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PAPER 5

# APPLIANCE OF INFRARED-THERMOGRAPHY IN EXAMINING AIRLEAKAGE OF BUILDINGS

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## PREFACE

Ventilation of buildings proceeds from actual ventilation due to applied ventilation-facilities in conformity with the standards and regulations, and from unaware ventilation due to cracks and seams in the building envelope. This uncontrolled air-exchange can substantially influence the total ventilation and can therefore result in problems.
The capacity of heating-installations have become considerably small as a result of increased thermal insulation of buildings. Due to this it is quite possible that the installation can no longer provide the required indoor-climate at a too large undesirable infiltration of outdoor-air under extreme outdoor-climate conditions. There is hardly any capacity left to deal with these unexpected interferences. Besides, excessive outdoor-air infiltration leads to extra energy consumption because the air in winters must be heated, and, in complete air-conditioned buildings, air in summers must be cooled. This excessive infiltration can interfere with the aimed ventilation of rooms via ventilators, flap-windows and mechanical systems. There is also a higher risk for damages by condensation at concentrated leakages.

The previous motivates the setting of a (maximum) limit to the airtightness requirements in The Netherlands. Since 1982, the Rijksgebouwendienst have made demands into practice on the minimal airtightness of building façades. These demands were formulated according to the NEN 3660 and NEN 3661: "window frames - air permeability, rigidity and strength - methods of test, requirements".These standards contain product-requirements for the texture elements of the buildings envelope, such as lower fronts of buildings, windows and doors, and therefore have no (direct) regard to the in the practice occurring airtightness of the building envelope as a whole.
The joints between the several texture building elements play an important role for the airtightness of the complete envelope. However, the demands in these standards are being reconsidered at the moment.

Based on guide-lines formulated by the Rijksgebouwendienst, a standard is being prepared in which demands on airtightness of the complete building envelope in the practice will be formulated. This implies that an evaluation measuringsprocedure is to be prescribed. The application-field of these new norms concerns primarily the utilitarian buildings, such as office buildings.
Meanwhile, two draft standards for dwellings (or all buildings intended for occupation) have been prepared. (NEN 2686 and NEN 2687 concerning measuringprocedure, respectively requirements) The demand for dwellings (or buildings intended for occupation) merely involves a net airvolume- current at a destinct pressure difference between the building and outside. On account of this, a rough indication of the construction quality is given in relation to the chosen ventilation system. Interpretation of the ventilation system to the energy consumption requires knowledge of several aspects such as distribution of airtightness over the envelope, the ventilation system and the distribution of temperature in the building.
The standards with regard to the utilitarian buildings as well as the standards for buildings intended for occupation, merely state a minimal required quality: in which manner this should be realized is not stated. Naturally, the airtightness will for a large part depend on the attention, which has already been paid in the design proces to an airtight detailing.

After this the guide-lines for façades operated by the Rijksgebouwendienst (The Government Buildings Department) as well as the measuring-procedure as an evaluation of those in the practice will be dealt with. Fifty airtightness-measurings in thirty government buildings have been carried out in the period 1980 up to 1985. The measurements have been evaluated.

The measuring-procedure operated so far by the Rijksgebouwendienst is an evaluation of the quality of the façade by means of a random test: a representative considered fragment of the façade, mostly a repeating part is tested. This procedure should be carried out in an as early as possible stage, so that systematical errors can be determined.
Beside this, evaluations in problemsituations can be carried out afterwards. The use of infra-red thermografy as an aid has been researched to achieve a qualitative and if possible, quantitative indication of airtightness(distribution) of the complete building envelope. The results of this thermografical research, which is combined with architectural research on the spot, are dealt with in paragraph 7, 8 and 9.

## 1 GUIDE-LINES OF THE RIJKSGEBOUWENDIENST

The Rijksgebouwendienst have, so far, set demands on airtightness of façades as a whole as well as average airtightness of cracks and seams separately. The requirements formulated for airtightness of façades as a whole are decisive. The requirements on cracks and seams (this is the space between construction parts which are meant to be able to move in respect to one another) differs from the product demand in the NEN 3661 in that it may not conflict with the demand on the façade as a whole. This means that buildings with a large crack length per $m^2$ façade have an increased requirement on the airtightness of the cracks/seams. (limit-value of 0,6 $m^1$ seam per $m^2$ outdoor-surface).

The requirement on the façade was set at that time according to the standards NEN 3660 and NEN 3661. This implies that the following is considered acceptable: 'the situation, in which during one hour a year at the most, an amount of outdoor air gets in through cracks and seams which is equal to or lager than the desired amount of air necessary for ventilation'.
In the derivation of the requirements on façades as a whole, we started from a standard office, in which in case of a single room there is question of an average outdoor-surface of 8,4 $m^2$ and in case of rooms for more than one person, the outdoor-surface varies form 4,0 to 4,7 $m^2$. At a minimum amount of ventilation of 9,7 l/s a person (= 3,5 $m^3$/h a person) in terms of fragrance hinder, a minimum ventilation necessary is found varying form 1,2 to 2,4 l/s.$m^2$.
According to the starting-point of the NEN 3661, these amounts serve as a model for the admissable infiltration (amount) at a distinct pressuredifference over the façade, the so-called evaluation-pressure. At the starting-point of exceeding a maximum of one hour, the evaluation-pressure is co-determined form wind-velocities, which at certain heights at a maximum of one hour a year are exceeded.
An admissable airtightness of the façade of 1,8 l/(s.$m^2$) at evaluation-pressure has been determined to set a uniform demand on grounds of economical considerations. This requirements applies to façades with parts that can be opened. A slight airleakage for completely sealed façades is believed in practice to be reasonably attainable so that a more aggravating demand can be used: 0,5 l/(s.$m^2$) has been chosen as a first, naturally arbitrary, criterium.

A distinction in demands for façades with openable elements and entirely sealed façades is not relevant on grounds of the chosen starting-point: the same admissable volumecurrent applies for both. Aggravating the demand for sealed façades cannot be motivated on grounds of economical considerations. Buildings with completely sealed façades, however, will mostly be entirely (air)-conditioned, so that aim at slighter airleakage is advisable in terms of interference of the installation. Concerning the preparation of a Duth standard, this subdivision is still up for discussion with regard to the airtightness of the entire building envelope.
The guide-lines of the 'Rijksgebouwendienst' will link up to this new standard.

The present-day guide-lines of the 'Rijksgebouwendienst' have been evaluated to find out to what extent these can be realized in the practice. This was done on grounds of an evaluation of 50 airtightness measurings in the pratice carried out by the 'Rijksgebouwendienst' in the period of 1980 up to 1985. The conclusions which were drawn are dealt with in paragraph 3.

## 2 MEASURINGPROCEDURE AIRTIGHTNESS OF FAÇADES

The procedure used by the 'Rijksgebouwendienst' for determining the airtightness of a representative esteemed façadefragment, is in principle as follows: an airtight pressurechamber is placed on the inner-side of the construction up for testing. The sealed experimental room is brought to a certain over- or underpressure by means of a ventilator. The pressure difference of the experimental room and the outdoor-climate as well as the air quantities supplied and drained are registered. The netammount of $m^3$ air is determined by measuring the pressure difference over a measuring-flance assembled in the air supply hose. The Afdeling Bouwfysica of the Rijksgebouwendienst use two slanting tube manometers (pressure-gauges). In preparation of the measuring, the airtightness of the room's walls are checked and a short pre-pressurization is carried out according to the testprocedure for façade-elements in the NEN 3660. Pressure is built up gradually when determining the airtightness of the façade-element. The testing takes place at overpressure as well as underpressure. If the measurements show that the façade does not meet the demands, another closer investigation for air-leakages in the façadeconstruction takes place. The measuringprocedure is repeated after sealing the (possible) leakage. The average airtightness of cracks/seams is also determined in that manner. The measuring is mostly concluded by the conducting of a smoke-experiment. The most important airleakages can be localised by placing a smoke source and the airtightness of the pressure chamber can be evaluated in comparison with the tested façadefragment. A quantitative evaluation on grounds of withdrawing smoke quantities is naturally not possible.

## 3 EVALUATION OF MEASURING AIRTIGHTNESS IN PRACTICE

Table 1 shows an overall picture on airtightness measurements with façades in the practice, conducted by the Afdeling Bouwfysica of the Rijksgebouwendienst in the period of 1980 up to 1985. On ground of these results, the following conclusions are drawn:

The current guide-line of 1,8 $l/(s.m^2)$ for façades with openable elements at a well-considered specification of the sealing of cracks/seams and a careful execution in the practice as well is stated to be easy to realize if airlosses through leaks in the testroom walls to other rooms in the buildings are taken into account. Almost all investigated projects during the execution-stage appeared to be able to meet the requirements, although this was realised after dealing with the matter. The extreme benefit of airtightness measurings in an early stage of the construction is therefore emphasized; problems occuring later can be solved at an early hour.
In general it is concluded that in case the façade does not meet the requirement, the cause must mostly be searched in a insufficient sealing of the cracks/seams, where the joints of the façade-elements and the surrounding buildingconstructions are. Especially the joint of the window-frame and the surrounding masonry and in particular the joint of the bottom rail on the parapet is a regular noted leak. It has also appeared that seams cause problems more often than cracks.

From the measurements, it appears that the airtightness of cracks at evaluation pressure vary from 0,04 $1/(s.m^1)$ to 2,46 $1/(s.m^1)$ with an average of 0,95 $1/(s.m^1)$ (excepting the 'Belastinggebouw' in Haarlem and the 'Gerechtelijk laboratorium' in Rijswijk: here no sealing was applied).
It is also stated that the current requirement can simply be met although the airtightness of cracks has been determined seperately in a limited number of measurings. It has appeared from experience that most critical constructions, concerning crack-sealing, mostly sash-window, can meet this requirement. Besides this, it is stated that a requirement for cracks of 2,5 $l/(s.m^1)$ in the draft version of the NEN 3661 (august 1986) will be copied. Therefore the current guide-line of the 'Rijksgebouwendienst' can be maintained or a reference to the new version of the NEN 3661 can in due time be enough.

An airleakage of maximum 0,5 $l/(s.m^2)$ in the practice is in fact realizable for buildings with entirely sealed façades. This is concluded from the measurements, taking into account the aircurrent from the testroom to other rooms in the building. Same as with the façades with openable elements, it has appeared that insufficient sealing of the seams mostly leads to dramatical consequences for the airtightness of the façades as a whole.

With regard to the requirements to the airtightness of seams in the practice, it is concluded that an (average) quality requirement per $m^1$ seam is not manageable, since the in the practice occuring problems when determining the active seamlength and the interpretation of the definition : seam.
Besides, it is not relevant to set a requirement to the average airtightness of all other leaks, mostly seams, since the requirement to the airtightness of the façade is representative and that also a seperate reguirement to cracks is set. It is recommended to prevent concentrated airleakages in terms of human comfort and risc for local condensation.

| | $l_c$ | $P_{eva.}$ | $Q_f$ | $C_f$ | $Q_c$ |
|---|---|---|---|---|---|
| Rijksinkoopbureau Zwolle | 0,53 | 150 | 2,2 | 76 | - |
| Belastingkantoor, Assen | 0,46 | 150 | 1,8 | 62 | - |
| (after sealing) | | | 0,6 | 22 | - |
| Rijkspolitie, Waddinxveen | 0,35 | 150 | 0,7 | 24 | - |
| CBS, Heerlen | 1,08 | 200 | 1,0 | 29 | 0,48 |
| Min. O&W, Zoetermeer | 0,65 | 200 | 3,9 | 115 | - |
| (after sealing) | | | 1,5 | 44 | - |
| (after sealing) | | | 0,5 | 15 | - |
| Belastinggebouw Haarlem | 0,64 | 200 | 8,4 | 247 | 7,39 |
| Min. O&W, Zoetermeer | 0,70 | 200 | 0,6 | 18 | - |
| Rijkskantorengebouw, Lelystad | 0,85 | 200 | 4,1 | 119 | - |
| (after sealing) | | | 1,2 | 36 | - |
| Min. Bu.Za., Den Haag | 0,23 | 200 | 4,1 | 120 | - |
| (after sealing) | | | 1,1 | 33 | - |
| R.S.G., Steenwijk | 1,22 | 150 | 2,6 | 91 | 0,11 |
| Topografische Dienst, Emmen | 0,99 | 200 | 3,5 | 101 | - |
| (after sealing) | | | 1,3 | 38 | - |
| Belastinggebouw,Haarlem | 0,33 | 200 | 2,6 | 75 | - |
| Belastinggebouw, Hoorn | - | 200 | 2,6 | 75 | - |
| Gerechtelijk Lab. Rijswijk | 0,70 | 200 | 8,8 | 259 | 5,38 |
| (after sealing) | | | 2,2 | 64 | - |
| C.B.S., Haarlem | - | 200 | 4,4 | - | - |
| Rijkskantorengebouw Eindhoven | 0,78 | 200 | 2,2 | 64 | 0,04 |
| G.A.B., Lisse | 0,50 | 150 | 20,9 | 740 | - |
| (after sealing) | | | 4,0 | 142 | - |
| Gerechtsgebouw, Breda | 0,98 | 150 | 4,1 | 144 | 0,25 |
| (after sealing) | | | 2,0 | 70 | 1,16 |
| Nieuwbouw P.T.T., Krommenie | 0,23 | 150 | 1,0 | 37 | 1,70 |
| Rijkspolitie, Den Bosch | 0,22 | 150 | 2,5 | 90 | - |
| R.P.A., Alkmaar | 1,14 | 150 | 5,1 | 180 | 1,10 |
| R.S.G., Epe | 0,69 | 159 | 4,1 | 144 | 2,46 |
| R.S.G., Enkhuizen | 0,30 | 150 | 30,6 | 1085 | - |
| (after sealing) | | | 8,2 | 292 | - |
| Rijks Inkoop Bureau, Zwolle | 0,33 | 200 | 3,7 | 107 | - |
| R.S.G., Harderwijk | 0,31 | 150 | 2,4 | 85 | 1,33 |

**Table 1** Measurements of buildings with openable elements.

Symbols:

$l_c$ mean crack lenght per $m^2$ façade ($m^1/m^2$)

Peva. evaluation-pressure (Pa)

$Q_f$ net airvolumecurrent per $m^2$ façade at evaluation-pressure ($l/(s.m^2)$)

$C_f$ "C-coefficient" ,air-leakage per $m^2$ façade per Pa pressure difference ($l/(s.m^2.Pa^{2/3})$)

$Q_c$ net airvolumecurrent per $m^1$ cracklength at evaluation-pressure ($l/(s.m^1)$)

| | $P_{eva.}$ | $Q_f$ | $C_f$ |
|---|---|---|---|
| Koninklijke Bibliotheek, Den Haag | 200 | 1,0 | 30 |
| Centraal Belastingkantoor, Utrecht | 250 | 1,4 | 36 |
| Min. Bi.Za., Den Haag | 250 | 3,4 | 86 |
| Nieuwbouw Ac. Ziekenhuis, Leiden | 250 | 0,5 | 12 |
| Rijkswaterstaat, Den Haag | 250 | 2,8 | 70 |
| (after sealing) | | 0,7 | 18 |
| R.I.V.M., Bilthoven | 200 | 6,9 | 202 |
| (after sealing) | | 2,3 | 67 |
| W.V.C.-A, Leidschendam | 200 | 10,1 | 296 |
| (after sealing) | | 7,9 | 230 |
| W.V.C.-M, Rijswijk | 200 | 19,5 | 570 |
| (after sealing) | | 17,7 | 517 |

**Table 2** Measurements of façades without openable elements.

Symbols:
Peva. evaluation-pressure (Pa)
$Q_f$ net airvolumecurrent per $m^2$ façade at evaluation-pressure ($l/(s.m^2)$)
$C_f$ "C-coefficient" ,air-leakage per $m^2$ façade per Pa pressure difference ($l/(s.m^2.Pa^{2/3})$)

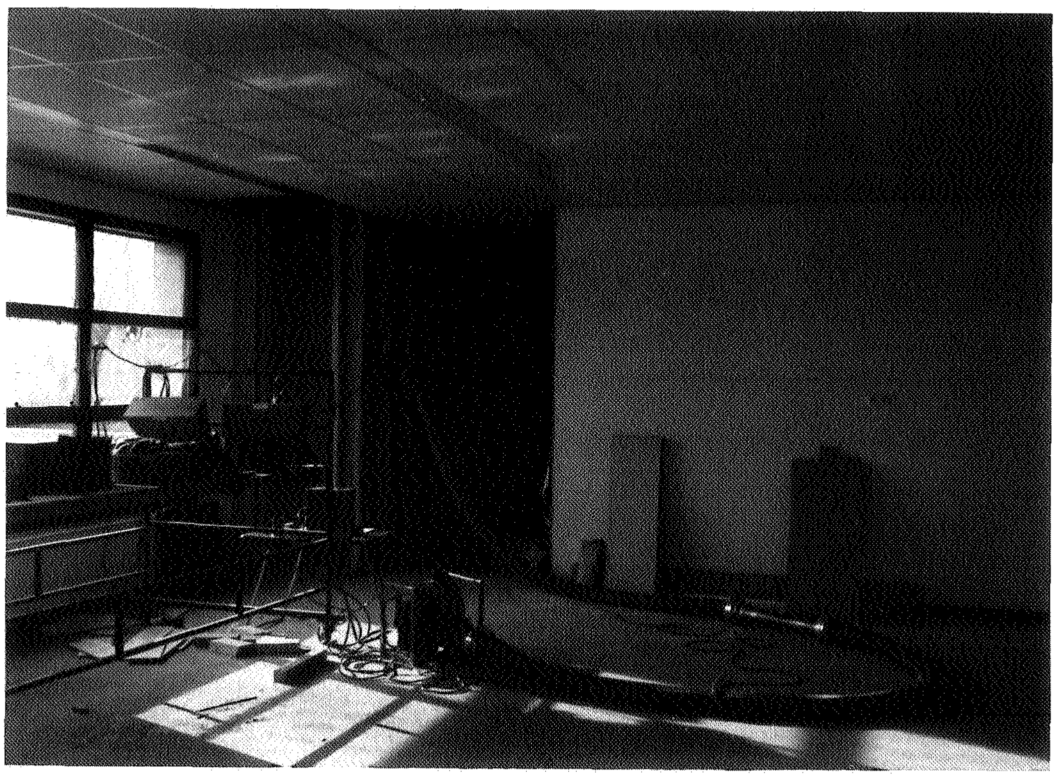

**Fig. 1** Airtightness measuring in practice; equipment of the Rijksgebouwendienst.

## 4 INFRA-RED THERMOGRAPHY

Infra-red thermography, in short: thermography, is based on detection of longwave radiation sent out by solid bodies. A difference is made between absolute and differential thermography. Surfacetemperatures can be read directly by means of absolute thermography, differential thermography visualizes temperature-differences on surfaces. As a result of difficult controlable measuring circumstances, application of thermography in analysing building constructions mostly refers to differential thermography. Infra-red thermography must also not be confused with infra-red photography. Radiation can be visualized as well by means of infra-red photography, however the wave-lengths for which photografic material is sensitive, are much shorter. This implies that infra-red photography can only be used if solid bodies have a relative high temperature (of more than 250 °C), or if radiation from a radiator with a high temperature (for instance the sun 5000 K) is reflected. We shall not go further into the matter of infra-red thermography technics (recording, videoamplifying, display).

Figures 2 and 3 show the recording of a construction part with visible light and infra-red thermography respectively. The local white discolorations in the thermo-graphical recording are higher surface temperatures.

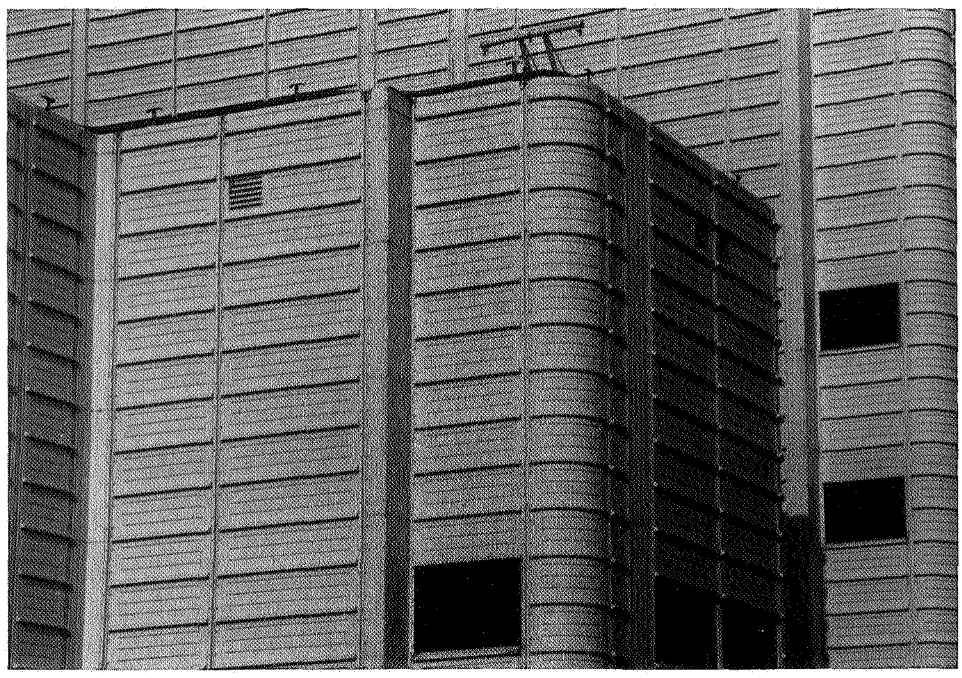

**Fig. 2** Visible light recording of af construction part.

## 5 THERMOGRAPHICAL RESEARCH IN AIRTIGHTNESS

### 5.1 Introduction

In the beginning the application of thermography was primarily focussed on examining retrofit-projects. Inspections were carried out during retrofit or afterwards by means of thermography. Two types of temperature differences were regularly noticed when carrying out the thermography and its pre-discribed objective:

- *differences regarding the conduction of the construction (thermal bridges)*
- differences as a result of airleakage

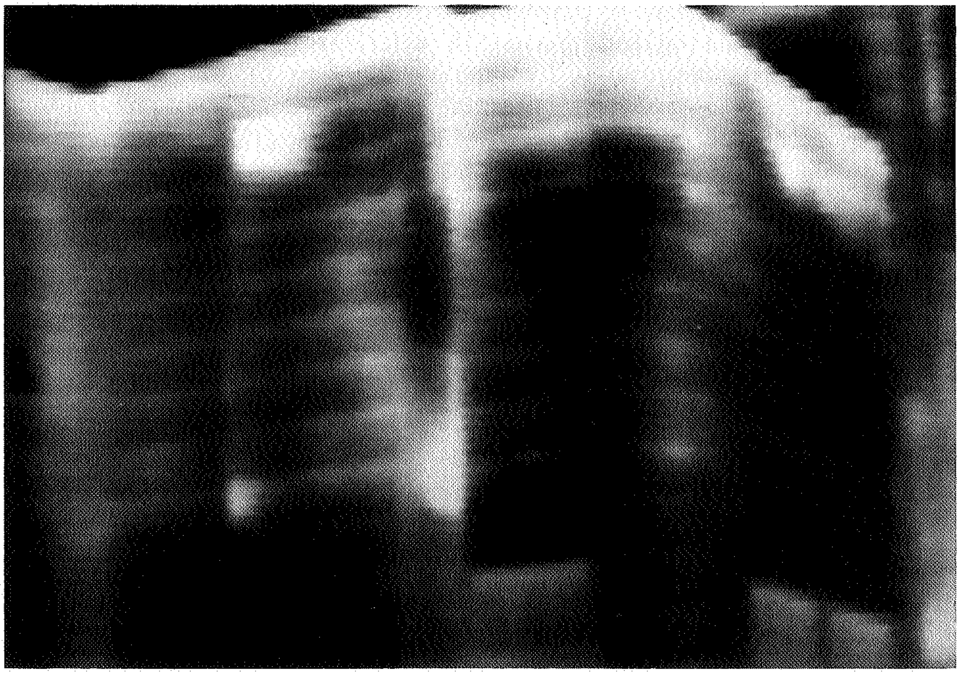

Fig. 3 The same building part shown in figure 2 as a thermografical recording. The local white discolorisations in this recording are higher surface temperatures.

Thermographical analysis of a number of buildings with problems with regard to airtightness showed, if the building is brought to a slight overpressure, infra-red thermography could possibly be used for detecting airleakages. From this a pre-investigation started to the applicability of infra-red thermography for detecting airleakages.

## 5.2 Research objective

The research has two objectives:

- Utility of infra-red thermography for detecting airleakages.
  . evaluation of the ability to detect differences in airtightness.
  . evaluation of the ability to distinguish differences in airtightness from all other causes of temperaturedifferences by means of this method.
  . formulation of the conditions in which the method can be succesfully applied.
  . research in possibilities to quantify airloss on grounds of thermographical recordings.

- Architectural evaluation of the detected dificiencies
  . systemize the detected deficiencies according to cause and location in the construction of the building.
  . On grounds of this, development of architectural recommendations to prevent problems with airtightness.

## 5.2 Research procedure

The research consists of 3 parts:

- Thermographical research of 11 (eleven) officebuildings,
- Architectural research of the reported temperature differences,
- Airtightness tests accordingly to the procedure described in 2, combined with thermography, of a façadefragment at three of the researched buildings.

The thermographical research in the eleven buildings was aimed at locations on the building surface wich seemed to be airleakages. In the architectural research is determined whether there is a question of airleakage at the distinct locations. Furthermore is determined how leakages occur and if no airleakage is the cause of the temperature difference: Wat is ? The thermographical recordings contain quantitative information on temperature differences on the facade. Researched is whether it is possible to calculate the leaking volume current from this information. Therefore airtightness tests have been carried out together with thermographical analysis.The results of airtightness tests contain the absolute airlosses through a façade element at a distinct pressure difference between indoor and outdoor. The thermography, which is carried out at the same time, supplies information on the involved temperature differences. The connection between both is examined.

# 6 THE RESEARCH

## 6.1 Building selection

Eleven buildings were selected from all governments buildings for this investigations. All buildings were thermographically researched. From the buildings researched in this manner, 3 buildings were selected. Here an airtightness test was carried out together with thermography.

## 6.2 Thermographical research

The thermographical research was focussed on detecting different temperature-differences on each building surface. It was therefore not necessary to investigate the entire building. Only a few smaller buildings were almost completely investigated at the outside. In most buildings also an investigation was carried out at selected locations on the inside. The thermographical recordings were recorded on video-tape during the investigation and then worked out in a report wich contained selected thermogrammes for architectural research.

Only those recordings were worked out where the temperature differences were interpreted as airleakages. The distinguish between temperature differences as a result of airleakage and other temperature differences was made on grounds of the type of difference in the thrmogramme and the location on the construction.

### 6.2.1 Circumstances during thermographical analysis

Before carrying out the thermographical research, several requirements were set with regard to measuring period, difference between outdoor- and indoortemperature and wind-velocity in connection with pressure difference over the façade.

- The measuring period.
  The measuring period is in the second half of the night, so that temperature

differences on the façade surface as a result of difference in radiation during the previous day can be avoided as much as possible. The analysis was stopped before or around sunrise.

- Temperature difference between indoor and outdoor.
  Because a difference between airtemperature indoor and outdoor must be available, a requirement of minimum 10 K has been set. This has never been a problem during the investigation. The difference has always been amply realized by increasing the temperature in the building.

- Pressure difference over the façade and windvelocity.
  Windvelocity influences the pressure difference over the façades. At higher windvelocities, the weather-side has an overpressure and the lee-side an underpressure. Therefore the thermographical visualization will differ from façade to façade. Also temperature patterns if any, become blurred at high windvelocities.
  Many buildings have a mechanical ventilation system which makes it possible to create an overpressure in the building. By creating an overpressure in the building the influence of airvelocity is deminished. First the choice fell to measuring at low windvelocities particularly in buildings wich have a mechanical ventilation sytem to create an artificial overpressure. The presence of such a ventilation system however was not a guarantee for sufficient pressure difference over the façade. In later investigations the expectable pressure difference was evaluated first (as far as possible). Measuring at low windvelocity was chosen whenever sufficient pressure build-up by the ventilationsystem was expected.

## 6.3 The architectural research

The report of the thermographical research was used as starting-point for the architectural research. From this report detailed inspection of the construction of the building was carried out. Parts of the construction were even dismantled if neccessary. The dismantling was done as far as possible without damaging the construction and within the available time (which appreared to be insufficient in several cases). Especially those deficiencies which had literally deep-seated causes, could not be inspected. Sometimes caretakers fear of doing destructive research influenced the investigation. Furthermore in a number of cases the available information on the buildingdrawings appeared not to conform with the reality. Details were probably adjusted during the construction of the building and were not worked into the revision-drawings. The architectural research was held to search for:

- the cause of temperature differences,
- the architectural cause of detected deficiencies,
- information to remedy or prevent such deficiencies.

The results of the investigation was reported together with the thermograms made in the thermographical research. A general report for the entire building was sufficient at systematically occuring dificiencies.

## 6.4 Simultaneous measuring of airtightness and thermographical analysis

The airtightness of a façadefragment was determined in three of the investigated buildings. Simultaneously thermography on the outside of the façadefragment was carried out. These thermographical recordings, made during the airtightness tests, have been worked out quantatively. The concerning pictures, recorded on a video-tape were digitized for a quantative working-out. Calculations can be performed with this digitized picture on the screen. The surface, the average temperature difference and the integral of product of temperature difference and surface have been calculated for quantative evaluation of airleakage patterns.

# 7 ABILITY TO DETECT AIRTIGHTNESS DEFICIENCIES WITH THERMOGRAPHY

## 7.1 Recognizing of temperature differences

Only the temperature differences which according to the interpretation are connected with airlakeage are mentioned in the thermographical research reports. Almost all these probable leakages have been architecturally examined. One or two locations for research were sufficient with systematically occuring temperature differences. If no airleakage could be found, other reasons for temperature differences were looked for. Other possible reasons might be:

- a local higher indoor temperature,
- a thermal bridge,
- an insulation deficiency.

The last possible cause for temperature differences has not been detected. The number of reported differences and the number and percentages of the causes mentioned above are listed in table 3.

| building | number of differences | air-leakages number | % | thermal bridges number | % | increased Ti number | % | unknown number | % |
|---|---|---|---|---|---|---|---|---|---|
| WVC-M, Rijswijk | 9 | 7 | 78 | 2 | 22 | - | - | - | - |
| Belastingkantoor, Alphen | 12 | 8 | 67 | 1 | 8 | 1 | 8 | 2 | 17 |
| Centr. Belastingk., Utrecht | 17 | 9 | 54 | - | - | 4 | 23 | 4 | 23 |
| WVC-A, Leidschendam | 8 | 6 | 75 | - | - | 2 | 25 | - | - |
| WVC-B, Leidschendam | 7 | 4 | 57 | 3 | 43 | - | - | - | - |
| Luchtmachtstaf, Den Haag | 20 | 19 | 95 | - | - | - | - | 1 | 5 |
| Rijksluchtvaartschool, Eelde | 17 | 8 | 47 | - | - | - | - | 9 | 53 |
| RIB, Zwolle | 15 | 7 | 47 | 4 | 27 | 2 | 13 | 2 | 13 |
| Rijksbel., Amstelveen | 11 | 9 | 82 | 1 | 9 | - | - | 1 | 9 |
| Kantongerecht, Amsterdam | 13 | 5 | 38 | 1 | 8 | 4 | 31 | 3 | 23 |
| RKG, Zwolle | 14 | 14 | 100 | - | - | - | - | - | - |

**Table 3** Distinction of the detected temperature differences with the detected causes.

About 67 % of the reported differences from the thermographical research appeared to be caused by airleakages. In 14 % of the differences the cause remained unexplained and 18 % appeared not to be the result of airleakages.

## 7.2 Detection of airtightness deficiences

If all locations of airleakage in the investigated buildings indeed have been detected cannot be evaluated correctly from this investigation. It would be necessary to make an inventory of the buildings in a complete other manner concerning airleakage. If circumstances for thermographical research are favourable, one can start form the case that also small airleakages can cause temperature differences. In such circumstances, systematically occuring deficiencies will not be missed. Once-only occuring airleakages can be missed easily. However these are of less importance in the whole airleakage of a building.

# 8 ABILITY OF QUANTIFICATION OF AIRLEAKAGE

## 8.1 Theory

In the research for possibilities of thermography for quantification of airleakages three flowtypes are distinguished in possible airleakages:

- free flow,
- unilateral limited flow,
- flow to a cavity.

The following theoretical approach has been set up for the flow-principle to a cavity. A steady state situation is presumed. The temperature of the air flowing into the cavity is supposed to be equal to the indoor-temperature Ti. The heat-current inwards is neglected, which is justifiable when there is insulation material on the outside of the inner cavity wall. This is mostly the case. The air flowing from the leakage releases its heat to the outer cavity wall and through the outer cavity wall to the atmosphere. At some distance from the leakage the temperature of the air flowing from the leakage reaches the same temperature as the cavity-air. In its turn this will almost be equal to the temperature of the outer cavity wall. As a result of the airleakage an increase in heatflow through the outer cavity wall develops on a certain area, which can be detected as a higher surface temperature. This additional heat-current Qad can be phrased as follows:

$$Qad = \alpha.(Ta-To).A$$

Where:

$\alpha$ the sum of the transfercoefficient for convection and radiation between atmosphere and outer cavity wall (W/m2.K)
Ta the average temperature of the temperature differences (K).
To the temperature of the outer cavity wall with no airleakage (K).
A the surface of the temperature differences (m2).

The airflow that enters the cavity supplies this heat. The additional heat-current can therefore also be phrased as:

$$Qad = V.\ c.\ (Ti-To)$$

Where:

V the volumecurrent (flow) of indoor air (m3/s).
c volminous heat capacity of air (J/m3.K).
Ti the temperature of indoor air (K).
To the temperature of the outer cavity wall with no airleakage (K).

From both equations follows:

$$V = (\alpha.(Ta-To).A)\ /\ (c.(Ti-To))$$

The integrated temperature difference (Ta-To).A can be deduced from the thermogramme. The transfercoefficient can be estimated from the windvelocity and -direction. The temperature of the outer cavity wall can be determined with a contactthermometre, or with thermography apparatus with regard to the airtemperature. So the volumecurrent of the air flowing from the leakage can be deduced from the integrated temperature difference and additional data. This approach is reasonable if the heatresistance from the cavity outwards is smaller than the heatresistance from the cavity inwards.

With heavier outer cavity walls the final temparature of air flowing outwards is not equal to that of the outer cavity wall, and the additional heatcurrent inwards can also be larger. Also if the air from the leakage reaches outside with a temperature which is higher than that of the cavity air this appraoch is not applicable because the amount of heat reaching the outdoor air remains unknown.

When airleakage is of the 'free-flow type', at low velocities there is a connection that makes calculation of airflow possible. The connection is lost at increased airvelocity.

A theoretical deduction for unilateral limited flow has not been further developed within the scope of this pre-investigation.

## 8.2 Quantification from thermographical recordings

The thermographical recording is recorded on analogue video-tape. This tape can be played on a video-recorder connected to a computer. Every recording can be digitized and drawn into memory-banks of the computer. The digitizing occurs in a capacity that no detail recorded on the original tape is lost. Once the picture is available in numbers, calculations can be performed. One possiblity is classifying the numbers represented in the picture. Every class has its own colour, up to six colours plus black and white, each colour representing a temperature range. A reproduction can be made my means of a colourprinter.

Thermographical recordings have been made at each step in the increase of pressure during the airtightness tests. The integral of temperature times surface has been calculated in these recordings. A reference should be available when comparing different recordings because they only reproduct temperature differences with regard to an adjustable level. The temperature of the reference may not be influenced by occuring airleakages. A number concerning the airloss through the façade part can be deducted from the quantative working up of two pictures recorded in different pressure situations. Quantification of airleakage can only be carried out for buildings with mechanical ventilation while at least two recordings at different pressure situations are neccessary.

The previous mentioned deductive formula is used for calculation of the airflow through the facade. It is assumed that all air flowing from the leakage releases its heat to the construction before mixing with the open air. Naturally this is an approach. The calculated airloss undervalues the actual airloss. The amount of calculated flow will be equal to or smaller than the actual flow while free-flow and unilateral limited flow is underestimated.

In figure 4 and 5 there are graphs in which the airflow by measuring is plotted together with the calculated values according to the previous described method of thermography.

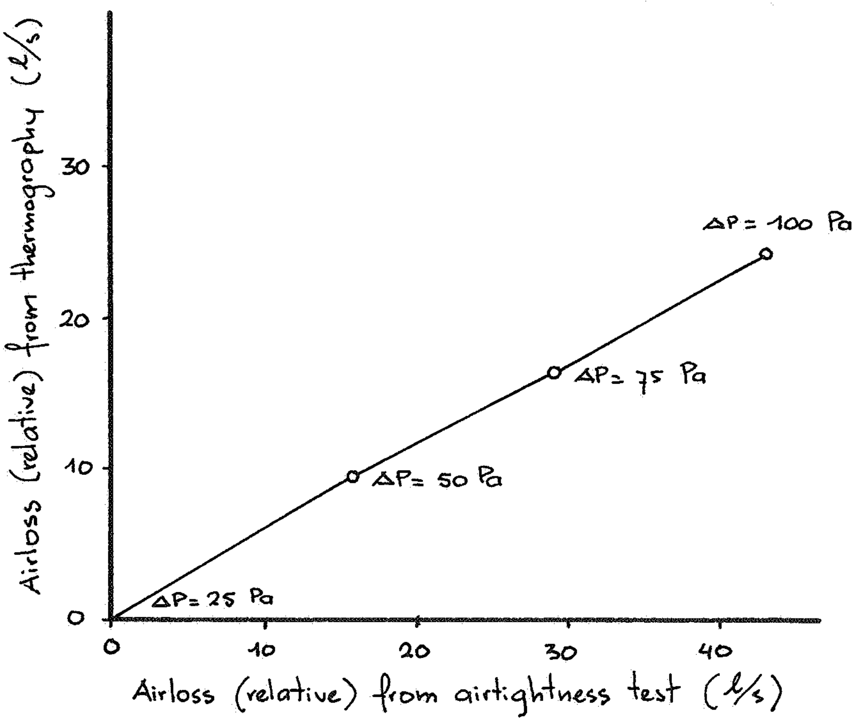


**Fig.4** Measured airflow from airtightness test vs. calculated airflow from thermography, building 1.

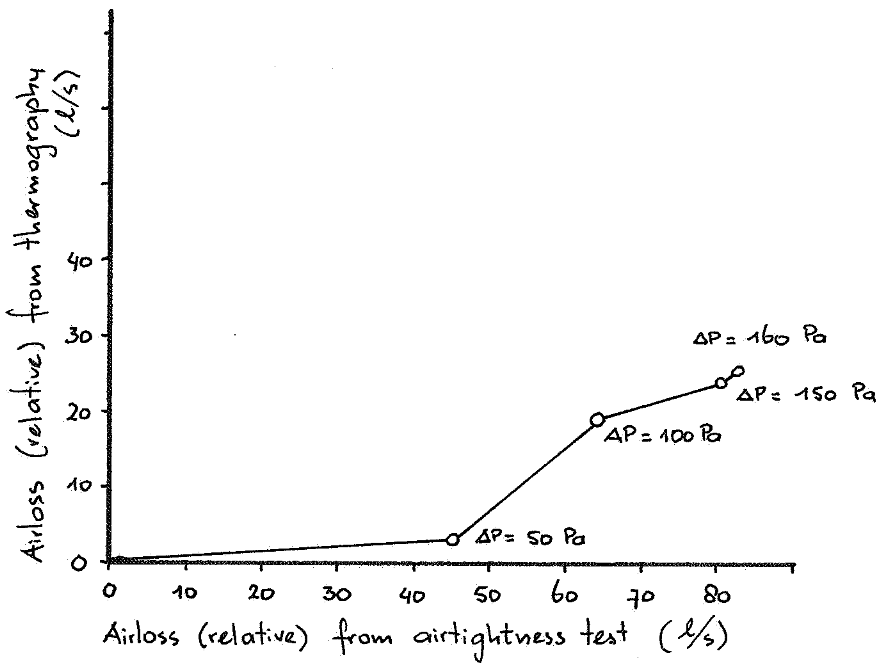


**Fig.5** Measured airflow from airtightness test vs. calculated airflow from thermography, building 2. The first step in pressure build-up doesn't produce temperature differences. The cause of this lies in poorly controlable indoor temperatures. Furthermore the calculated airflow is much lesser than the measured flow because not the whole surface of the temperature difference is digitized.

## 9 ARCHITECTURAL ANALYSIS OF AIRTIGHTNESS DEFICIENCIES

A systematical framework has been developed in which the detected deficiencies from the architectural research according to location and number, together with potential additional information can be classified, in aid of architectural analysis. (Figure 6)

A classification in open and closed elements of the outside wall was chosen. This classification is almost analogue to primary and secondary elements according to the Sfb classification. "The secondary elements in outside walls (Sfb 31) are windows, doors and window-frames, made of wood, steel, aluminium or synthetic material, applicable in outside walls of buildings." This classification offers prospects to unequivocally indicate airleakages at three locations on the building surface:

- in the open façade parts,
- on the deviding line of open and closed façade parts,
- in the closed façade parts.

Furthermore a distinguish was made in the following types of deficiencies:

- Design deficiencies.
  Design deficiencies originate in the planpreparation- and materialization phase of the building. Often insufficient insight in the manner in which airtightness must be accomplished is the cause of this. Beside this, wrong choice of materials can result in airtightness deficiencies.

- Construction deficiencies.
  Deficiencies during the construction often originates from neglect or carelessness. There is a relation, however, between complexity of specification and chance of construction deficiencies. Many joints or different materials for instance in a construction detail increases the danger of construction deficiences.

- Maintaince deficiencies.
  Deficiencies during maintainance of a building can also cause insufficient airtightness. These deficiencies can be summarized as overdue or not systematic maintainance.

Naturally this distinguish is somewhat arbitrary. An incorrectly sealed joint can be the result of an incorrect tolerance during the design, so that maintainance problems originate sooner than expected. An incorrect chosen sealing during the design can give problems with attachment during construction etc.

## 10 CONCLUSION AND RECOMMENDATIONS

### 10.1 Use of thermography for detection of airtightness deficiencies in buildings.

- The circumstances for thermographical research, as set in this pre-investigation (see 6.2.1) seem to be satisfactory.

- About two/third of the temperature differences wich were interpreted as airleakages indeed showed to be caused by airleakage. Hereby the cause of 14 % of the differences is still unexplained. If all locations of airleakage will be detected by thermography cannot be evaluated correctly from this investigation. Nevertheless thermography is very useful in qualitatively examining airleakage of a whole building envelope.

Gebouw : Luchtmachtstaf, Binckhorsthof fase II
Binckhorstlaan 135
's-Gravenhage

bouwjaar : 1984
geveltype :

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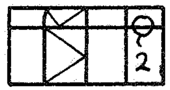
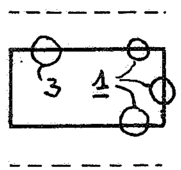
| lekken in open geveldelen | | detailprobleem | ontw | uitv | ond | lektype |
|---|---|---|---|---|---|---|
|  | 2 doorvoer bediening zonwering | 2 geen afdichting | – | X | – | |

| lekken op de grens van open en gesloten geveldelen | | detailprobleem | ontw | uitv | ond | lektype |
|---|---|---|---|---|---|---|
|  | 1 kozijn/metselwerk<br>3 stalen kozijn (glas in lood) op konstruktie | onjuiste hoekoplossingen en holle afdekprofielen | X | – | – | |
| | | afdichting niet aangebracht | – | X | – | |

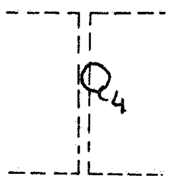
| lekken in gesloten geveldelen | | detailprobleem | ontw | uitv | ond | lektype |
|---|---|---|---|---|---|---|
|  | 4 kolom/beplate gevel | ? onjuiste afdichting | | | | |

**Fig.6** Sample sheet for cataloging the detected deficiencies.

- From quantitative working-out of two thermogrammes taken under different pressure-situations, an estimate can be made of the airloss trough a façade-part. This calculated airloss underestimates the real airleakage. For performing this calculation the following extra information is neccessary:
  . pressure-differences over the façade-part,
  . in- an outdoor airtemperature,
  . windvelocity and -angle.

  Results of airloss calculation by means of thermography as this moment are not satisfactory. Only when calculated airlosses are less than according to the guide-lines they are useful.

- It deserves recommendation to detect airtightness deficiencies supported by thermography, especially with large and complex buildings. By means of thermography, it is relatively easy to qualitatively examine the entire envelope of the building, which is otherwise impossible or extremely expensive. After this, on grounds of thermographical recordings, specific architectural research or airtightness tests can take place. Guide-lines for an eventual standard research- or evaluation procedure are as follows:
  . analysis of building-drawings with regard to critical construction details.
  . decision for qualitative application of thermography on grounds of this analysis.
  . analysis of thermographical recordings on locations and frequency of air-leakages.
  . specific inspection by means of architectural research and/or airtightness measurements.

## 10.2 Recommendations on grounds of architectural research

- For an important part the detected deficiencies can be explained by lack of knowledge. Prevention of airtightness deficiencies starts with instruction and education. This applies to all three types of the detected deficiencies (design-, construction- and maintainance deficiencies). Some elements of instruction and education are mentioned:
  . principles of reliable airsealing,
  . systematical errors often have serious consequences for an entire project,
  . influence of wear of sealants on airtightness,
  . aged and mudhaven sealings besides waterleakage often also have airleakage.

- The following recommendations can be mentioned on grounds of the detected deficiencies which cause lies in the phase of the building design.
  . Extra attention should be paid to prevention of airleakages when considering 'special' detailing in façades, especially with in- or outdoor ceilings which hide façade-parts.
  . The appliance of hollow window-frames or window-profiles and concave 'cope-laths' can give cause to airleakages at unexpected locations when poorly sealed.
  . The manner of sealing of window-frame systems should be chosen, next to all other requirements, in view of airtightining.
  . At unsuspectable (small) openings in façades, airleakages can easily originate. (for instance a small opening for operation of sun-blinds)
  . It is recommended to carefully evaluate a design on airtightness, for design deficiencies often display systematical characteristics. Problems with airtightness occur therefore in the entire building, and not in an incidental detail. Costs of adjustments afterwards often are considerable.

- It is desirable to pay attention to critical details with regard to airtightness during the construction. So-called 'forgotten' and incorrectly placed sealings might be decreased by instruction of the constructional workers and the constructional foreman.

- It is desirable that the management and maintainance of buildings refers to preservation of airtightness. Systematic maintainance implies regular inspection of sealings of cracks and seams.

- The classification of airtightness deficiencies used in this research deserves the recommendation to further develop such an instrument. In this way information is easily transferred and interpretable. At the same time it is an instrument to advance knowledge build-up on airtightness deficiencies.