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VENTILATION IN SMALL UTILITY BUILDINGS:

MEASUREMENTS ON AIR-LEAKS IN INSIDE WALLS

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SUMMARY

A report on the first part of this investigation of the possibilities of natural ventilation in small utility buildings was presented in 1982. During that investigation it became clear that it was necessary to gather information regarding air-leaks from inside walls and inside doors. This information is required in order to be able to determine the magnitude of the mutual influence of the ventilation in one room on the ventilation in other rooms.

But it may also be important to know about the leakage of air from the inside walls in places where there are special requirements as regards the internal atmosphere, for example rooms in hospitals, or some computer rooms.

In the present investigation some 23 measurements were conducted on a number of partitions, inside doors and a brick-built inside wall. The measurements were made in four buildings, three in The Hague and one in Leidschendam. With the largest air-leaks that were measured in these four buildings, a strong mutual influence on the ventilation in the adjacent rooms is to be expected.

Opening a window in one room produces clearly noticeable results on the ventilation and current directions in the other rooms.

The air-leaks in these walls measured 0.0038 to 0.0068 m^2 per wall (38 to 68 cm^2).

The total measured air-leak for a room is 0.0131 to 0.0529 m^2 (131 to 529 cm^2).

VENTILATION IN SMALL UTILITY BUILDINGS: MEASUREMENTS ON AIR-LEAKS IN INSIDE WALLS

1. INTRODUCTION

The Division of Sound, Light and Interior Climate of the TNO Institute for Environmental Hygiene and Health Technology (IMG) was requested by the Energy and Buildings Steering Group (SEG) to undertake an investigation of the possibilities for natural ventilation in small utility buildings. A report on the first part of this investigation was presented in 1982.

The first part of this investigation consisted of a computer study, using the IMG ventilation computer model. In the present second part of the investigation a number of measurements were conducted on air-leaks in inside walls and inside doors.

These orienting measurements were made on inside walls selected at random since, as far as we could discover, no data are available regarding such air-leaks.

The measurements were made using the 'blow-in' method, in which a volume flow is introduced into a room through a defined opening and the difference of atmospheric pressure between the room and its surroundings is measured. By repeating the measurement, while maintaining an adjacent room at the same pressure, it is possible to calculate from the difference between the two measurements the size of the air-leak between the two rooms. This method, in which the pressure difference may or may not be kept at zero over a definite portion of wall, is known as the 'compensation method'.

Although with the blow-in method it might be presumed that the measurement is performed only by blowing air into a given room, it is equally possible to make the measurement by sucking air out of a room.

It seemed interesting to examine whether it might not be possible to use this type of blow-in measurement for determining air-leaks in the outside wall ('gevel'). In principle, this can be done by taping plastic sheets over the outside wall, but the sticking-up is time-consuming. Moreover there is a high probability that the sticky-tape may work loose due to the blow-in pressure or that on breaking off the measurement set-up the sticky-tape may leave detrimental traces behind.

For this reason, during these measurements in some cases use is also made of a frame with a plastic sheet in the room by the outside wall. An opening is made in this screen, through which the measurement is made of the volume flow which escapes through the outer wall during the blowing-in. The difference of air pressure across this measurement opening in the sheet is relatively small, hence the forces on the frame remain relatively low.

In a number of cases the influence of the wind was so great that it was only possible to obtain a satisfactory measurement at rather high 'blow-in' pressures.

2. PURPOSE

The purpose of this second part of the investigation is to determine the magnitude of air-leaks in inside walls of utility buildings, in order to be able to determine whether opening one or more (casement) windows in rooms can possibly have an adverse influence on the ventilation pattern in other rooms. By 'adverse influence' is to be understood here for example: a variation of the ventilation currents of more than 20% in adjacent rooms; but not, for example, draughts.

3. PRINCIPLE OF MEASUREMENT

The mesurement method used is known as the 'blow-in' test (1) (see Fig 1). Briefly, this consists of blowing a known volume flow into a room and measuring the difference of pressure with respect to the surroundings of this room. On performing this measurement for a number of volume flows and associated pressure differences and plotting the results on double-logarithmic paper, a straight line is obtained (see Fig 2). This line is represented by the following formula.

$$qv = C*(\rho)^{1/n} \qquad (1)$$

This formula can also be written in the somewhat more physical form:

$$qv = A* v$$

where A is the surface area or section of the air-leak and v is the air speed.

The air will undergo a certain contraction on passing through an opening, hence when calculating the leak area from a measurement of pressure and volume flow the value obtained will always be smaller than the actual geometric area. And with cracks which are long in the direction of the air current, the area determined from a measurement of pressure and volume flow will be smaller than the crack length multiplied by the crack width.

Using the variable A*mu (leak area multiplied by the contraction coefficient), the volume flow can be expressed as

$$qv = A*mu* (2*\rho)^{(1/n)} *(1/rho)^{0.5} \qquad (2)$$

This formula appears somewhat strange since for the factor representing the volumic mass it is the square root that is indicated, while the factor representing the pressure difference has an exponent involving n. This has come about due to our requirement that the ratio between the mass flow and the volume flow should be the volumic mass. Presented as a formula:

$$qm/qv = rho$$

Thus the formula for the mass flow through an opening becomes:

$$qm = A*mu* (2*\rho)^{(1/n)*} (rho)^{(0.5)} \qquad (2a)$$

Since in formula 2 rho appears in the form of a square root, in formula 2a rho should have an exponent of the form $(1 + 1/n)$. It may be that investigation of the temperature dependence of the flow through an opening (variation of the exponent n) would make a well-founded choice of the form of the formula possible here. However, in the present investigation the form of the formula does not play a decisive part, and receives no further consideration.

From two measurement points, delta p1, qv1 and delta p2, qv2, the following relations may be established:

$$n = \log (p2/p1)/\log(qv2/qv1) \qquad (3)$$

$$C = qv1/(p1)^{(1/n)} \qquad (4)$$

$$A*mu = qv1* (rho)^{(0.5)}/(2*p1)^{(1/n)} \qquad (5)$$

Further, C and A*mu can be calculated in terms of one another using the formula:

$$A*mu = C* (rho)^{(0.5)}/ (2)^{(1/n)} \qquad (6)$$

In the foregoing, C is the air-transmission-value and A*mu is the leak area multiplied by the contraction coefficient. The exponent n is very important for characterising the air-leak. It is not sufficient to speak of an air-leak of, for example, A*mu = 1 m^2, it is essential also to state the value of n.

Table 1. qv in m^3/s for $A*mu = 1\ m^2$			
p in Pa	1	20	100
n			
1.0	1.8	37	183
1.5	1.5	11	31
1.7	1.4	8	21
2.0	1.3	5.7	13

From this example in Table 1 it is seen that for n = 1.5 to 1.7 and for pressures of 1 to 20 Pa there are already large differences in the volume flow transmitted. At the rather more extreme values of n and pressure the difference is even greater, by a factor more than 10.

It is not possible to calculate the air-leak of an inside wall from the difference of two measurements by subtracting one measured volume flow from the other. This is because the pressure levels at the two measurements are generally not equal. The procedure followed here is not exact but is nevertheless serviceable for the present orienting measurements. From the line drawn joining the points of the first measurement, C1 (or A*mu1) and n1 are determined. Similarly C2 (or A*mu2) and n2 are determined from the second measurement. From these two lines it is now possible to calculate the volume flows for two pressure levels and, by subtracting one from the other, to determine C3 and n3 from the difference.

Represented in formulae:

$$p1 = 1\ \text{Pa},\ p2 = 100\ \text{Pa}$$

$$n3 = \log(p2/p1)/\log[\{C1(p2)^{(1/n1)} - C2(p2)^{(1/n2)}\}/(C1-C2)]$$

$$C3 = C1 - C2$$

This method is only exact when n1 = n2. It is seen, however, that the deviations are small, even when n1 = 1 and n2 = 2[2].

In Figs 3 and 4 the air-leak of wall 1 is measured by blowing in to room '2', with the doors of rooms '1' and '3' open. Then this blowing-in to room '2' is repeated, with the pressure difference across wall (now adjusted to zero by regulating the electrical voltage on the ventilator fan in the partition in the door-opening of room '1'. The air-leak of wall 1 can be determined from the difference between these measurements (see Fig 4). This method is known as the 'compensation' method. In a number of rooms the outside wall was provided with a frame with plastic sheet. By this means it was possible to determine the order of magnitude of the air-leak in the outside wall also.

The frame with the plastic sheet is clamped between the inside walls or between the concrete structure and the inner side of the outer wall.

side of the outer wall.] Between this frame and the inside wall or the concrete there is additionally a gap of 1 to 4 cm. Into this gap is introduced an inflatable plastic hose-pipe which is then inflated so as to make the cracks tight (see Fig 5). There is still some leakage at the corners and some other places. The size of these leaks is estimated as 0.0019 m^2. In the sheet there is an opening for the measurement, in which there is an IMG anemometer for determining the mean air speed. The volume flow was determined by multiplying this speed by the area of measurement opening and by a contraction factor, thus taking account of the leak area between the hose and the inside wall or the concrete structure. Presented in formulae:

$$qv\ sheet = v\ \{0.9 * 0.25 * pi * (D\ measurement\ opening)^{(2)} + 0.0019\} \quad (7)$$

when D = 0.304 m then qv = v* 0.0672

when D = 0.150 m then qv = v* 0.0178

The rather high value of the contraction coefficient (0.9) was obtained experimentally. With a measurement-opening diameter of 0.15 m the area of the leak roundabout the frame was about 10% of the section of the measurement opening, hence the measurement accuracy is not really increased by adding the term 0.0019. The possible error in this determination of the volume flow through the outside wall is estimated to be about 30%.

The results of these measurements are only used to give an idea of the possibilities of such blow-in measurements and are not necessary under the terms of the present investigation.

In the determination of the value of C or A*mu of the outside wall, the pressure difference across the foil sheet has to be subtracted from the excess pressure in the room in order to obtain an estimate of the pressure difference across the outside wall. The pressure difference across the foil sheet can be estimated from the measured air speed in the measurement opening in the sheet, using the following formula:

$$p \text{ foil sheet} = \text{zeta}* 1/2 *\text{rho}* (v)^{(2)} \qquad (8)$$

Zeta is the reciprocal of the square of the contraction coefficient, and its value for this measurement opening is estimated to be 1.2.

The lines obtained from the readings of the anemometer in the measurement opening are in all cases found to be curved. This phenomenon is not investigated in detail, but possible causes are:

- the flow profile is influenced by the jet from the blow-in ventilator/fan;
- the foil sheet sags, hence the anemometer, which is on a stand, is always located at a different point in the stream;
- the leak area between foil sheet and concrete depends on the pressure difference across the sheet;
- wind causes a shift in the zero-point, hence for example with a blow-in pressure of 0 Pa air flows inwards through the outside wall and through the measurement opening.

Wind disturbs the measurements since the volume flow through the outside wall is not constant then, and there is a shift in the pressure levels, hence the pressure difference between the room and the surrounding space is not zero when the ventilator/fan is switched off (see also paragraph on accuracy in Section 3). This became very marked especially when the pressure across an inside wall was adjusted to zero. This may be due to the fact that the ventilator fan with the measurement section is influenced by pressure fluctuations before the determination of the volume flow much less than the detached ventilator fans in the partitions in the door openings of the adjacent rooms. This might possibly have been improved by turning down these ventilator fans, but the capacity of these ventilator fans was in any case on the low side.

Theoretically, it is also possible to measure the air-leak of an inside wall without adjusting the pressure difference across it to zero. Our ideas are directed to a recursive method of estimating the air-leaks in inside walls. For this purpose an automatic data acquisition system is of course needed. A pre-condition for a method of this kind is that the variations in the pressure and the volume flow are so slow that within a definite time interval a mean value of the pressures and volume flows can be determined. The pressure variations in the rooms generally give rise to a deformation of the walls.

Panels (glass panes) bend, for example, and even system-built walls and certain ceilings bend through several millimetres. This gives rise to a variation of the volume of such a room within the time interval in which the pressure or the pressure difference is varying. This produces a phase difference between the blown-in volume flow and the over- or under-pressure in the room. As a result, the measured values deviate from the relation that exists between the volume flow and the pressure difference in the steady state. During the outward bending of the walls a certain portion of the blown-in volume flow is 'gobbled up' by the increase of volume of the room. The pressure variation is then initially smaller and only just attains the expected value after there is no further bending of the walls.

There is also a certain phase shift resulting from the compressibility and the pressure variations caused by the blowing-in (initially adiabatic, later isothermal).

Measurements made during the variation with time of a pressure or volume flow thus introduce a number of additional unknowns. This has an adverse effect on the accuracy and the ease of interpretation of the mesurements.

4. RESULTS

From the 23 measurements it was possible to make 16 calculations of the air-leak of an inside wall. However, one of these yielded a negative value of the leak area, thus leaving 15 more or less significant calculations. In addition, in 5 of the 23 measurements the air-leak of an inside door was determined by the direct method. The air-leak of a number of inside walls could be calculated from various combinations of measurements, hence in some cases two or three values were obtained for the air-leak. From this it is possible to learn something as regards the accuracy with which compensation measurements of this type can be performed. The measured and calculated values are summarised in Table 2. The walls are identified by the numbers of the rooms which they separate. In Building 4 the room numbers could not be distinguished owing to painting work. These rooms

TABLE 2 MEASURED AND CALCULATED VALUES OF THE AIR LEAKS

Building No	Wall No	Door No	C m^3/s at 1 Pa	n	A*mu	qv at 100 Pa m^3/s	Measurement No

*) extremely high value probably mainly due to the large error (41%) in this measurement (see also Table 4, 41%)

are therefore indicated by '1' to '3', they are located in block 1 on the fourth floor at the NW end of the corridor.

Walls 222/223 and 223/224 are partition walls with gypsum slabs on wood. The walls were fixed later. The existing ceiling tiles, which are mounted directly on the ceiling concrete, run right through from room to room above the partition walls. In one of the rooms this construction was recently modified, with the partition walls now running through to the concrete and the ceiling tiles interrupted. No measurements have yet been made to determine the influence of this on the air-leak.

Walls 348/350, 351/53, 308/309 and 309/310 are partition walls of plastics-covered ('geplastificeerd') sheet material (wood) in aluminium profiles. The ceiling here is system-built.

Wall '1'/'2' is a partition with gypsum sheet on steel profiles. The ceiling consists of sheet material on *frames which are fixed directly to the ceiling concrete. The top profile of the partition is located on a *frame which runs through.

Wall '2'/'3' is a brick-built wall with an inside door in it.

The areas of the air-leaks A*mu are between 0.003 and 0.0068 m². Assuming that the length of the crack of interest with these partition walls is equal to the periphery of the wall (2*(5.5 + 2.8) = about 17 m), then the effective width of the crack is 0.17 to 0.4 mm. However the leaks are not so uniformly distributed over the junctions and cracks that a crack width like this is actually present. Usually it is a few corner junctions, a particular ceiling construction or a large number of cracks, as eg with gypsum sheet on wood, that cause the most important leaks.

In view of the data in Section 3, Table 1, it is not good enough to compare the leaks exclusively by reference to the values for C or A*mu. In order to deal with this problem it is necessary to define a certain pressure spectrum from which a mean volume flow for a leak can be calculated. A pressure spectrum for this purpose can be made dependent on the climatological data of the frequency distribution of the wind speed. This seems to us to be a sensible approach for outside walls, but not for inside walls, since the pressures on the latter do not have such a direct relation with the wind speed as the former. For this reason we choose here a pressure of 10 Pa for comparing the volume flows through the different leaks. We can visualise that pressures of about 10 Pa can occur regularly when there is a window open in one room and not in the other room. But it remains an arbitrary choice, and perhaps it would have been just as good to choose 5 or 30 Pa.

The smallest leak was to be found in the brick-built inside wall in Building 4 between rooms '2' and '3', but since this was determined together with the leak of the inside door in this wall, the accuracy of this calculation is low. This is seen from the value of 3.9 found for the exponent. This value of n can of course be explained by the size of the error of this measurement, which was 41% (See Annex 2, Table 4). The value of n can only be above 2 in the transition region from laminar to turbulent. At 10 Pa the volume flow through this brick-built wall was 0.0075 m^3/s.

Wall '1'/'2' in the same building was next also found to have a small air-leak, with 0.019 to 0.024 m^3/s at 10 Pa.

The largest air-leak was found in wall 222/223, namely 0.046 to 0.054 m^3/s at 10 Pa.

It is noticeable that although the investigated walls were of very different constructions the air-leaks from room to room were nevertheless found to be of fairly similar values.

This may be largely due to the fact that the leaky partition walls 222/223 and 223/224 are installed in a building without system-built ceiling while the less leaky (?) walls 348/350, 309/310 and 308/309 happen to occur in combination with a system-built ceiling.

The measured values for the inside doors also lie close to one another, but this is less surprising, in view of the small spread in the heights of the cracks under these doors. The door with the smallest air-leak is the one in room 308 with a volume flow of 0.0155 m^3/s at 10 Pa. The other doors are found to have a leak flow of 0.020 to 0.021 m^3/s at 10 Pa, with a somewhat higher value of 0.028 m^3/s at 10 Pa for the door in room 223 in Building 1.

ACCURACY

The pressure detectors used (Validyne -70 to +70 Pa) have an error less than 1% of .70 Pa. They are calibrated against a Betz micromanometer before each group of measurements in a building.

The blow-in measurement-set is described in Annex 4.

The measurement section for the determination of the volume flow is calibrated against the IMG-TNO 'small wind-tunnel' for volume flows up to 0.15 m^3/s. For the larger volume flows calibration is effected by traversing with a Pitot tube. For the small wind-tunnel the inaccuracy is kept within 1%. The windmill-type anemometer used in the measurement section for determining the volume flow has a reading inaccuracy of 1% at the lowest air speed in the measurement section. With repetition of the calibrations the reproducibility was not found to lie outside this figure of 1%.

Thus the inaccuracy in the volume flow measurements comes to +/- 2%.

Most of the results are obtained from the calculation of the difference between two measurements. The errors in these measurements are then passed on. If qv1 and qv2 are the volume flows for two measurements at a definite pressure (eg 70 Pa), and the pressure difference across one of the walls is adjusted to zero at the second measurement, then the inaccuracy of the volume flow through this wall is:

$$\text{inaccuracy} = 2^* \,(qv1 + qv2)/(qv1 - qv2) \text{ in } \%$$

These inaccuracy values are given in Table 4, Annex 2. The largest error occurs in the determination of the air-leak of wall 308/309, +/- 47%, and with wall '2'/'3' without the inside door which is located in it, +/- 41%. The values for the other walls lie between 6 and 18%.

The wind is also a source of error in the measurements. It is difficult to estimate the magnitude of this error on account of the many variables which are involved. When the pressure difference across a wall is adjusted to zero, the wind in some cases gives rise to a fluctuating residual signal, generally having a mean value of less than 1 Pa and peaks of about 4 Pa.

If we take this residual signal as a measure of the wind influence, we find for measurement 1 and measurement 2, from which the air-leak of wall 222/223 is determined, at a blow-in pressure of 70 Pa, the following:

$qv1 = 0.45 \pm 0.009 \ m^3/s$

$qv2 = 0.224 \pm 0.004 \ m^3/s$

and a further leak of 0.009 m^3/s through the inside wall.

As a result, the total maximum measurement error rises to 10% instead of the 6% figure given in Table 4 of Annex 2. In these measurements the residual pressure signal across a wall across which the pressure is adjusted to zero is found to depend very little on the magnitude of the blow-in pressure. Consequently the influence of this residual pressure is great at low values of the blow-in pressure.

5. DISCUSSION

With the values found here for the air-leaks in inside walls and system-built ceilings between rooms an estimate can be made of the volume flows which may occur in neighbouring rooms when a window is opened in a first room. This situation is depicted in Fig 6.

The values of the air-leaks are obtained from Building 1. The wind pressure on the outside wall is 10 Pa. The pressure on the corridor is 0 Pa. When there are no windows open there is a volume flow of 0.0176 m^3/s through all the rooms. The volume flows were calculated for the presumed temperature of the air stream. Air coming from outside has the outside temperature, air flowing from room to room has the temperature of the room from which it issues. The mass flow balance is brought into equilibrium in the computer programme used. There is however also a term included in the air flows for direct exchange of air from a room with outside air, due to pressure fluctuations, and this exchange sometimes occurs also for air transported from room to room. Because of this, the air flows sometimes seem to be out of balance, a certain portion of the incoming air immediately turns back, hence it is not possible to calculate net mass flows from the volume flows given here.

When there is a window open there is a volume flow of 0.0257 m^3/s through the partition walls towards the adjacent rooms. In these latter rooms the infiltration stream through the outside walls is diminished, but the total flow entering these rooms nevertheless increases to 0.039 m^3/s. This is not a worrying increase, in relation to the desired fresh-air volume flow of about 0.007 m^3/s per person. Whether complaints of draughts are to be expected depends to some extent on the location of the biggest air-leaks. These are generally in the corners or along the edges of the partition wall, so presumably they do not blow directly into the living-area. At the bottom of the wall, moreover, the leaks are generally smaller, due to the presence of the floor covering.

From Fig 6 it is also seen that, with a wind pressure of 10 Pa on the outside wall, the opening of a window (compare Fig 6a and 6b, middle room) produces only 4.5 Pa across the inside wall of the room. While in Fig 6a the pressure in the adjacent rooms is still 2.8 Pa, it becomes 5.5 Pa in Fig 6b after the window is opened. (10 Pa in the middle room, 5.5 Pa in the adjacent one = 4.5 Pa across the inside wall.) In general, the picture is that a local variation of pressure gives rise to smaller variations of the pressure differences across the walls. This is because the pressures in the adjacent rooms are 'pulled along with'. The degree to which this happens depends on the proportion between the air-leaks in the outside wall, the partition walls to the other rooms and the wall to the corridor. The volume flows calculated from the measurements in this investigation are 0.0075 to 0.054 m^3/s at 10 Pa and volume flows like this will thus hardly occur at wind pressures which will have to be considerably higher than 10 Pa.

Again, in relation to the desired volume flow of 0.007 m^3/s per person, this means that the air flows through the inside walls are higher by a factor of 1 to 8. Thus a leak current like this (if it involved fresh air) would be able to provide ventilation for eight people. This comparison of the volume flows which may take place through inside walls with the necessary supply of fresh air per person (0.007 m^3/s) is only made in order to provide a reference scale for the flows. It is not intended to suggest in this way that the air flow through inside walls could also really provide for the fresh air requirements.

Another aspect is that of controlling the directions of air flow between different rooms in hospitals and laboratories. The volume flows required for this can be determined in detail from measurements of this kind. In this connection the value of the air-leak of the outside wall is important.

The class of buildings in which a definite pressure 'hierarchy' is considered necessary is also of primary importance. In order to emphasize this, an example which is fairly self-explanatory is given in the following Figures. In Fig 7 an example is given of the volume flow required in order to hold room 3 at over-pressure with a wind pressure of 100 Pa on the facade. A volume flow of 0.167 m^3/s is required in order to maintain an over-pressure of 2.5 Pa with respect to room 2. It should be noted that a design condition with a wind pressure of 100 Pa is very extreme; the mean wind pressures on buildings with a height of about four *storeys are of the order of 5 Pa.

Fig 8 illustrates the situation in which the same result can be obtained for room 3 with a much smaller volume flow.

Generally, a 'guard-ring' structure of the type illustrated is not possible, and in order to minimise the perturbations caused by wind and the opening of doors it is useful to make the air-leaks of the outside wall small in comparison with the air-leaks of the inside walls, and possibly to fill them in with grids. An approach of this kind is known as the excess-flow principle. The partition walls measured here are not so leaky that they would form a short-circuit for this principle, since the volume flows required would be too great.

6. CONCLUSION

The air-leaks of inside walls measured in this investigation exhibit an unexpectedly low spread with the various constructions. At a pressure difference of 10 Pa the leaks give volume flows of minimum 0.0075 to maximum 0.054 m^3/s. In order to given an idea of the magnitude of these flows: 0.0075 to 0.054 m^3/s is about 1 to 8 times the amount of the volume flow of fresh air required per person.

Consequently, with these leaks it is to be expected that the ventilation in one room will have a noticeable and in, some cases unpleasant effect on the ventilation in adjacent rooms.

Hence it appears necessary to set limits to the air leakage of inside walls. From these measurements estimates were made of the leakage area of the walls; this lies between 0.003 and 0.0068 m^2, but in this connection the value of the exponent $\underline{n}$ should also be considered. On taking the crack length to be equal to the periphery of the wall (about 2* (5.5 + 2.8) = about 17 m), then the effective crack width is 0.17 to 0.4 mm.

The inside doors have air-leaks of 0.0155 to 0.021 m^3/s at 10 Pa. The error in the values of the air-leaks of the inside doors is about 2%. With the compensation measurements and the calculation fo the air-leak from the difference between two measurements, errors of about 4 to 18% arise, in some cases an error of about 45% with relatively air-tight walls and another large leak in the room, which occurred in two cases in these measurements where there was a system-built ceiling behind which there were leaks. With the blow-in method, the largest volume flows are required in rooms with a system-built ceiling, 0.18 to 0.25 m^3/s at 10 Pa, and the smallest volume flows in the rooms without a system-built ceiling, 0.087 to 0.11 m^3/s at 10 Pa. These data relate to a small number of buildings, hence it is not possible to conclude that system-built ceilings would imply bigger leaks; the construction used behind these ceilings determines whether the leaks are bigger than or equal to the leaks in buildings without system-built ceilings.

7. SYMBOLS

A*mu (Aμ)	area multiplied by the contraction	m^2
C	air transmission	m^3/s at 1 Pa
p	difference of air pressure across an air-leak	Pa
n	exponent indicating the nature of flow: n = 1: laminar flow (narrow openings, filters) n = 2: turbulent flow (wide openings, open windows)	
qv	air volume flow	m^3/s
rho	volumic mass of air (density of air) rho = 1.293 kg/m^3 at 0°C	kg/m^3
@	signifies 'at' eg m^3/s @ 1 Pa	

8. LITERATURE REFERENCES

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ANNEX 1 EXPLANATION OF SOME TERMS USED.

anemometer:	air-speed meter.
inside walls:	wall inside a building not constituting part of the outside wall.
compensation method:	blow-in method in which, by means of a second ventilator/fan, the pressure difference across certain elements is adjusted to zero.
contraction:	concentration of an air jet through an opening, in consequence of which the air speed measured in the middle is greater than the air speed averaged over the area of the opening.
direct method:	blow-in method in which the air-leak of a crack or opening can be measured by fixing up a sheet of plastic, without carrying out a difference measurement.
dynamics:	relation between the lowest and the highest value.
phase difference:	the non-simultaneous increasing and decreasing of pressure and volume flow.
film sheet:	plastic sheet used for screening off the outside wall and measuring the volume flow in this way.
infiltration:	the entry of air inside the building
isothermal:	with temperature remaining constant.

air-leak:	hole, opening, crack or join through which air can flow.
net flow:	difference between the inflowing and outflowing air through a wall or element in a building. This net flow is important in the determination of the pressure 'hierarchy'. The inflowing and outflowing air is important in the determination of the ventilation of a room.
blow-in method:	method of determining the air-leak by blowing in a known volume flow and measuring the resulting 'rise' in the air pressure in the room receiving the blown-in air.
recursive method:	method in which estimates of a given unknown quantity are used to arrive at an improved estimate, in the present case by means of subsequent measurement points.
partition wall:	what is meant here is an inside wall which is not brick-built and which can be moved when it is desired to change the divisions of the building. These are often system-built walls consisting of a framework with sheet material on both sides.
throttling: ('smoren')	reducing the volume flow by reducing the cross-section of the suction or exhaust side of a ventilator/fan.
stationary state:	a state in which the important parameters remain constant in time.
system-built ceiling:	a ceiling consisting generally of loose slabs fixed under the (concrete) ceiling by stirrups or profiles.

utility building:	buildings for use other than dwellings, eg offices, schools, public institutions.
ventilation:	replacement of 'used-up' inside air by 'fresh' air from outside.
volume flow measurement section:	tube with a diaphragm inside, with a windmill-type anemometer, the readings were calibrated in a volume flow.
zeta:	the value of zeta is the square of the reciprocal of the contraction coefficient. The pressure difference across an opening is the product of zeta and the 'speed pressure' ('snelheidsdruk') of the mean speed in the opening.

ANNEX 2 SUMMARY OF THE MEASUREMENTS

TABLE 3 MEASUREMENT, ROOM AND BUILDING NUMBERS

Measurement	Building	Room	Description
1	1	223	partition, gypsum sheet on wood.
2	1	223+222	(Ceiling slabs fixed direct to
3	1	223+224	(concrete; these slabs run through
4	1	223+222+224	(from room to room above the
			(partition.
5	1	222	
6	1	222+223	
7	2	350	(partition constructed of plastic-
8	2	350+348	(covered sheet material (wood) in
9	2	353	(aluminium profiles on a steel
			(frame.
10	2	353+351	system-built ceiling
11	2	door 353	
12	2	door 351	
13	3	309	same construction as in Building 2
14	3	309+310	
15	3	307/308+309	
16	3	307/308	
17	3	door 308	
18	4	'2'	(wall '1'/'2' partition made of
19	4	'2'+'1'	(gypsum sheet on a steel frame.
20	4	'2'+'1'+'3'	(wall '2'/'3' of brickwork and an
21	4	'2'+'3'	(inside door from room '2' to '3'.
22	4	door '2'/'3'	ceiling slabs on *stirrups(?) to
			the concrete.
23	1	door 223	

*'rachels'

TABLE 4 Measured and calculated values of air leaks. See Figs 10-18.

Column headings: Building no; Wall no; Door no; C, m^3/s at 1 Pa; error, %; n; A*mu, m^2, qv at 100 Pa, m^3/s; Measurement no.

ANNEX 3 Measurements 1-23. See Figs 19-41.

Measurement 1

Air-leak measurements of inside walls. Building 1.

Blow-in to room 223, outside wall provided with plastic sheet.

The over pressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door; it blows into the room.

The volume flow through the opening in the plastic sheet, which is located in the room in front of the outside wall, is reproduced positively with flow from the room towards the outside wall.

Overpressure Pa	Volume flow ventilator/fan m^3/s	Volume flow plastic sheet m^3/s

Measurement 2

Air-leak measurements of inside walls. Building 1.

Blow-in to room 223, outside wall provided with plastic sheet.

Room 222 at the same pressure.

The over-pressure in the room with respect to the corridor is measured.
The ventilator/fan is located in the opening of the inside door, it blows into the room.
The volume flow through the plastic sheet, which is located in the room in front of the outside wall, is reproduced positively with flow from the room towards the outside wall.

Overpressure Pa	Volume flow ventilator/fan m^3/s	Volume flow plastic sheet m^3/s

Measurement 3

Air-leak measurements of inside walls - Building 1.
Blow-into room 223, the outside wall is provided with plastic sheet.
Room 224 at the same pressure.
The over pressure in the room with respect to the corridor is measured.
The ventilator/fan is located in the opening of the inside door, it blows into the room.
The volume flow through the plastic sheet,.which is located in the room in front of the outside wall, is reproduced positively with flow from the room towards the outside wall.

Overpressure Pa	Volume flow ventilator/fan m^3/s	Volume flow plastic sheet m^3/s

Measurement 4

Air leak measurements of inside walls, Building 1.

Blow-in to room 223, the outside wall is provided with plastic sheet.

Rooms 222 and 224 at the same pressure.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door, it blows into the room.

The volume flow through the plastic sheet, which is located in the room in front of the outside wall, is reproduced positively with flow from the room towards the outside wall.

Overpressure Pa	Volume flow ventilator/fan m^3/s	Volume flow plastic sheet m^3/s

Measurement 5

Air leak measurements of inside walls, Building 1.

Blow-in to room 222, the outside wall is provided with plastic sheet.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door, it blows into the room.

The volume flow through the plastic sheet, which is located in the room in front of the outside wall, is reproduced positively with flow from the room towards the outside wall.

Overpressure Pa	Volume flow ventilator/fan m^3/s	Volume flow plastic sheet m^3/s

Measurement 6

Air leak measurements of inside walls. Building 1.

Blow-in to room 222, the outside wall is provided with plastic sheet.

Room 223 at the same pressure.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door, it blows into the room.

The volume flow through the plastic sheet, which is located in the room in front of the outside wall, is reproduced positively with flow from the room towards the outside wall.

Overpressure Pa	Volume flow ventilator/fan m^3/s	Volume flow plastic sheet m^3/s

Measurement 7

Air leak measurements of inside walls. Building 2.

Blow-in to room 350.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door, it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 8

Air leak measurements of inside walls. Building 2.

Blow-in to room 350. Room 348 at the same pressure.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door, it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 9

Air leak measurements of inside wall. Building 2.

Blow-in to room 353, the outside wall is provided with plastic sheet.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door, it blows into the room.

The central-heating pipes are located between the outside wall and the plastic sheet.

The volume flow through the plastic sheet, which is located in the room in front of the outside wall is reproduced positively with flow from the room towards the outside wall.

Overpressure Pa	Volume flow ventilator/fan m^3/s	Volume flow plastic sheet m^3/s

Measurement 10

Air leak measurements of inside walls. Building 2.

Blow-in to room 353; the outside wall is provided with plastic sheet.

Room 351 at the same pressure.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door; it blows into the room.

The volume flow through the plastic sheet, which is located in the room in front of the outside wall, is reproduced positively with flow from the room towards the outside wall.

Overpressure Pa	Volume flow ventilator/fan m^3/s	Volume flow plastic sheet m^3/s

Measurement 11

Air leak measurements of inside walls. Building 2.

Inside door of room 353. The frame is provided with a rubber draught profile which however is missing at the top of this door.

The crack over the threshold is about 5 mm high.

Plastic sheet is stuck on the passage side of the frame of the inside door; the ventilator/fan is connected to this, and blows into the room.
The overpressure between the plastic sheet and the door with respect to the pressure in the room is measured.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 12

Air leak measurements of inside walls. Building 2.
Inside door of room 351. The frame is provided with a rubber draught profile. The crack over the threshold is about 6 mm high on one side and about 10 mm on the other side.
Plastic sheet is stuck on the passage side of the frame of the inside door; the ventilator/fan is connected to this, and blows into the room.
The overpressure between the plastic sheet and the door with respect to the pressure in the room is measured.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 13

Air leak measurements of inside walls. Building 3.
Blow-in to room 309.

The overpressure in the room with respect to the corridor is measured. The ventilator/fan is located in the opening of the inside door; it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 14

Air leak measurements of inside walls. Building 3.

Blow-into room 309. Room 310 at the same pressure.

The overpressure in the room with respect to the corridor is measured. The ventilator/fan is located in the opening of the inside door; it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 15

Air leak meaurements of inside walls. Building 3.

Blow-into room 307-308 (this is one room). Room 309 at the same pressure.

The overpressure in the room with respect to the corridor is measured. The ventilator/fan is located in the opening of the inside door; it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 16

Air leak measurements of inside walls. Building 3.

Blow-into room 307-308 (this is one room).

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door; it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 17

Air leak measurements of inside walls. Building 3.

Inside door of room 308. The frame is provided with a rubber draught profile. The crack over the threshold is about 4 mm high.

Plastic sheet is stuck on the corridor side of the frame of the inside door; the ventilator/fan is connected to this and blows into the room.

The overpressure between the plastic sheet and the door with respect to the pressure in the room is measured.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 18

Air leak measurements of inside walls. Building 4.

Blow-into room '2'.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door and blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 19

Air leak measurements of inside walls. Building 4.

Blow-into room '2', room '1' at the same pressure.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door; it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 20

Air leak measurements of inside walls. Building 4.

Blow-into room '2', rooms '1' and '3' at the same pressure.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door; it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 21

Air leak measurements of inside walls. Building 4.

Blow-into room '2', room '3' at the same pressure.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door; it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 22

Air leak measurements of inside walls. Building 4.

Inside door between room '2' and room '3'.

The overpressure in the room with respect to the corridor is measured.

The ventilator/fan is located in the opening of the inside door; it blows into the room.

Overpressure Pa	Volume flow ventilator/fan m^3/s

Measurement 23

Inside door of room 223.

The crack over the threshold is about 7 mm high.

Plastic sheet is stuck on the corridor side of the frame of the inside door; the ventilator/fan is connected to this and blows into the room.

The overpressure between the plastic sheet and the door with respect to the pressure in the room is measured.

Overpressure Pa	Volume flow ventilator/fan m^3/s

ANNEX 4 The blow-in measurement set

The blow-in measurement set used in this project (see Fig 9) consists of:

- a radial ventilator/fan
- a tube (inside diameter 304 mm)
- a slidable dummy door with a flange for the tube
- an interchangeable diaphragm (diameters 304, 150, 74, 37 and 19 mm)
- a windmill-type anemometer (drain - about 20 mm)
- a variance for regulating the number of revolutions of the ventilator/fan.

A windmill-type anemometer was chosen for this measurement rather than a measuring flange, because the dynamic range in the latter case is smaller than in the former. By changing the diaphragms a large measurement range is obtained, about 1:3500. Expressed in volume flows, this is about 0.0004 m^3/s to about 1.4 m^3/s.

In practice, measurements can be made on air leaks with an area of about 0.00005 to about 0.3 m^2. At the top end this was sometimes somewhat insufficient, but at the bottom end it is possible by this method to measure even the smallest air-leaks we know of, with extremely well closing windows or doors.

Care is necessary when blowing into rooms having a small leak with a large diaphragm in the measurement set. In this situation the blow-in pressure may reach undesirably high values.

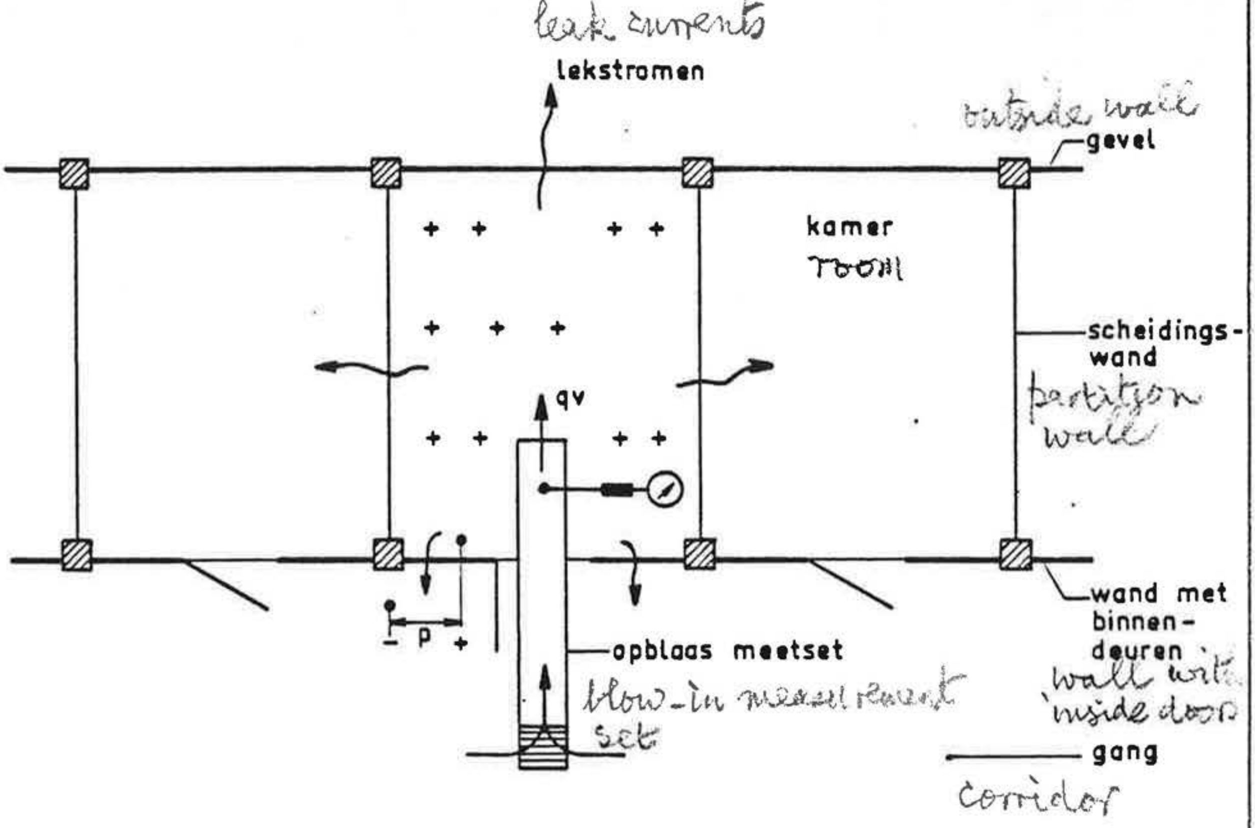
The measurement set is used in combination with difference-pressure detectors, usually in the range -70 to +70 Pa.

The calibration of this measurement set is performed in the IMG-TNO small wind-tunnel for volume flows from 0.002 to 0.15 m^3/s. Above this value the calibration is performed by traversing with a Pitot tube with a diaphragm of 304 mm.

ANNEX 5

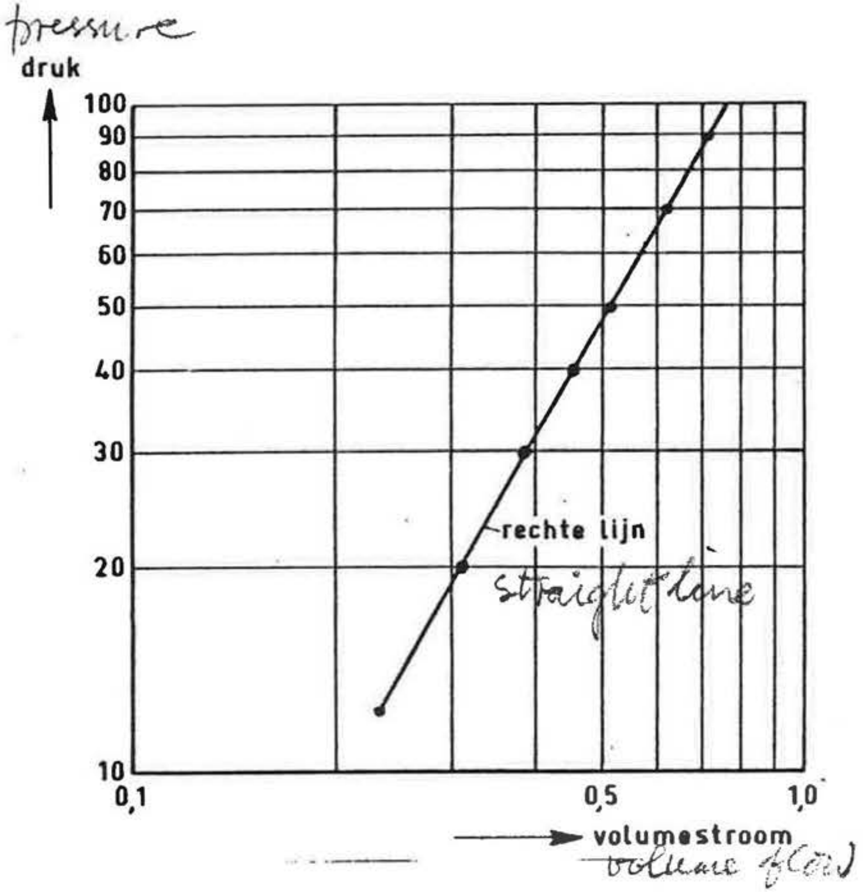
FIGURES

Annex 5. Figures



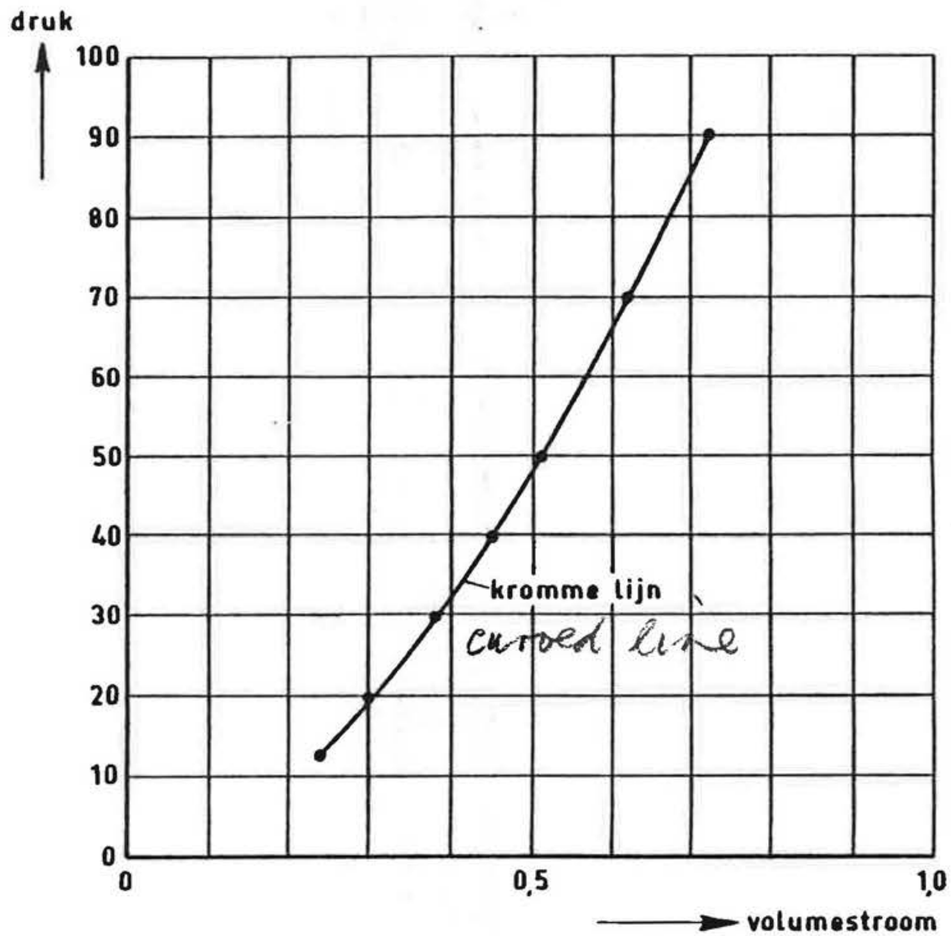
Figuur 1. Opblaastest voor de meting van het totale lek van een kamer (plattegrond).

Fig. 1. Blow-in test for measuring the total leak from a room (ground plan)



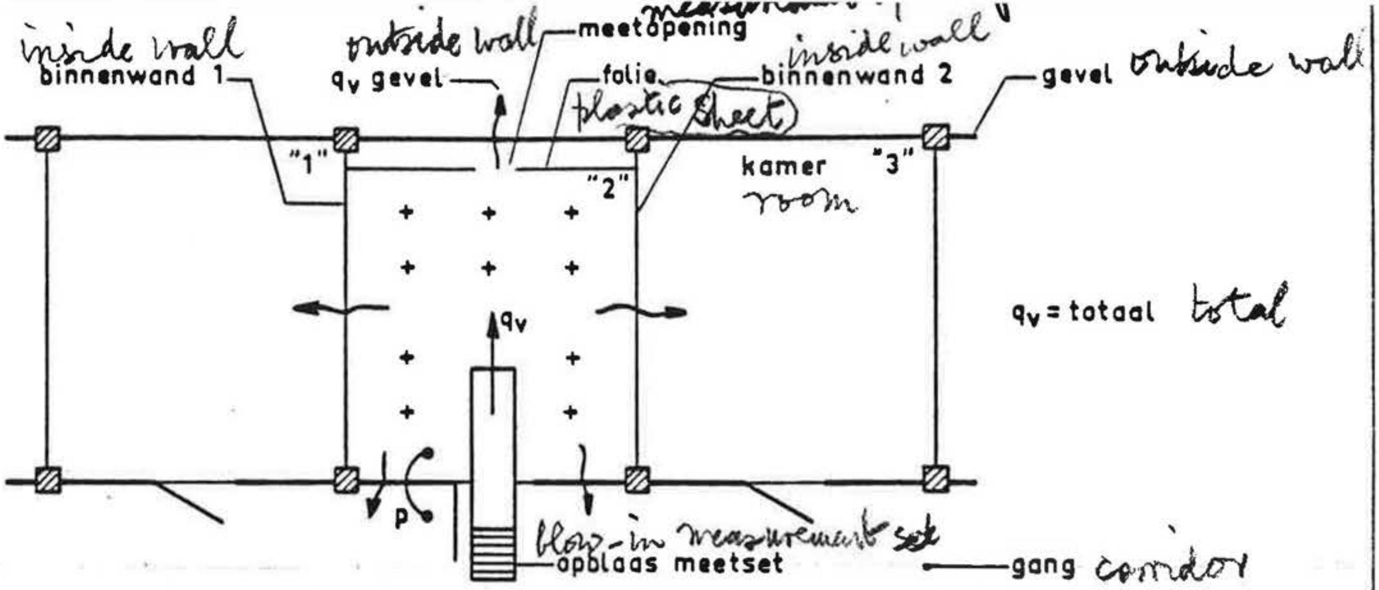
Figuur 2a. Meetpunten p en qv uitgezet op dubbellog papier

Fig. 2a. Measurement points p and qv plotted on double-log paper

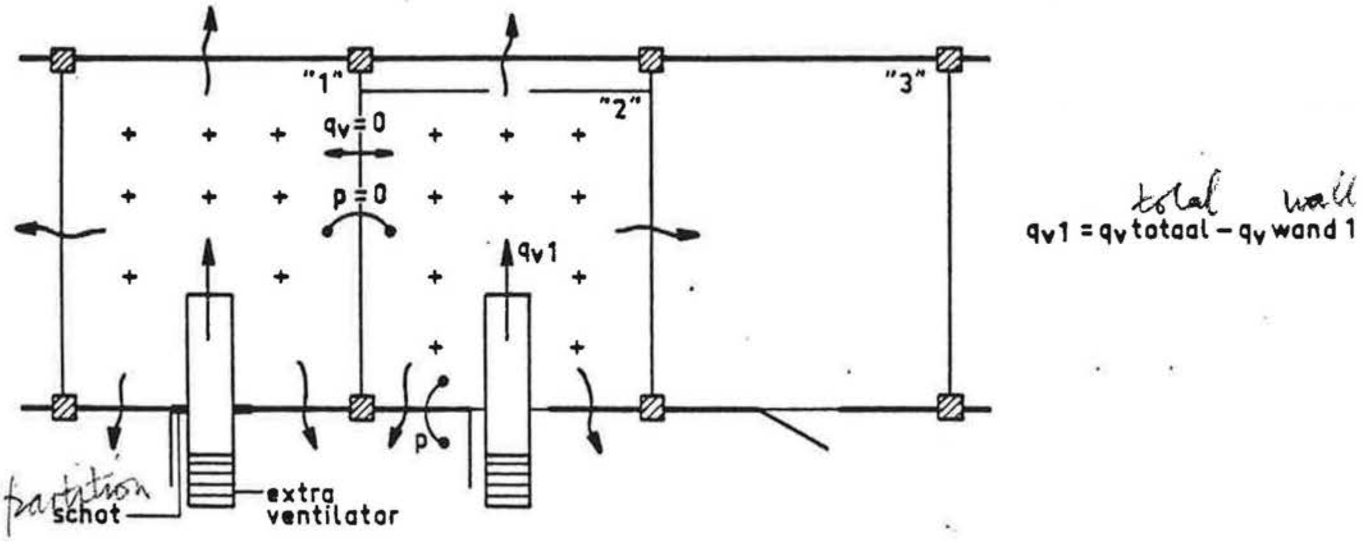


Figuur 2b. Meetpunten p en qv uitgezet op lineair papier.

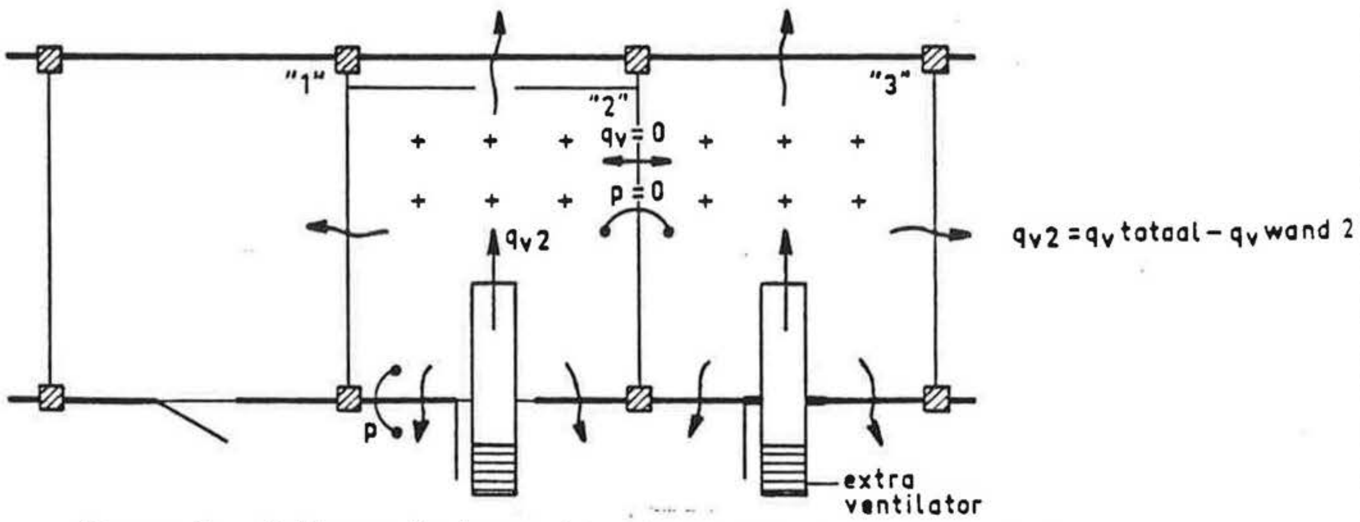
Fig. 2b. Measurement points p and qv plotted on linear-scale paper



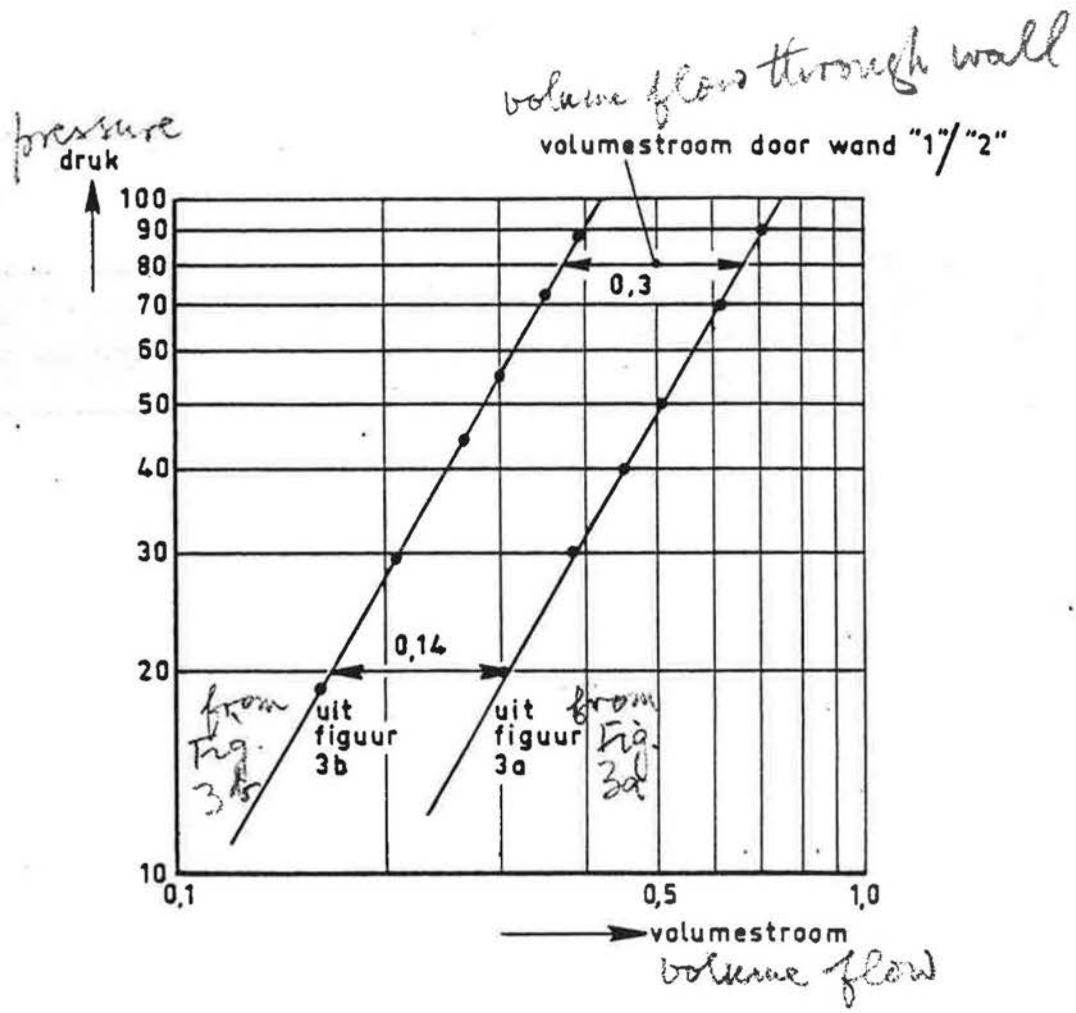
Blow-in to room "2"
Figuur 3a. Inblazen in kamer "2".



Figuur 3b. Inblazen in kamer "2", kamer "1" op dezelfde druk.
Blow-in to room "2", room "1" at the same pressure

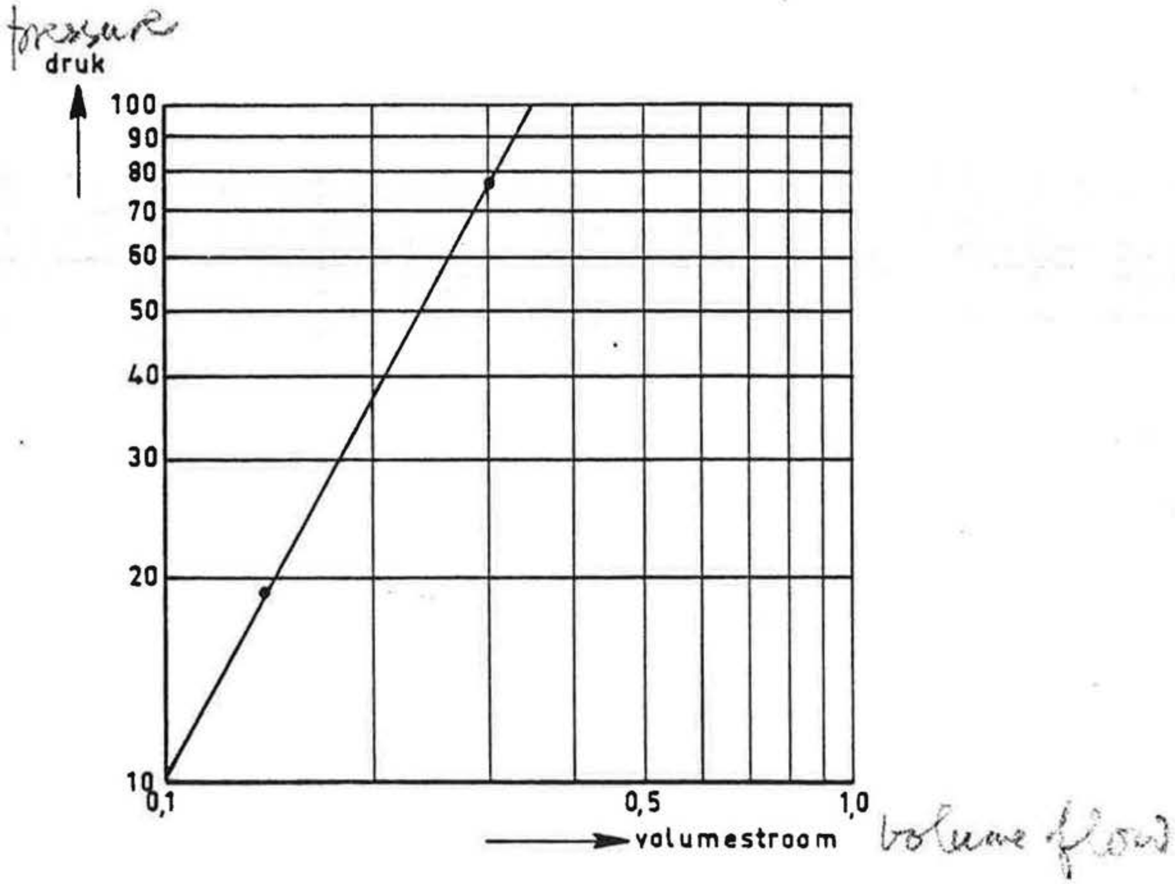


Figuur 3c. Inblazen in kamer "2", kamer "3" op dezelfde druk.



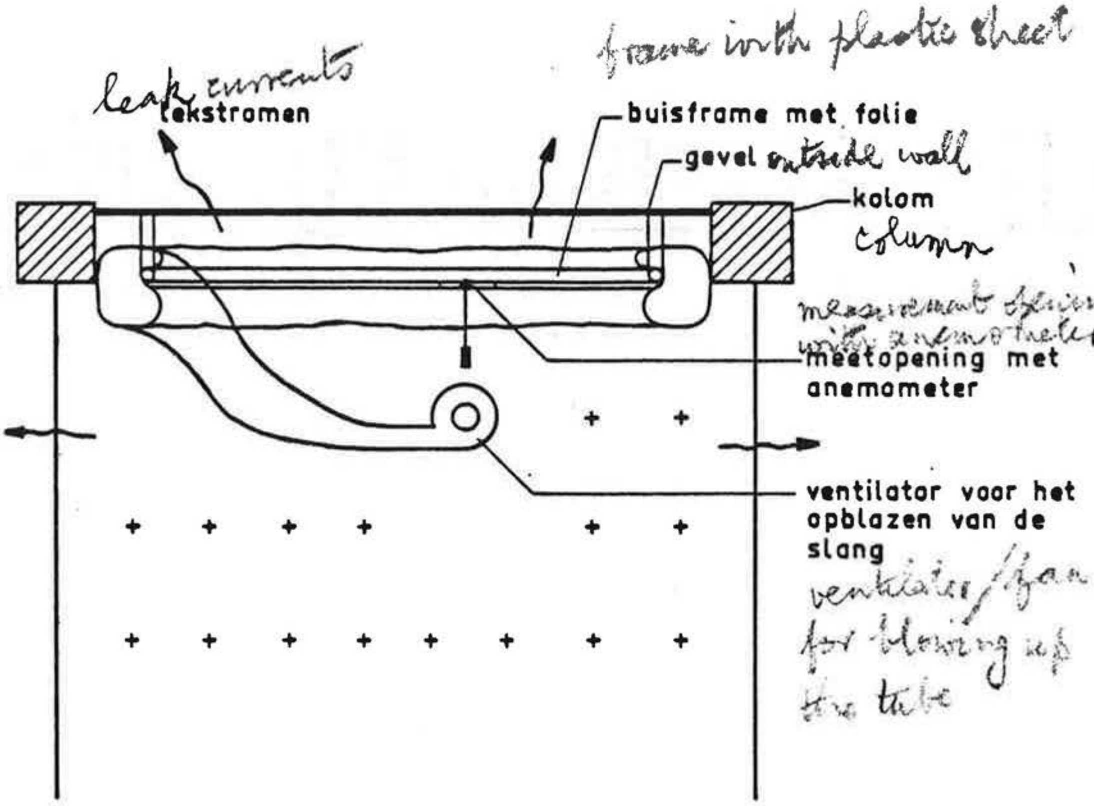
Figuur 4a. Metingen uit figuur 3a en 3b. Het verschil tussen de volumestromen bij een bepaalde druk is de volumestroom door de wand.

Measurements from Figs 3a and 3b. The difference between the volume flows at a given pressure is the volume flow through the wall.



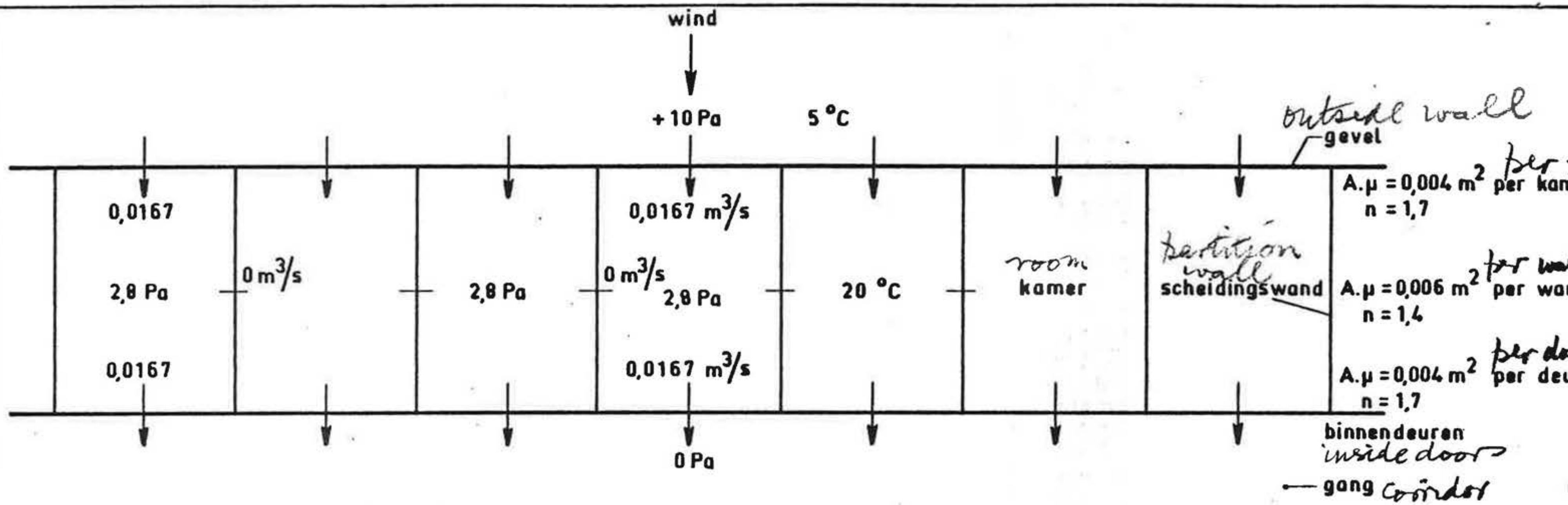
Figuur 4b. De verschilvolumestroom geeft het luchtlek van wand "1"/"2" weer.

The difference-volume-flow corresponds to the air leak of wall "1"/"2"



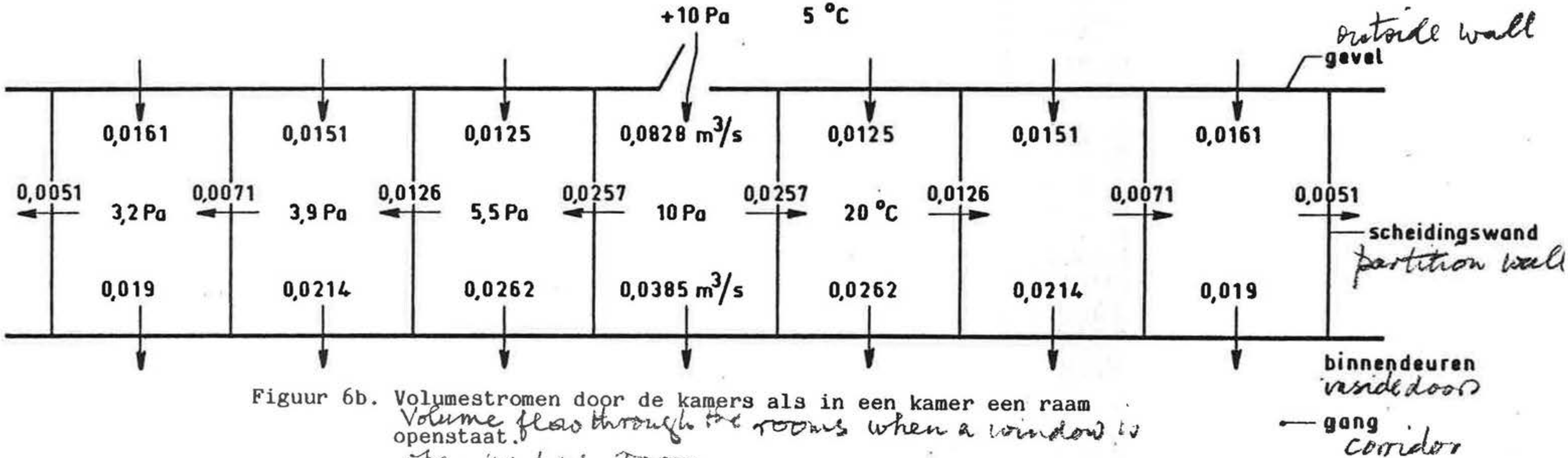
Figuur 5. Frame met plasticfolie en de meetopening voor de bepaling van de volumestroom door de gevel.

Frame with plastic sheet and the measurement opening for determining the volume flow through the outside wall



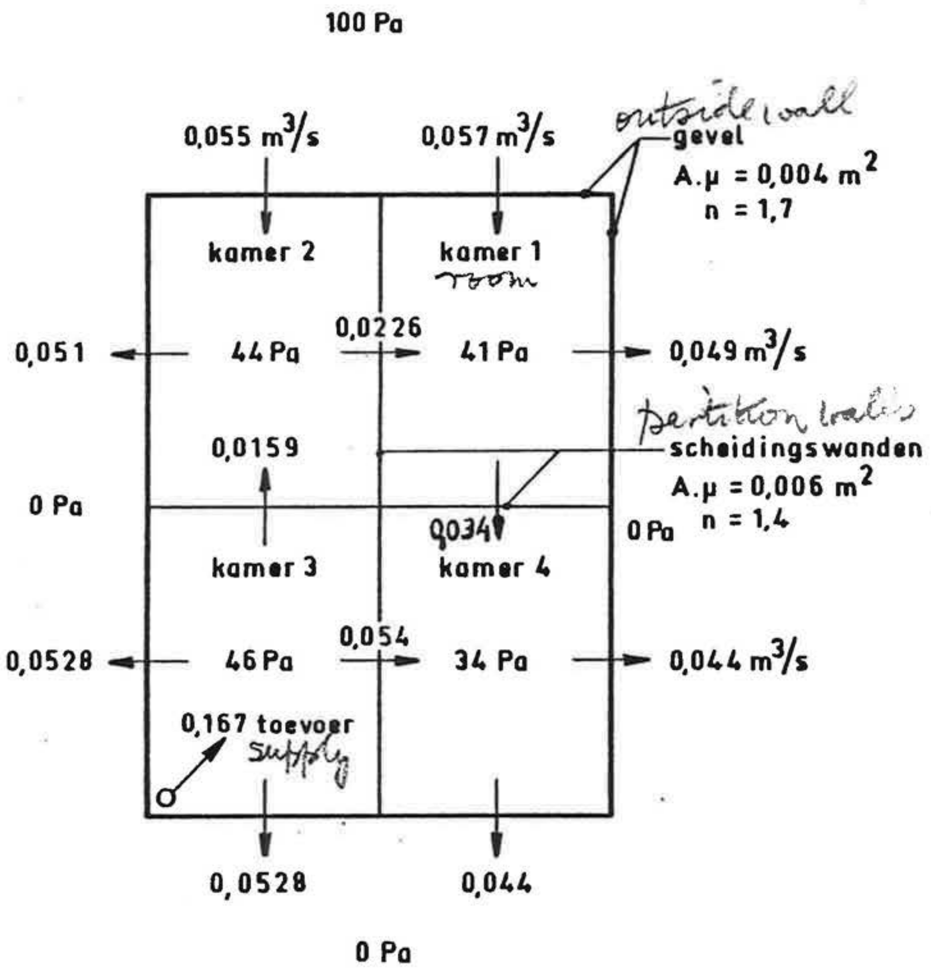
Figuur 6a. Volumestromen door kamers bij een winddruk van 10 Pa op de gevels.

Volume flow through rooms with a wind pressure of 10 Pa on the outside walls



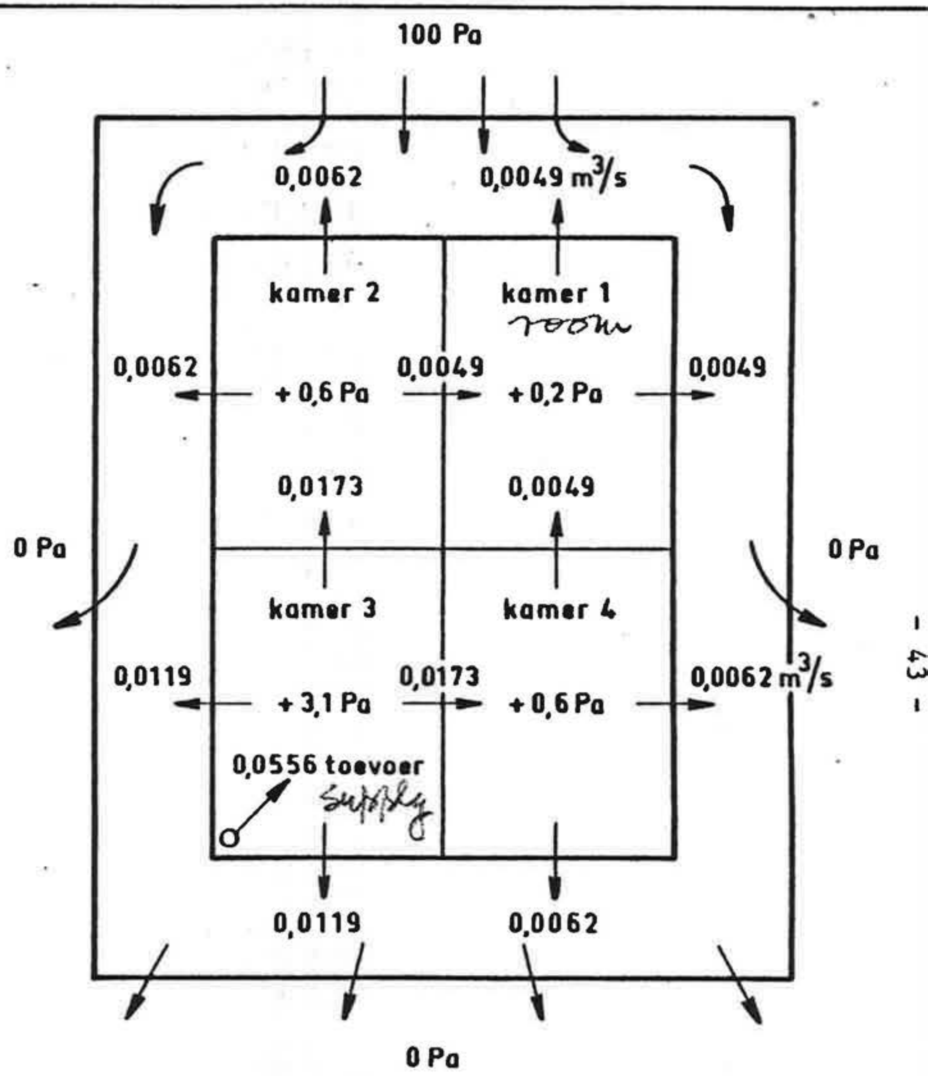
Figuur 6b. Volumestromen door de kamers als in een kamer een raam openstaat.

Volume flow through the rooms when a window is



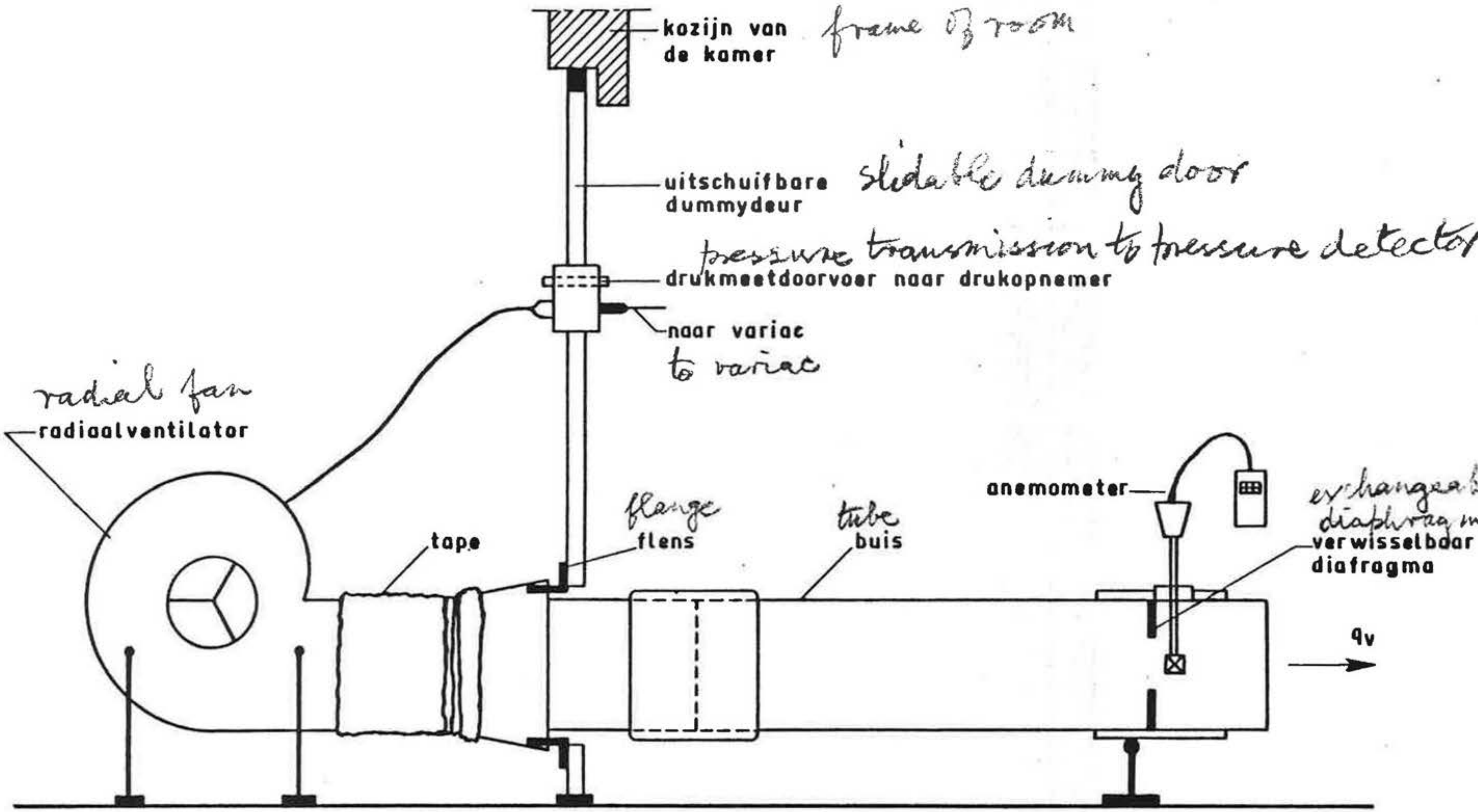
Figuur 7. Beheersing van de stromingsrichting. In kamer 3 is een toevoer van 0,167 m3/s nodig bij een winddruk van 100 Pa op de gevel.

Control of flow direction. In room 3 a supply of 0.167 m³/s is required with a wind pressure of 100 Pa on the outside wall.

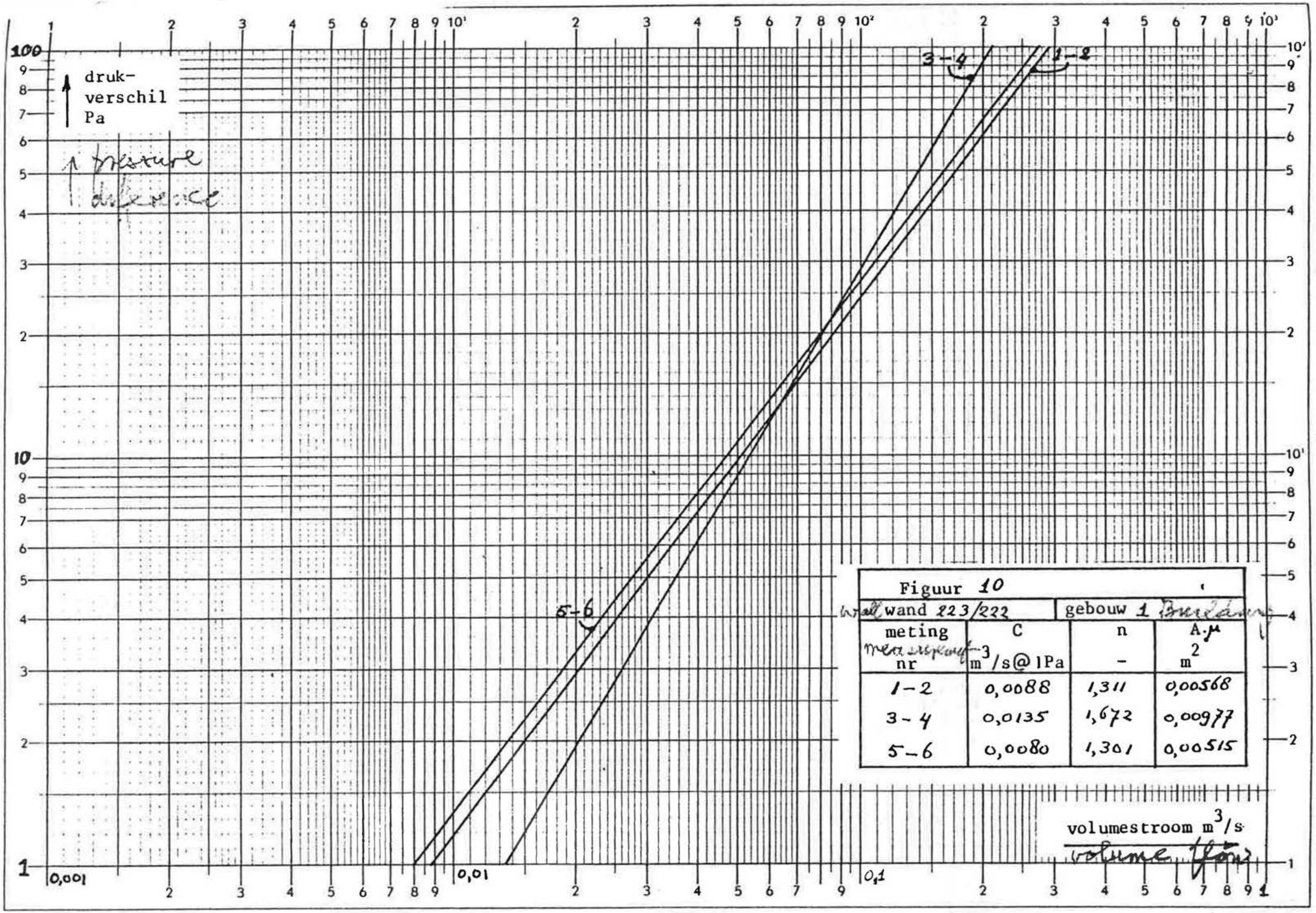


Figuur 8. Bij toepassing van een gang om de kamers (guard-ring) kan met een kleinere volumestroom worden volstaan (0,0556 m3/s) en lopen de drukverschillen over de wanden minder hoog op.

If a corridor is provided round the rooms (guard-ring), a smaller volume flow may be sufficient (0.0556 m³/s) and the pressure differences across the walls do not rise so high

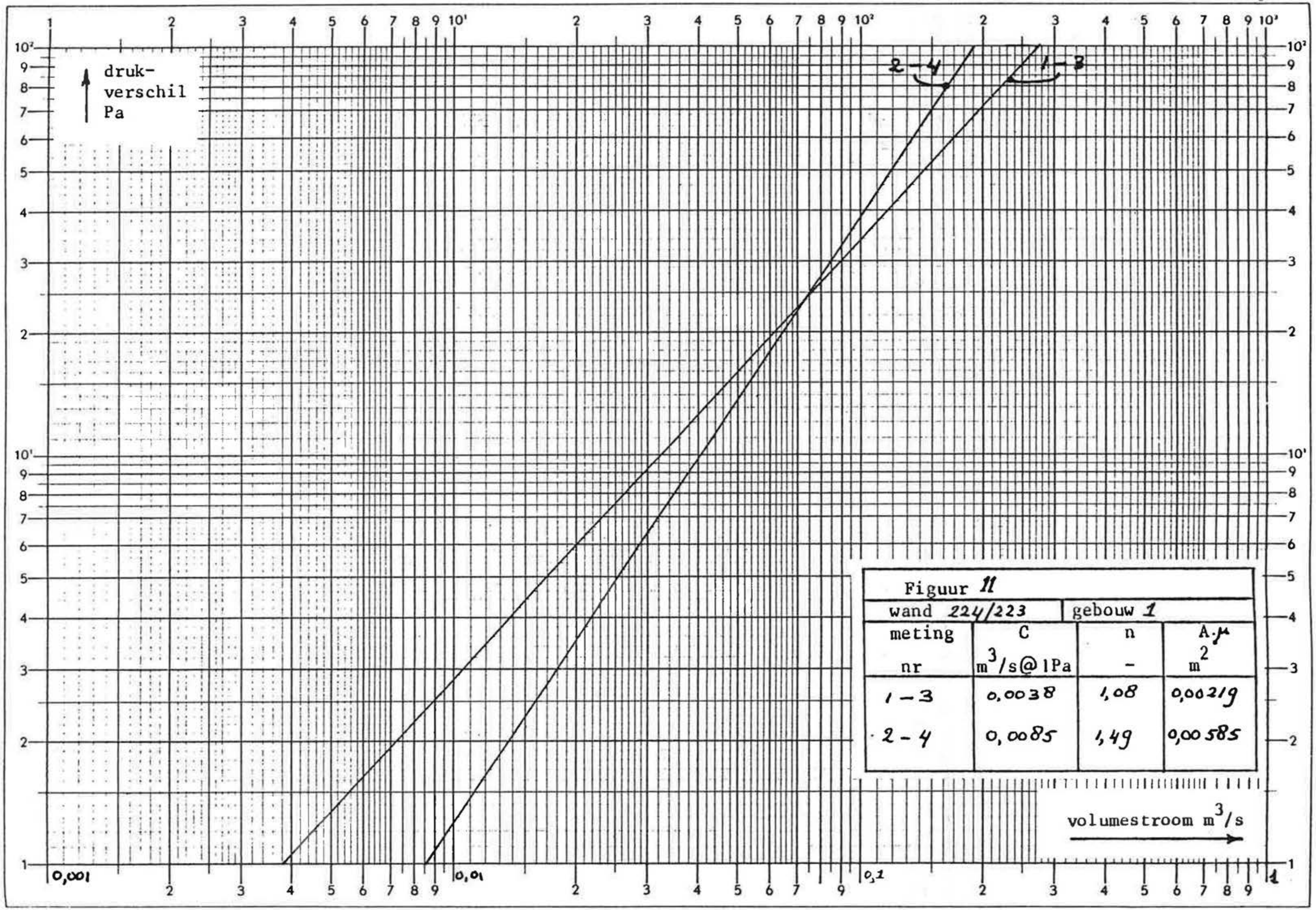


Figuur 9. De opblaasmeetset.
The blow-in measurement set

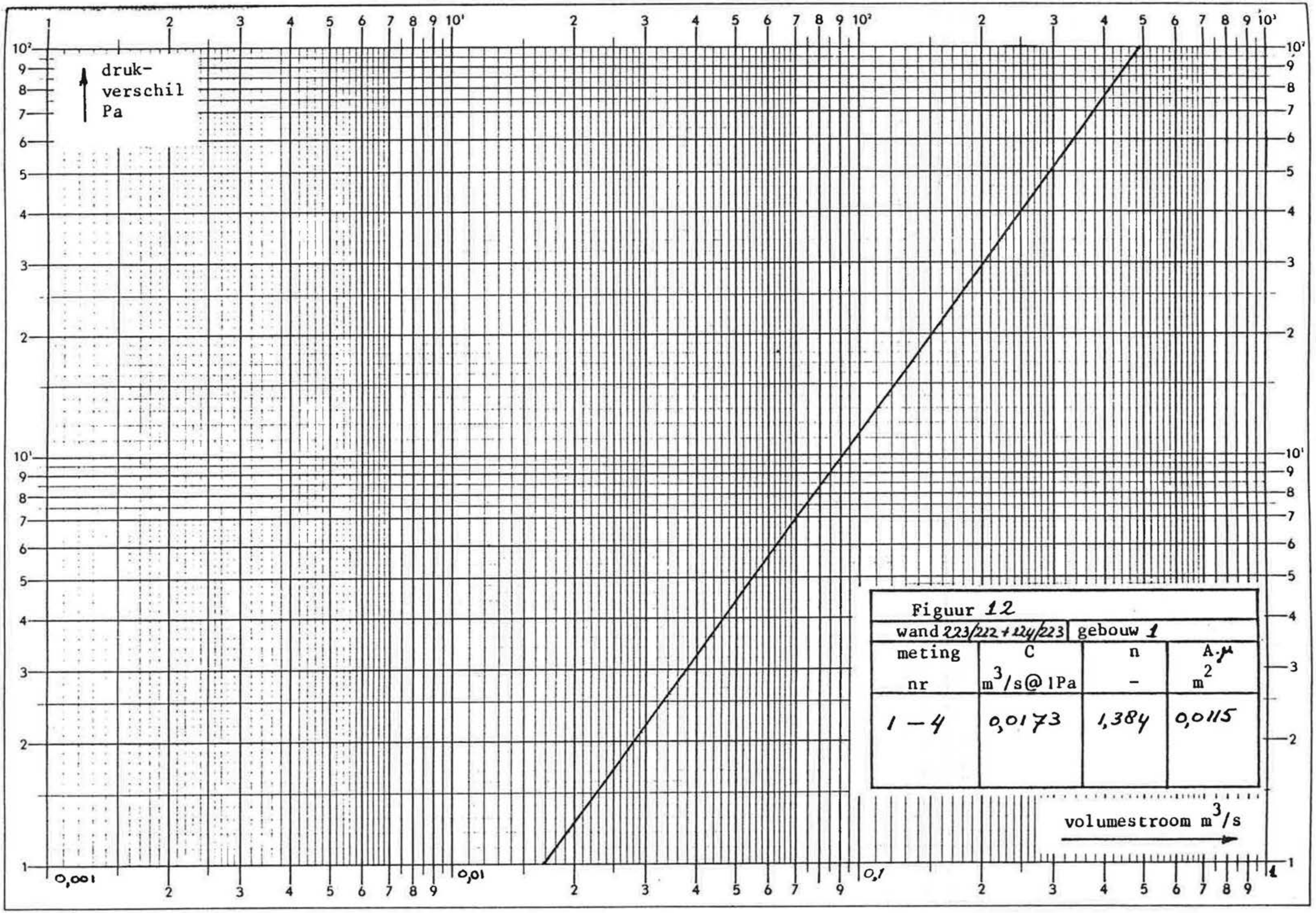


Figuur 10			
wall wand 223/222		gebouw 1 building	
meting measurement nr	C $m^3/s@1Pa$	n -	A·μ m^2
1-2	0,0088	1,311	0,00568
3-4	0,0135	1,672	0,00977
5-6	0,0080	1,301	0,00515

meetpapier - wormer No. 20 H X-as log. verdeeld 1-10³ Y-as log. verdeeld 1-10² Eenheid 83.33 mm.



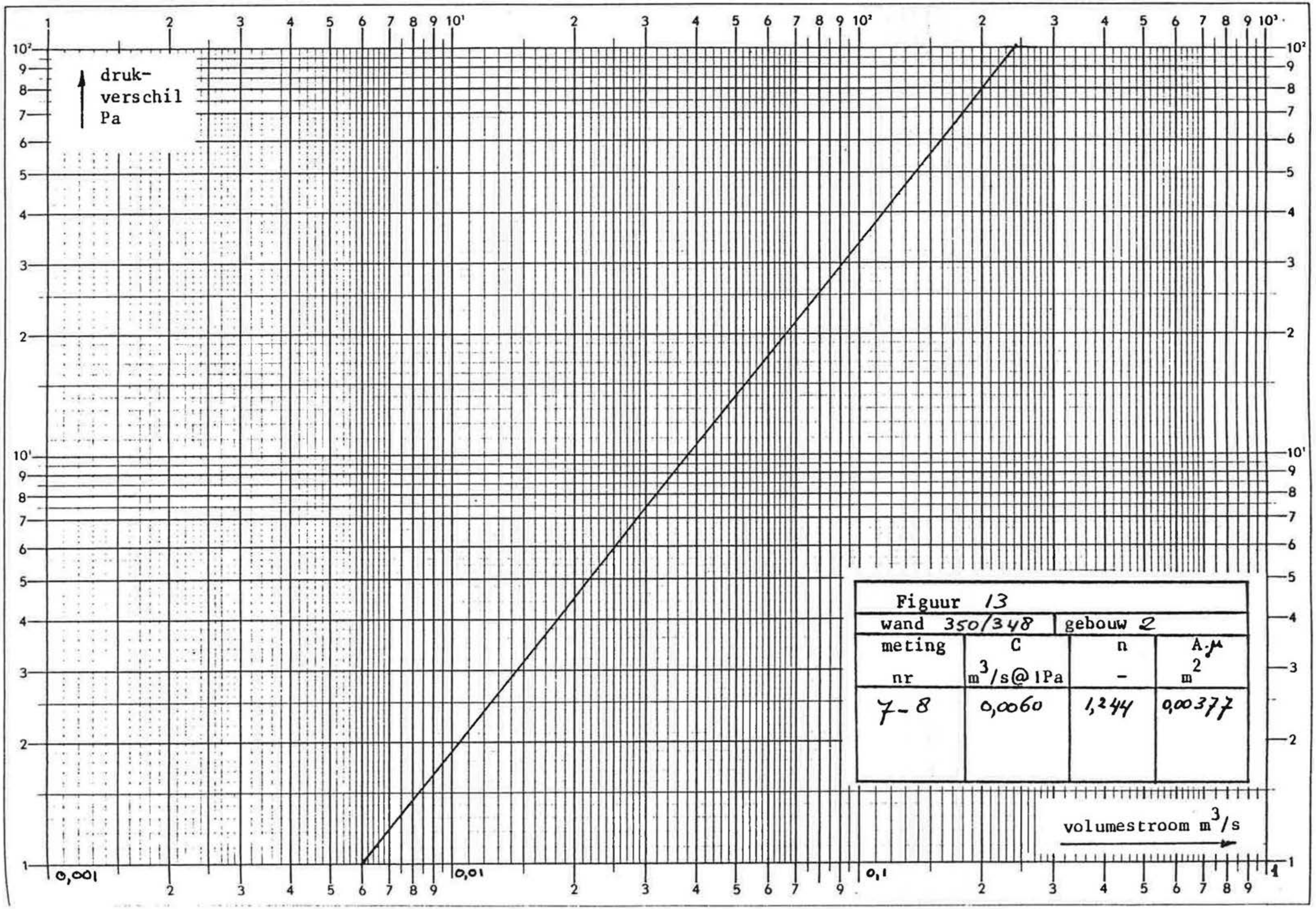
Figuur 11			
wand 224/223		gebouw 1	
meting nr	C m^3/s@1Pa	n -	A.μ m^2
1 - 3	0,0038	1,08	0,00219
2 - 4	0,0085	1,49	0,00585



Figuur 12

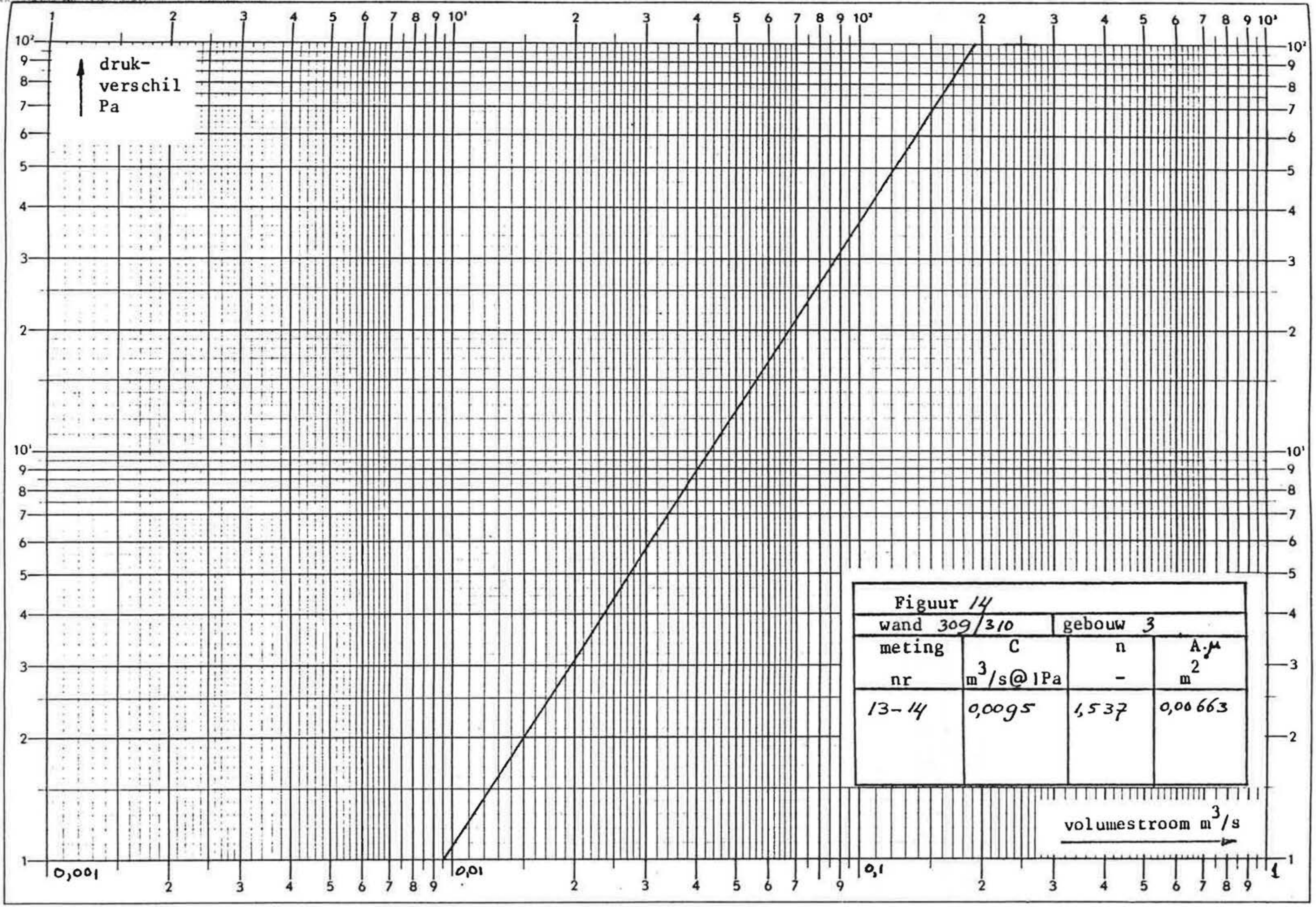
wand 223/222 + 224/223 gebouw 1

meting nr	C m^3/s@ 1Pa	n -	A.μ m^2
1 – 4	0,0173	1,384	0,0115



Figuur 13

wand 350/348		gebouw 2	
meting nr	C m^3/s@1Pa	n -	A.μ m^2
7-8	0,0060	1,244	0,00377

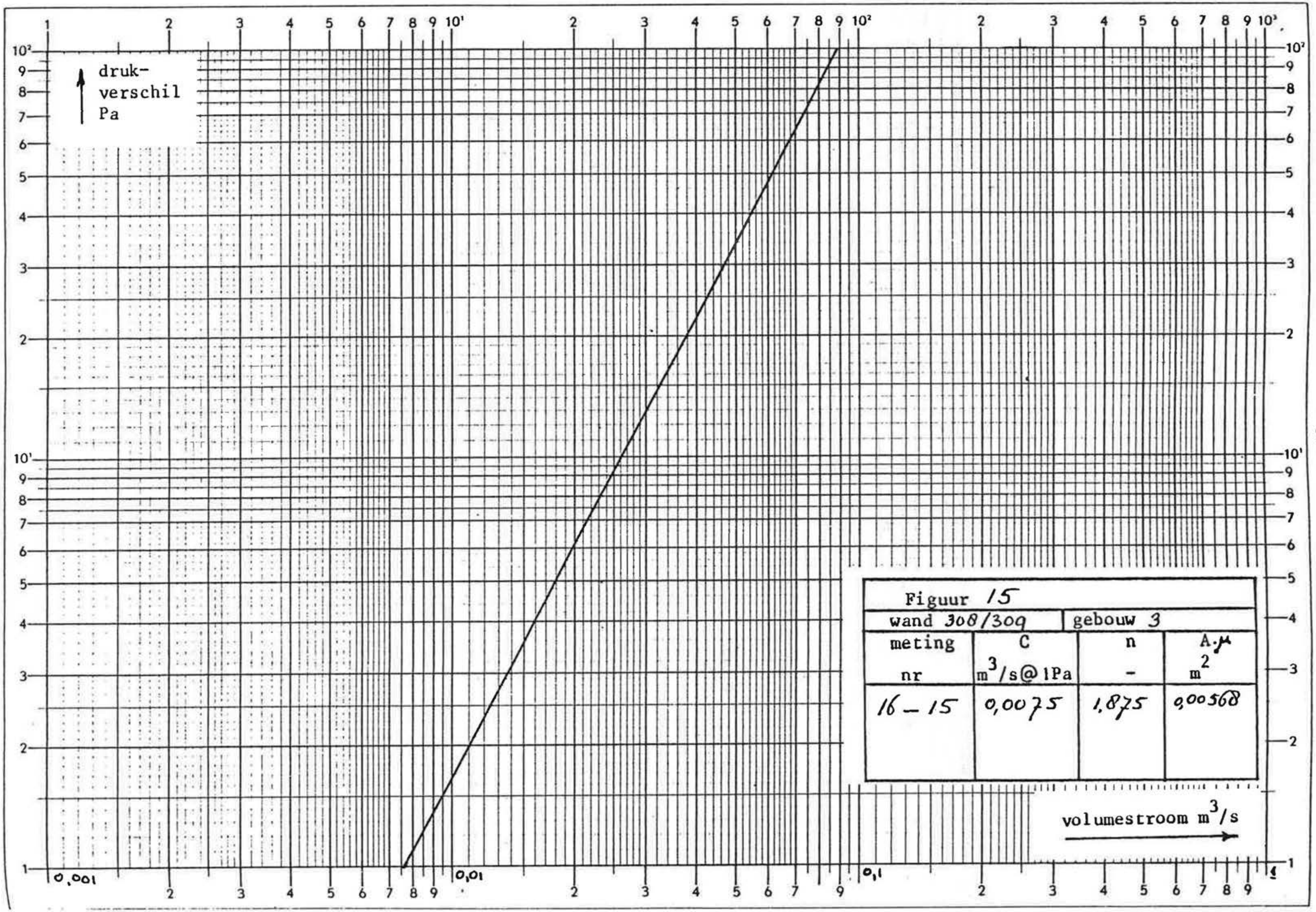


Figuur 14			
wand 309/310		gebouw 3	
meting nr	C m^3/s@1Pa	n -	A.μ m^2
13-14	0,0095	1,537	0,00663

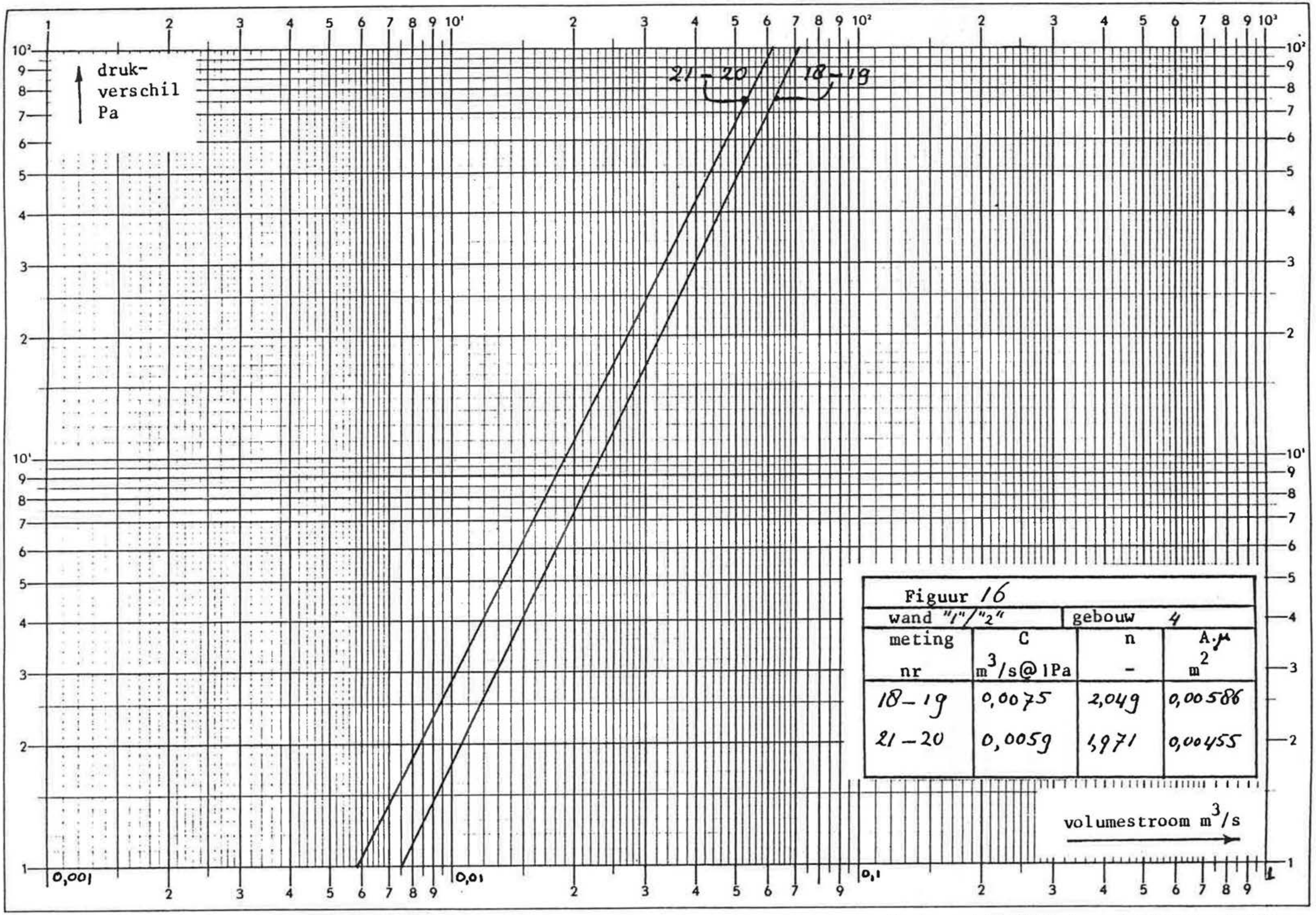
meetpapier - wormer

No. 20 H

X-as log. verdeeld 1-10³ Y-as log. verdeeld 1-10² Eenheid 83.33 mm.

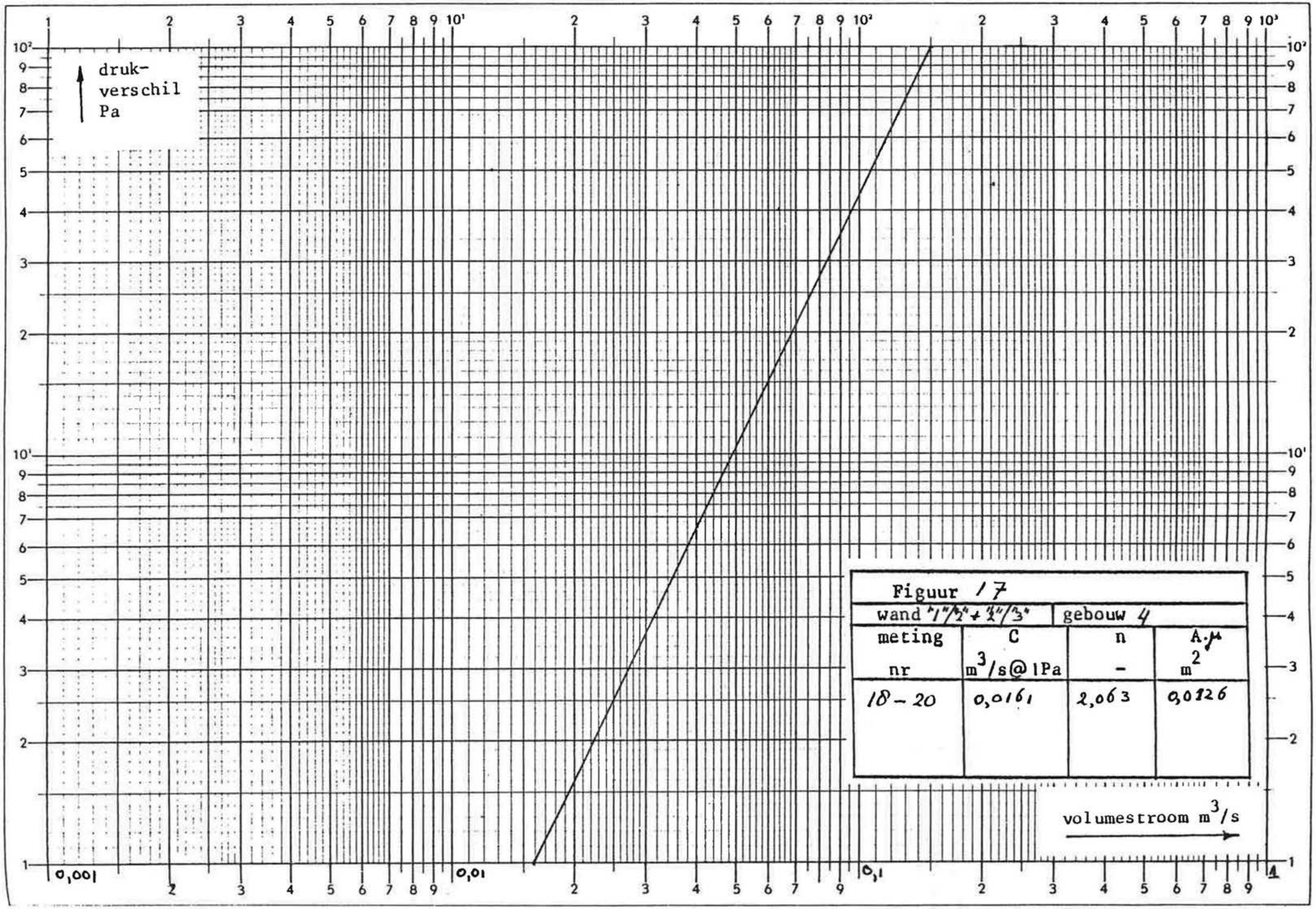


Figuur 15			
wand 308/309		gebouw 3	
meting nr	C m^3/s@1Pa	n -	$A.\mu$ m^2
16 – 15	0,0075	1,875	0,00568



Figuur 16

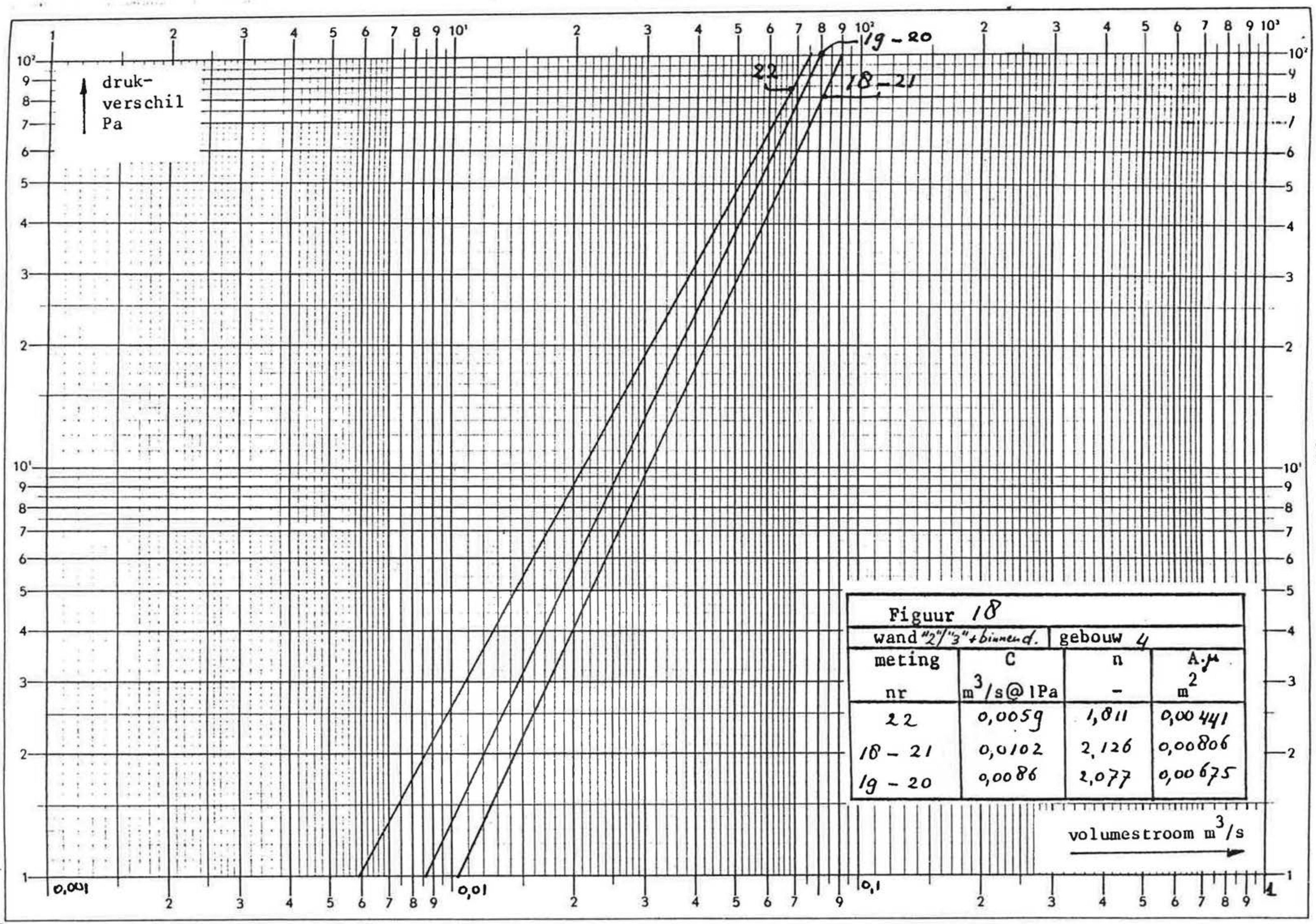
wand "1"/"2"		gebouw 4	
meting nr	C $m^3/s@1Pa$	n -	$A.\mu$ m^2
18 – 19	0,0075	2,049	0,00586
21 – 20	0,0059	1,971	0,00455



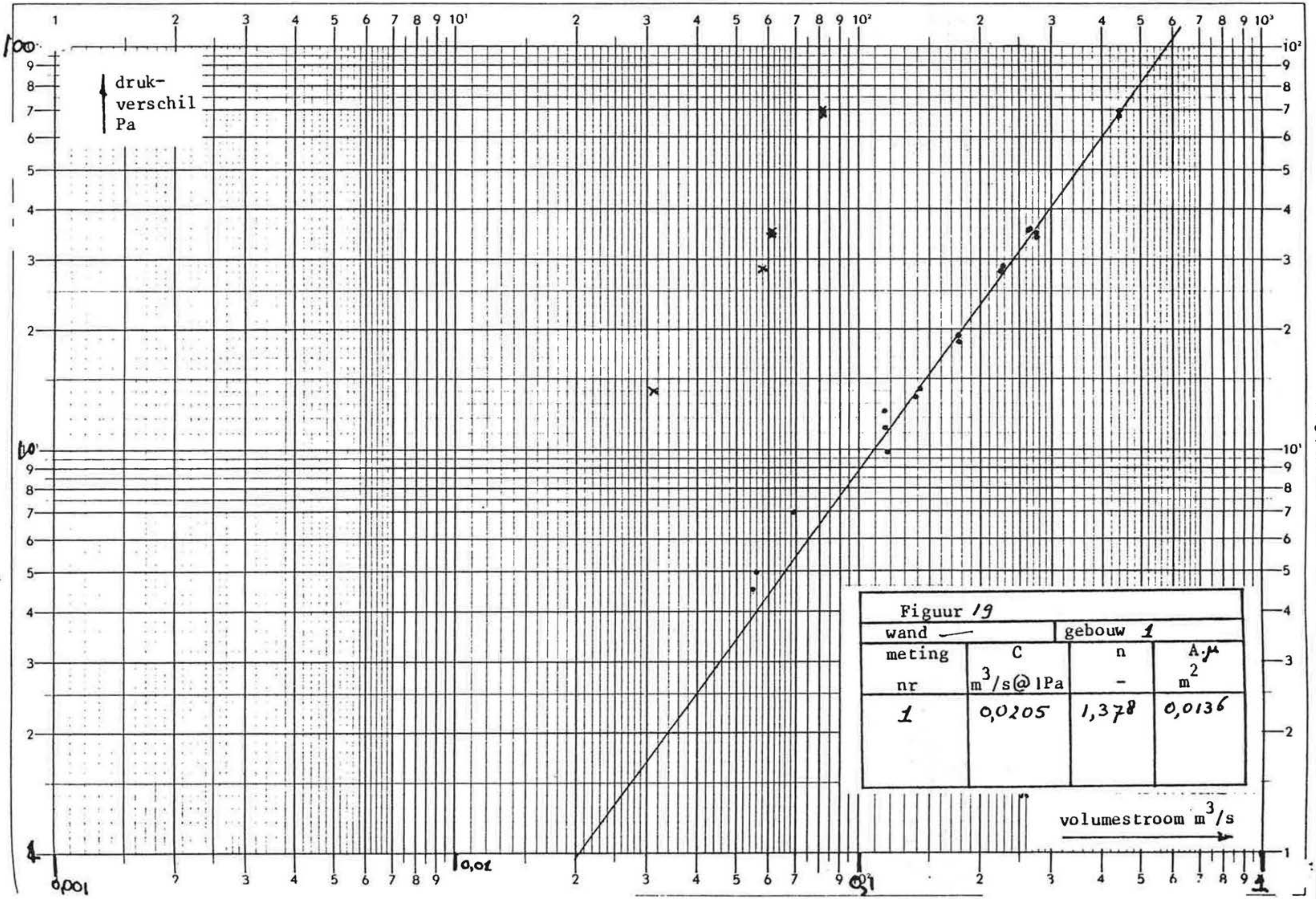
Figuur 17			
wand "1"/"2" + "2"/"3"		gebouw 4	
meting nr	C m³/s@1Pa	n -	A.μ m²
18 – 20	0,0161	2,063	0,0126

No. 20 H

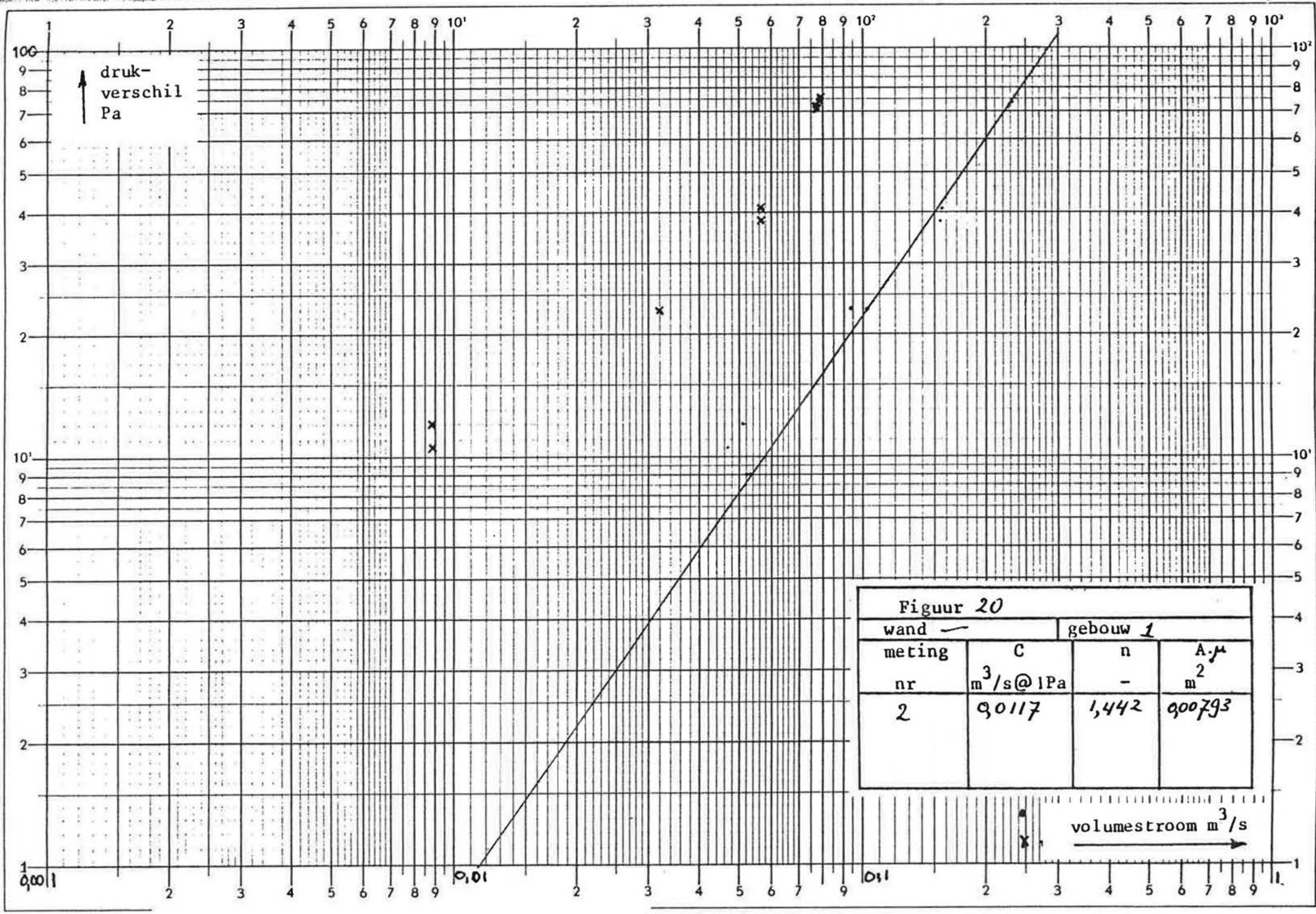
X-as log verdeeld 1-10³ Y-as log verdeeld 1-10² Eenheid 83.33 mm



Figuur 18			
wand "2"/"3" + binnend.	gebouw 4		
meting nr	C m^3/s@1Pa	n -	A.μ m^2
22	0,0059	1,811	0,00441
18 - 21	0,0102	2,126	0,00806
19 - 20	0,0086	2,077	0,00675

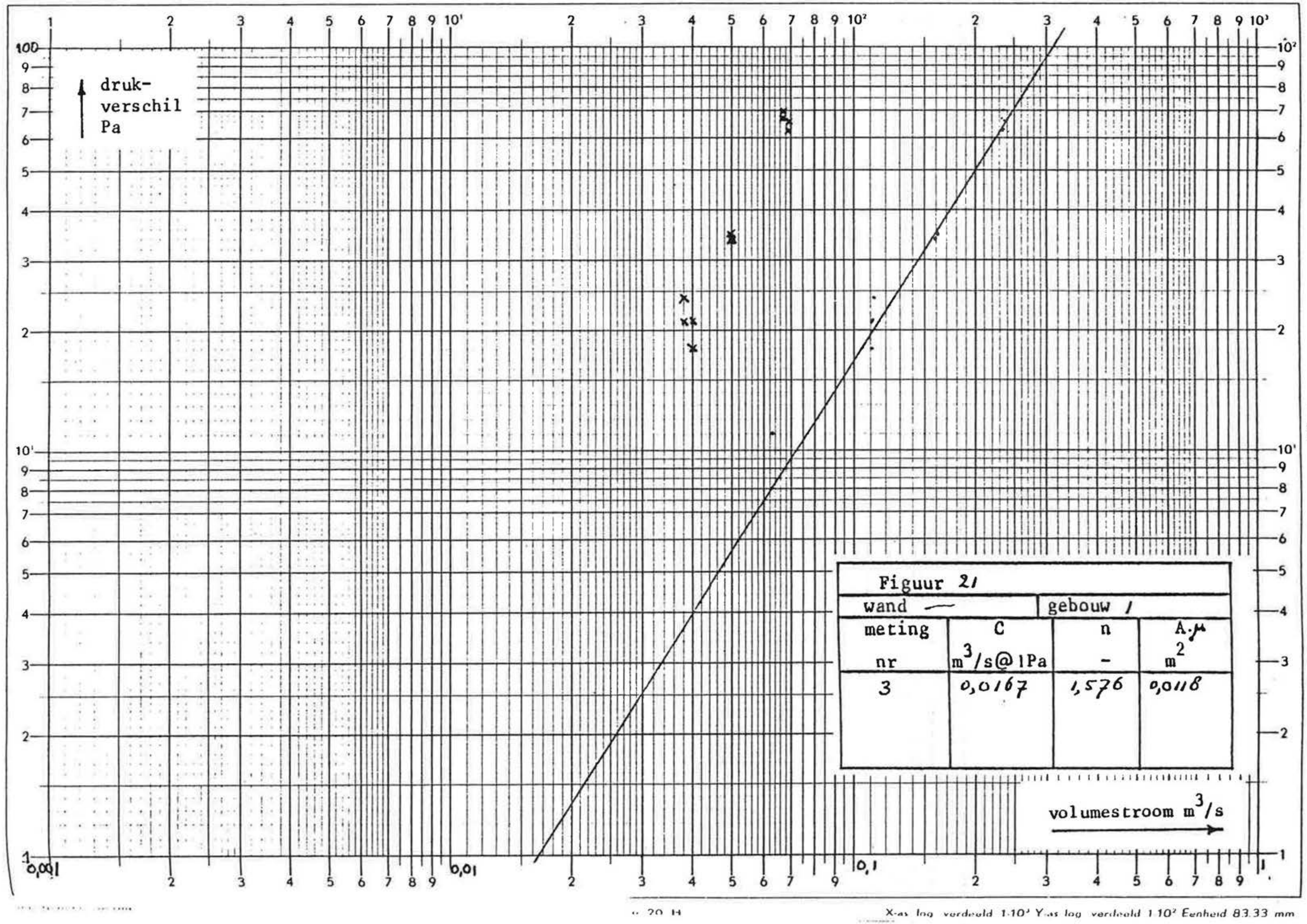


meting nr	C m^3/s@1Pa	n –	A.µ m^2
1	0,0205	1,378	0,0136

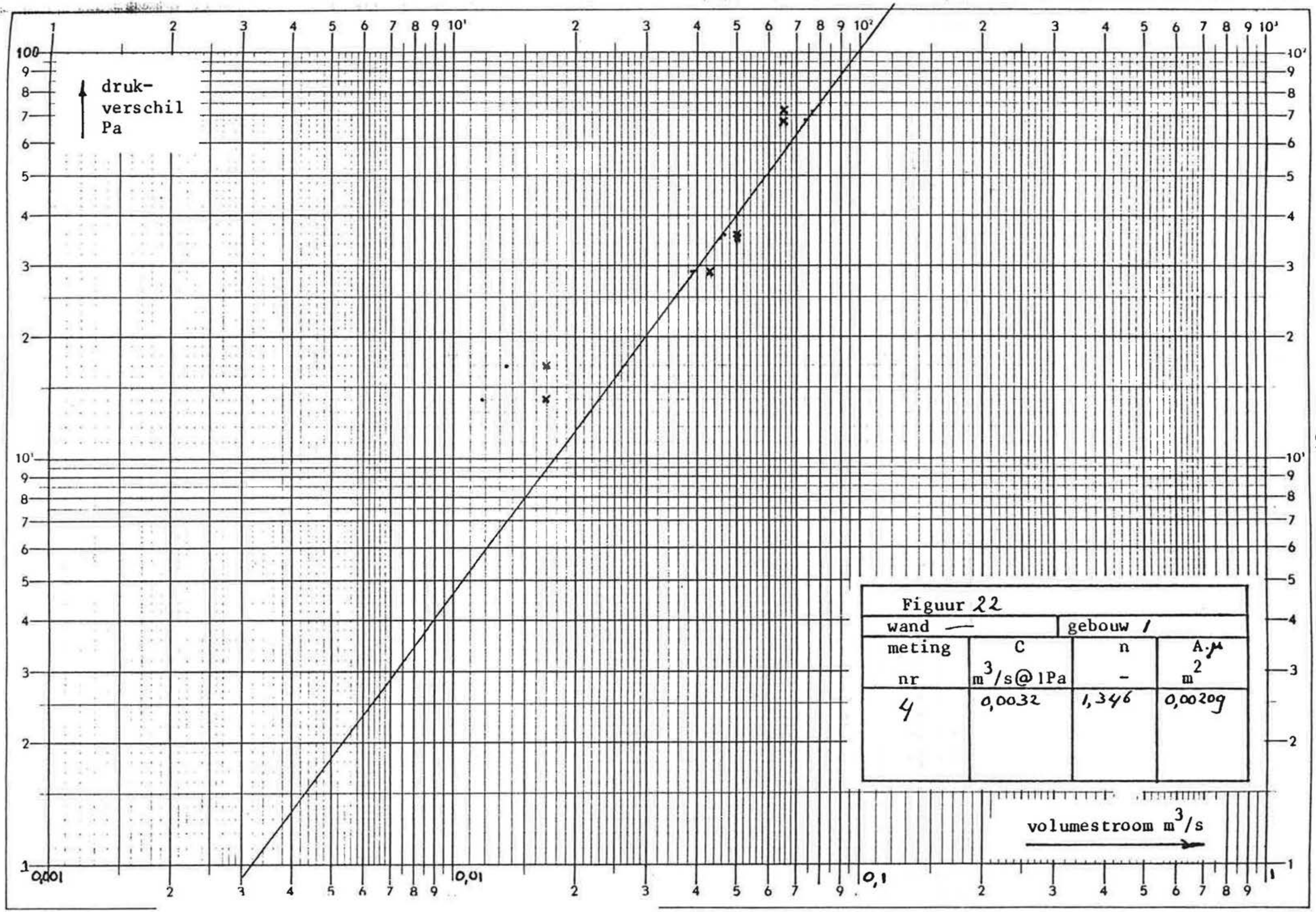


Figuur 20

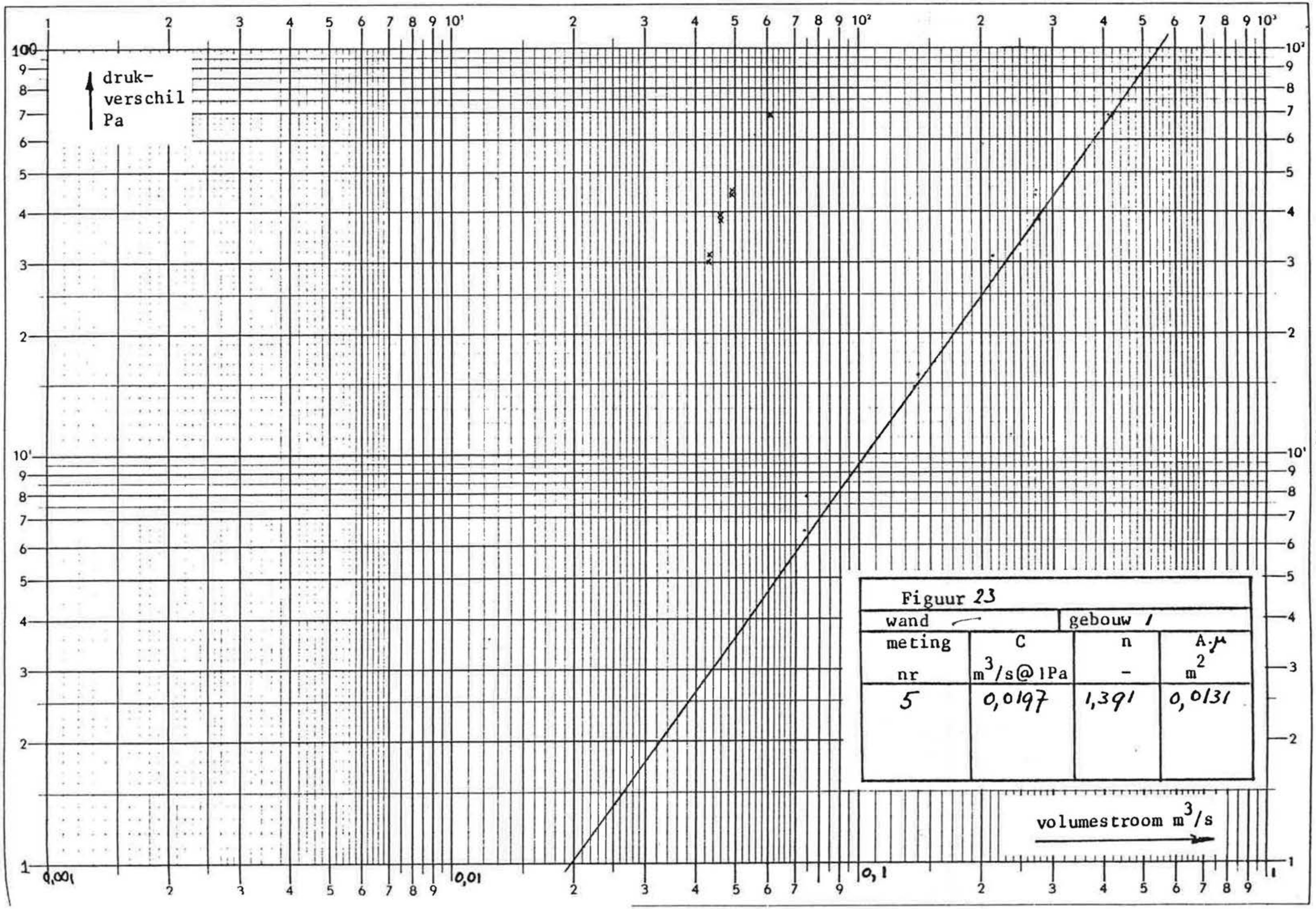
wand —		gebouw 1	
meting nr	C m^3/s@1Pa	n -	A.μ m^2
2	0,0117	1,442	0,00793

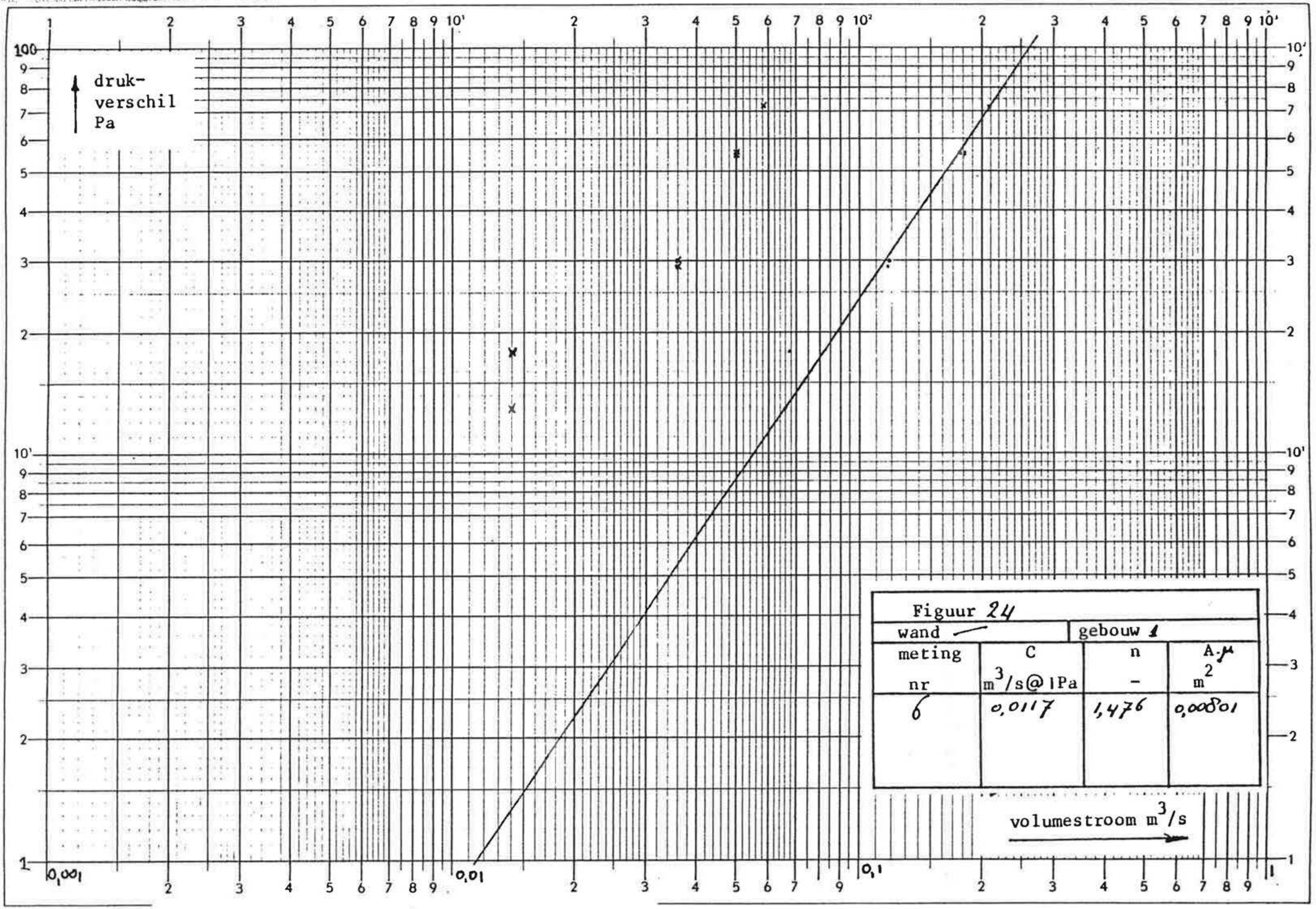


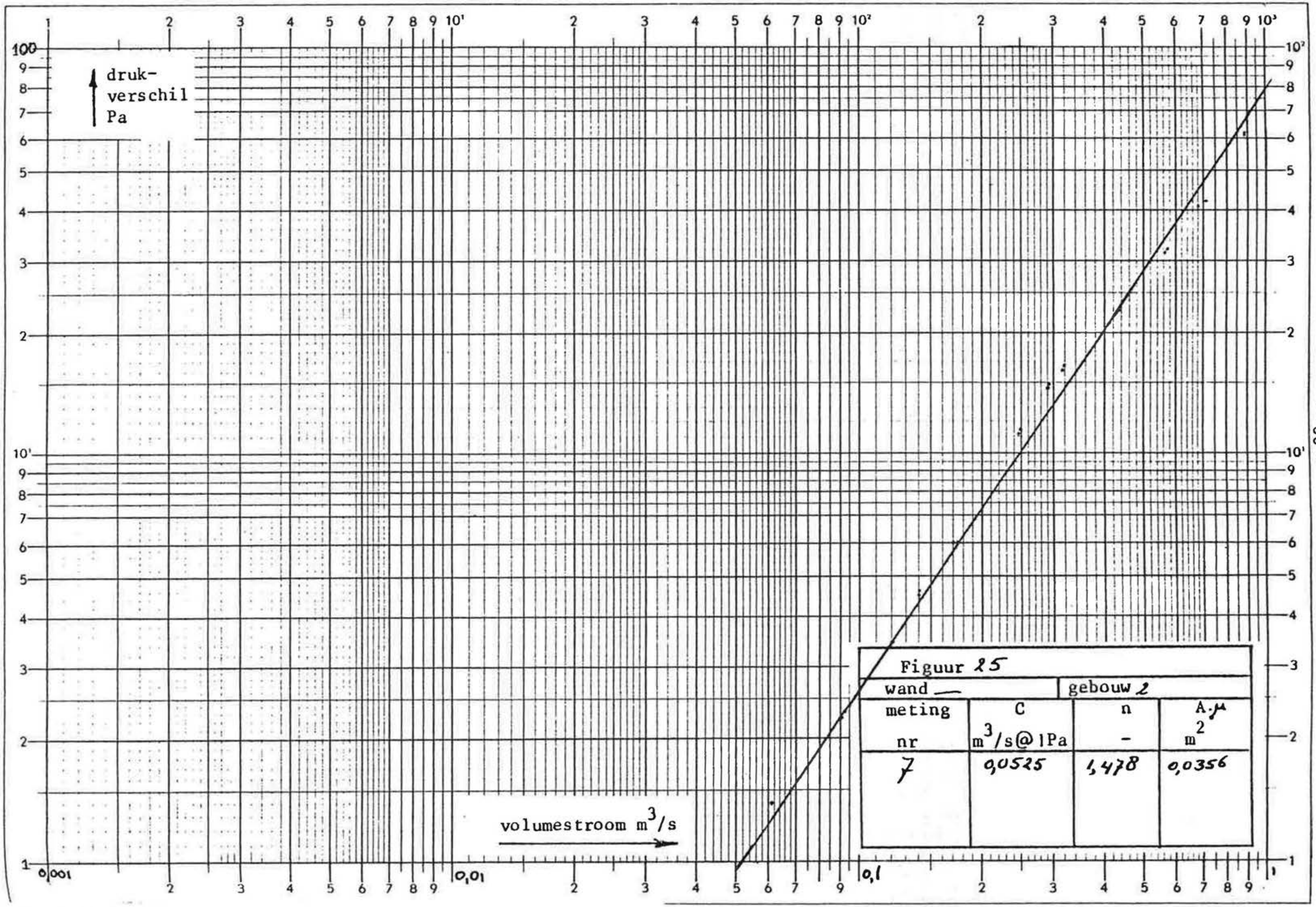
druk-
verschil
Pa
volumestroom m³/s
Figuur 21
wand —
gebouw 1
meting nr
C m³/s@1Pa
n -
A.μ m²
3
0,0167
1,576
0,0118
0,001
0,01
0,1
X-as log verdeeld 1.10³ Y-as log verdeeld 1.10² Eenheid 83.33 mm



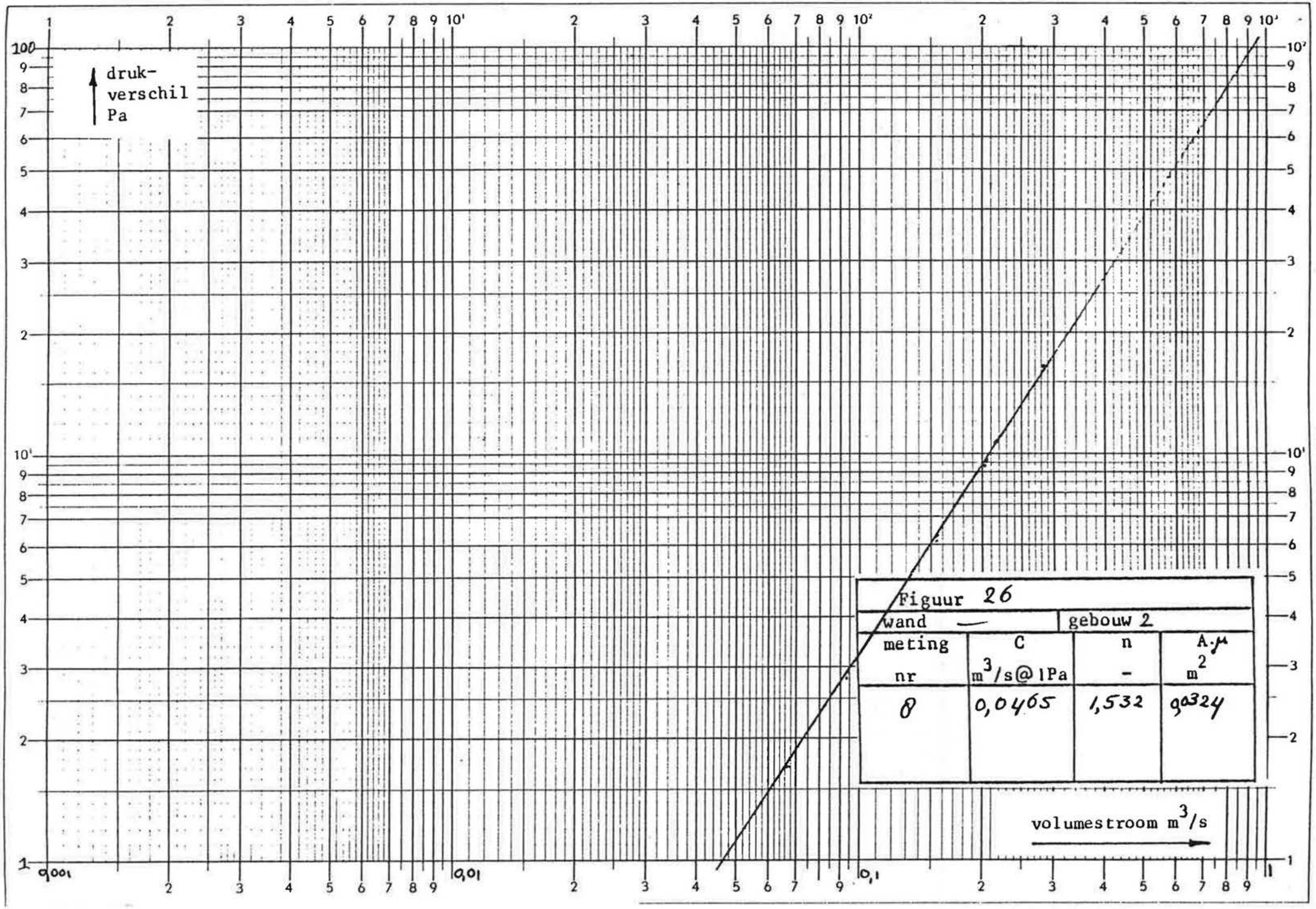
Figuur 22			
wand —		gebouw 1	
meting nr	C $m^3/s@1Pa$	n –	A.μ m^2
4	0,0032	1,346	0,00209

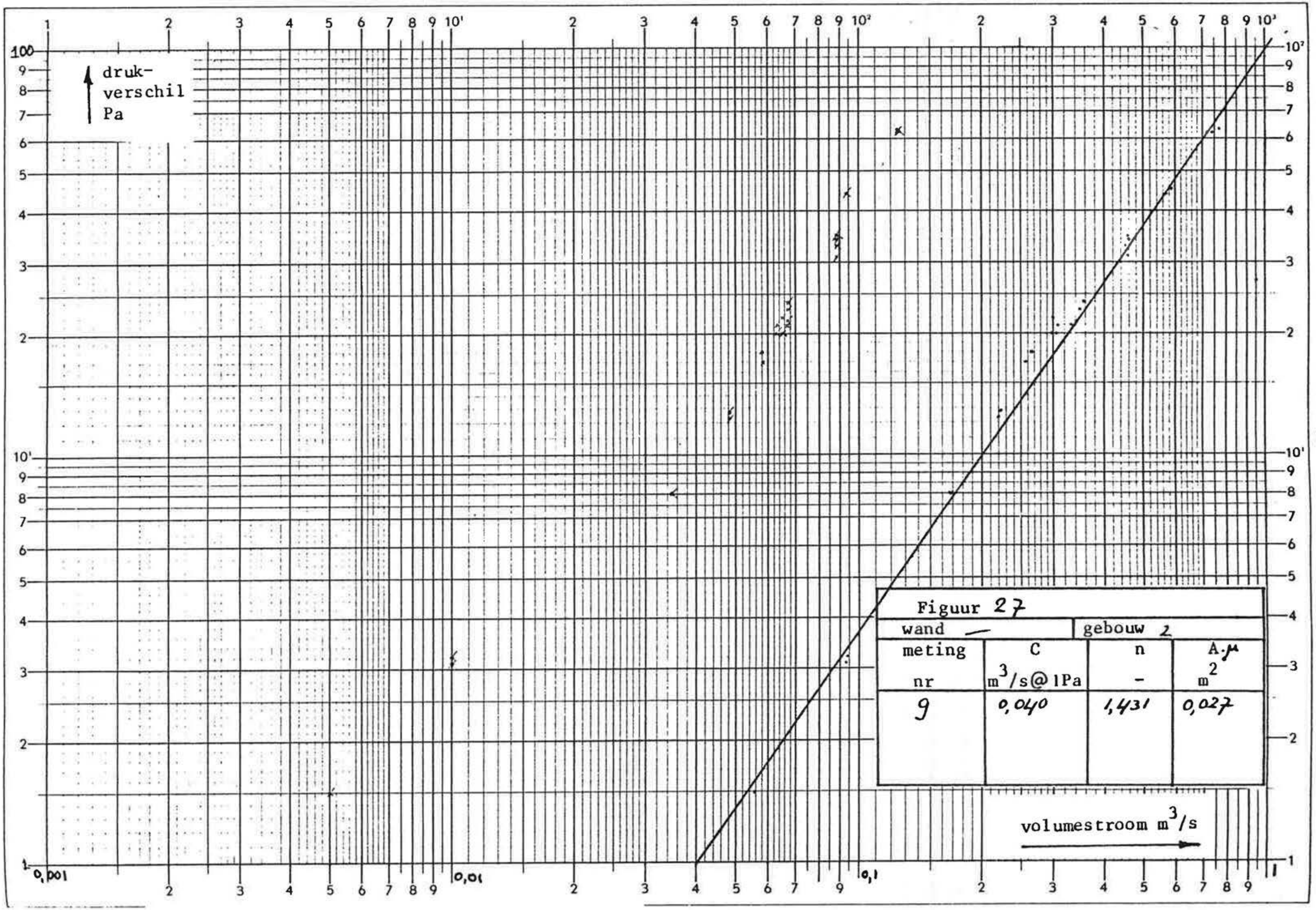

druk-
verschil
Pa
volumestroom m^3/s
Figuur 23
wand —
gebouw 1
meting nr | C m^3/s@1Pa | n - | A·μ m^2
5 | 0,0197 | 1,391 | 0,0131


druk-
verschil
Pa
volumestroom m³/s
0,001
0,01
0,1
1
Figuur 24
wand —
gebouw 1
meting nr
C m³/s@1Pa
n -
A.μ m²
6
0,0117
1,476
0,00801



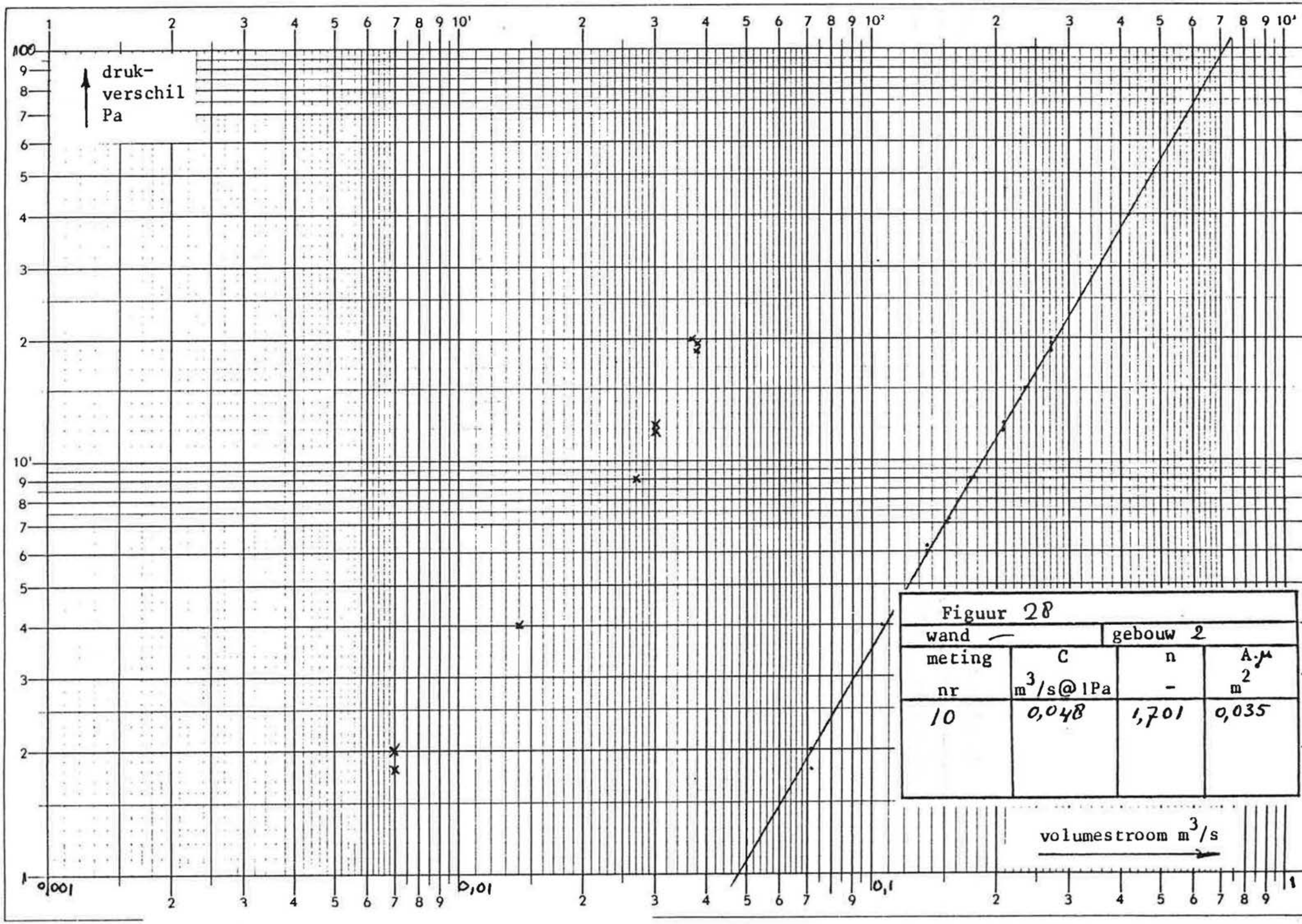
Figuur 25			
wand —		gebouw 2	
meting nr	C m³/s@1Pa	n -	A.μ m²
7	0,0525	1,478	0,0356


X-as log verdeeld 1-10³ Y-as log verdeeld 1-10² Eenheid 83,33 mm
druk-
verschil
Pa
volumestroom m³/s
0,001
0,01
0,1
1
Figuur 26
wand —
gebouw 2
meting nr
C m³/s@1Pa
n -
A.μ m²
8
0,0465
1,532
0,0324



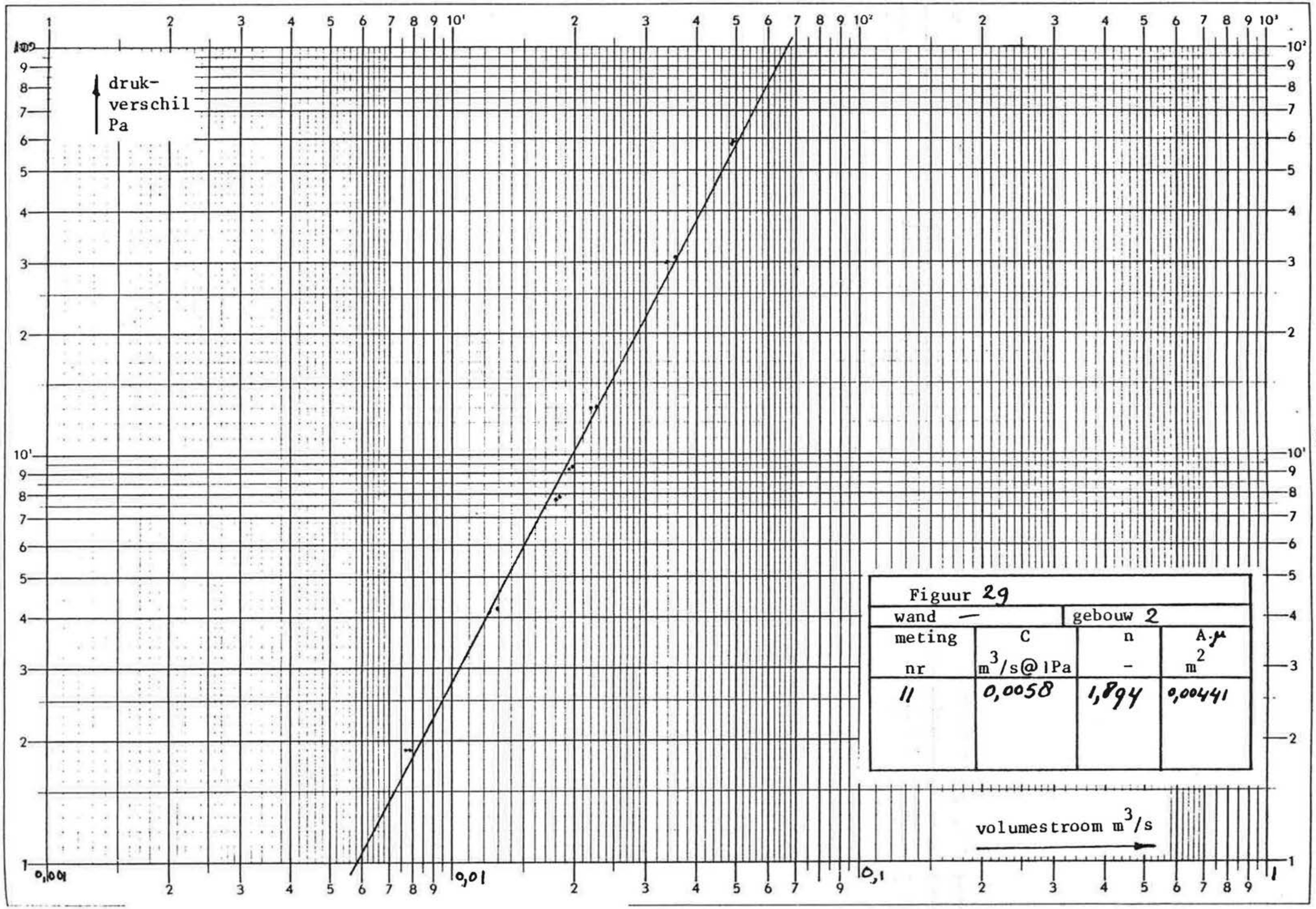
wand –		gebouw 2	
meting nr	C m³/s@1Pa	n -	A.μ m²
9	0,040	1,431	0,027

X-as log. verdeeld 1-10³ Y-as log. verdeeld 1-10² Eenheid 83,33 mm

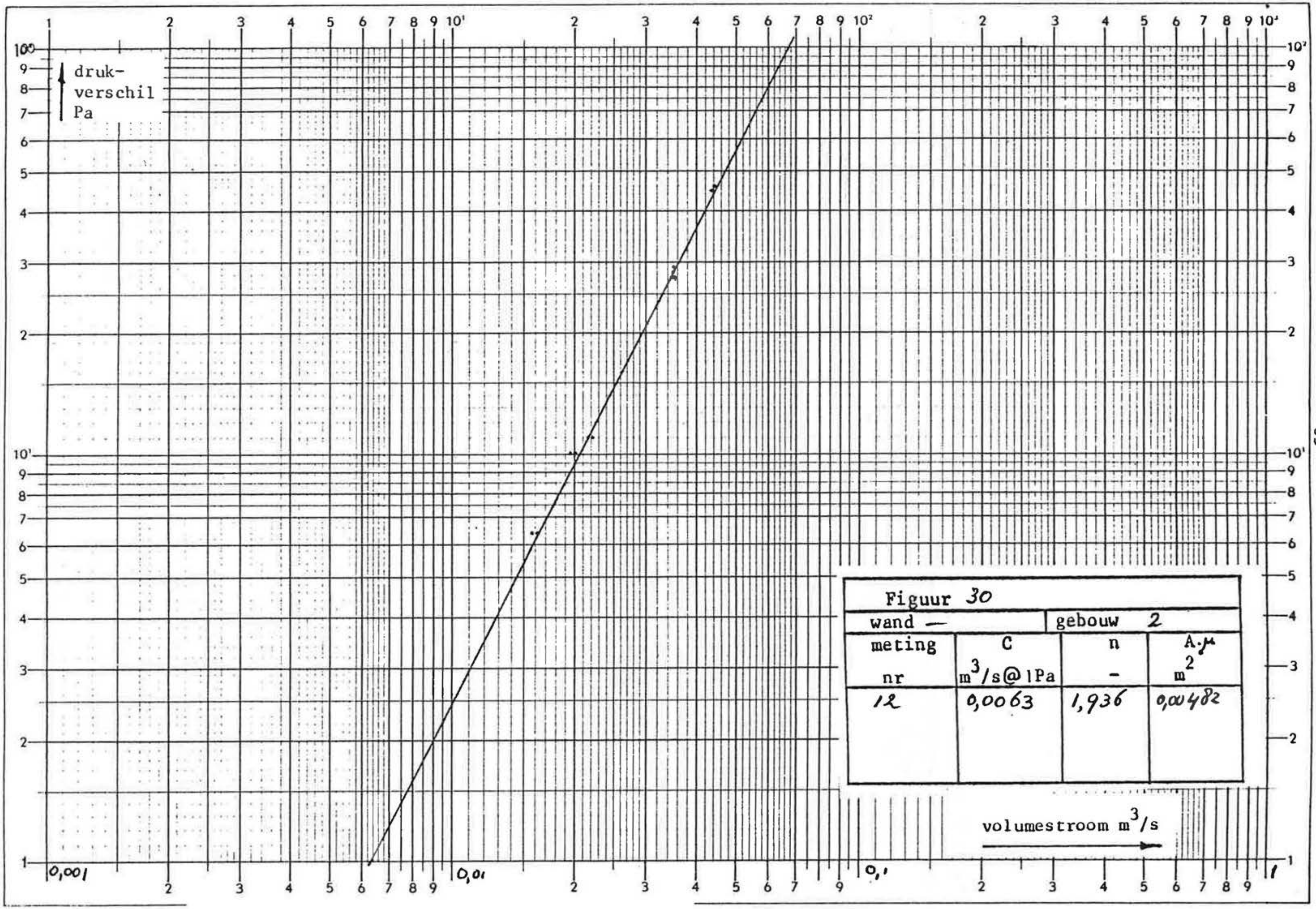


Figuur 28

wand —		gebouw 2	
meting nr	C m³/s@1Pa	n -	A.μ m²
10	0,048	1,701	0,035



druk-verschil Pa
volumestroom m3/s
0,001
0,01
0,1
1
Figuur 29
wand —
gebouw 2
meting nr
C m3/s@1Pa
n -
A.μ m2
11
0,0058
1,894
0,00441

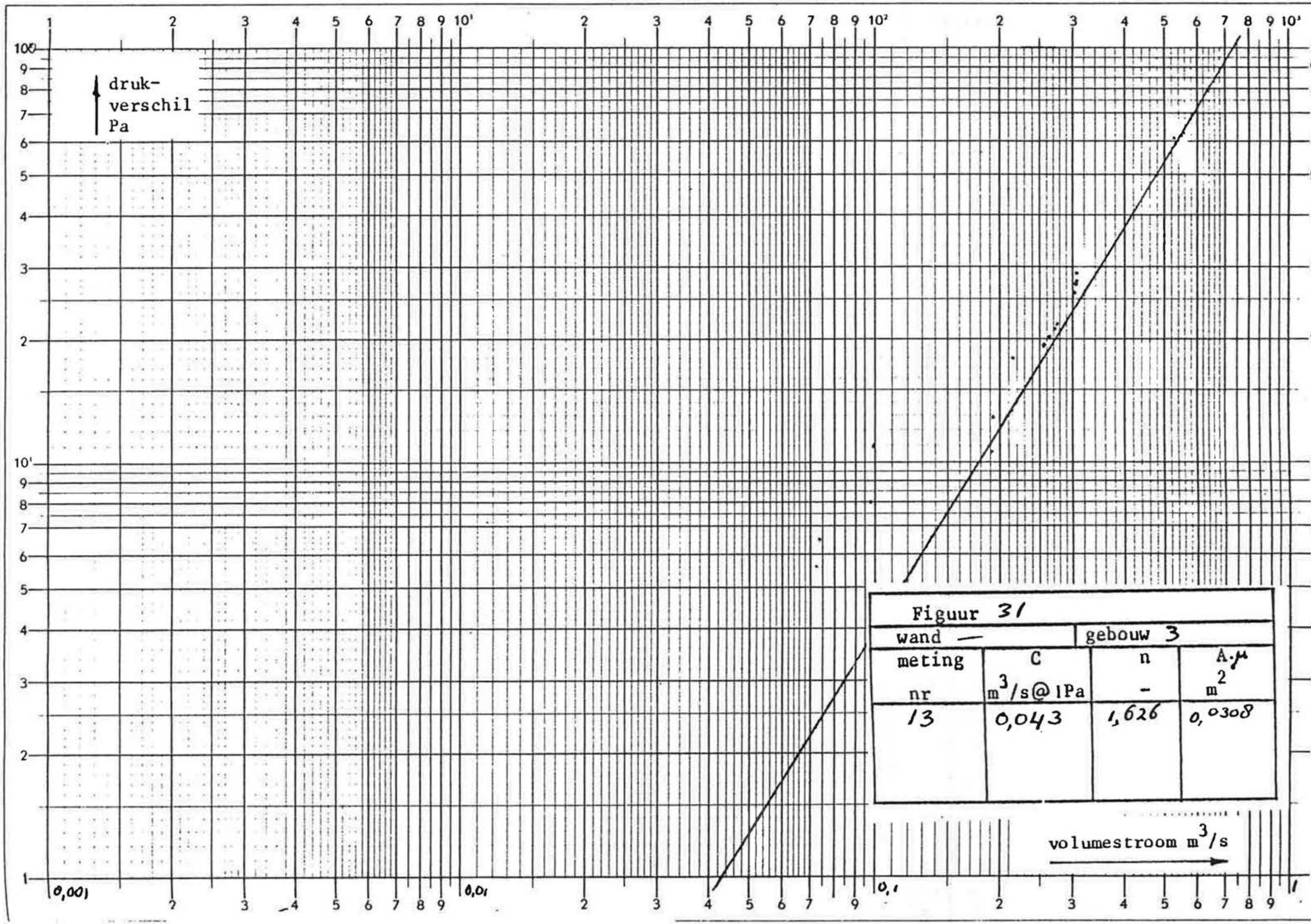


Figuur 30

wand —		gebouw 2	
meting nr	C m^3/s@1Pa	n -	A.μ m^2
12	0,0063	1,936	0,00482

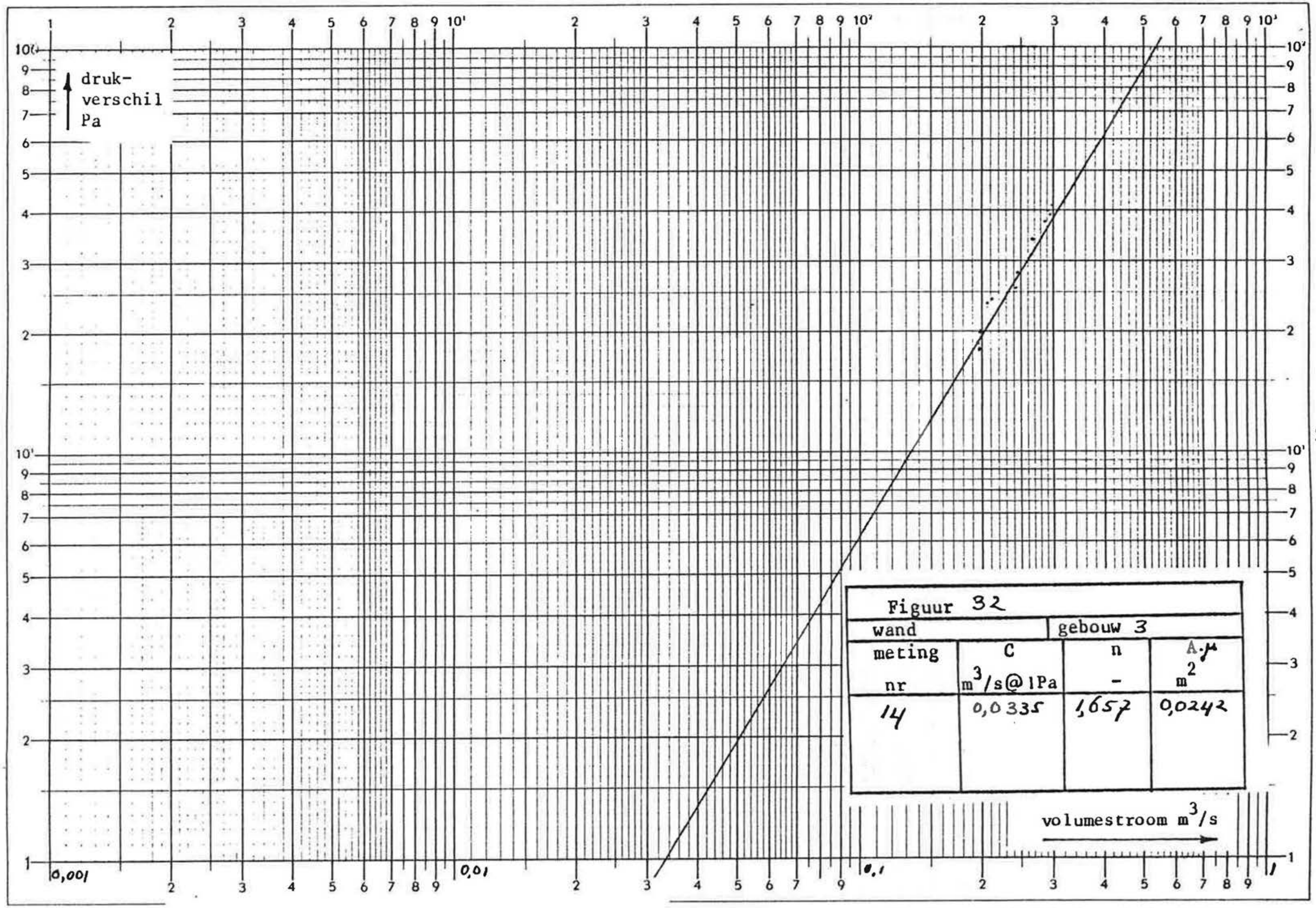
meetpapier - wormerveer

X-as log. verdeeld 1-10³ Y-as log. verdeeld 1-10² Eenheid 83.33 mm.



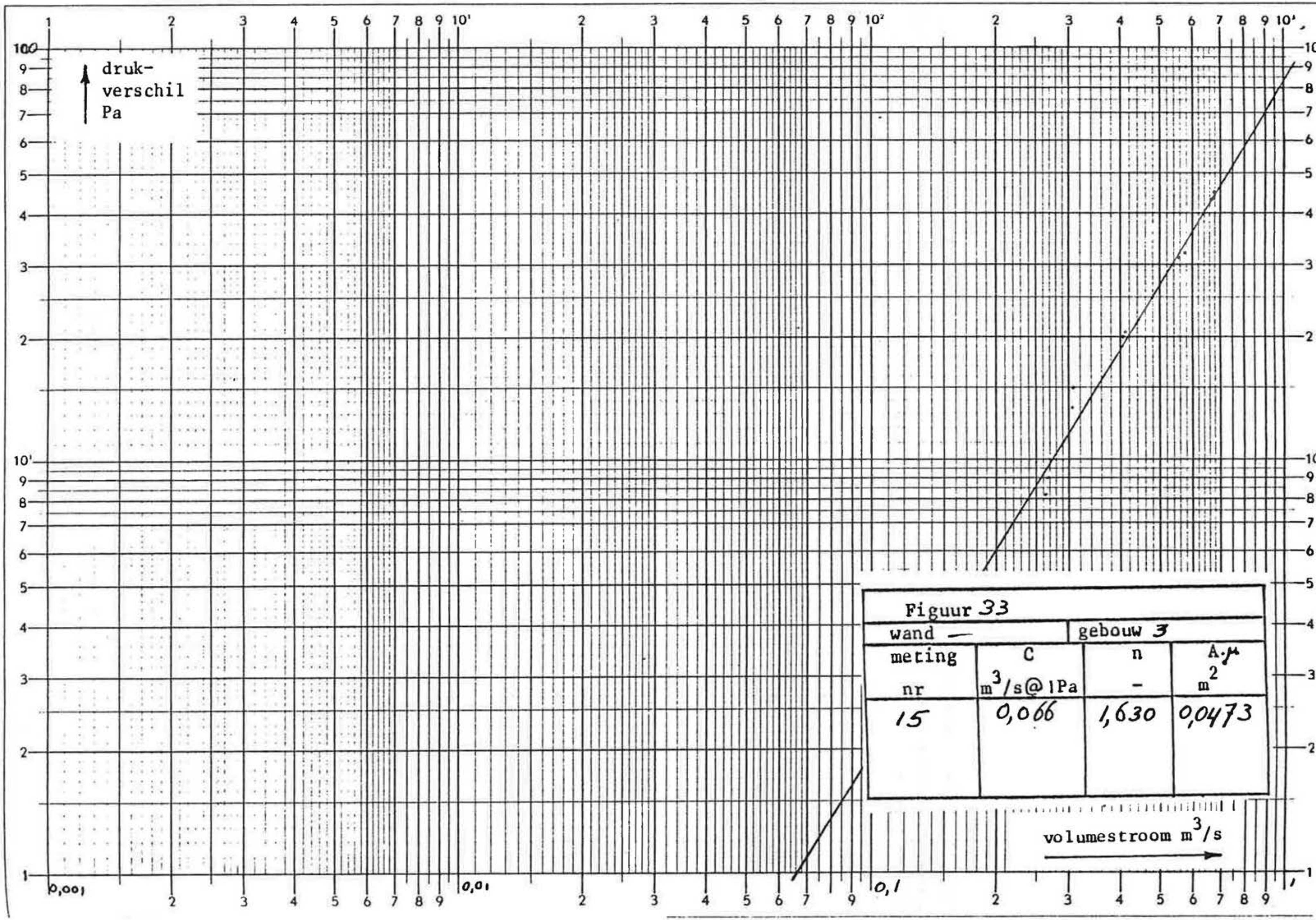
Figuur 31

wand —		gebouw 3	
meting nr	C m³/s@1Pa	n -	A·μ m²
13	0,043	1,626	0,0308

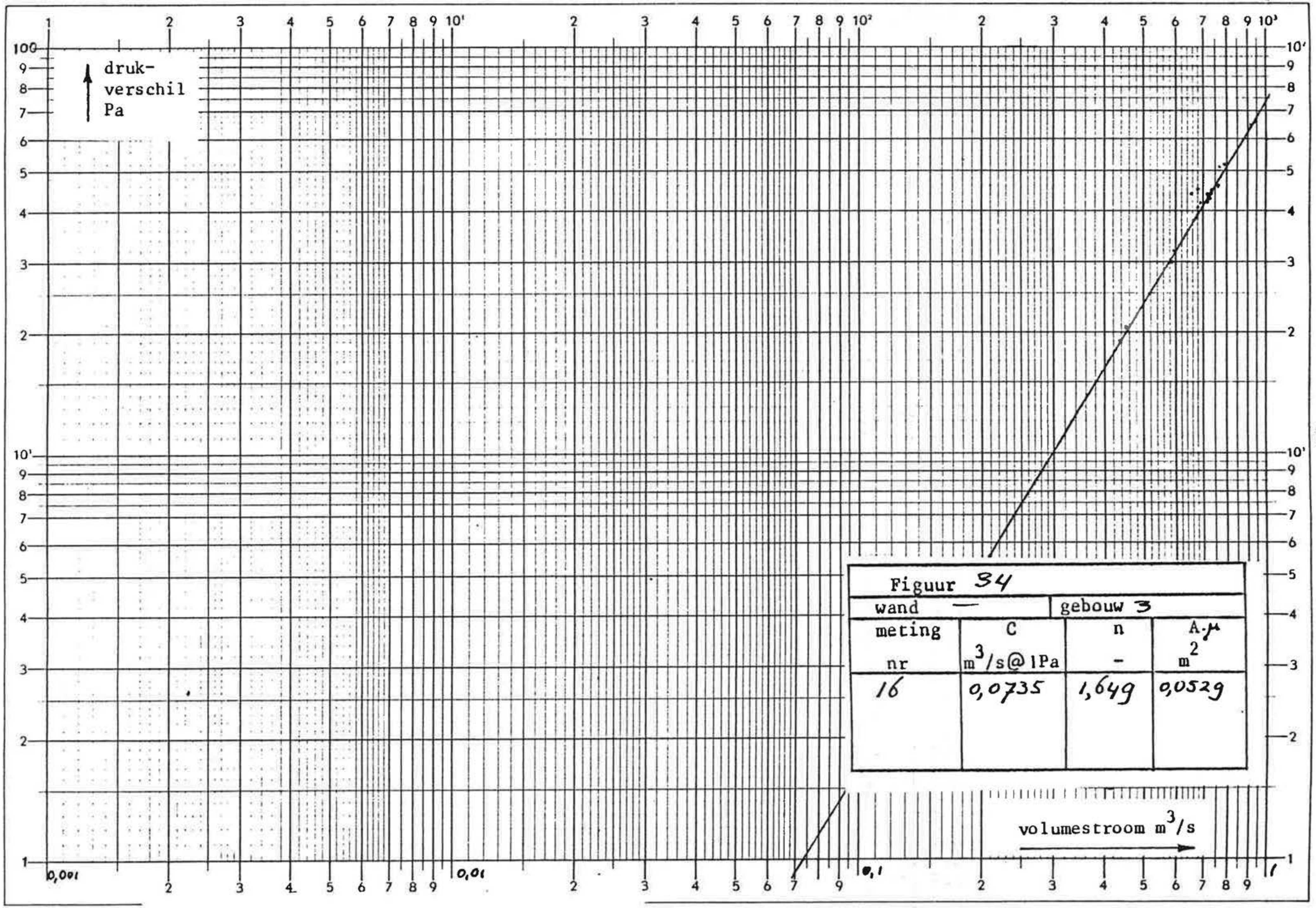


Figuur 32			
wand		gebouw 3	
meting nr	C m³/s@1Pa	n -	A.μ m²
14	0,0335	1,657	0,0242

X-as log. verdeeld 1-10³ Y-as log. verdeeld 1-10² Eenheid 83.33 mm.

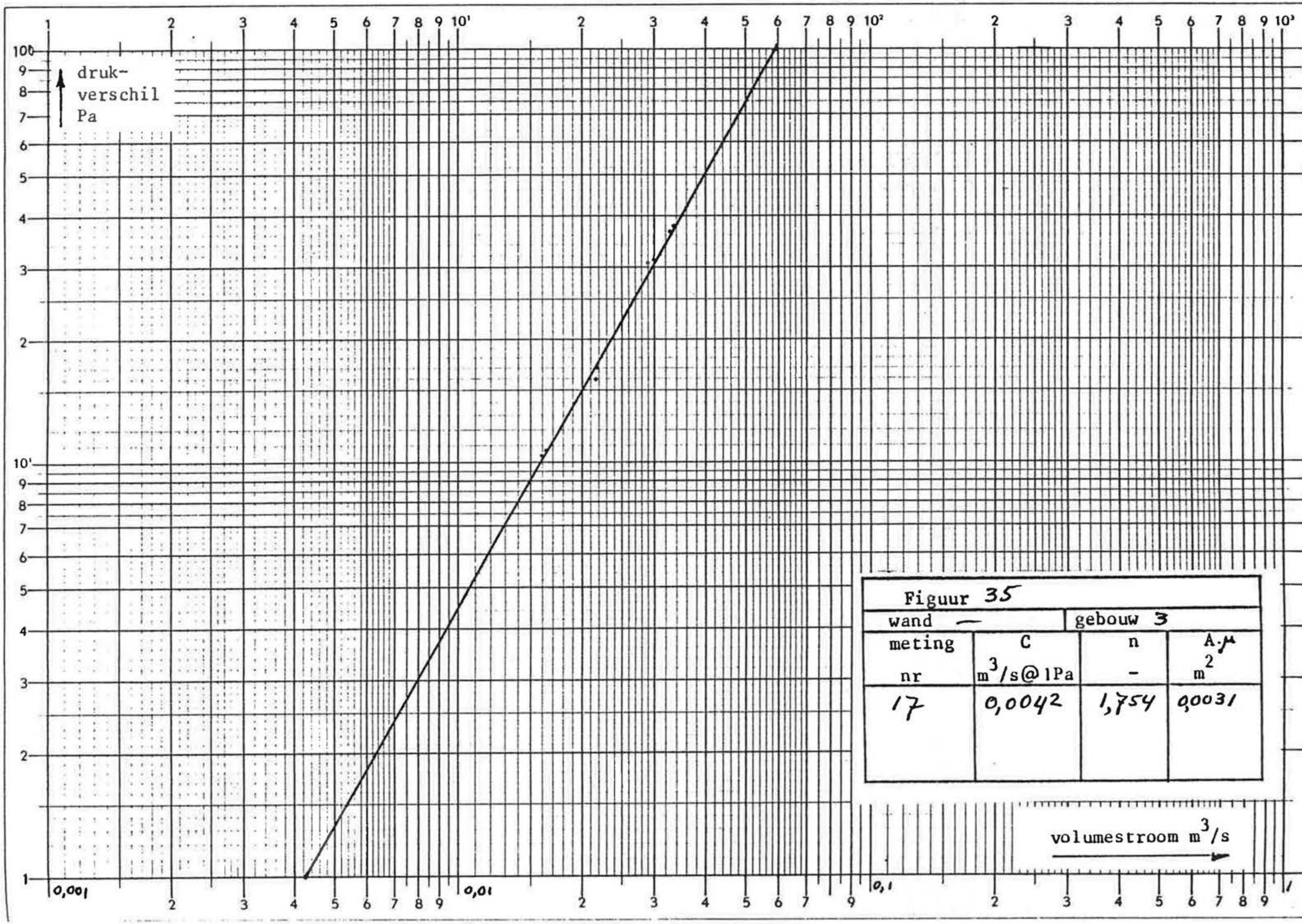


Figuur 33			
wand —		gebouw 3	
meting nr	C m^3/s@1Pa	n –	A.µ m^2
15	0,066	1,630	0,0473



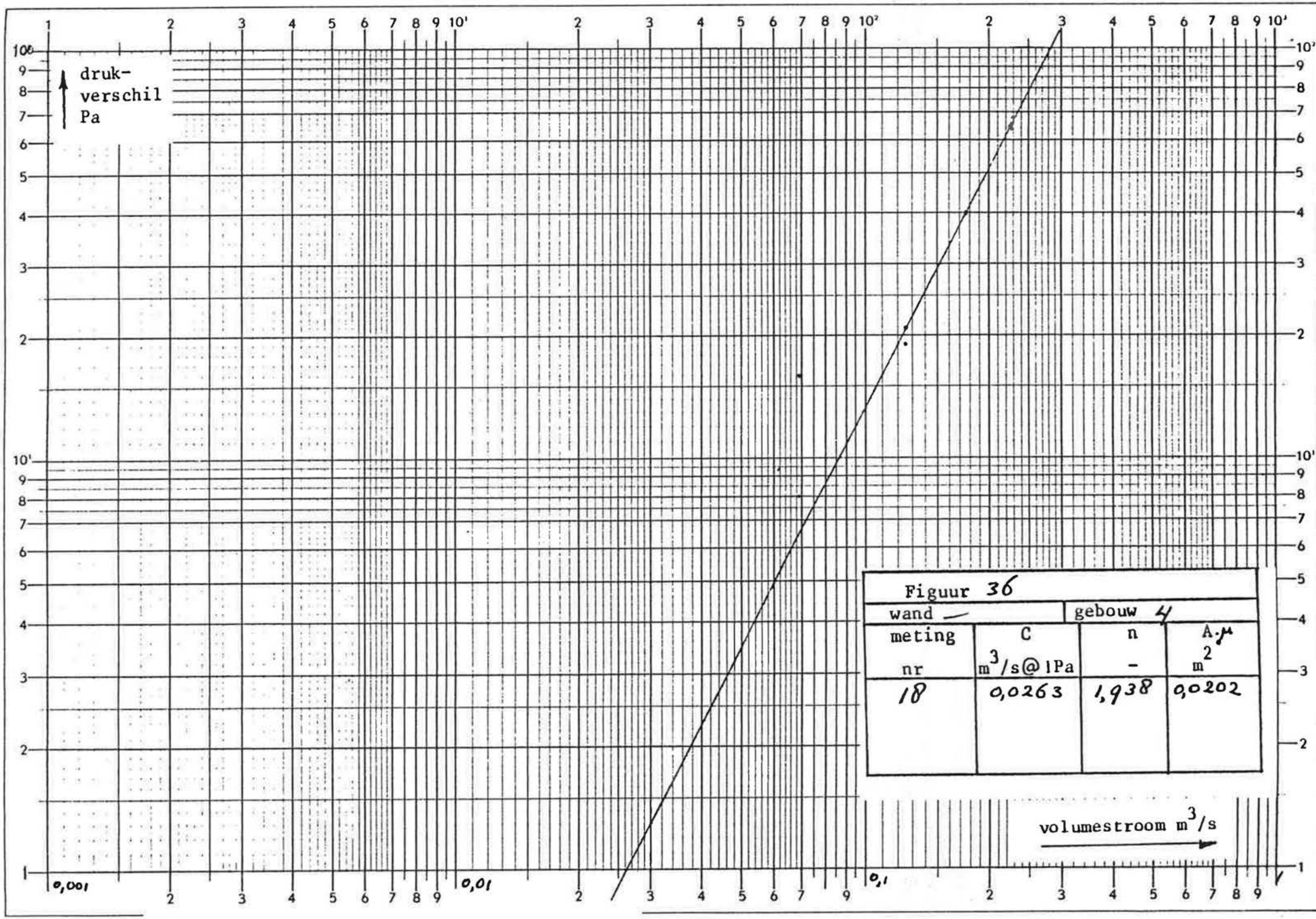
Figuur 34

wand —		gebouw 3	
meting nr	C $m^3/s@1Pa$	n -	$A.\mu$ m^2
16	0,0735	1,649	0,0529



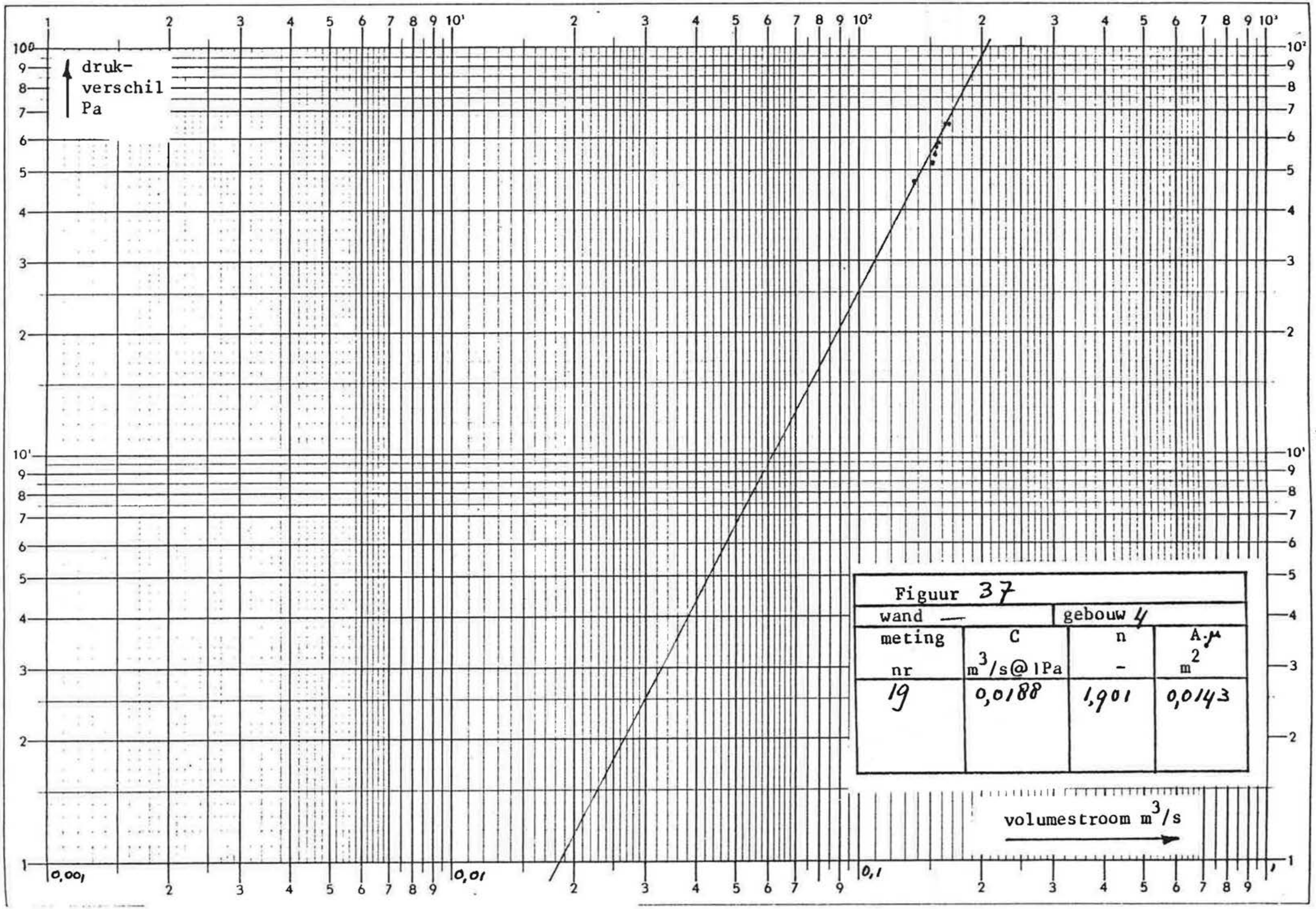
Figuur 35

wand —		gebouw 3	
meting nr	C m^3/s@1Pa	n -	A.μ m^2
17	0,0042	1,754	0,0031

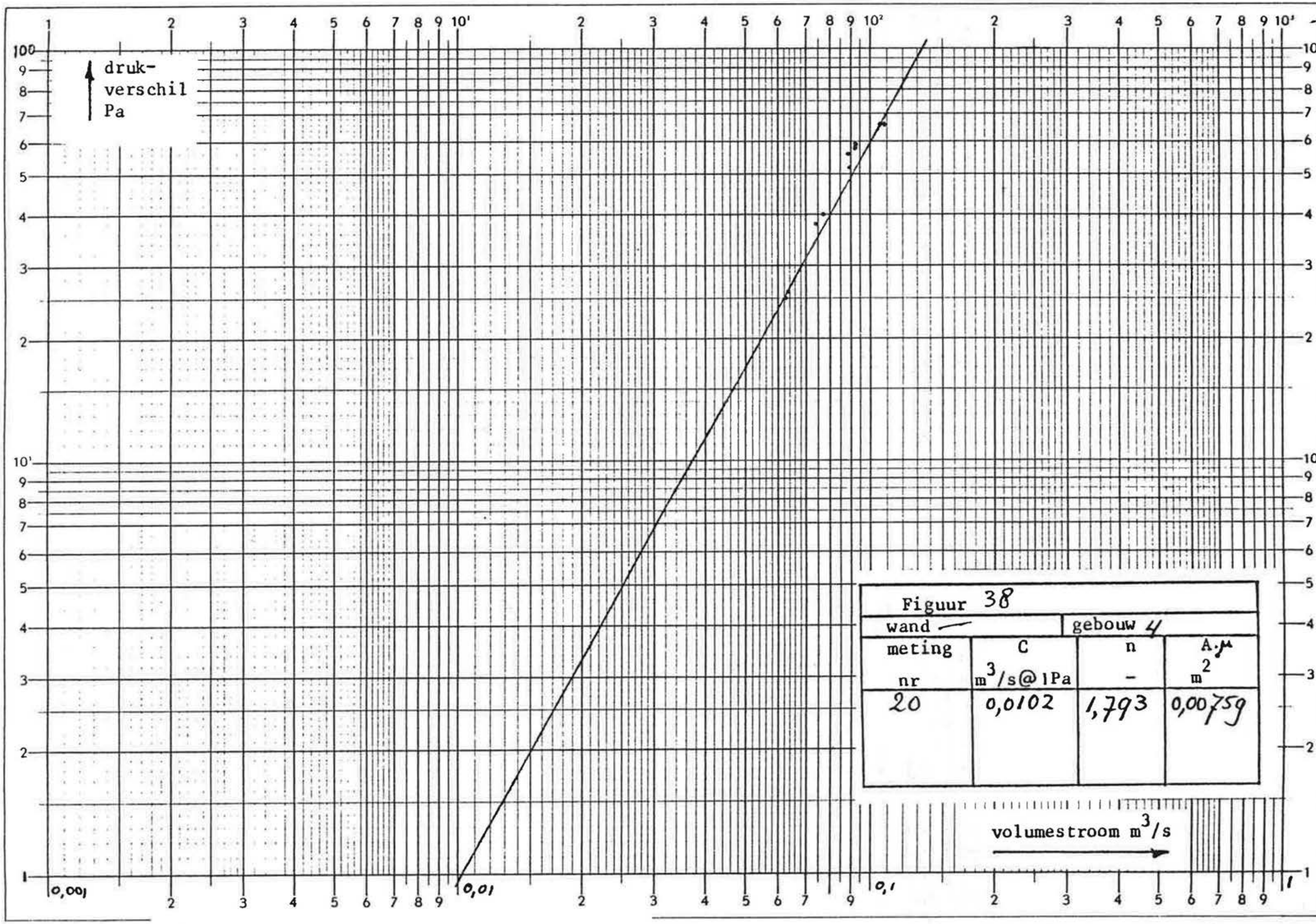


Figuur 36

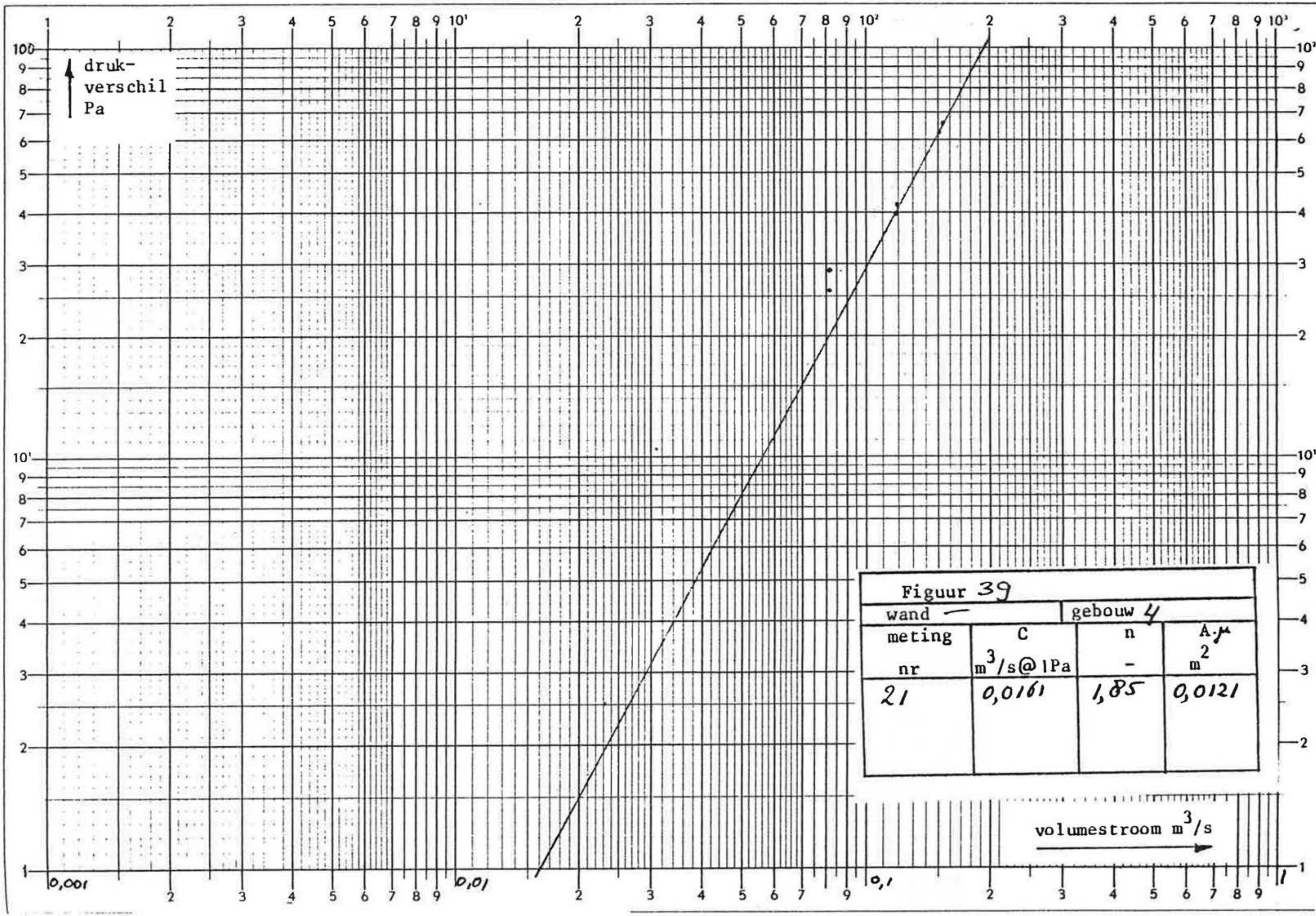
wand —		gebouw 4	
meting nr	C $m^3/s@1Pa$	n -	$A.\mu$ m^2
18	0,0263	1,938	0,0202



Figuur 37			
wand —		gebouw 4	
meting nr	C $m^3/s@1Pa$	n -	A.μ m^2
19	0,0188	1,901	0,0143

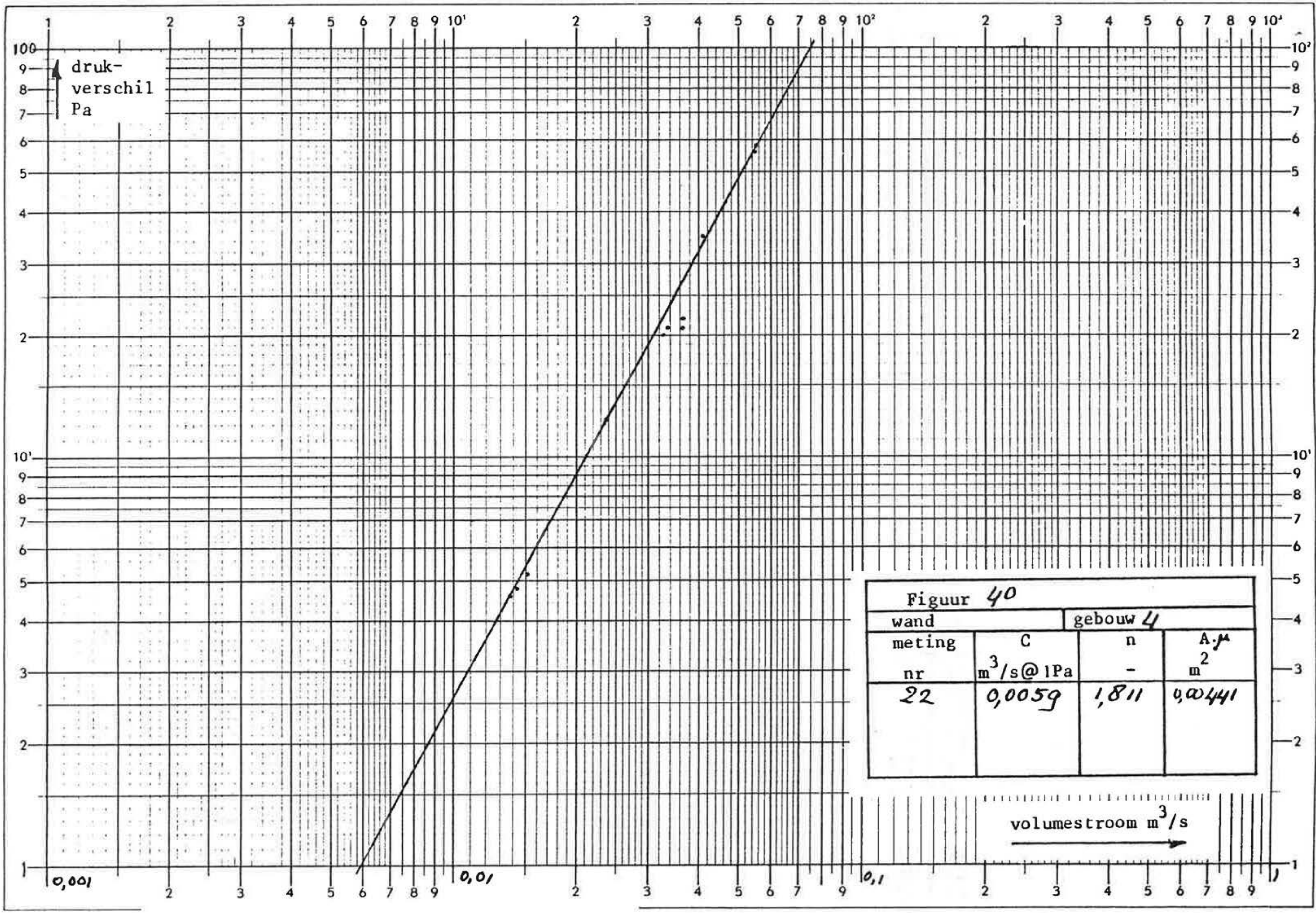


Figuur 38			
wand		gebouw 4	
meting nr	C $m^3/s@1Pa$	n -	A.µ m^2
20	0,0102	1,793	0,00759

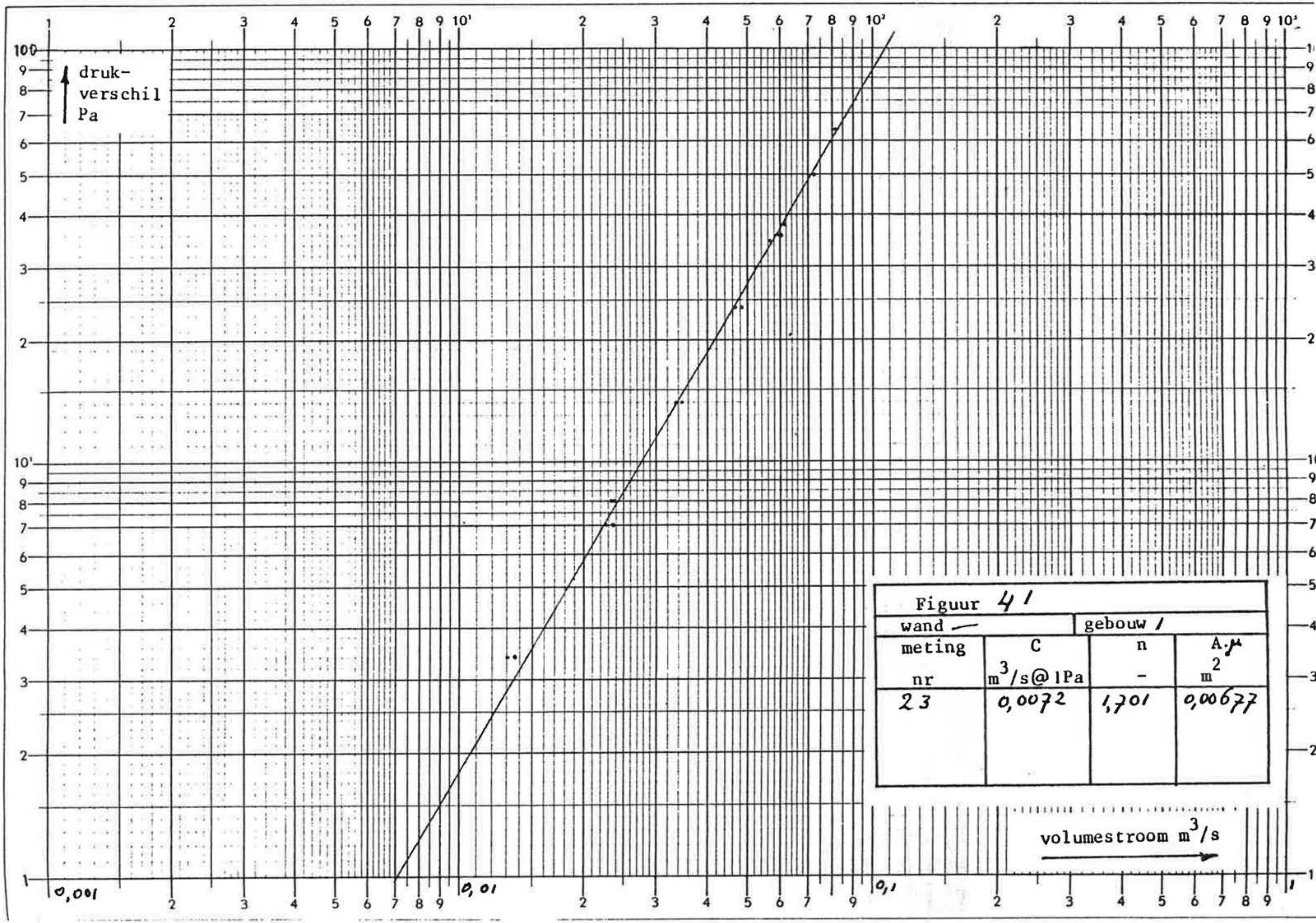


Figuur 39

wand –	gebouw 4		
meting nr	C $m^3/s@1Pa$	n –	A.μ m^2
21	0,0161	1,85	0,0121

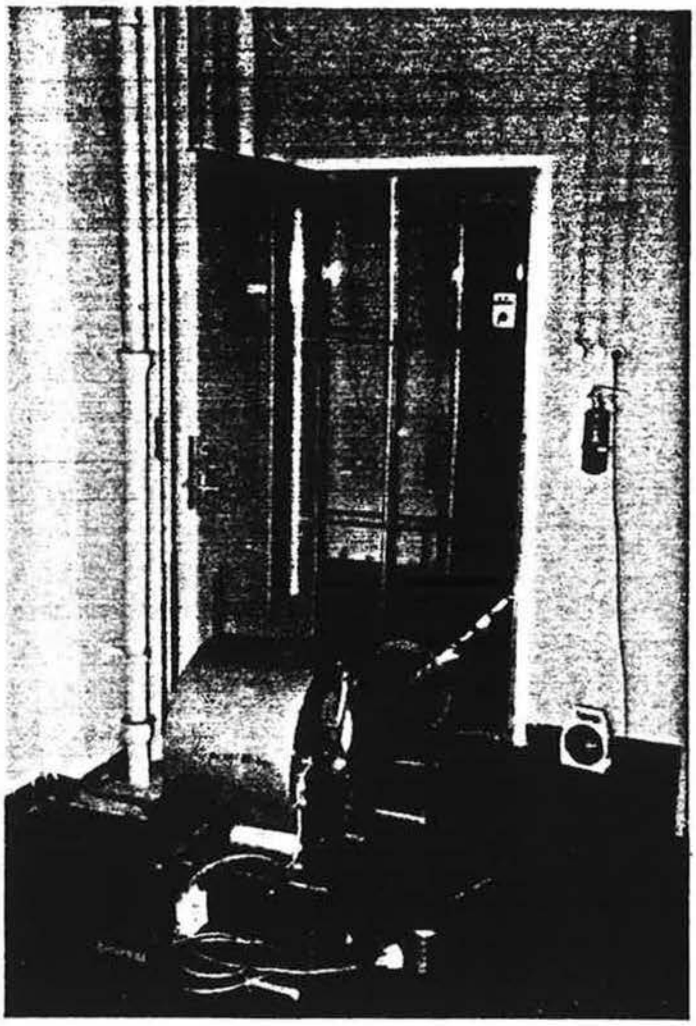


Figuur 40			
wand		gebouw 4	
meting nr	C m^3/s @ 1Pa	n -	A.μ m^2
22	0,0059	1,811	0,00441



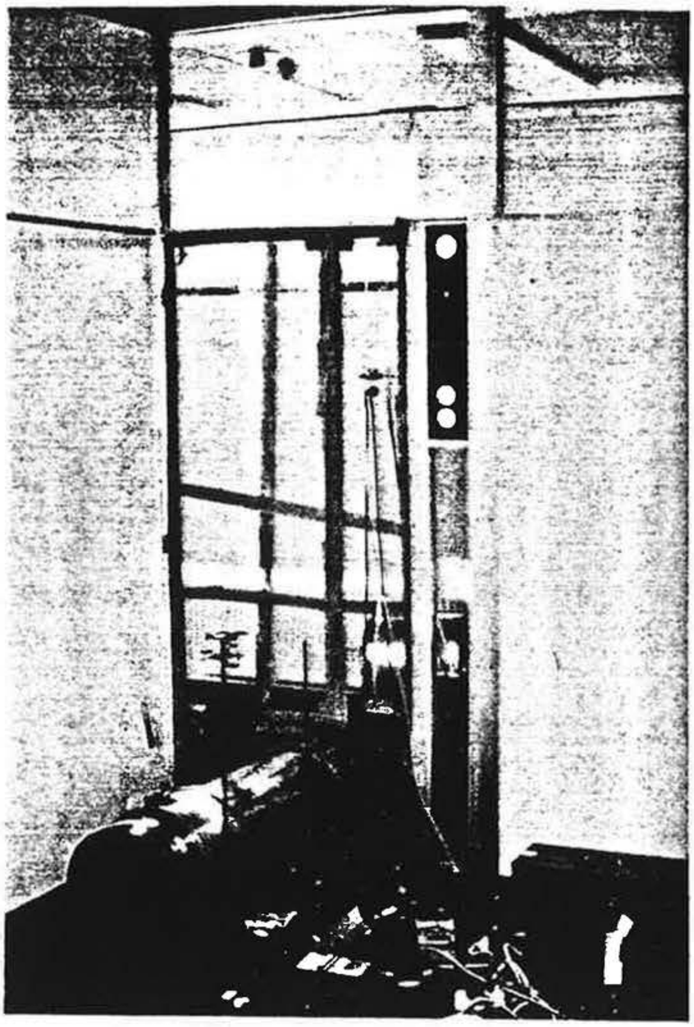
Figuur 41

wand —		gebouw /	
meting nr	C $m^3/s@1Pa$	n –	A.μ m^2
23	0,0072	1,701	0,00677



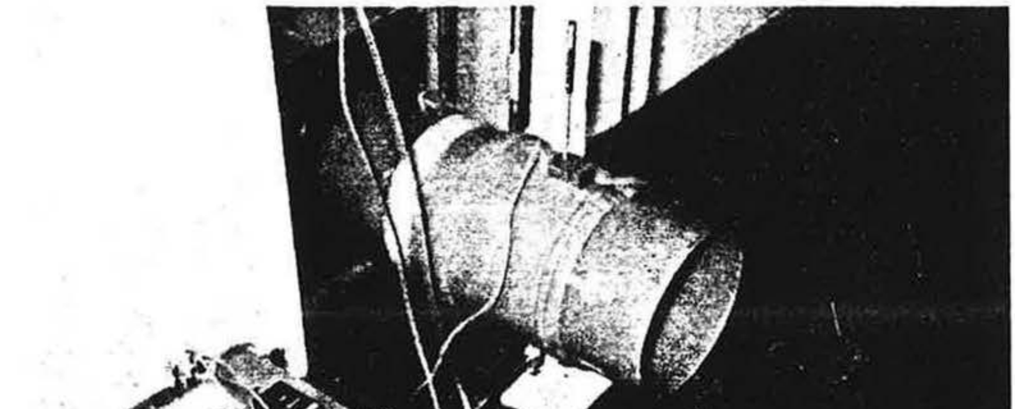
Figuur 42. De opblaasmeetset.

The blow-in measurement set



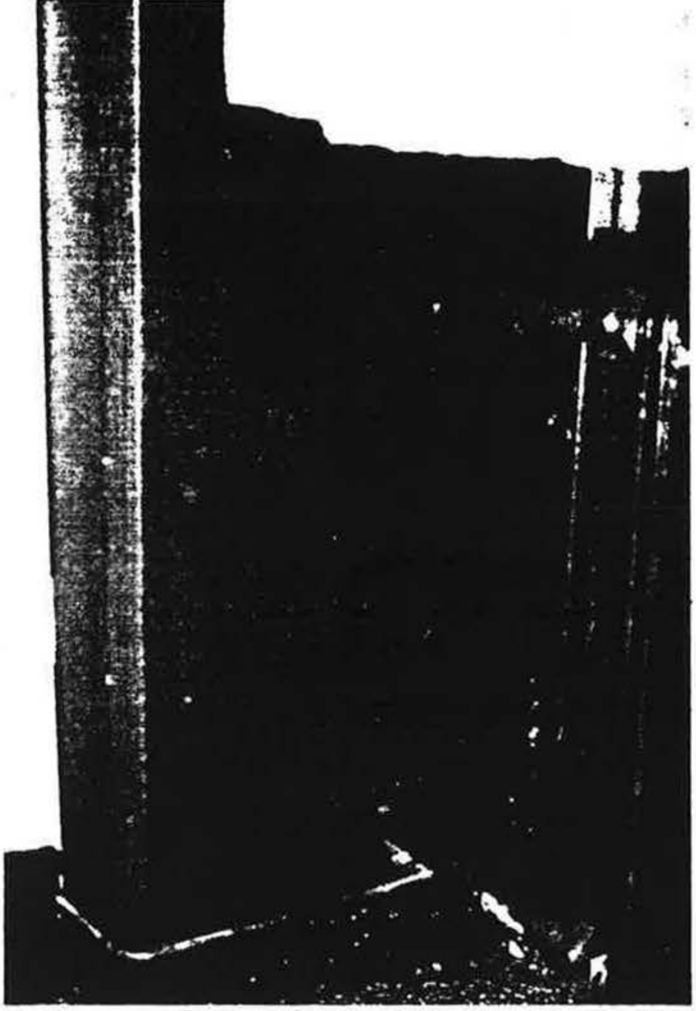
Figuur 43. De uitblaaszijde van de opblaasmeetset in kamer 309 van gebouw 3.

The exhaust side of the blow-in measurement set in room 309 of building 3.

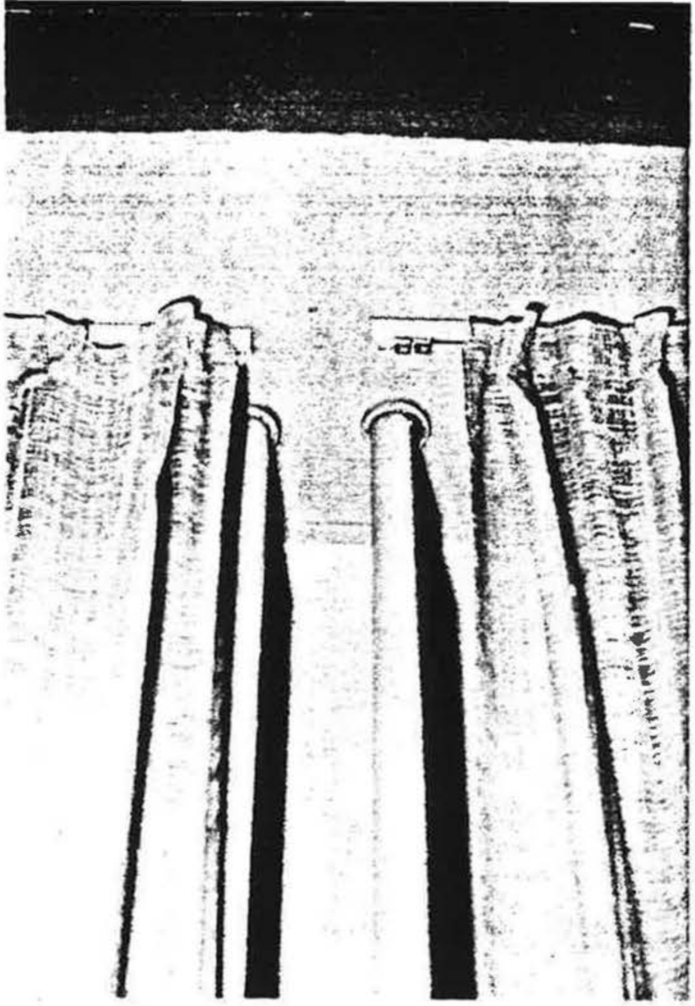


Figuur 44. De uitblaaszijde, drukopnemer (kast links) de verwisselbare diafragma's (op de grond) en de anemometer (uitstekend boven de pijp)

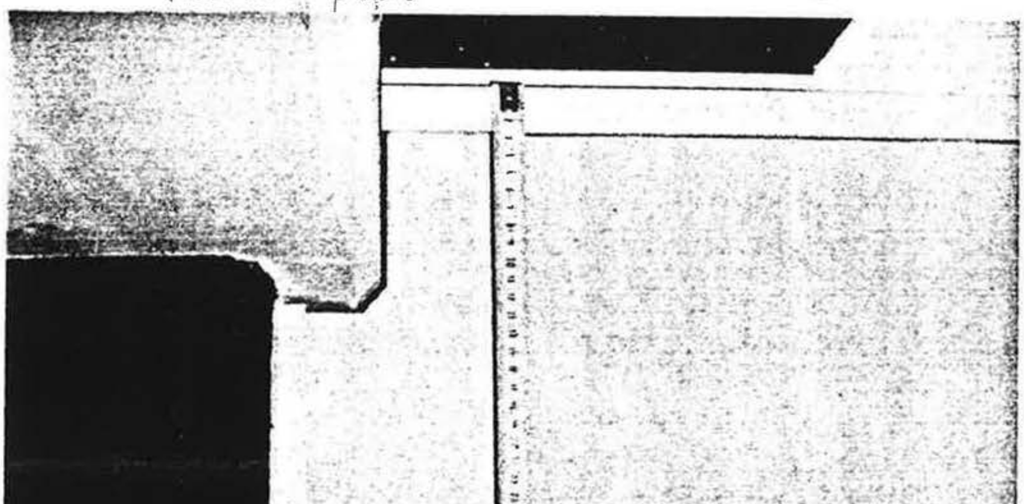
The exhaust side, pressure detector (case shown on the left) the exchangeable diaphragms (on the floor) and the anemometer (protruding above the tube



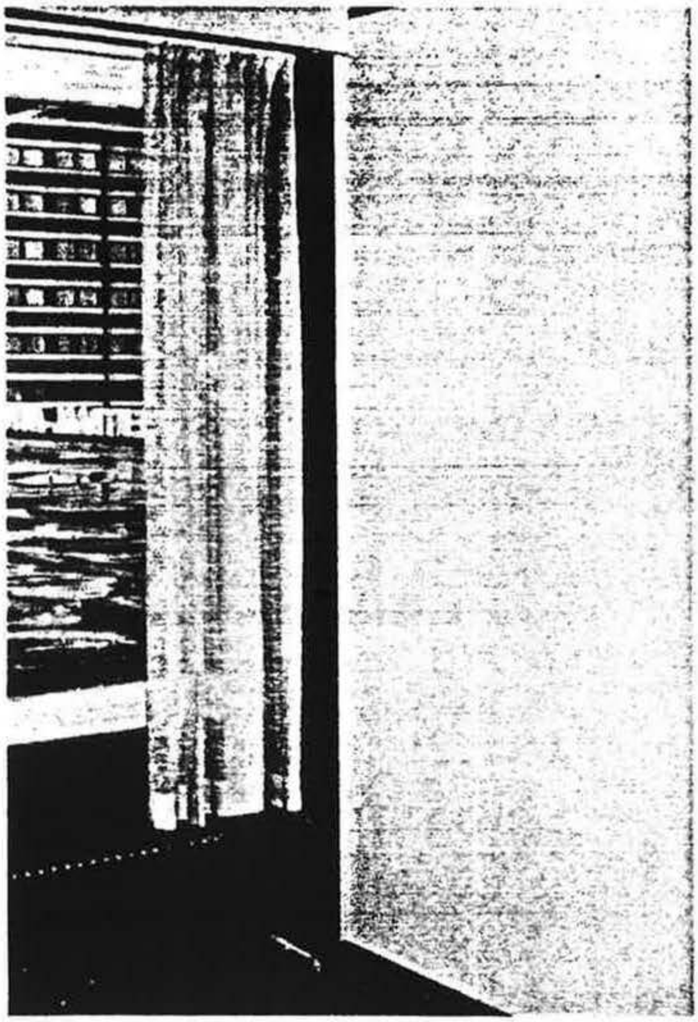
Figuur 45. Zichtbare lekken bij verwarmingsbuizen.
Visible leaks in heating pipes



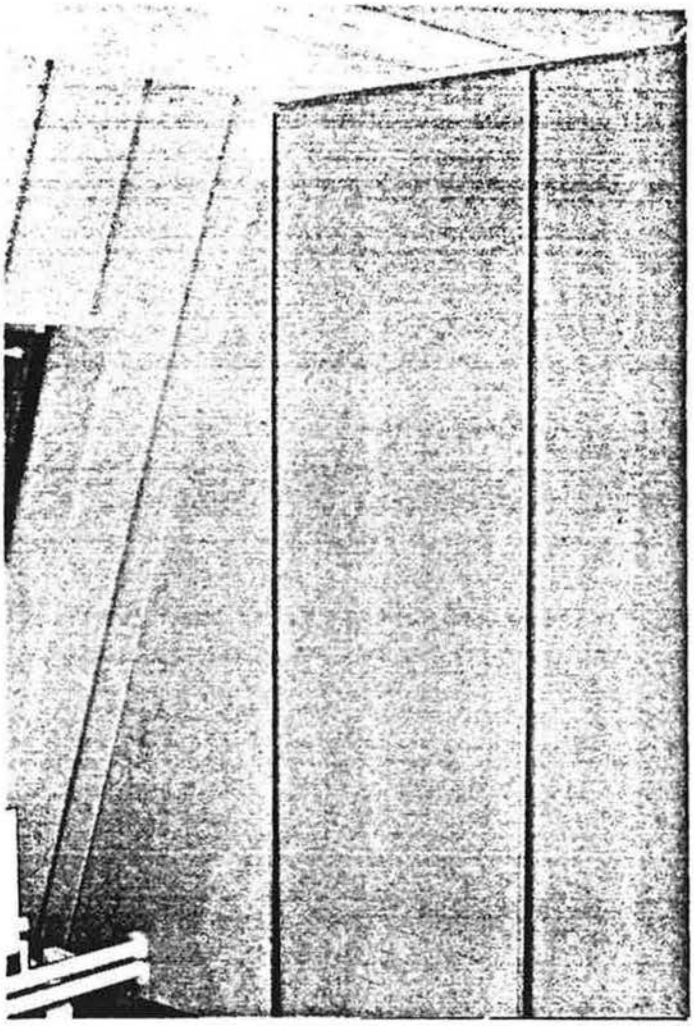
Figuur 46. Zichtbare lekken.
Visible leaks.



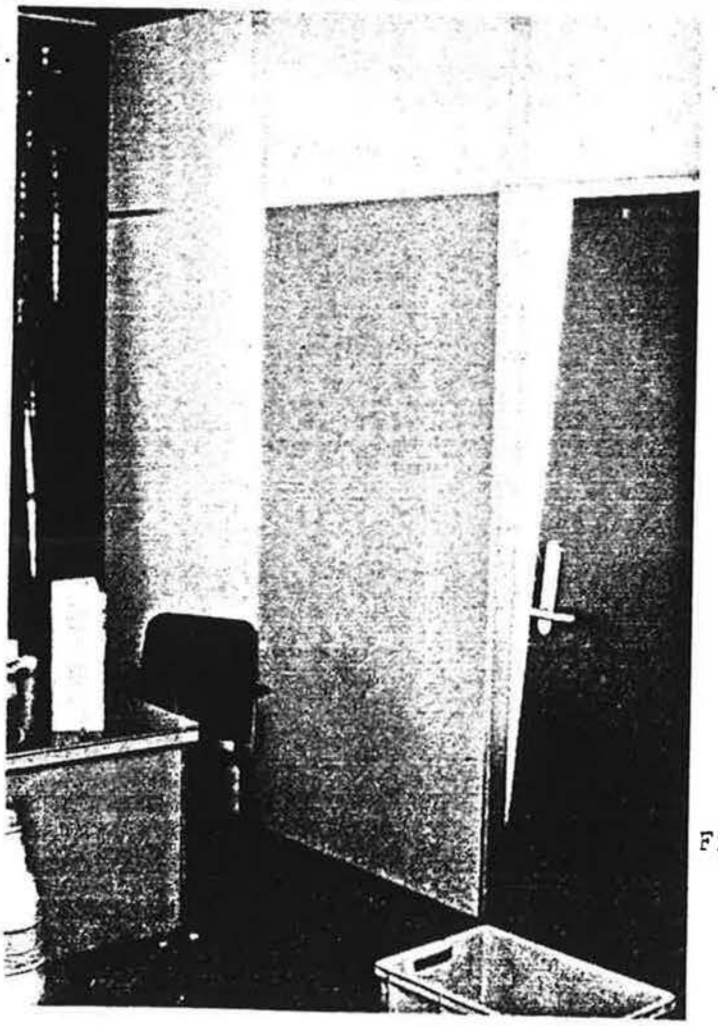
Figuur 47. Lekkende hoekaansluiting van een binnenwand. Door de kier kan in de andere kamer worden gekeken.
Leaky corner joint of an inside wall. It is possible to see into the next room through the crack.



Figuur 48. Gebouw 1.
Building 1.



Figuur 49. Gebouw 2.
Building 2.



Figuur 50. Gebouw 3.
Building 3