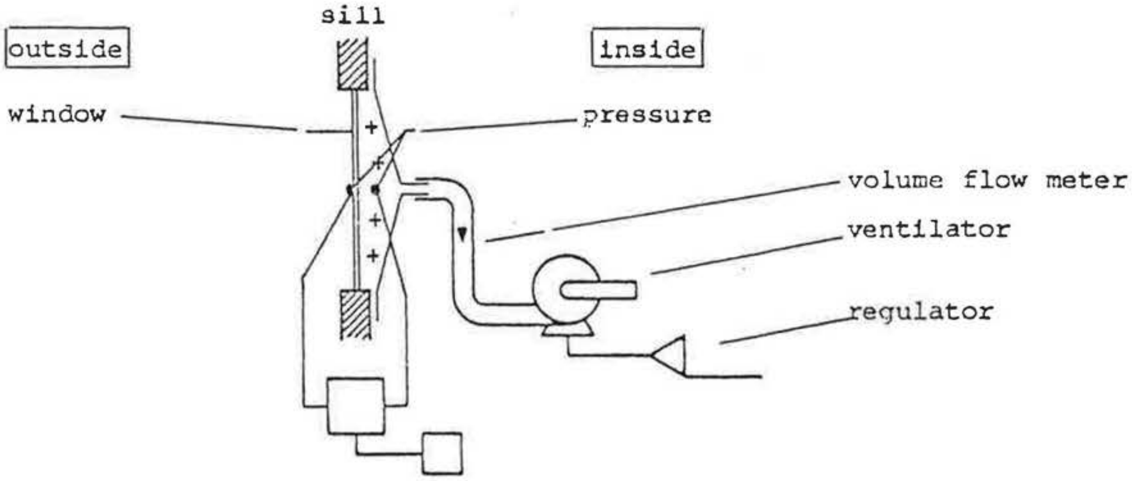


Figure 4. Direct measuring method.

It is also possible to determine once separately the volume flow permitted to pass through the remaining openings by sealing all untightnesses in the facade and thus executing an additional measuring (figure 5b). It is then possible to deduct this volume flow from the volume flow is is permitted to pass through the entire space, including the facade, at the same pressure difference (p) and which has been determined by measuring without a sealed facade (see figure 5a). The difference is then the volume flow which has passed through the facade. This is indicated as the "difference method".

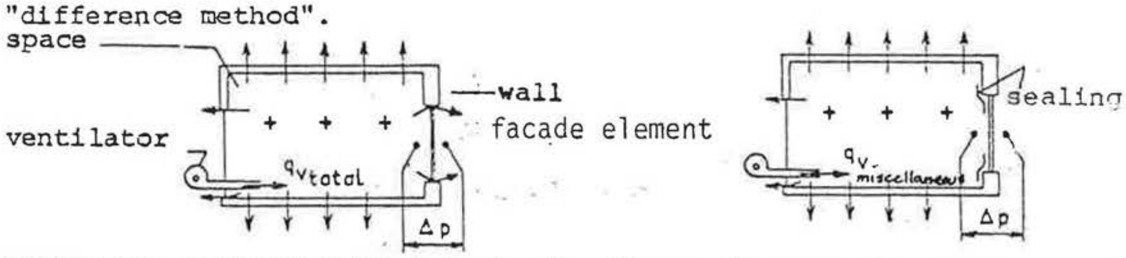


Figure 5a. Measuring total leak of the room

Figure 5b Measuring with sealed facade

$$q_{v_{\text{gevel}}} = q_{v_{\text{totaal}}} - q_{v_{\text{overig}}}$$

(gevel: facade; totaal: total; overig: miscellaneous)

Figure 5 Difference method.

Finally, a third method has been applied, which is indicated as "the compensation method". In it the air transport through miscellaneous openings in the space is prevented by setting the pressure difference across these openings at zero with a second ventilator (figure 6).

As with the direct measuring method, the air volume flow displaced by the first ventilator escapes then exclusively through the untightnesses in the facade and this volume flow is measured directly. For other particulars of the described measuring methods and a more extensive description, we refer to appendix 2. We shall further deal with the pressure differences at which measuring was carried out.

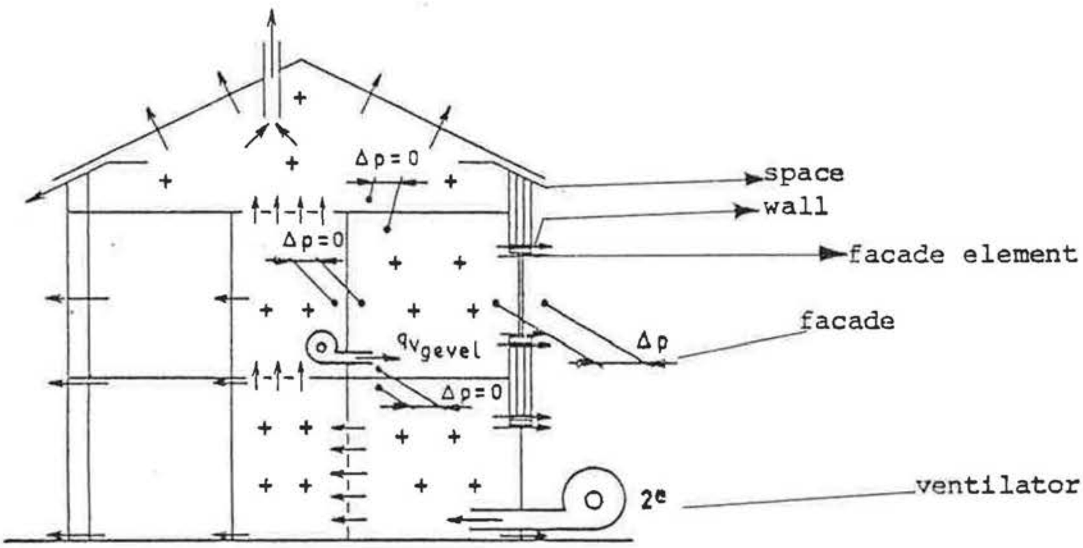


Figure 6. Compensation measuring method.

4.4. Pressure differences across the facade at which the air permeability IS DETERMINED

Above we constantly refer to the air permeability as the volume flow which is permitted to pass across the facade at a specific pressure difference. Different values can be chosen for this pressure difference. The air permeability has practical value if it is determined by a pressure difference which appears to occur in practice. However, the pressure differences in reality vary greatly, both on the spot and depending on the time. They depend on:-

- the prevailing wind speed
- the wind direction
- the degree of protection against the wind by the environment,
- the temperature differences between inside and outside
- the relationship of the untightnesses in the facade as compared to the untightnesses and openings in the rest of the house.

At high wind speeds average pressure differences may occur up to a magnitude of size of 100 Pa. During short lasting gusts the pressure differences may even increase to multiples of this value. According to (4) during the major period of time pressure differences may be expected between 0 and 10 Pa.. Owing to the change of wind direction, the pressure differences can be either "positive" or "negative", which means that at the outside of the facade there can be either overpressure or underpressure respectively. This means for the execution of the measurements: the volume flows through the facade are determined by a number of pressure differences increasing in magnitude. From this a relationship between the pressure difference across the facade and the volume flow through the facade can be deduced. The air permeability is determined at one frequently occurring pressure difference. The range within which measurements a-e carried out is roughly between 0 and 300 Pa pressure difference. In principle both in the event of over-pressure as well as under-pressure measuring will have to be carried out at the outside of the facade.

4. For example, in the event of over-pressure the gaps of the windows can become smaller by the pressure of the window against the rebate and in the event of under-pressure the gaps may become larger. This creates differences in the air permeability. However, it is apparent from (5) that statistically no differences can be shown. Consequently, it has been decided to carry out all measurings unde conditions when the gaps are pressed closed, unless the weather conditions necessitate a deviation from this.

4.

5. MEASURING RESULTS

In the three seasons similar relationships have been established for the various facades between pressure difference and volume flow as shown in figure 8. These results can be seen in figures 1 to 59 of appendix 3. Figure 8 which has been worked out as an example has been composed with the aid of figure 7. This concerns the result of the winter measuring at facade 2 (for the description see appendix 1), after which measuring took place in accordance with the "difference measuring method" as described in the above chapter. Figure 7 shows two lines with the measuring points (+) from which these have been composed. Each measuring point indicates a setting of the ventilator, at which a specific pressure difference has been created across the facade (vetical axis) and consequently a volume flow (horizontal axis) displaced by the ventilator.

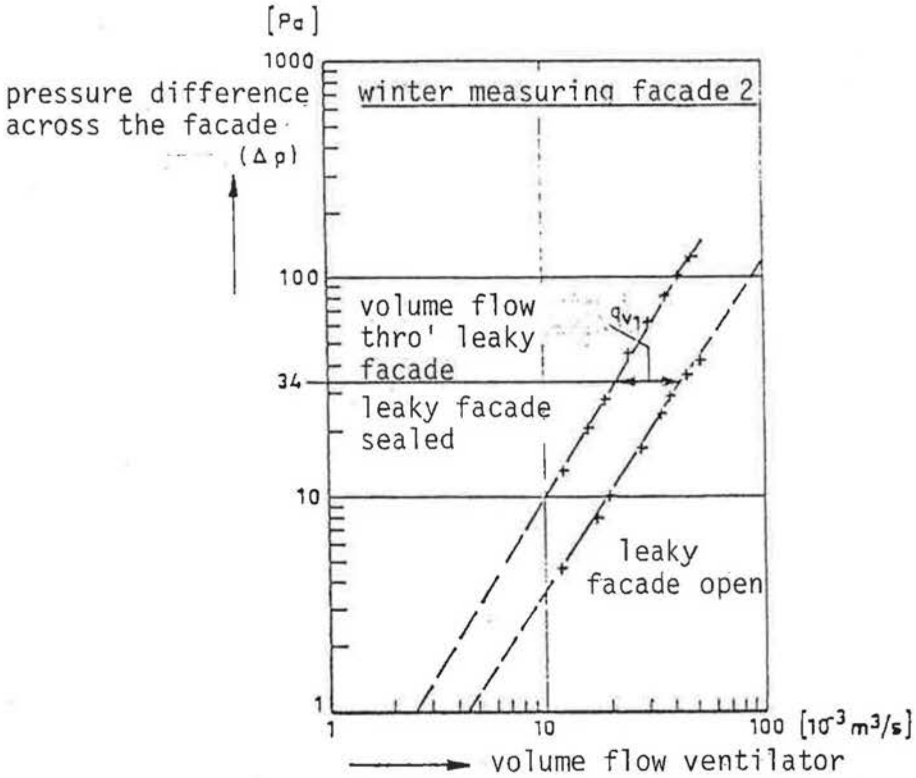


Figure 7: Relationship between the pressure difference across a facade and the volume flow which is permitted to pass through a space with and without a sealed facade.

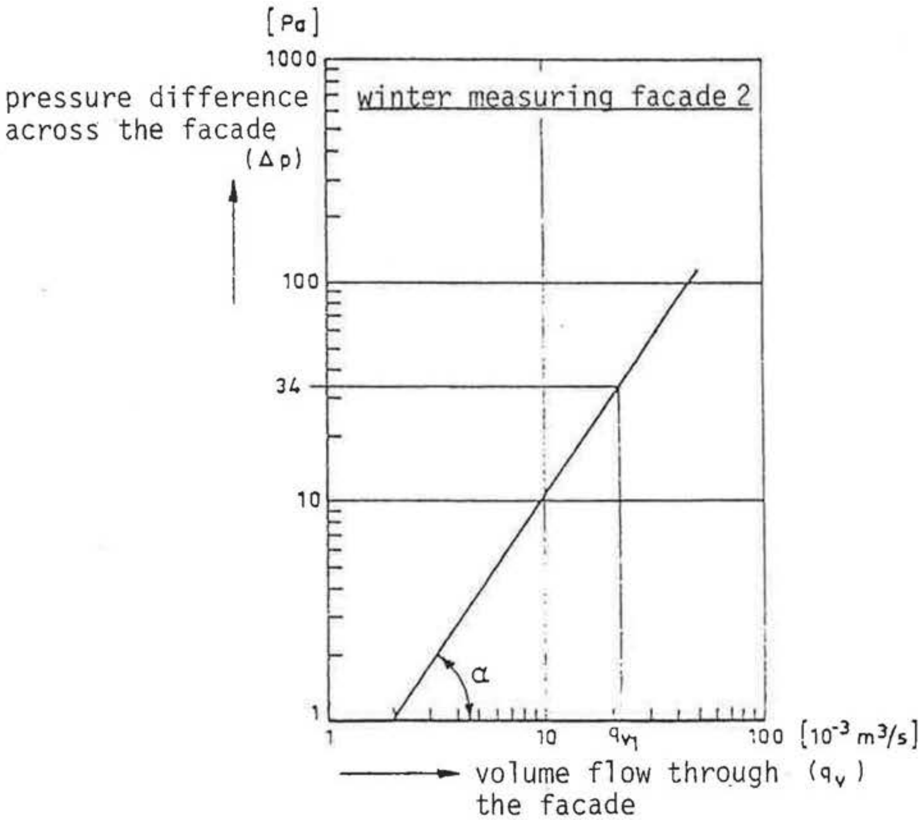


Figure 8: Relationship between the pressure difference across a facade and the volume flow through the leaks in the facade

The volume flow displaced by the ventilator has escaped through the untightnesses and openings in the space brought up to pressure. In this the untightnesses in the facade belong in the case of the measuring points on the right line in figure 7. To the measuring points on the left line the untightnesses do not belong to it, as they were sealed. This line therefore indicates the remaining leakages of the space.
The difference in the volume flows, which are represented at a specific pressure difference by the two lines, is the volume flow through the facade at that pressure difference.
In figure 7 that is, for example, at 34 Pa pressure difference a volume flow q_{v_1} of $22 \times 10^{-3} m^3/s$.
It is thus possible to determine the differences in volume flows at different pressure differences. By plotting them against the relating pressure differences one acquires the relationship indicated in figure 8 between the pressure difference across the facade and the volume flow through the facade. When applying the other two mentioned measuring methods the direct characteristics as in figure 8 are obtained.
The manner in which the characteristics are obtained and the relating precision of the characteristics is further examined in appendix 3.
It may already have been observed??the relationship between the pressure difference across the facade and the volume flow through the facade on double logarithmic paper usually appears to be a straight line. This line can be described by the general formula:-

$$q_v = C \times (p)^{1/n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

in which

q_v	= the air volume flow through the untightnesses of the facade	$(10^{-3} m^3/3)$
p	= pressure loss across the facade	(Pa)
C	= air permeability coefficient	$(10^{-3} m^3/s$ at 1 Pa)
n	= flow coefficient	(-)

From a mathematical point of view, C indicates the position of a line, as this is the point of inersection of the line with the axis p = 1 Pa is. The slope of a line is represented by n, in which n = tgx (see figure 8). From a physical point of view, C is the volume flow which was permitted to pass through at a pressure difference of 1 Pa. C is a measure for the air permeability of the facade, even though this still depends on the size of the facade. A measure which is suitable for mutual comparison of the air permeability of facades can be obtained by dividing C in a dimension which is characteristic for the size of the facade. The physical meaning of n is in the nature of the flow through the untightnesses in the facade.

n = 1 indicates a laminar flow

1 < n < 2 is a so-called transition flow

n = 2 means turbulent flow

In the discussion of the results in the next chapter, C and n will be further dealt with. The C and n values for the various facades in the three seasons are shown in table 1, in the back of the report. This table additionally shows the units which are characteristic for the size of the facades. Additionally there is a summary of the remaining characteristics of the facades.

The results in table 1 include for twelve facades also the C and n values of the movable parts.

These valurs have been determined from individual measuring at the movable parts. The measurements were made only in one season.

The relating characteristics are shown in figures 60 to 73 of appendix 3. Most characteristics for the movable parts have been determined in accordance with the principle of the earlier described "difference measuring method", possibly in combination with the measuring method applied for the entire facade. Three characteristics have been determined with the "direct measuring method".

The precision of the measuring results depends besides the used measuring method, on a numer of other issues. This is further explained in appendix 3. It results in a precision which varies practically per measuring.

The precision has therefore been worked out per measuring and where necessary considered in the processing of the measuring results.

Finally, it must be observed that the measuring results of some facades are not available for one season.

This is the result of the sale of the premises or essential structural changes during the course of the investigation.

6. DISCUSSION OF THE MEASURING RESULTS

6.1. Air permeability

6.1.1. General

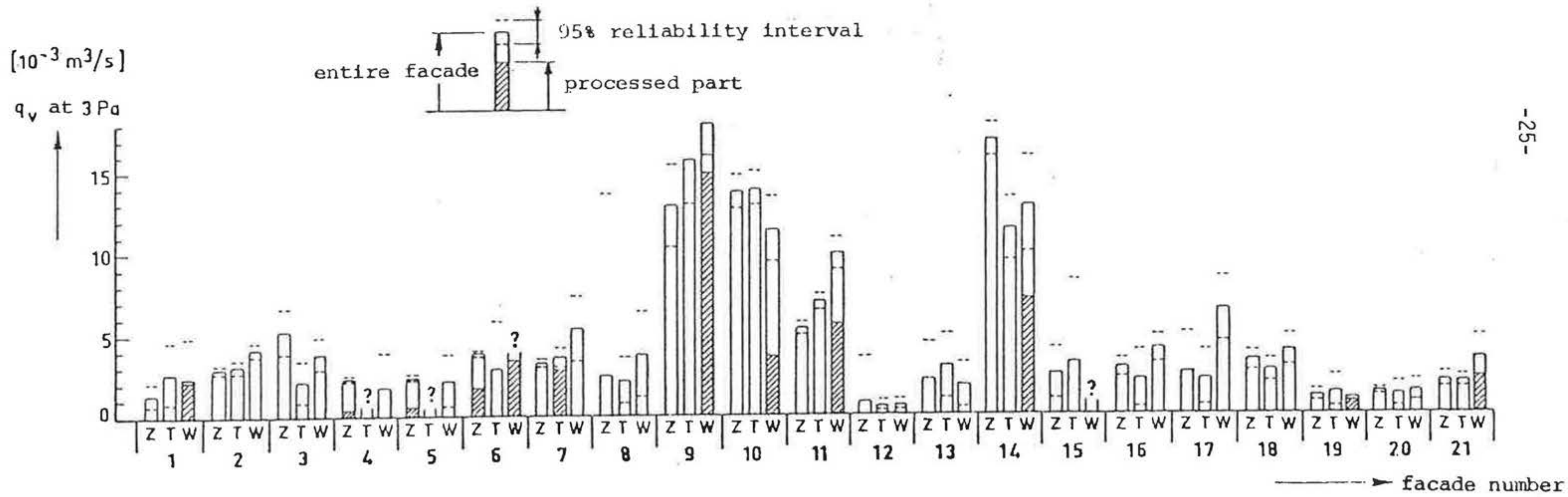
Chapter 4.1. provides the description of the concept air permeability. In the reproduction of the air permeability two issues are important. In the first place at which pressure difference across the facade the air permeability is reproduced. We have dealt with this already in chapter 4.4. In the second place it is important in which way the size of the facade is weighed. For the pressure difference it has been decided to select a value of 3 Pa. According to (4) this is the value which frequently occurs for one-family houses. The majority of the facades at which measuring took place concerns one-family houses. In any case, the selection of the pressure difference at which the air permeability is shown is not so important if the n-values (table 1) per measuring do not greatly vary. We shall now deal with the second point with regard to the weighing of the facade size in the air permeability.

6.1.2. Air permeability of facades irrespective of size

In figure 9 the air volume flow which has passed through has been shown at a pressure difference of 3 Pa per facade. The results for each facade can be seen for the three different seasons. The shading shows which part of the volume flow is passed through the gaps of the movable parts in those cases when individual measuring was carried out. Additionally, for each measuring the limits of the 95% reliability interval (precision) have been shown by way of a dotted line. The shown volume flows have been determined in a number of cases by extrapolation, as no measuring occurred at 3 Pa.
The results of figure 9 can only be considered as decisive for the aire permeability, if the size of the facade is of minor importance. However, this will not be the case, as the dimensions of the places which allow air to pass (gaps and joints) in the facade influence the results in figure 9. As these dimensions may not influence the air permeability one of the repreductions discussed below is possible.

Figure 9. Air volume flow which has passed through at a frequently occurring pressure difference of 3 Pa for 21 facades in three seasons

z = summer T= in between (spring or autumn), W= winter, ? = not measured



6.1.3. Air permeability of the facades per m^2 facade element

The dimensions of gaps and joints are in some relation to the size of the facade element in the facade.
Such a relation has in some parts about this subject caused a reproduction of the air permeability per m^2 area of the air permeable part. Following this the air permeability of the facades per m^2 facade element has been shown in figure 10. Owing to the fact that between the measurings per season the same relationship per facade remains as shown in figure 9, only the winter measurings have been shown in the stated manner.
If no winter measuring are available, the inter-seasonal measurings have been quoted. The stated reproduction of the air permeability only provides a rough indication. This is owing to the fact that the relationship between the area of the facade element and the air permeable parts thereof (gaps and joints) may differ considerably per facade.

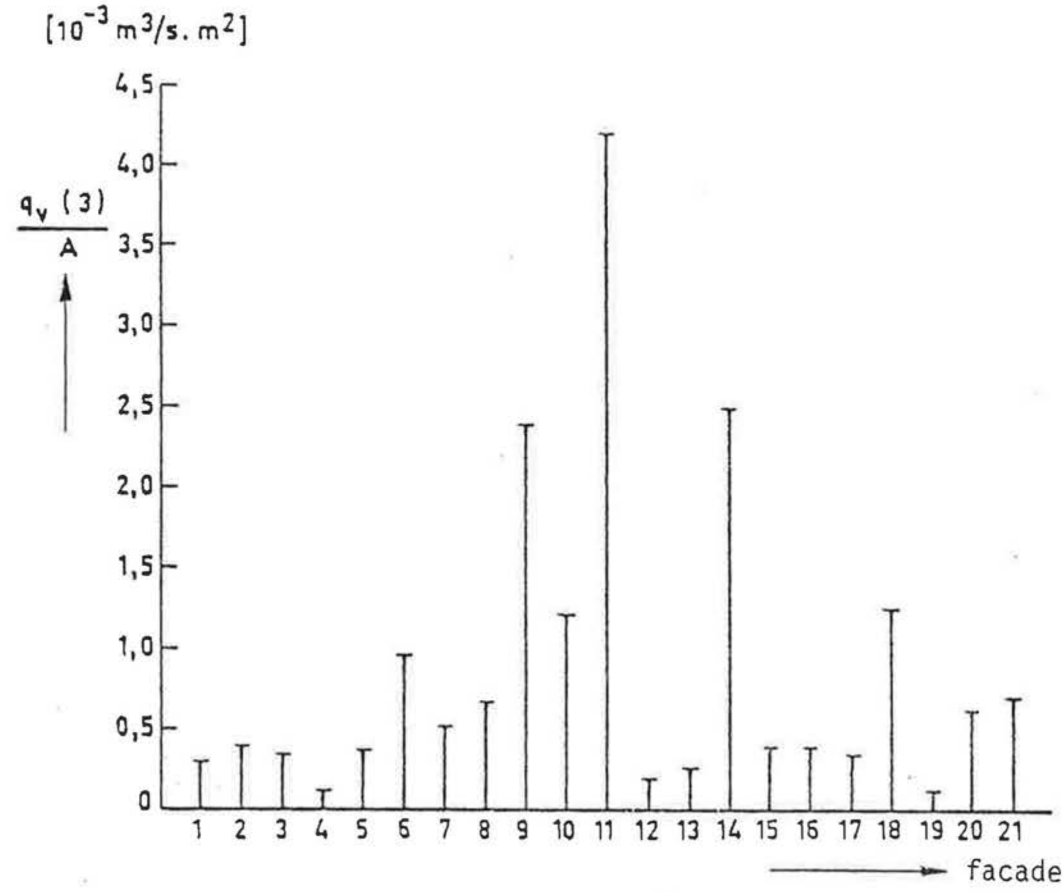


Figure 10. Air permeability of 21 facades (winter recordings) expressed in the air volume flow which passed through at 3 Pa (qv(3)) per m^2 area of the facade element (A).

2. 6.1.4. Air permeability of the facades per mtr. gap

In NEN 3661 the the air permeability of the joints in the facade is assumed negibly lwo (1%) as compared to the gaps in the facade. Accepting this assumption, it is possible to relate the air permeability of the facade exclusively to the gaps, namely the gap length. The air permeability of the facades per metre gap is shown in figure 11. The measuring results in figure 9, which show the share of the movable part (gaps) in the volume flow which passed through at 3 Pa, indicate that the above assumtion is not warranted.
The reproduction in figure 11 is therefore not correct.

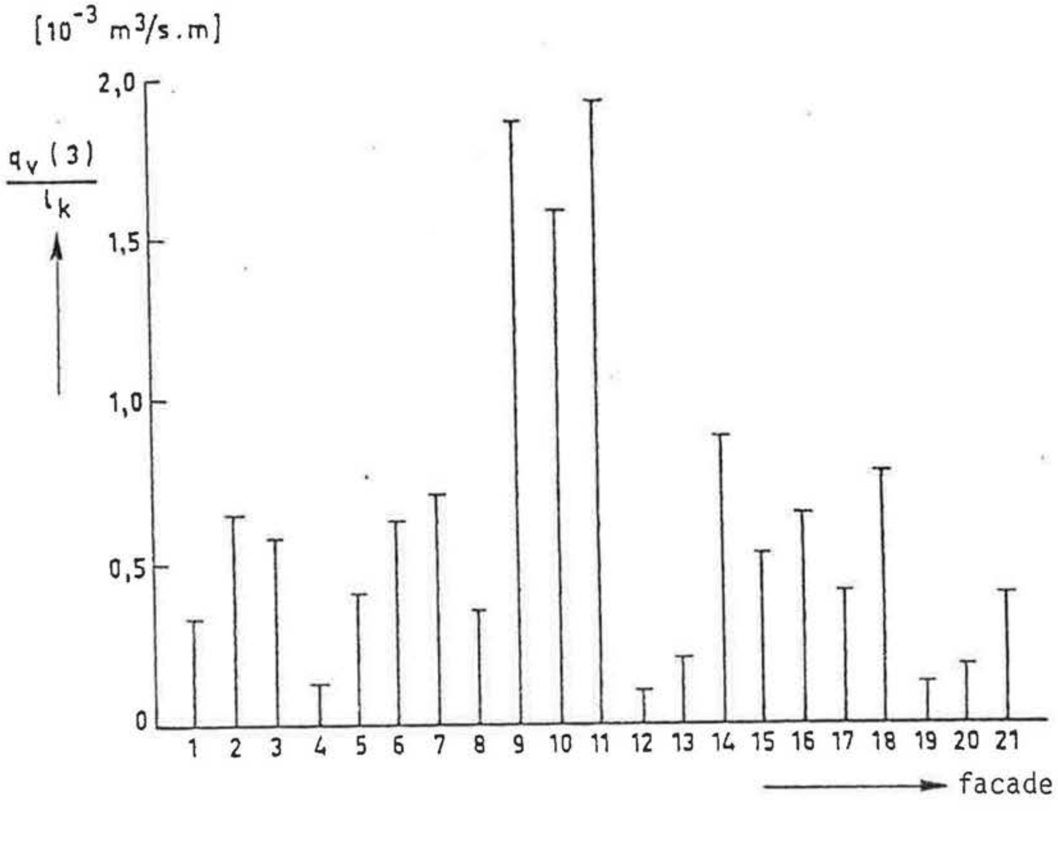


Figure 11. Air permeability of 21 facades (winter observations), expressed in the ~~passed through~~ leakage air volume flow at 3 Pa (qv(3)) per mtr. gap length (l_k).

6.1.5. The air permeability of the facades per characteristic length of the untightnesses.

Smoke

Smoke tests during the measuring have shown that besides the connections of the movable parts (gaps) mostly the connections (joints) of the facade elementswith the surrounding facade parts (sill on wall) allow air to pass through.

It is therefore obvious to express the air permeability of the facades not only per metre gap but also per metre circumferential joint of the facade element. These gaps and joints should for this purpose each be weighed according to their share. The following became apparent from the 12 of the 21 measurings at which the said shares have been determined individually.

The air permeability of the circumferential joints in on average approximately 40% of the air permeability of the gaps. The spread in this ratio is great, It varies up to a factor 5 higher and lower.

With the provided ratio between the air permeability of circumferential joints and gaps, a characteristic length of the untightnesses has been determined, that is the gap length (l_k) plus 40% of the length of the circumferential joint (l_n):-

$$l_o = l_k + 0.4\, l_n \qquad (2)$$

Figure 12 shows the air permeability per characteristic length of the untightnesses.

This reproduction provides already a better relation with theparts which allow air to pass through of the facade. However, owing to the great spread in the ratio between the air permeability of gaps and circumferential joints, also this reproduction is not entirely correct. This objection is avoided when the air permeability of the facades is subdivided into the air permeability of specific untightnesses such as gaps and joints, reproduced per length dimension

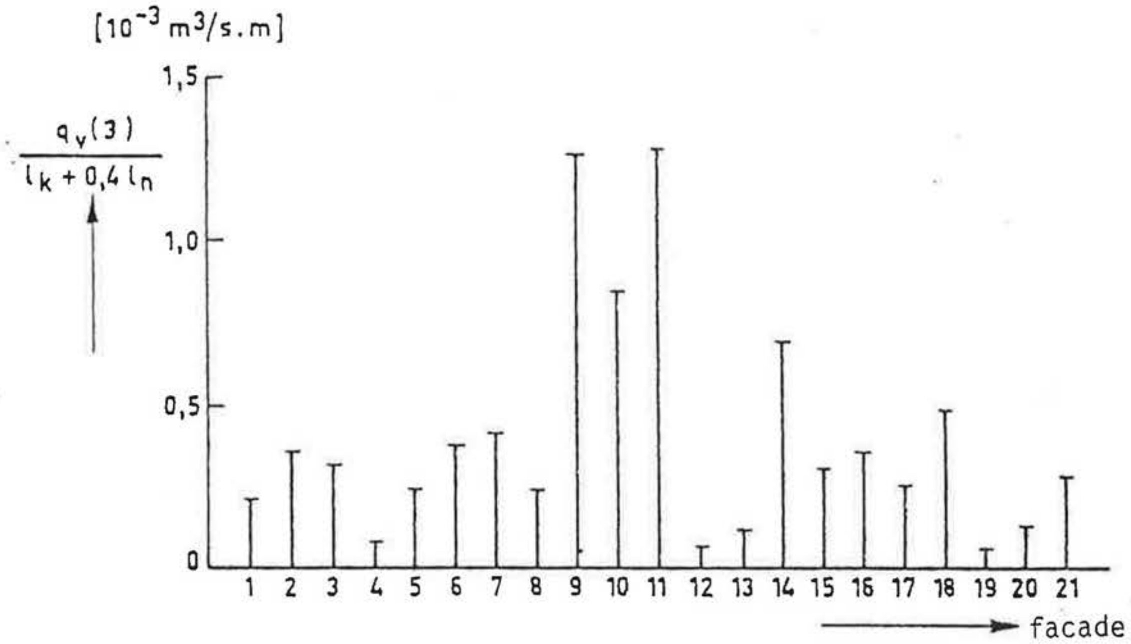


Figure 12 Air permeability of 21 facades (winter observations) expressed in air volume flow ~~passed through~~ leakage at 3 Pa (qv(3)) divided by the sum of the gap length (l_k) and 0.4 x the length of the circumferential joint (l_n) The leak of the circumferential joints is on average o.4 x the leak of gaps.

6.1.6. Air permeability of facade gaps per mtr. gap

At 12 of the 21 facades the movable parts (gaps have been measured separately. It is possible to plot for these facades the air permeability of the gaps per metre. This is shown in figure 13. It is apparent that the air permeability of the gaps in these few facades may differ already a factor 20.

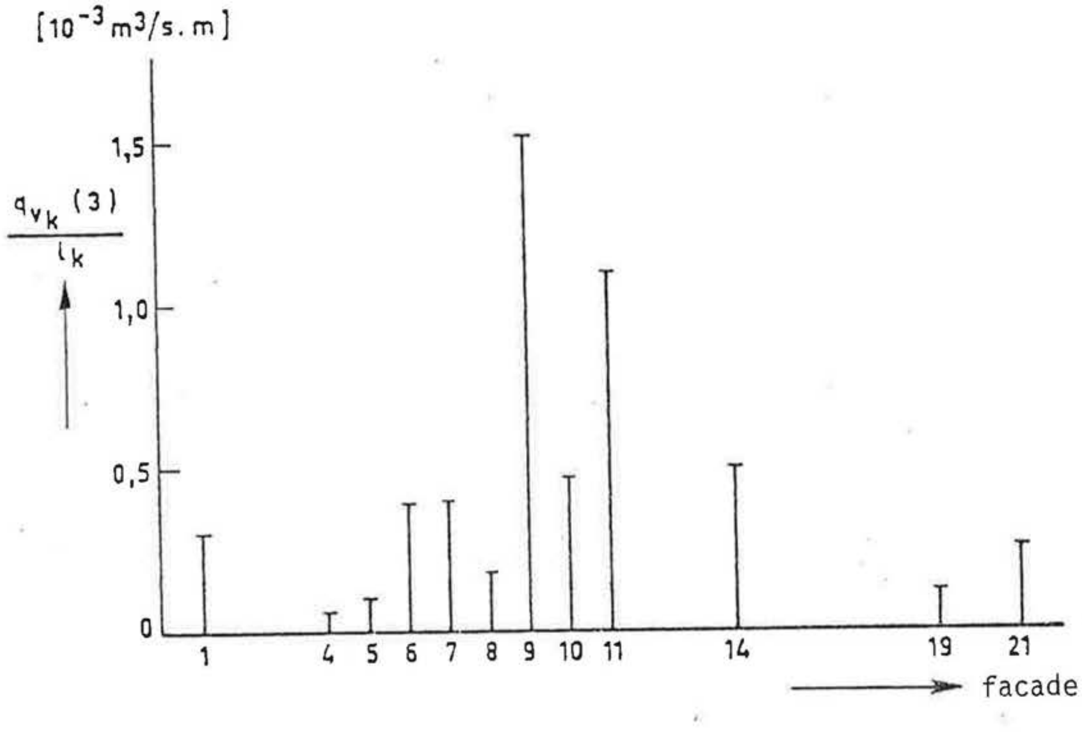


Figure 13. Air permeability of gaps of 12 facades, expressed in the air volume flow ~~passed through~~ leakage at 3 Pa ($qv_k(3)$) per mtr. gap length (l_k).

26. 6.1.7. Air permeability of facade joints per mtr. circumferential joint

IFor 12 facades both the leakage of the movable part as well as the one of the entire facade has been measured. The difference is the leakage of the joints and other untightnesses in the facade. As stated before, smoke tests showed that the circumferential joints provide by far the major share in this. Consequently, the difference in leakage of the movable part and the entire face is therefore approximately equal to the leakage of the circumferential joints. This difference is plotted in figure 14 per meter circumferential joint. It provides by approximation the air permeability of the circumferential joints per metre for the 12 facades. The spread in the air permeability of the circumferential joints appears to be considerably larger than for the gaps, namely a factor 65.

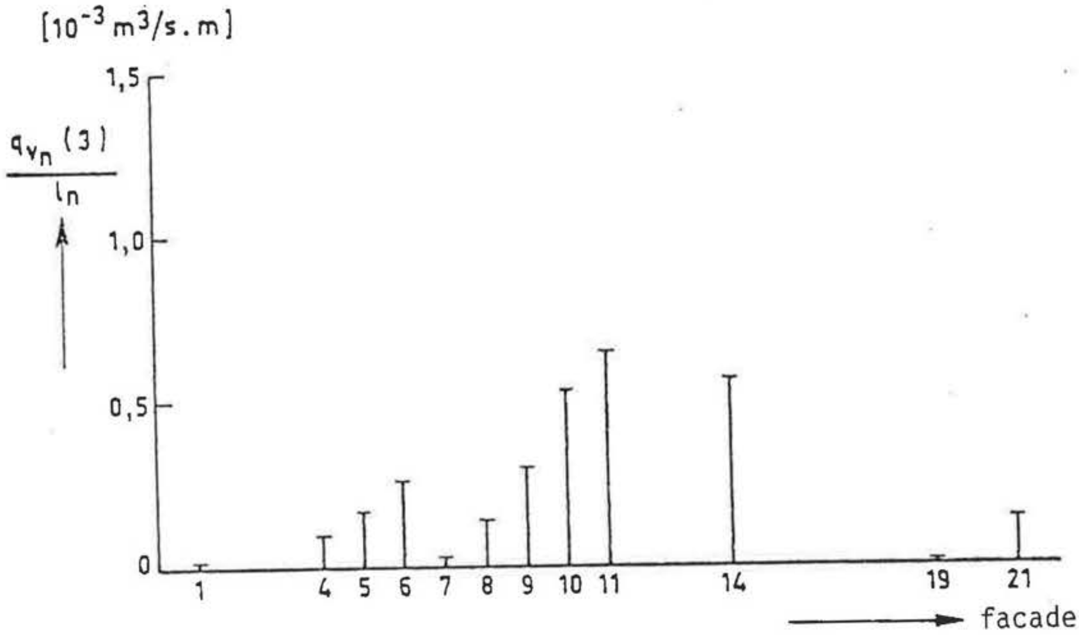


Figure 14. The air permeability of 12 facades expressed in the ~~passed through~~ leakage volame flow at 3 Pa ($qv_n(3)$) per mtr. length of the circumferential joints (l_n).

7. ## 6.2. Seasonal influences

Figure 9 show for each facade the passed through volume flow at 3 Pa in the three seasons. For ten of the 21 facades the air permeability during the winter appears to be greater than during the summer and interim seasons. There is one case of a facade with an air permeability which is in the winter season more or less equal to the one in the summer season. For four facades the air permeability in the winter is in between the air permeability of the summer and the interim season. It must be observed that one facade (facade 3) had a higher air permeability during the summer owing to a broken window closure. For five facades the air permeability during the winter is smaller than during the summer or interim season. There are two facades of which no air permeability was measured in the interim season.

Finally there are two facades of which one was not measured at all during the winter and only the movable part of the other. This last one shows an increase of the air permeability of the movable part during the wibter period as compared to the summer period. No clear seasonal influence can be concluded from these results. The most prevailing tendency is clearly a larger air permeability in the winter. For the conclusion of certain tendencies the precision must be taken into consideration. The results in figure 9 shows this by way of dotted lines, which indicate the limits of the 95% reliability interval (see for an explanation of the precision appendix 3). This shows that only for some facades the differences per seasob are really significant. The reliability of the said tendencies is therefore smaller than 95%. .

The differences in tendencies cannot be explained based on the more or less large differences in weather type when measuring one or other facade. The measuring per season was always carried out under very good comparable weather conditions. Additionally, the possible slow reaction of the facade
8. to weather conditions has been taken into account as much as possible.
As a rule, measuring only proceeded after three days of the same weather type. A few times a positive deviation was made. This was the case in the autumn of 1980. After an autumnal period during which measuring was carried out, a winter period suddenly started for one week. This was followed again by an autumnal period. Measuring was carried out on some facades (7 and 16) immediately before the start of the winter period and at the beginning of the winter period. On some other facades (2,3 and 13)

measuring took place at the end of the winter period and immediately afterwards, at the beginning of the new autumnal period. Both mutually as well as compare to the other facades, these facades do not show a great difference with regard to the seasonal influence. Apparently, the seasonal influence is determined to a great extent by the rather rapidly acting meteorological magnitude. In this respect we think of the outside temperature, which causes differences in expansion. A less rapidly changing influence on the air permeability is expected from the air humidity. The changes of the air humidity cause a change of the humidity of moisture absorbing construction materials such as wood and stone. We know of wood that i owing to that swells or shrinks. As the moisture ènters or leaves the wood by diffusion, this swelling or shrinking process is a very slow process, unless the swelling or shrinking is already considerably inflienced by the moisture at the surface of the wood. This last fact is generally speaking not assumed.

A second reason for the assumbtion that the temperature differences contribute considerably to the seasonal influence are the measured changes with the season at the facades 16, 17 and 18. Facade 16 has steel sills and frames and facades 17 and 18 aluminium ones. No seasonal influence as a result of moisture is expected for these materials.

In order to gain a better understanding in the origin of the seasonal influence , a further research is needed of the influence of the various meteorological magnitudes on the air permeability.

We are thinking of a continuous recording of the air permeability of a facade, the locally predominat meteorological magnitudes and the material changes such as timber humidity.

Another effect which may considerably influence the seasonal influence, is the condition under which the installation of the facade element has taken place.

This is illustrated by the following, perhaps slaightly extreme imaginary examples.

Example 1: In a traditionally built house the sills are pointed immediately after the holidays of the building trade. During the holidays the frames had already been set on the site. The building workers were not very lucky, it rained during the whole of their week. Owing to the moisture in the timber, the frames were somewhat swollen.

In this condition the sills were cemented in with the smallest possible slits. Tje air permeability would therefore be small. During the winter period with dry freezing weather, the sills evaporated a good deal of moisture. This was even encouraged by the heating of the house. The timber of the sills therefore shrank. This shrinkage was even slightly increased by the lower outside temperatures, which cause differences in expansion. The air permeability of the facade has increased considerably owing to the larger gaps.

Example 2: In the same type of house, the frames were installed and cemented in straight from the factory. During the installation the weather was dry and cold. In that situation the air permeability is slight.

After a wet period in the summer the timbers swell and somewhat expanded owing to the higher temperatures. This caused deformation of the frame and the gaps and joint to become larger. As compared to the winter period, the air permeability during the summer has increased.

30. These examples illustrate that in one and the same type of building and with the same precision of finish, a completely opposite seasonal influence can be created owing to varying installation circumstances. It is also very well possible that the manner of building and the precision of the finish may influence the seasonal influence. This is, for example, apparent when considering the influence of draught strips in windows and doors. It is known that the gap width of windows and doors may vary considerably with the period of the year. Think only of jamming doors and windows in some seasons. This change in the gap width will have hardly any influence at all on the air permeability if the draught strips provide an equally satisfactory sealing also in the event of a change of gap width. No details could be traced of the measured facades with regard to the installation circumstances. For the differences in building construction, the availability of draught strips, the condition of maintenance etc. we refer to appendix 1 and the summary as expressed in table 1 at the end of the report.

6.3. Air permeability set against the initial points of NEN 3661

The Dutch Standard NEN (6) contains as requirement for the manufacture of facade elements a maximum air permeability per metre gap length of $5 \times 10^{-3} m^3/s$ at a testing pressure depending on the location of the facade. In it the air permeability of joints is assumed to be 1% of the air permeability of gaps. If one assumes the initial points to apply to the of the manufacturing requirements to apply to the measuring results in the existing situation, the following emerges after comparison with the requirement:

- in five of the twelve facades the air permeability of the gaps exceeds the limiting value set out in the standard. This can be seen in figure 15 which shows the air permeability of the gaps of twelve facades per metre gap length at a test pressure of 150 Pa. The largest excess amounts to approximately three times the limiting value.

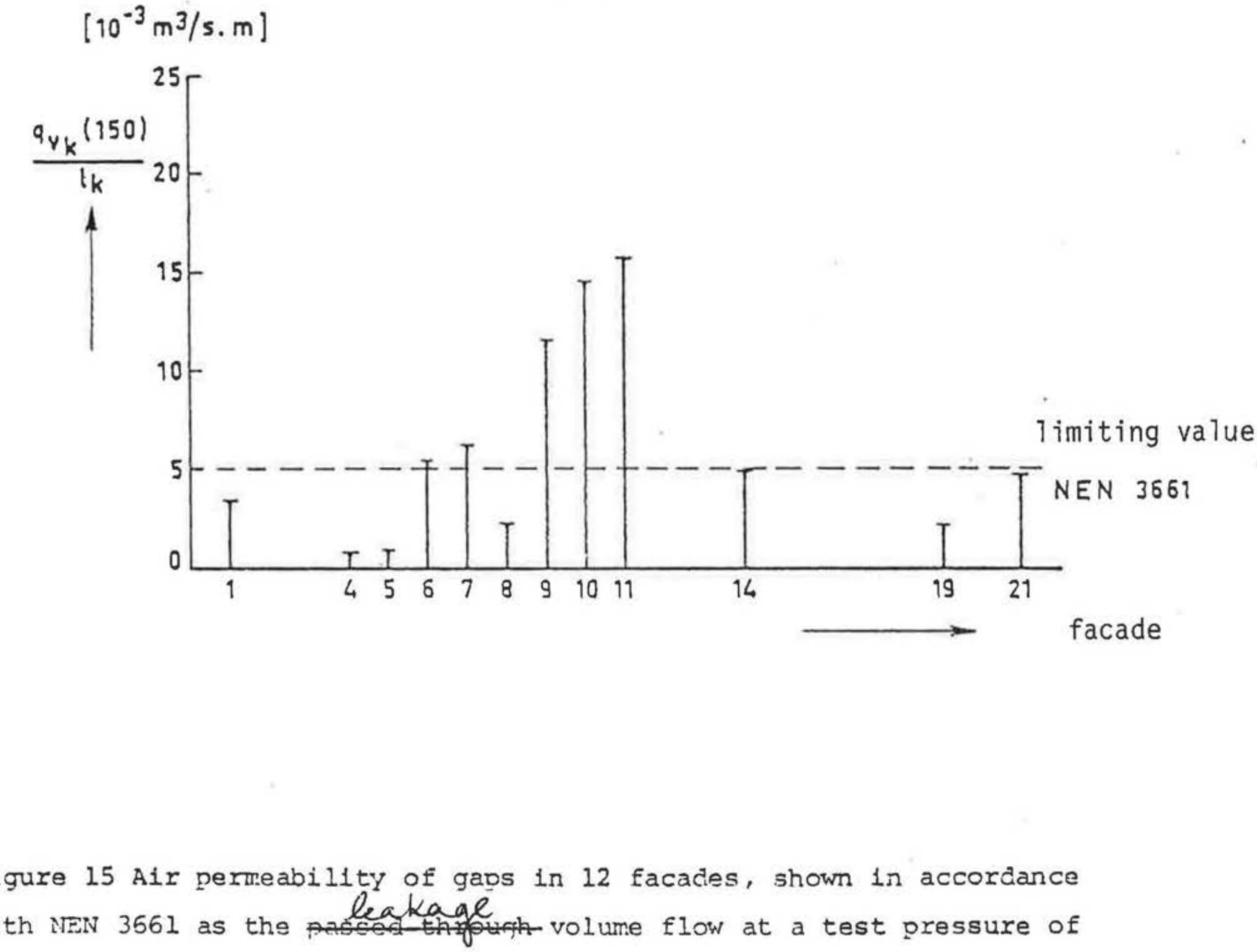


Figure 15 Air permeability of gaps in 12 facades, shown in accordance with NEN 3661 as the ~~passed through~~ leakage volume flow at a test pressure of 150 Pa (qv_k(150)) per gap length (l_k).

- In all twelve facades with which this could be established, the air permeability of the joints exceeds the 1% of the maximum permitted air permeability of the gaps as laid down in the standard. This can be deduced from figure 16. In this figure the air permeability of the $joints has been set against a test pressure of 150 Pa.

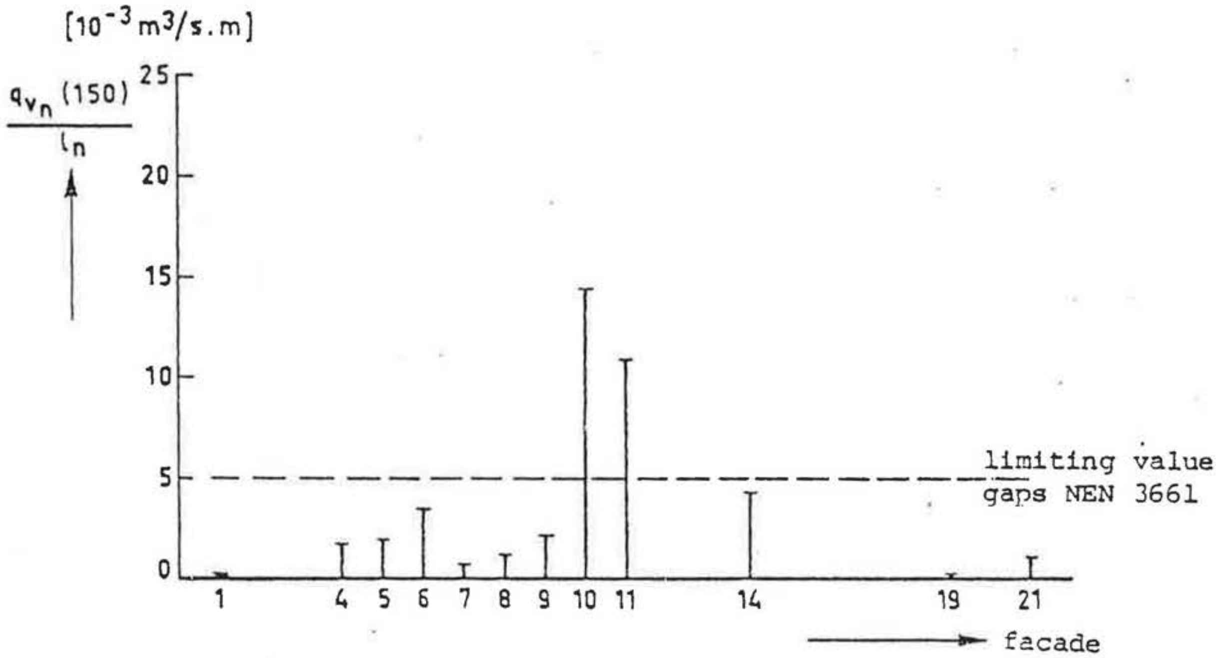


Figure 16 Air permeability of joints in 12 facades, reproduced according to NEN 3661 as the ~~passed through~~ leakage volume flow at a test pressure of 150 Pa ($qv_n(150)$) per mtr. joint length (l_n).

6.4. The importance of the C and n value with regard to the air permeability.

It was indicated in chapter 5 that the relationship between the pressure difference across a facade and the volume flow which is passed through can be mathematically described by the formula (1):

$$q_v = C \times (\ p)^{1/n}$$

in which C and n are the describing magnitudes. The C-value expresses the volume flow passed through at a pressure difference of 1 Pa. The air permeability can be expressed in C-value, if the C-value is related to the size of the parts of the facade which allow the air to pass through. The difference with the in this report used degree for the air permeability is in the pressure differences at which the air permeability is shown. These pressure differences are in the same order of magnitude. Mutual comparison of the facades based on one of these two measures for the air permeability will result in practically the same for both measures. In connection with this, it may be better to use the C-value per size of the parts ~~passing~~ which pass through air as measure for the air permeability. This in connection with the mathematical meaning of the C-value

As for the n-value, it has been posed already that this represents the nature of the flow. An n-value of 1 indicates a laminar flow and an n-value of 2 a turbulent flow. At an n-value between 1 and 2 there is a transition from laminar to turbulent. At a laminar flow de frictional forces at the slit wall dominate the flow. At a turbulent flow the inertia forces dominate. At a low n-value one can therefore expect slits of a reduced width (extensive wall influence).
Narrow slits will allow less air to pass through than wide slits. There may be some relationship between these two characteristics of the slit.
34. In order to examine this the relationship between the air permeability of the gaps and joints has been plotted against the relating n-value in figure 17. The air permeability has been expressed in the C-value, shown per characteristic length of the untightnesses. The characteristic length is equal to the gap length plus 40% of the length of the circumferential joints. This approximation has been selected in order to be able to use a maximum number of observations. It appears that

the points which belong to facades 9, 10 and 11 fall somewhat outside the point clouds (encircled points). Without these points a straight line is found on single logarithmic paper with a considerably improved correlation coefficient (o.76) than with these points (0.46).
The plotting of the points on single logarithmic paper provides in both cases a better correlation than on double logarithmic or linear paper.
In order to establish to what extent it is warranted to ignore facades 9, 10 and 11, a statistical distribution of the air permeability has been made (figure 18). This concerns the air permeability per characteristic length of the untightnesses in the 21 facades, shown in figure 12.
Even though the number of observations is not adequate in order to obtain a satisfactory impression of the distribution, facades 9 and 11 appear to be somewhat outside the distribution, so that the points in figure 17 relating to these facades, can be considered as exceptional.
Additionally, one should not forget that the expression used in figure 17 for the air permeability contains a certain amount of inaccuracy (see chapter 6.1.5.), as well as the used C- and n-values (see appendix 3). This is why no conclusions can be formed based on figure 17. However, it is interesting to investigate this point further.
We must then pay attention to a good physical explanation of the n-value in the transition region 1 n 2. If we get a better understanding in this area, it may be possible based on the n-value to assess the quality of the facade with regard to air permeability in a more simple manner.

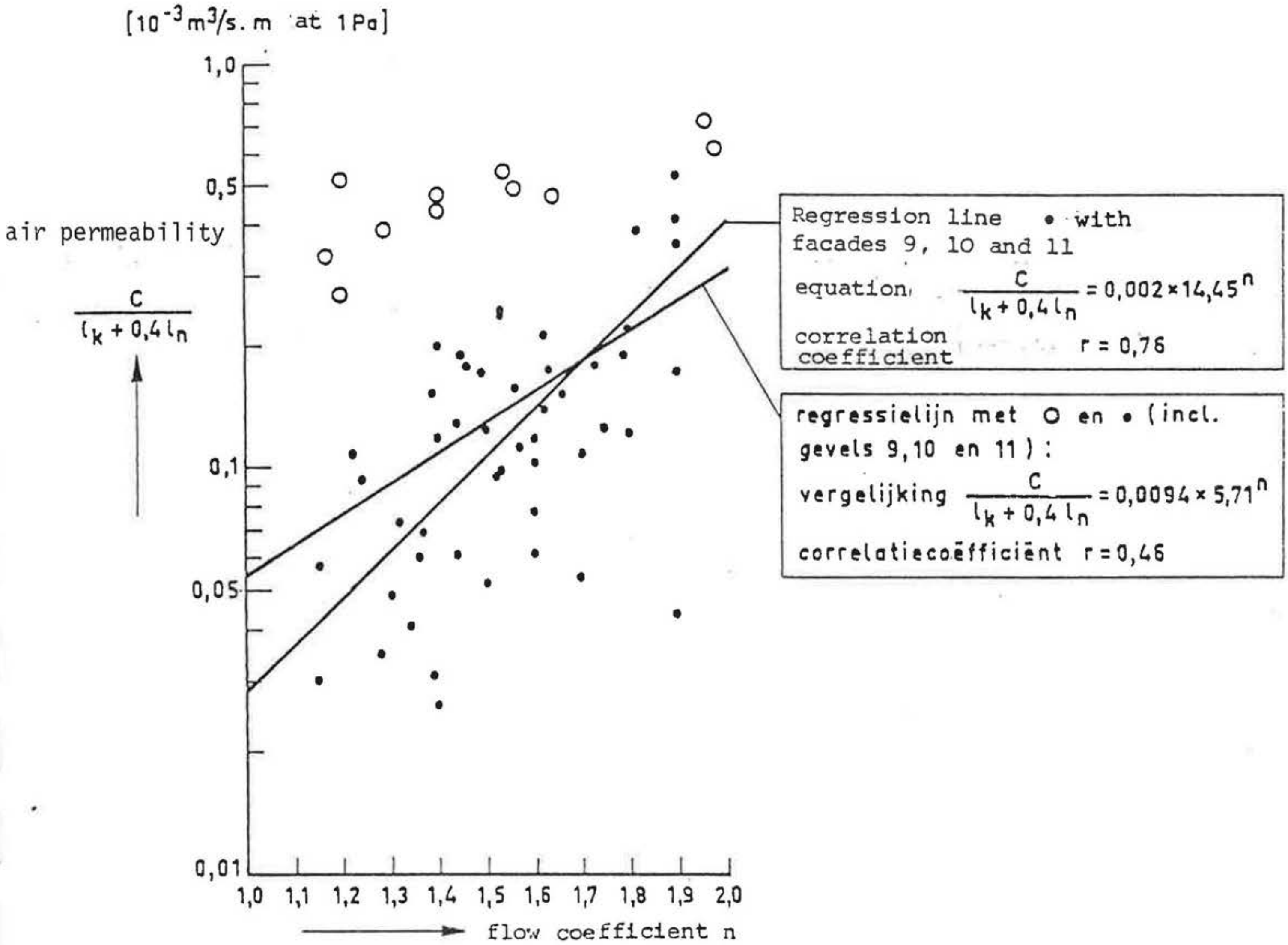


Figure 17. Relationship between the air permeability and the flow coefficient.

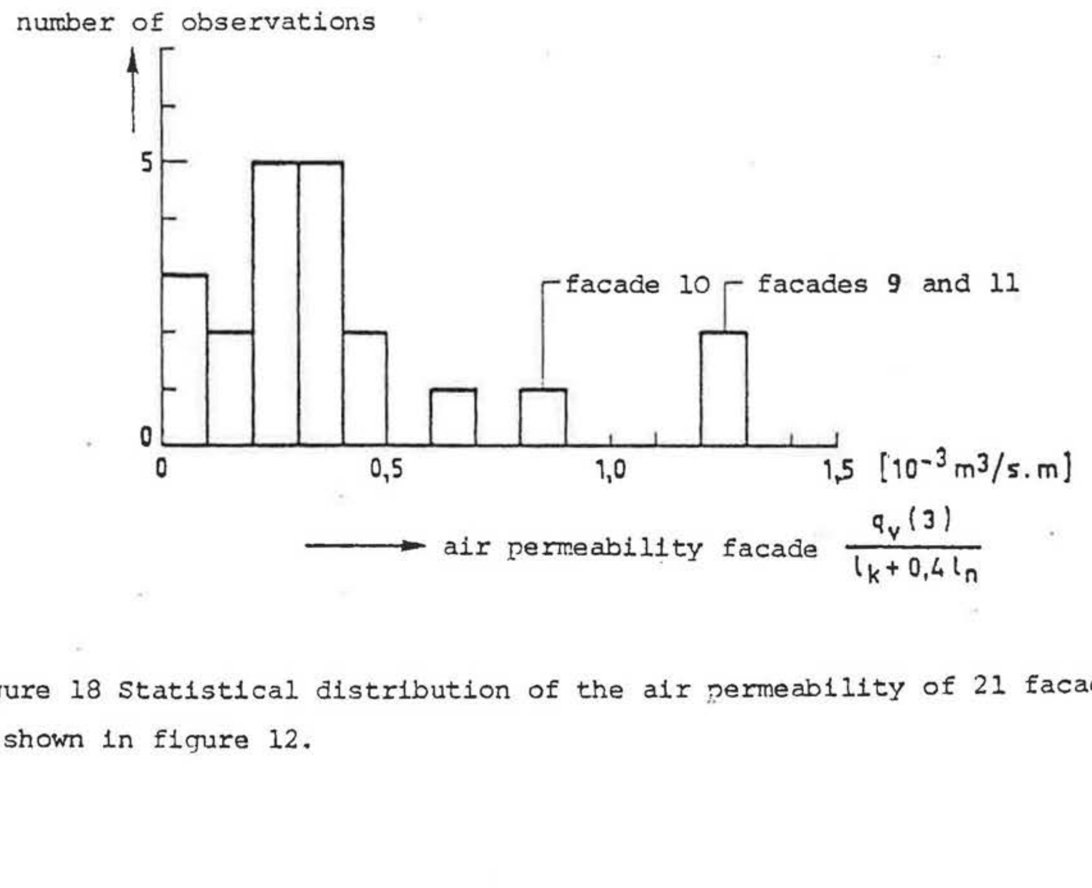


Figure 18 Statistical distribution of the air permeability of 21 facades as shown in figure 12.

Attention must also be paid to the non-constant n.-value, as was noticed for example, in facade 3. In this facade the n-value changes with the pressure difference. It is assumed that this is caused by the open or closed pressing of certain facade components, such as a window, or the deformation of facade parts under the influence of the pressure change. This changes the gap or joint width and as such the ratio between the friction and inertia forces on the flow medium. This is expressed in a different n-value.

6.5. Factors which influence the spread in the air permeability

In chapter 3.1. a number of factors have been mentioned which may influence the air permeability. It is not possible within the scope of this investigation to trace the individual influence of specific factors. The number of variables per facade is too great. In order to understand the individual influence of specific factors, a further research will be necessary.
In this direction one could consider facades with only one essential difference or measurings carried out immediately before and after a change in the facade.
The selected numbers of facades should warrant a statistically sound conclusion.

6.6. Ventilation and air permeabilityof facades

Owing to the air permeability the facades provide a specific share in the ventilation of the rooms of the house. Figure 9 shows per facade the air volume flows which have passed through the facade at a frequently occurring pressure difference of 3 Pa.
They vary from 0.5 to 18 x $10^{-3} m^3/s$
However, the pressure difference may vary considerably. This may cause the passed through air volume flows to increase to the sixfold of the stated values in pressure difference of approximately 40 Pa, which are extremely high for single family houses. However, it is not possible to decide about the desirability just like that.
On the one hand the ventilation need per room per moment in time varies greatly. It depends on issues such as the number of people in the room concerned and the production of heat and harmful or objectional substances.

On the other hand one should not forget that for the ventilation of a room not only the air permeability of the facade is important. Often a greater influence is exerted by:-

- the distribution of the other untightnesses in the space
- the position of the windows, doors and grids both in the partition walls as well as in the outside walls of the considered room and other rooms,
- the air permeability of other parts of the outer shell of the house,
- the location and size of ventilation and flue gas disposal channels

All these "openings" are subjected to chaning pressure differences of various magnitues, just as the air permeable facade. The combined action determines the ventilation of a living room at any time. If one is interested in the heat loss which occurs owing to ventilation at a specific time, the temperature ~~changes~~ differences with surrounding rooms and with the outside must be considered.
The study of the influence of the air permeability of the facade on a process which depends on so many factors and strongly varies in time, demands a separate calculation study (9). This calculation study should include also the results of other investigations in the ventilation region, as described in (2), (3) and (4).

39. 7. CONCLUSIONS

1. Measuring the individual contribution of gaps and joints in the air permeability of facades shows that in practice especially the share of the circumferential joints must not be ignored. This is contrary to the contents of the Dutch Standard NEN 3661. The twelve measurings on which this is based provide an average air permeability of the circumferential joints per metre length which is approximately 40% of the air permeability of gaps. The standard supposes this to be less than 1%.

2. The air permeability of the circumferential joints of twelve facades varies from $0.01 \times 10^{-3} m^3/s$ per metre at a pressure difference of 3 Pa for the joints which lets through least to $0.65 \times 10^{-3} m^3/s$ for joints which leak most, consequently a variation with a factor 65. In no facade is the air permeability of the joints 1% of the limiting value for gaps as is stated in the standard.

3. The air permeability of the gaps of twelve facades varies from 0.07 x $10^{-3} m^3/s$ per metre gap at a pressure difference of 3 Pa vor the least leaking gaps up to 1.52 x $10^{-3} m^3/s$ for the maximum leaking gaps, consequently a variation with a factor of more than 20. The gaps of five out of the 12 facades appear not to meet the initial points of the standard. The maximum excess of the in the standard stipulated limiting value is a factor three.

4. The combined air permeability of gaps, joints and other untightnesses in facades can be expressed in various ways. A fairly good expression is as passed through volume flow at a specific pressure difference per metre of the total gap length increased by 40% of the length of the circumferential joints. If the air permeability of the 21 facades at which measuring was carried out is measured, is expressed in this manner, it appears that the air permeability may vary from 0.06 tot 1.28 x $10^{-3} m^3/s$ per metre of the said length at a pressure difference of 3 Pa. Consequently, the variation is more than a factor 20.

5. At a frequently occurring pressure difference of 3 Pa the least leaking of the 21 facades has through all gaps and joints a trough flow of air volume of 0.5 x $10^{-3} m^3/s$. The facade which has most passing through at the same pressure difference record 18 x $10^{-3} m^3/s$. If the pressure difference across the facade increases to the little occurring value of 40 Pa, then approximately the sexfold is allowed to pass through. As both the need in ventilation as well as the share of the facade in the ventilation per room may differ considerably, one should not pronounce based on these figures on the admissibility of the said air transports through the facades.

6. There does not appear to be a uniform relationship between the air permeability of the facades and the season. The most frequent tendency is the occurrence of the maximum air permeability during the winter.

7. There are indications that the air permeability is not only influenced by the air humidity, but also to a considerable degree by the air temperature.

8. RECOMMENDATIONS

It is recommended to re-formulate the requirements laid down in the standard for the air permeability in connection with the contribution of the joints in the air permeability of the facade. The present requirement does not adequately take into account the ratio gap length/ joint length of the facades.

9. SUGGESTIONS FOR FURTHER RESEARCH

1. In order to get a better understanding of the seasonal influence the following investigation is proposed:-
   continuous recording of the passed through volume flow at a specific pressure difference at one facade, as well as the meteorological magnitudes, the temperature and humidity of the air inside and possible material properties such as the humidity of the timber. The investigation must be carried out during the summer, the interim and winter season. Separate recording of the volume flow through gaps and joints must be taken into consideration. The results of the investigation should indicate a possible connection between the air permeability and the various physical magnitudes.

2. The data of this research only provide a rough impression with regard to:-
   . the quality assessment of gaps and joints based on the n-value,
   . the share of gaps and the various joints in the air permeability of facades,
   . the spread in the air permeability of gaps and of joints,
   . the influence of the building method and other factors on the air permeability.
   In connection with the requirements to be laid down, recommendations for building methods, assessment criteria etc. a continuation of this research may be desirable. The arrangement of a subsequent research depends on the objective.
   In order to gain a better understanding of specific phenomena the physical backgrounds must be studied. A subject with a physical importance which requires further study is the nature of the flow, characterized by n, in the transition region 1 n 2.

3. In order to determine the influence of the air permeability of facades on the ventilation and on the loss in energy by ventilation, a calculation study is proposed. The facade should then be considered as par of a dwelling with it total package in openings. For the composition of this calculation model of the dwelling the results of other investigations are required. The manner of ventilation must also be included in the calculation model.

   This calculation study could then show the share of facades in the ventilation. Based on the results decisions could be made about:-

- the permissibility of the present air permeability of facades in connection with the energy consumption on the one hand and the supply of fresh air on the other hand.
  A possible relationship with the manner of ventilation to be applied must be indicated.
- The efficiency of the sealing of gaps and joints. This may lead to the issueing of priorities to the various sealing measures.

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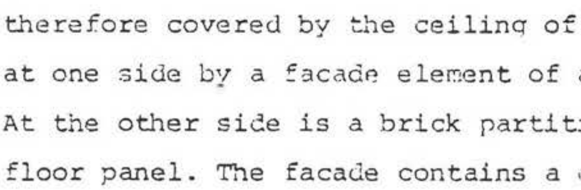
Appendix 1.

Survey of the facades

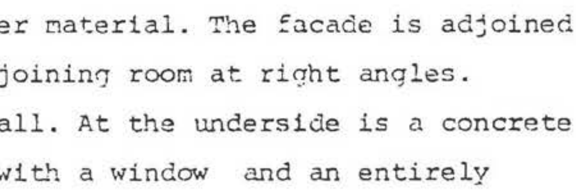
This appendix contains the details of every facade. Additionally a photo of each facade is shown together with a photo which gives an impression of the surrounding area. The data are summarized in table 1 at the end of the report.

Facade 1

The house is situated in a newly built quarter and dates from 1971. It is a corner house in a row. As the house itself, also the surrounding houses are low. At some distance there is a single higher rise building containing flats. The house is what we call a single family house consisting of two storeys and an attic which can be occupied. The facade concerned is on the first floor and faces east. The room of the facade serves as a bed/playroom and is centrally heated during the winter. The building manner is so-called traditional; half-brick interior and exterior cavity panel. Soft wood has been used for frame material. The facade recesses and is therefore covered by the ceiling of timber material. The facade is adjoined at one side by a facade element of an adjoining room at right angles. At the other side is a brick partition wall. At the underside is a concrete floor panel. The facade contains a door with a window and an entirely timber skylight has been incorporated. Both rebates have been provided with draught strips. The closures are one-point closures. All glazing is single. The balustrade contains two-sided panel material with insulation in between. The finish of the joints is good, as well as the closure of the movable parts on the draught strips. The entire maintenance is good. The length of the circumferential joint of the facade is 10.8 m. The total gap length is 7.3 m.
Smoke tests show that the joints of the balustrade hardly contribute at all to the total air permeability. The joints of glass to frame of the condens profiles appear to be here and there slightly leaking.



View from the window

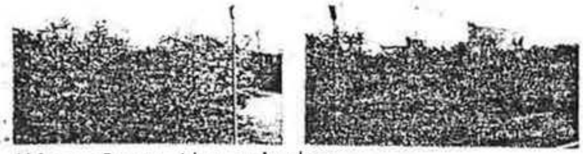


View of the facade

Facade 2

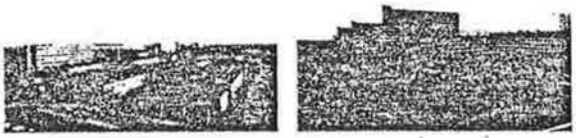
The house is in a newly built quarter and dates from 1965. The quarter has low and high rise buildings. The ~~house~~ dwelling is on the first floor of a building in a row containing flats. Below the dwelling at street level are garages. The building contains partially six, partially

seven floors. At both sides of the flat are continuous galeries, one serving as entrance and one as balcony.
The livingroom with the facade used for measuring purposes, adjoins the balcony and faces south. The room is centrally heated. The building is concrete skeleton building with prefabricated facades. The connections of the facades to the concrete structure have been sealed. The frames are made of soft wood. The facade contains one casement window and a glazed fanlight. The gaps have been provided with draught strips.
The casement window has a two-points closure. The glazing of the movable part is single, the remaining glazing is double. The balustrade has double panelling. The finish of the joints and the connection of the movable parts on the draught strips is good. The length of the circumferential joint is 13.6 m. The length of the gaps is 6.6 m. The property is well maintained.


View from the window


Facade view

Facade 3
The accommodation is situated in the same block of flats as the previous flat, however this one is on the sixth floor and the highest floor of the section. The other details are the same as for facade 2 but there is no overhang created by a higher balcony.
Additionally, the circumferential joints have been cemented by the occupant from the inside. It must be noted that the window closure of the fan light was defect at the summer measuring.


View from the window


Facade view

Facade 4
The dwelling is in a newly built quarter and dates from 1971. The surrounding houses are low-rise, with polders adjoining to the South. The accommodation is a one-family house in a row, with two floors and one attick which mainly serves as storage. The examined facade faces West in the livingroom on the ground floor. The room is centrally heated. The building manner is traditional with twice half-brick walls. The frames are made of hard wood. There is a casement window in the facade

and a fan light, both provided with rubber draught strips. All glazing is single. The casement window has a two-points closure. The windows fit well against the draught strips. The joints of the glass to the frame also here appear to be somewhat leaking at the condens profiles. The length of the circumferential joint of the facade is 9.8 m. The total gap length is 5.4 m. The property is in a good state of repair.

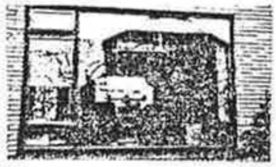
View from the window

View of the facade (see facade 5)

Facade 5

This facade is the mirror image of facade 4. It is situated in the same livingroom at the east side. For particulars see facade 4.

View from the window



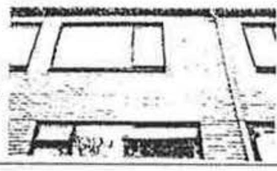
View of the facade

Facade 6

The facade is in the same dwelling as facades 4 and 5. This facade concerns the facade of a bedroom on the first floor. As in facade 4, the facade faces east. The room has central heating which is not used. Besides a casement window with two points closure and draught strips, the facade has also a sliding grid for regulating the ventilation. The total joint length is 7.4 m. The gap length of the wondow is 3.5 m. The circumference of the air leaking openings of the ventilation grid is 1.1 m This circumference has also been considered as being a gap. Further details are the same as those of facade 4.

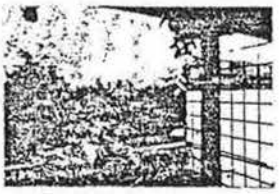
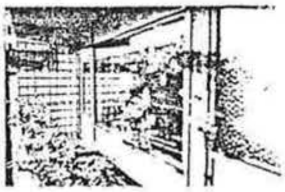
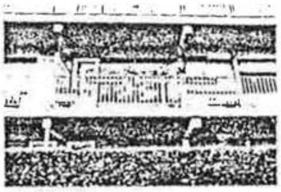
View from window (see facade 5)

View of facade

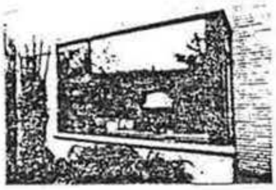


Facade 7

The dwelling is in a newly built quarter and dates from 1970. Around are low rises with four storeys. The accommodation is a flat in between on the second floor, for accommodation, which is in fact on the first floor. The flat has on both sides continuous galeries. The livingroom adjoins the balcony and faces south. The facade was measured. The room is central heated, The building is cast concrete building. The frames are made of hard wood. The facade contains a door and a timber fanlight. The gaps have been provided with draught strips. The circumferential joints of the facade have been cemented. The balustrade and the upper strip of the facade

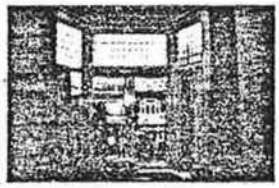





Facade 7

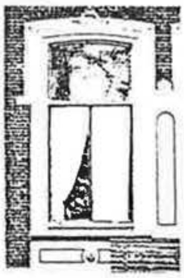

Facade 8


Facade 9




Facade 10


Facade 11

Facade 12

are made of single panel material. The centre section contains single glass. The facade is in good condition. The closure of the movable sections is good. The gap length is 7.2 m. The length of the circumferential joint is 12.6 m.

View from the window View of the facade

Facade 8

The accommodation dates from 1973 and is a so-called linked one family dwelling with a flat roof. The house has two storeys. Around are low rise houses. The livingroom window looks out on a row of the same houses. Between the houses are gardens. The air permeability of the livingroom facade has been measured. The facade faces south. The room is central heated. The radiator has along the full length a wide water container on top, from which the water can evaporate. The building of the house is traditional. Between the half brick cavity walls an insulation of stone wool flakes has been provided. The frames are made of soft wood. The facade contains a corner with and extended living space. A door has been provided in the short side of the facade. On top of it and high up in the long side of the facade are ventilation grids. Teh two grids can be closed by means of a slide. The door is provided with draught strips. All glazing is double. The length of the joints between frame and wall is 13.8 m.
The length of the door gap is 5.7 m. The total circumference of the openings in the ventilation grids is 4.8 m. This length is also considered as being gap length. Measuring to find out the individual share in the air permeability of the facade of the ventilation grids and the door shows that the air permeability of the door gaps is in the same order of magnitude as the air permeability of the grid gaps. The facade is well maintained. The closure of the moving parts is good.

View from the inside View of the facade

Facade 9

The accommodation dates from 1909. The house is of a type which was built a good deal during that period and many of which are still to be found in The Hague and the surrounding area. The accommodation is half of a semi-detached house. The traditionally built dwelling has two storeys and one attick with living accommodation. Around are similar houses. The walls are single brick. The frames are of deal. No insulation measures

have been taken. The accommodation has central heating.
The facade of the livingroom on the ground floor was measured and faces south-west. One looks out on well established gardens and houses at the back. The house has been extended at the place of the facade. On top is a balcony. The facade element continues up to the floor of this balcony. The facade contains a french window with espagnolette closure. The glazing is single. The length of the gaps is 9.9 m. The length of the circumferential joints is 11.5 m. From the outside a space between frame and wall can clearly be seen. At the inside these joints have been covered by the wall covering. The facade is moderately maintained. In some places there is a clearly visible space between the glass and the hard putty. The gloss paint shows slight damages. The French ~~windows~~ doors have a big gap at the bottom. In the winter this is covered.

View from the inside View of the facade

Facade 10

This facade is in the same house as facade 9, on the first floor facing north-east. This side looks out on the street and the houses opposite. The room is used as bedroom. The facade contains a timber bay-window in which there is a double casement window. Next to the bay-window is a long, narrow window, and the top can be folded out (cannot be seen on the photo). The above side wall is only partially an exterior wall. the house has been extended there along the entire heigth. The double casement window has been provided with an espagnolette closure, the top hung window has a snap closure. The total gap length is 7.3 m. The length of the circumferential joints is 15.4 m. Additionally there are joints in the wainscot of the balustrade , the roof and the floor of the bay-window. Their contribution to the air permeability is not known. The measuring results indicate that they must not be ignored.
For the other details see facade 9.

View from the inside through the bay-window View of the facade (bay-window to the right)

Facade 11

This facade is in the same house as facades 9 and 10. It is the facade of a small bedroom on the first floor at the north east side. The facade has a sashwindow. The length of the joints between facade and wall is 6.6 m. The length of the gaps of the sashwindow is 5.2 m. The play between the sashwindown and the rebate is fairly large.
For other particulars see facade 9.

view from the inside | view of the facade (sashwindow to left)

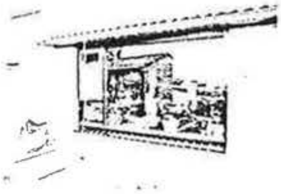
Facade 12

The property is just outside the centre on the eastside of a village. Around are agricultural greenhouses with the relating houses and sheds. The house is a double fronted free standing dwelling dating from 1877. The house has a ground floor and a not lived in attick The construction is traditional with brickwork one-stone exterior wall and a timber interior cavity panel. The frames are of deal. The connections of frame to wall are probably of the so-called 'klooster' rebates. Measuring was carried out at the facade of the kitchen which is at the northside of the house. The room has central heating. The movable part is a sashwindow, which is no longer in use. Consequently the gaps have blocked up with dirt etc. On the whole, the maintenance is bad. The puty is broken in various places and here and there completely vanished. In these places air appeared to escape between the single glass and the rebate.
Additionally it became apparent during the smoke tests that the joints between frame and wall hardly allow any air at all to pass.
The length of the circumference joints is 7.3 m. The length of the gaps is 5.6 m. The kitchen contains two of the described windows. However, measuring was carried out for one window.

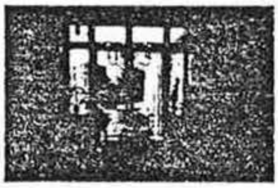
View from the window | View of the window.

Facade 13

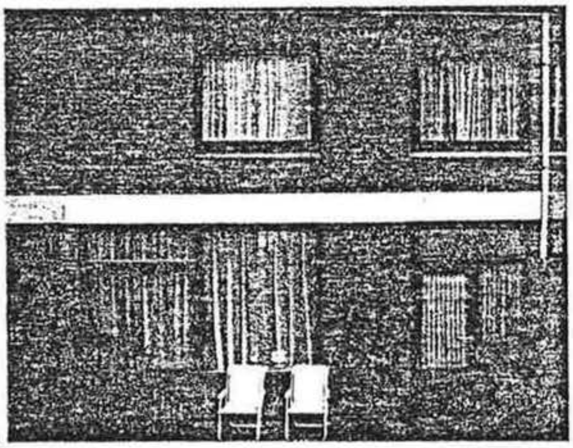
The property is situated in a new residential quarter. The entire quarter is low rise. The house is a traditionally built singèe family house at the corner of a row. It dates from 1979.
The facade is in the livingroom at the westside of the house.

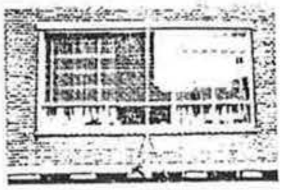
Facade 13

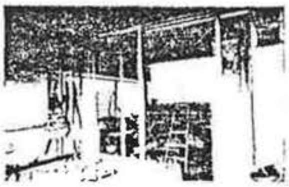
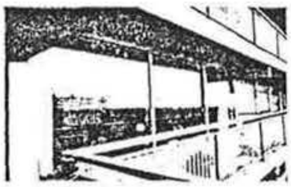
Facade 14



Facade 15

Facade 16

Facade 17

The livingroom is at ground level. There is another floor and a inhabited attic. The house has central heating. The facade is in the extended part of the house. The exterior wall has a brickwork exterior cavity panel and ab insulated sandwich panel as interior cavity panel. At the top the facade is adjoined by a lowered slanting roof section. The two facade elements continue up to this roof section. The one part includes a top hinged window with one wedge and a ventilation grid (see photo). The other part consists solely of a door with relating frame and a ventilation grid above. The material of door, window and frame is hard wood. The joints between frame and wall are cemented. The movable part contains draught strips. The glazing of the movable part is single, the remaining glazing is double. The length of the circumferential joints is 15.2 m. The gap length is 8.7 m. The circumference of the openings of the ventilation grids is 4.4 m.

4. The air permeability of these grids has not been included. The condition and the closure of the movalble parts is good. The joints between frame and wall are also well finished. However, there is a large joint visible at the connections of the masonry op the roof.

View from the window   View of the facade.

Facade 14

The house is situated behind the outer row of dunes. At the rear and some meters lower is agricultural ground. The house forms part of a so-called ribbon-building. The property is one of a double house. There are two storeys and an attic serving as storage space. Measuring was at the facade of the rear room, looking east. The room has a stove, which is seldom used. The traditionally built dwelling dates from 1939. The exterior walls have brickwork of twice half bricks . The frames are of white fir wood. The facade contains French windows which are no longer in use. The available hinged sashwindow and the fan light are still used. The French windowdoors have an espagnolette closure, the hinged sashwindow has a wedge. The facade is in a bad condition. The putty is dried out and in places vanished altogether. This allows air to leak through in various places between the glass and the rebate. The connections between

frame and wall are also bad. A slit can clearly be seen.. In some places where the wallpaper has not been stuck over this slit, the light can be seen through it. Also the connections of the moving patts are bad. The movable parts are somewhat lopsided and consequently show gaps of reducing width. During the winter the occupants make provisions against the draught (see photo) the Glazing is single.
The circumferential joints have a total length of 9.6 m. The length of the gaps is 14.3 m.

View from the inside Protection against draught View of the facade.

Facade 15

The house is in a newly built residential quarter and dates from 1968. Around the house is low-rise building. The property is situated in a row. The house has two storeys and an attic which is partially inhabited. Measuring was carried out at the facade of the livingroom, The facade faces east. The livingroom is at ground level. From the window one looks out on the rear gardens and the row of houses opposite. The room has central heating. The house is traditionally built. The exterior walls are twice half-brick twice. The partition walls are made of concrete. The frames are made of firwood. The facade has onepivoted window with two-points closure. The window has been provided with draught strips. The glazing is single. The balustrade has double panelling. The joints between frame and wall are cemented. The draught strips seal well to the rebate. The facade is well maintained. The length of the circumferential joint is 11 m. Thegap length is 6 m. Owing to the reduced expansion depth of the pivoted window the ratio between the area which passes through air of the opened windo and the gaps appears to be unfavourable.

View of facade (living room bottom left.

Facade 16

The house dates from 1965. It is a flat situated on the third floor out of four. At the one side of the accommodation is a galery. The house is situated next to the staircase. The first storey contains shops and protrudes as compared to the three upper storeys. At right angles to the flat is a similar flat. The ground floor continues underneath the two flats. Measuring took place at the livingroom facade from which

one looks out on the right-angled flat. The facade faces south. Around are similar buildings of the same height. The quarter is amply set up. The building is concrete skeleton with masonwork facades. The frames are made of steel.
The facade contains a casement window with espagnolette closure. The entire facade is well kept. The length of the circumferentialis 12 m. The gap length is 6.2 m. The glazing is single.
The flat has central heating. Measuring was carried out with an overpressure at the inside of the facade, which differs as compared to the measuring at the other facades.

View from the window View of the facade.

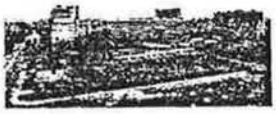
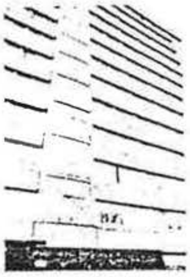
7. Facade 17

The accommodation is situated in a newly built quarter and dates from 1973. It is a flat on the eleventh floor of thirteen. Around are high-rise interspaced with low-rise buildings. The flat has on one side a continuous galery of changing width. The galery serves as balcony. The flat can be reached via a porch.
The proeerty is executed in concrete. Measuring was carried out at the facade of the livingroom and the adjoining sideroom. The facade orientation is southwest. The frames are of aluminium. They are cemented all around. The glazing is single. The facade contains a sliding door and a sashwindow, both moving in horizontal direction (sliding front) Some grids have been provided for ventilation. However, these have not been included in the measuring. The moving parts have been provided with brush seals. These do not seal the corner points of the window and the door. Everything is well kept. The length of the circumferential joints is 22.4 m. The gap length is 15.4 m.
The accommodation has central heating.

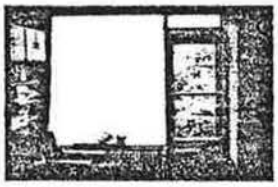
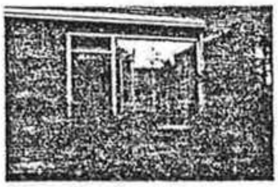
View from the window. Side room livingroom View of facade

Facade 18

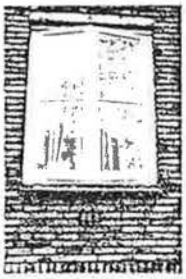
This is situated in the same dwelling as facade 17. This concerns the facade of the kitchen. The orientation is northeast. The facade has a sashwindow and a fixed window of the same type as in the livingroom, but of smaller dimensions. The joint length is 7.2 m. The gap length 5 m.

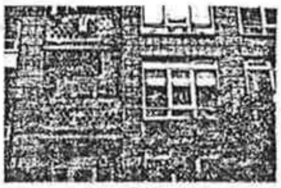
Facade 18

Facade 19




Facade 20


Facade 21

The other details are similar to those of the previous facade.

View from the window

View of the facade.
Kitchen to the right of the porch.

Facade 19

The accommodation is situated in a rather remote, small district.
All around are low-rise buildings. The street dates from 1967, single family houses in a row. The property has three storeys. The roof is flat. The first storey is more or less below ground level and contains a garage and storage. The second storey has the livingroom. Here measuring of the facade was carried out. The facade oreintation is southwest. From the window one looks out on the rear gardens and the houses at the back.
The house has central heating, is traditionally built with twice half brick exterior walls. The concrete floor continues outside as a veranda. The frames are of firwood.
The facade contains a door and a fanlight, both with single glas and provided with draught strips. The other glazing is double. The joints of the frames are cemented. The balustrade is of double panelmaterial. The joint length is 16.2 m. The gaplength is 5.2 m. The facade is extremely well kept. There are no visible open joints. The movable parts close well.

View from the inside

View of the facade

Facade 20

The property is situated in a district at the edge of a city. The house dates from 1952. It is a corner flat on the top storey of a porch flat with four storeys. Beneath the first storey and half below ground level are cellars. All around are similar buildings with three or four storeys, interspaced with low-rise. The inside cavity panel of the exterior walls is made of cast concrete. The outside cavity panel is masonry.
The slightly sloping roof is also made of concrete with roof covering.
The ceiling is of soft board panels. The frames are of a soft wood variety.

The glazing is single. Measuring was carried out at the facade of a bedroom. The room itself is not heated. However, owing to the heating of the livingroom and hall no pronounced cooling occurs. The north orientated facade contains an encasement window with espagnolette closure.
The maintenance is good. The joint length is 5.8 m. The gap length is 7.4 m.

View from the window. View of the facade.

Facade 21

The accommodation is situated in a district at the edge of a city and dates from 1952. It is a flat in between on the middle floor of three. The premises can be reached via a porch. Beneath the first floor are semi-underground cellars. All around are similar buildings consisting of [illegible]-flats on three floors and single family houses with two storeys built in the same style. The property has exterior walls with inner and outer cavity panel made of concrete.
The frames of soft wood have been placed in a concrete surround. Measuring took place at the livingroom facade. Its orientation is northeast. The room is heated with a stove. The livingroom facade has two casement windows, provided with draught strips which are in a poor condition. The closures are the one-point variety. All glazing is single. The upper narrow row of windows which can be seen on the photo has been covered from the inside with hardboard. One of the windows behind is a top-hinged window which can no longer operate. The facade is moderately maintained. Especially the paint coating is damaged. The length of the circumferential joint is 9.7 m. The gap length is 8.6 m.

1. View from the inside View of the facade.

Appendix 2 Methods of measuring

1. INTRODUCTION

In chapter 4 of the report we have briefly explained the measuring principle and the deduced three measuring methods. This appendix deals further with the execution of the measuring and the selection of a measuring method.

2. EXECUTION OF THE MEASURING

2.1. The difference-measuring method.

In the door opening of the room in which the facade is located, a dummy door is placed. The transparent door is stuck airtight as good as possible. The dummy door is provided with a hole for passing through a measuring tube with measuring flange or a long smooth pipe with a pitot's tube, which serve for measuring the volume flow. A ventilator is connected to the measuring tube or pipe, so that, if required and over or under pressure can be created in the room. Two different types of ventilator have been used: a high pressure ventilator for the use with a measuring tube with measuring flange and a radial ventilator for use with the pipe with a pivot's tube. With the high pressure ventilator volume flows are moved of $5 \times 10^{-3} m^3/s$ to $10^{-3} m^3/s$; with the radial ventilator volume flows are moved of $30 \times 10^{-3} m^3/s$ to $300 \times 10^{-3} m^3/s$. Pressure differences across the facade were reached by this amounting from 1 to approximately 100 Pa with the high pressure ventilator and of 10 to 250 Pa with the radial ventilator.

The pressure difference across the facade and the pressure difference across the measuring flange or the pivot's tube are measured with the aid of electric pressure recorders. The pressure recorders are connected to the pressure measuring points via hoses. The measuring point for the pressure at the outside of the facade is usually provided via the window of the adjoining room with the same orientation.

The electric signals issued by the pressure recorders are, if necessary somewhat damped with the aid of a linear signal damper without weakening. The thus acquired signals are recorded with the aid of a two channel writer. The ventilator is set with an adjustable voltagerecorder (variac) at different revolutions. At each number of revolutions the stationary conditions is maintained for a period of approximately 5 minutes and

the issued signals are recorded. This is necessary in order to be able to determine the representative average values of the sometimes greatly fluctuating pressure differences.
After measuring has taken place at adequate pressure levels in order to be able to deduce a connection between the pressure difference and the volume flow, all gaps and joints are sealed. This should be executed in such a way that no flow can find another way through gaps or joints. When the gaps and joints are well sealed, measuring is repeated. From this the connection between the pressure difference and the volume flow is deduced. The difference in volume flow established at equal pressure difference between the first measuring without sealed gaps and joints and the second measuring with sealed gaps and joints is the volume flow through the gaps and joints at that pressure difference.
The manner of sealing the facade must have the necessary attention. This is explained by the following example:-
A facade is taped on the outside. At the inside of it an underpressure is created. Owing to the fact that the joints at the inside have not been taped or sealed, air from the cavity is still sucked in through them. The cavity receives air through the cavity grids or similar arrangements. The measured reduction of the total passed through volume flow is therefore only the air volume flow through the gaps plus joints between frame and outside cavity panel. In this case it is much better to tape the joints from the inside, or the cavity grids and other air supplying openings to the cavity must be sealed.

54. 2.2. The direct measuring method

Across the facade element a plastic foil is fixed with tape. The space between the foil and the facade is connected to the high pressure ventilator with a measuring tube with the aid of a hose. A pressure measuring point is provided in the space between the foil and the facade. For the rest the measuring arrangement is similar to the one at the difference measuring method. The connection between the pressure difference across the facade and the air volume flow through the gaps and joints of the facade can be determined directly from the measuring by adjusting the ventilator again to a number of different speeds.

2.3. The compensation measuring method

In the room adjoining the facade, the measuring arrangement is provided as described for the difference measuring method. An additional hose is provided in the dummy door as connection with the adjoining room. All rooms surrounding the room of the facade are connected to each other by opening the doors. In one of those rooms a second ventilator is installed with a regulating device. Depending on the required pressure level, the press or suction side of this ventilator is conducted to the outside. For this purpose a second dummy door may be used.
The two ventilators are now adjusted in such a way that both in the room with the facade as well as in the surrounding roos the same pressure level is created. This is checked with the aid of the flow direction in the additionally provided hose in the dummy door between these rooms. The flow is made visible with smoke. If the flow is not moving in the tube, or somewhat pulses, it is assumed that there is hardly any pressure difference between the rooms.
Subsequently, the air volume flow through the ventilator in the room with the facade is measures as well as the relating pressure difference across the facade. After that another number of pressure levels are set, at which measuring is carried out.
In this way a direct connection is obtained between the pressure difference across the facade and the air volume flow through the gaps, joints and the other untightnesses in the facade. In principle, these untightnesses include also the untightness of the exterior wall.
If the exterior wall is provided with a layer of plaster and wall paper, the untightness of it can be neglected with regard to the gaps and joints.

3. SELECTION OF THE MEASURING METHOD

The measuring method to be applied depends on various factors. The "difference method" is most popular. One of the other methods is applied if it can be expected that the volume flow through the facade is in the order of magnitude of 20% of the total passed through volume flow through the pressurized room or even less. The volume flow through the facade then comes in the order of magnitude of the precision by which the total flow passed through the room can be measured. The measuring method then becomes not precise.

In some cases a solution has been found by separating a part of the room and using this as pressure area or by taping the largest openings of the pressure area. In other cases a pressure area is created by the provision of foil on the inside wall across the facade element ("direct measuring"). This often causes considerable damage of the wall covering owing to the airtight taping of the foil. Additionally the pressure difference across the foil must not become excessive owing to the low adhesion of the tape on the foil and the wall. The "compensation measuring" remains. This has as condition that the rooms adjoining the roof space and of which the separation is not airtight must be able to be brought at the same pressure level. For example, this is not possible for a room with a wooden floor at ground level.
Facades 10 and 11 have been measured according to the compensation method. The summer measurings at facades 4, 5 and 6 have been executed according to the direct measuring method. Facade 12 has been measured by a combination of the direct and the difference measuring method. In the other facades the difference measuring method has been applied. Orientating tests have shown that the three methods lead to results which can easily be compared.

7. Appendix 3.

Measuring results and precision

1. GENERAL

Chapter 5 of the report has already indicated how the measuring results lead to air permeability characteristics. The characteristics for the facades in the various seasons are shown in figures 1 to 69 of this appendix. Figures 60 to 73 show air permeability characteristics for moving parts of facades. The characteristics show additionally the measuring data from which the characteristics have been deduced. The figures show different lines. The uninterrupted lines are the characteristics determined in the graphical way. The characteristic magnitudes of them are shown in table 1 at the end of the report (C and n-values). The figures also show dotted lines. These lines indicate the calculated characteristics. The best straights which belong to the calculated characteristics are shown in foermule form with the figures. The lines formed by the +-signs indicate the precision of the calculated characteristics in the form of the 95% relaability interval. We shall further deal with the graphical determination of the characteristics, the calculation of the characteristics and the precision.

2. GRAPHICAL DETERMINATION OF THE AIR PERMEABILITY CHARACTERISTICS

For the graphical assessment the method as described in chapter 5 od the report was followed. That chapter mentions the assessment of the difference between two lines for the event that the difference method is used. The mentioned two lines in the graphic assessment are the drawn, best fitting line through two measuring point series. They represent a relationship between pressure difference and volume flow. In many cases the lines are staiahgt on double logarithmic paper. The difference between the two lines is determined as follows:-
At a value of the pressure difference the volume flows are read on the two lines. The two volume flows are deducted from one another. The same is done for various other values of the pressure difference. In this way one obtains for different pressure diffeeences differences in the volume flows. These differences in volume flows can be plotted

the relating pressure differences. If one draws a best fitting line through these points, one obtains the air pemeability characteristic for the facade concerned of the section of the facade concerned. When applying the direct measuring method or the compensation measuring method, it is possible to draw a best fitting line through the measuring points, which represents the air permeability characteristic. A C-value of a characteristic can be determined reading by the point of intersection of the characteristic with the axis "pressure difference = 1 Pa" . An n-value is determined as the tangent of the angle which makes the characteristic with the axis "pressure difference = 1 Pa".

3. PRECISION

When drawing best fitting lines such as concerns the graphical determination of the air permeability characteristics, we are dealing with estimates. The deviation with regard to the actual phenomenon must be expressed in the precision. The numerical fixing of the precision is not possible with the graphical determination of the characteristics. This is why it was endeavoured to find a method for the calculation of characteristics with the relating precisions. This calculation is explained below in an example. The precision by which the relationship between the pressure difference across the facade and the passed through volume flow can be determined depends on the following factors:-

- The measuring precision of the volume flow measuring,
- the measuring precision of the pressure difference measuring,
- the error at lineardamping of the pressure differences,
- the reading error of the recorded signal,
- the fluctuation of the outside pressure on the facade,
- the precision of the taping, especially with the direct measuring method,
- the pressure difference with the aurrounding rooms at the compensation measuring method,
- the ratio between the volume flows through the facade and through the other untightnesses in the room with the difference and compensation measuring method
- the reading precision of the difference in the passed through volume flow with gaps and joints and without gaps and joints at the difference measuring method with graphical assessment.

- the area inside which the pressure difference acroos the facade can be varied. This is most limited with the direct measuring method. Owing to this large number of influence factors the precision will generally differ per measuring. This is why the precision has been determined per measuring.

4. EXAMPLE OF A CALCULATION OF AN AIR PERMEABILITY CHARACTERISTIC AND THE RELATING PRECISION.

As an example, the autumn measuring at facade 1 has been worked out. Measuring took place according to the difference measuring method. The volume flow has been measured with the pitot's tube.
Based on the influence factors for the precision, stated in the above chapter, a maximum error can be indicated for each read pressure difference across the facade and for each relating volume flow. The principle of this error determination is as follows:-
the maximum deviation of each influence factor with regard to the measured signal is measured. For example, at a slight fluctuation of the measured signal for the volume flow, the reading precision of the signal recorded on the measuring paper has been estimated at 0.5 scale section. If the relating measuring signal covers 50 sclae sections, this means a maximum error of $\frac{0.5}{50}$ =1%. To this is added, for example, the maximum measuring error for the measuring of volume flows with a pitot's tube, which is generally estimated at 10%. After adding up the maximum errors of all remaining influence factors, one finally obtains the total maximum error of the measured signal. Figure 4.1. shows this maximum error per measuring point both for the volume flow as well as for the pressure difference. This concerns the measuring points belonging to the air permeability measuring of the total pressurized room including the facade.
The same can be done for the measuring points of the air permeability measuring of the room without the facade. The best fitting lines can be drawn through both measuring point series.
It can be shown physucally that the connection between the pressure

difference (p) and the volume flow (qv) can be shown with a very good approximation on double logarithmic paper at reduced wind influence byt a straight line, or to put it differently, by a linear connection between log (qv(x) and log p (y). The best straight line through anumber of measuring points with inaccuracies in the x- and y-direction and the differences in inaccuracies per measuring point is determined with orthogonal regression with weighing factors. The inaccuracy on the slope of the best straight line can be expressed in the variance in the slope. The inaccuracy in the location of the best straight line can be expressed in the variance of the weighed centre of gravity of the measuring point series.

The principle of orthogonal regression has been based on the smallest square method. That means to say that as best is chosen the line in which the sum of the sqaures of the distances between the measuring points and the line is minimum.

In orthogonal regression two lines are calculated. For the one line, the squares sum of the distances between measuring points and line, measured in x-direction is minimum. For the other line, the distances in the y-direction are considered. The orthogonal regression line is the mathematical average of these two lines. Howeverm in the determination of the two lines, each measuring point is not equally heavily weighed.

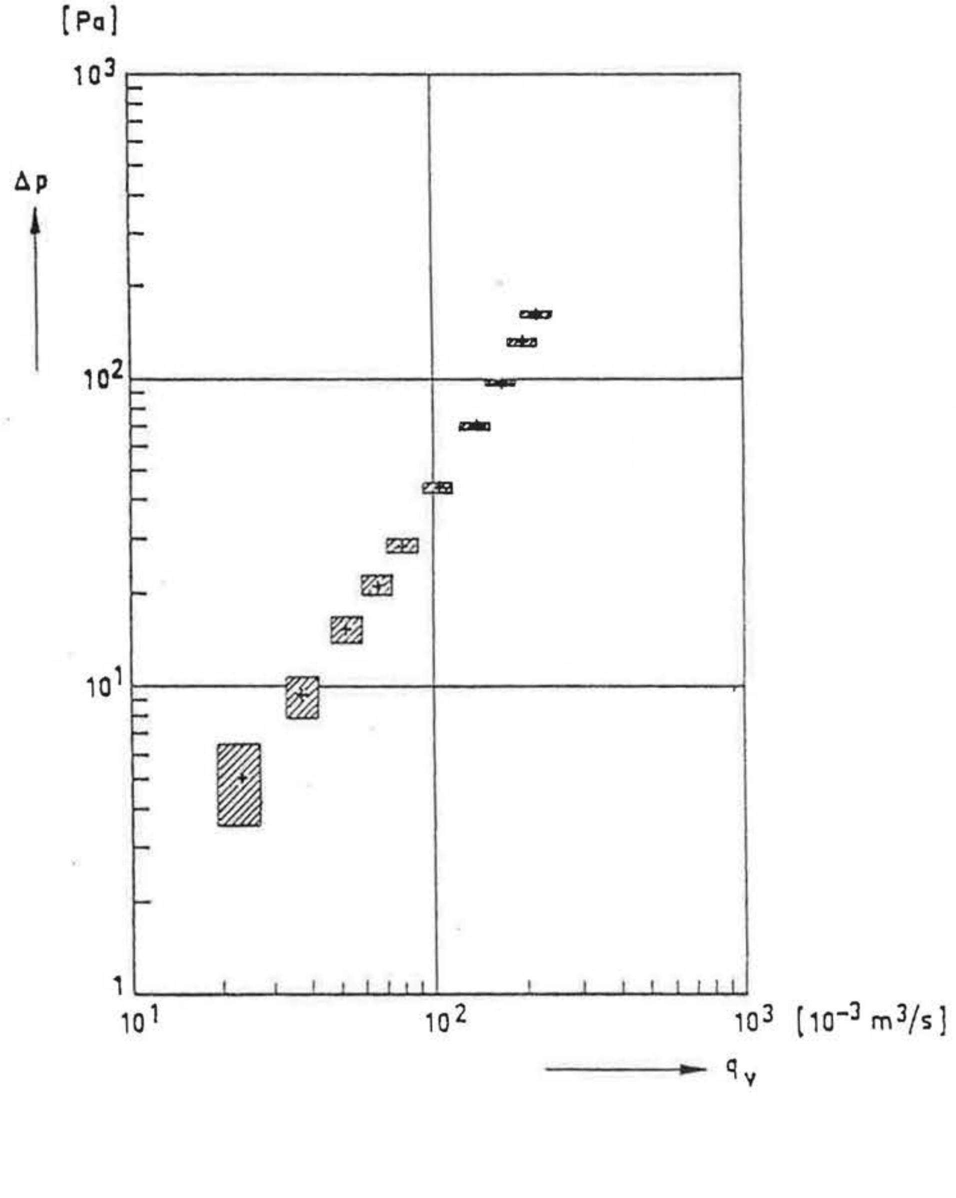


Figure 4.1. Maximum estimated error per measuring point for the air permeability measuring in the autumn at the room including facade 1.

The more inaccurate the measuring point, the least this measuring point is incorporated in the determination of the best straight line. This is expressed in the weigh factors. The sqaures of the distances between the best straight and the measuring points are each multiplied by the relating measuring factors when determining the minimum sqaure sum. Consequently, a weighed minimum square sum is determined in order to determine the best straight line.

The weighing factors are assumed to be proportional to the reciprocal value of the sqaure of the standard deviation, In equation:-

$$W = \frac{K_1}{s^2} \qquad (4.1.)$$

in which W = weighing factor

s = standard deviation

K_1 = contant

Howeverm the standard deviation of the measured values is not known, but the estimated maximum error is known (Pm - see figure 4.1.).

It can be assumed that the maximum error is proportional to the standard deviation. By assuming this, formula (4.1) is rewritten to read:-

$$W = \frac{K_2}{Pm^2} \qquad (4.2.)$$

in which K_2 is a new constant.

Additionally, the following applies

$$\sum_{i=1}^{i=N} W_i = N \qquad (4.3)$$

in which N = the number of measuring points of the measuring series,

i = indication of therank number in the measuring series.

In principle. it is possible to determine with this the weighing factors W_i for each measuring point i.

However, in this case ther is not a question of one but of two eighing factors, because am arror occurs both in the pressure (p) as well as in the volume flow (qv). As a linear connection is assumed between log qv and log p. to beindicated below respectively as x and y, it is assumed that it is more correct to talk about the error in x and y.

The weighing factor for the x-direction is now indicated by W_1 and for the y-direction by W_2. For the measuring point with rank number i the relating weighing factors are:- W_{1i} and W_{2i}.

In figure 4.2. a number of used terns are once again shown, a term which has not yet been mentioned is ψ , which represents the angle which makes the best straight line with the x-axis

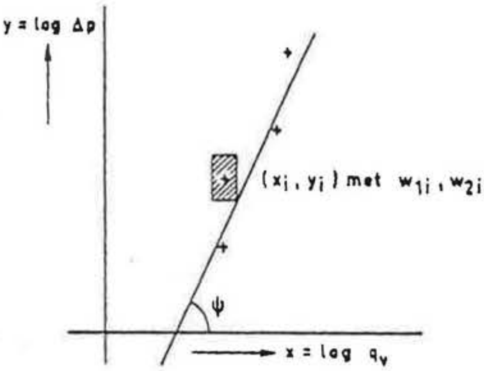


Figure 4.2. Some used terms.

The angle ψ is used for the composition of the two weighing factors W_{1i} and W_{2i} to a weighing factor W_{3i} per measuring point, according to:

$$W_{3i} = \frac{1}{\frac{\sin^2 \psi}{W_{1i}} + \frac{\cos^2 \psi}{W_{2i}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.4)$$

In this ψ is still unknown. It is a measure for the slope of the searched for best straight line. In principle, one should therefore make the supposition that this is tested after determination of the best straight line. On this a new calculation cycle should be started with a more precisely assumed ψ and to repeat this so often till the assumed ψ is equal to the calculated one.
However, it is apparent that by assuming ψ from the measuring point series as indicated in figure 4.1., adequately precise values can be obtained for the characterisation of the best straight liae.
4 When the weighing factors W_{3i} have been determined for each measuring point of the measuring series, the best straight line can be calculated with the formulas for orthogonal regression with weighing factors. First of all the terms $(W_3\overline{xx})$, $[W_3\overline{xx})$ and $(W_x\overline{yy})$ must be calculated via:-

$$[W_3\overline{xx}] = [W_3xx] - [W_3x].[W_3x]/[W_3] \quad \ldots\ldots\ldots\ldots\ldots (4.5)$$

$$[W_3\overline{xy}] = [W_3xy] - [W_3x].[W_3y]/[W_3] \quad \ldots\ldots\ldots\ldots\ldots (4.6)$$

$$[W_3\overline{yy}] = [W_3yy] - [W_3y].[W_3y]/[W_3] \quad \ldots\ldots\ldots\ldots\ldots (4.7)$$

The notation with straight hooks is the so-called notation of Gauss and is the manner of writing for the summation of the said term, in formula:-

for example $$[W_3x] = \sum_{i=1}^{i=N} W_{3i}.x_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.8)$$

With the terms calculated according to (4.5), (4.6) and 4.7) the slope b_1 of the regression line of y on x can be calculated via:-

$$b_1 = [W_3\overline{xy}]/[W_3\overline{xx}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.9)$$

and the slope b_2 of the regression line of x on y via:-

$$b_2 = [W_3\overline{yy}]/[W_3\overline{xy}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.10)$$

after which the slope of the orthogonal regression line can be concluded from:

$$b_n = \mathrm{sgn}\,[W_3\overline{xy}]\sqrt{b_1.b_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.11)$$

in which sgn $(W_x\overline{xy})$ is the sign of the term $(W_3\overline{xy})$

The variance in the slope $s^2(b_n)$ can be determined with:-

$$s^2(b_n) = 2.\ \frac{[W_3\overline{yy}]-b_n.[W_3\overline{xy}]}{(N-2).[W_3\overline{xx}]} \quad \text{.......................(4.12)}$$

The weighed centre of gravity of the measuring points is a point on the best straight line. The co-ordinateon of of the centre of gravity are called x_c and y_c. The are calculated with the formulas:-

$$x_c = [W_3x]/[W_3] \quad \text{.................................(4.13)}$$

$$y_c = [W_3y]/[W_3] \quad \text{.................................(4.14)}$$

The relating variances are determined with:-

$$s^2(x_c) = \frac{2.[W_3\overline{xx}]-(1/b_n).[W_3\overline{xy}]}{[W_3].(N-2)} \quad \text{.....................(4.15)}$$

and

$$s^2(y_c) = \frac{2.[W_3\overline{yy}]-b_n.[W_3\overline{xy}]}{[W_3].(N-2)} \quad \text{........................(4.16)}$$

By working all this out for the autumn measuring at facade 1, the following characteristics of the lines and their relating variances have been determined. For measuring at the room including the facade (line 1):

slope $b_{n_1} = 1.62$

variance in the slope $s^2(b_{n_1}) = 0.0010$

centre of gravity co-ordinates:-

$x_{c_1} = 2,16 \quad \rightarrow \quad q_{v_{c_1}} = 144,5 \times 10^{-3} m^3/s$

$y_{c_1} = 1,89 \quad \rightarrow \quad \Delta p_{c_1} = 77,6$ Pa

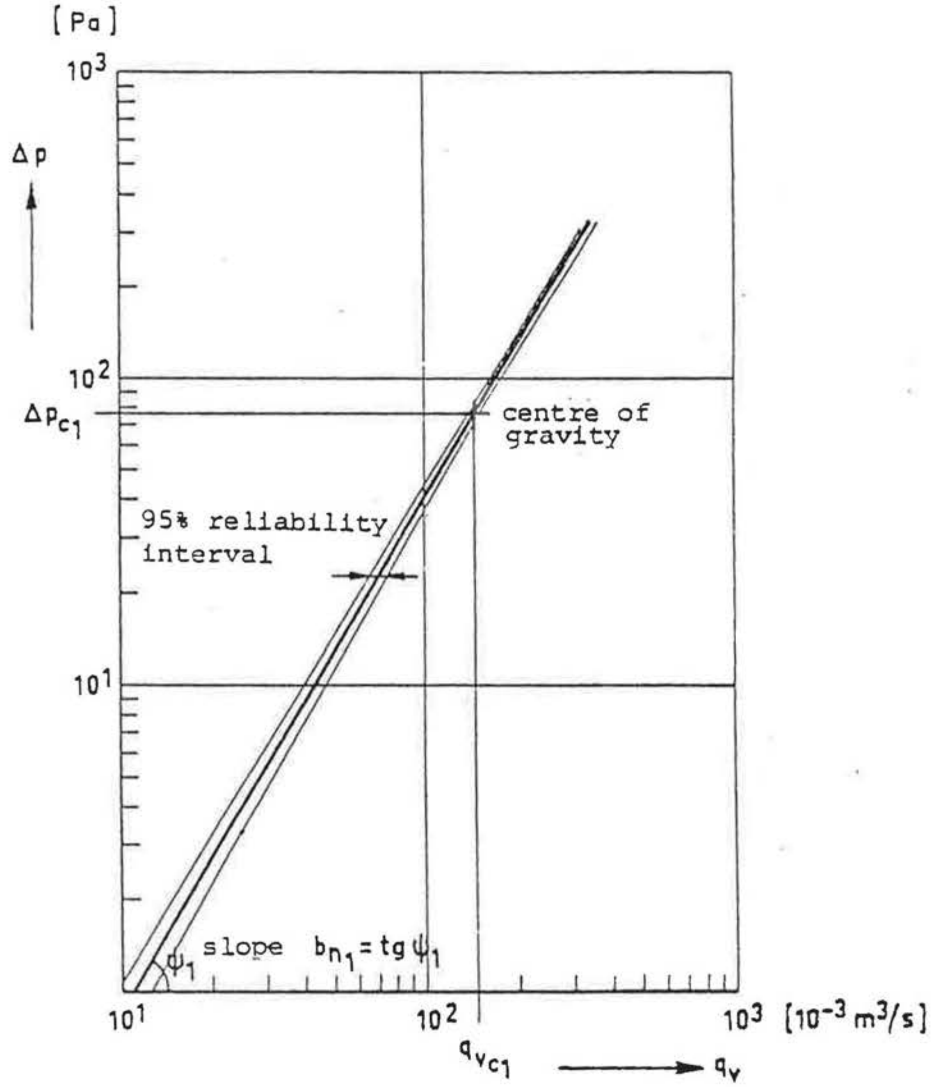


Figure 4.3. Best straight line with 95% reliability interval for the air permeability in the autumn measuring at the room inclusive facade 1.

variance $s^2(x_{c_1}) = 0.00000787$

Variance $s^2(y_{c_1}) = 0.00002361$

This line is graphically shown in figure 4.3. The figure also shows the limits of the 95% relåability interval (two-sided).
The 95% reliability ineerval indicates the area inside which the deviation of the line is not greater than $\pm$ 1.96 times the standard deviation s (s = the root from the variance). It can be said with 95% certainty that the line representing the relationship between the measuring points, should belong in this region.
A similar line can be shown for measuring at the room without the facade (line 2).
The characteristicsmagnitudes of this are:-

slope $b_{n_2} = 1.65$

variance in slope $s^2(b_{n_2}) = 0.0007$

Point of gravity co-ordinates:-

$x_{c_2} = 2.06$ - $qv_{c_2} = 114.8 \times 10^{-3} m^3/s$

$y_{c_2} = 1.82$ - $\Delta p_{c_2} = 66$+- Pa

varåance $s^2(x_{c_2}) = 0.00000526$

variance $s^2(y_{c_2}) = 0.00001436$

A random point of line 1, regarding the measuring at the room including the facade, can be shown by:-

$$x_1 = x_{c_1} + \frac{1}{b_{n_1}} (y_1 - y_{c_1}) \quad (4.17)$$

and of line 2, regarding measuring at a room without facade by:-

$$x_2 = x_{c_2} + \frac{1}{b_{n_2}} (y_2 - y_{c_2}) \qquad (4.18)$$

The air permeability exclusively of the facade is determined by the difference between measuring at the room inclusive the gaps (line 1) and measuring at the room without gaps (line 2). This is shown in figure 4.4.

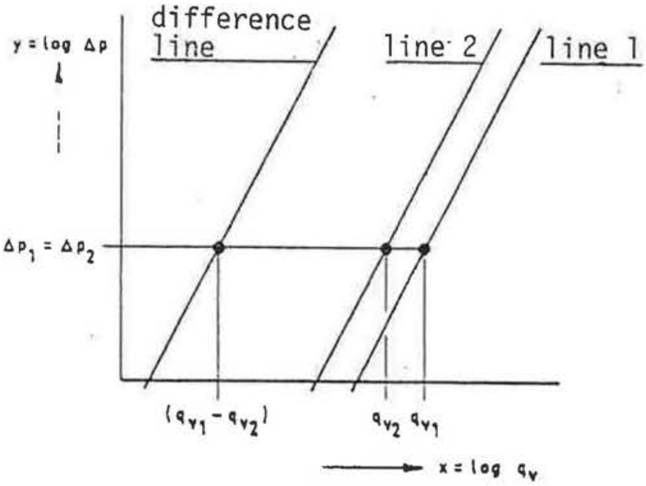


Figure 4.4. Determination of the air permeability characteristic of the facade.

The volume flow qv_1 passed through the untightnesses of the room at a specific pressure difference Δp_1 inclusive of the facade is reduced by the volume flow qv_2 which is passed through the untightnesses in the room without the facade and at the same pressure difference . The difference qv_1-qv_2 is the volume flow through the facade qv_{facade} at the considered pressure difference Δp_1.

Arithmatically this means:- In (4.17) and (4.18) y_1 and y_2 are equal because $\Delta p_1 = \Delta p_2$. With $x = \log qv$ or $qv = 10^x$, (4.17) can be re-written as:-

$$qv_1 = 10^{\{x_{c_1} + \frac{1}{b_{n_1}} (y-y_{c_1})\}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.17a)$$

and (4.18) as

$$qv_2 = 10^{\{x_{c_2} + \frac{1}{b_{n_2}} (y-y_{c_2})\}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.18a)$$

after which the volume flow through the facade as function of the pressure difference across the facade (Δp) with $y = \log \Delta p$ can be written as:

$$q_{v\,facade} = qv_1 - qv_2 = 10^{\{x_{c_1} + \frac{1}{b_{n_1}} (\log \Delta p - y_{c_1})\}} - 10^{\{x_{c_2} + \frac{1}{b_{n_2}} (\log \Delta p - y_{c_2})\}} \quad \ldots\ldots (4.19)$$

For the determination of the relating varance the transmission law of errors has been applied.

This is in general

$$s^2(F) = \sum_{k=1}^{k=p} \left(\frac{\delta F}{\delta V_k}\right)^2 . s^2(V_k) \quad \ldots\ldots (4.20)$$

in which F = function

V_k = every variable with an error

k = indication of rank number of the variable with error

p = number of variables with errors

For example, in function (4.19) x_{c_1} is called the first variable with error (v_1), b_{n_1} the second (V_2), etc.

When using the connection between the pressure difference across a facade (Δp) and the volume flow through a facade ($q_{v\,facade}$) one would be usually interested in the volume flow passed through (qv_{facade}) at a selected pressure difference (Δp).

As one selects Δp, this can be considered as an error-free value. One will also be interested in the error in the value related to Δp, namely qv_{facade}.

For the determination of the variable $s^2(qv_{facade})$ formula (4.20) must be applied to the connection between Δp and qv_{facade} which is shown by the appearance of (4.19).