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STUDY OF THE ERRORS OCCURRING IN MEASUREMENT OF LEAKAGE DISTRIBUTION IN BUILDINGS BY MULTIFAN PRESSURISATION

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The magnitude and the distribution of leakage in buildings is a major parameter in multizone modelling. The multizone pressurization method used to measure the leakiness is a complex method and the study of the confidence limits of the results shows how carefully they should be used in modelling and where effort should be concentrated to enhance the quality of measurements. In this paper the analytical error functions in two multizone pressurization techniques are derived and a sensitive study of the most important parameters is presented and commented. Finally a comparison of the two methods in realistic cases shows their respective properties and also the severe importance of such a study, the error overpassing in some cases 100%.

1. INTRODUCTION

1.1 Nomenclature

C	Air Conductance, [$m^3\ h^{-1}\ Pa^{-n}$]
E (x)	Relative error of the variable x
n	Exponent
P_m	Pressure in the guarding zone, [Pa]
P_r	Pressure in the room in the deduction method, [Pa]
Q	Airflow, [$m^3\ h^{-1}$]
$Q_{i,\ meas}$	Estimation of the flow Q_i (meas = measured), [$m^3\ h^{-1}$]
q_i	Participation of the element i in the measured flow Q_m, [$m^3\ h^{-1}$]
S (x)	Standard deviation of the variable x
t (P, N)	Student function for P probability and N degrees of freedom

Greek alphabet

ΔP	Pressure difference through a measured wall, [Pa]
ΔPo	Pressure difference which should be zero through a "guarded wall", [Pa]
ΔP_m	Pressure difference used in a measurement, [Pa]
ΔP_{max}	Maximum pressure difference, [Pa]
ΔP_{min}	Minimum pressure difference, [Pa]
δx	Absolute error of x
δq_i	Additional flow through the element i induced by a defect of zero pressure difference, [$m^3\ h^{-1}$]

Indices of Q, C and n

i could be :

e	Indicating a flow or an element between a given room and outside
2, 4	Indicating a flow or an element between a given room and a lateral neighbour
3	Indicating a flow or an element between a given room and the hall

Indices of S and Q

G	Measured with guarding zone technique, or referring to
D	Measured with deduction technique, or referring to
max	Measured at ΔP_{max}
min	Measured at ΔP_{min}
Qm	Referring to the flow measurement accuracy
ΔP	Referring to ΔP pressure measurement accuracy

Example
$S_G\ Q_m\ (Q_i)$ standard deviation in guarded zone technique induced by flow measurement inaccuracy on Q_i estimation

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1.2 Preamble

The multifan pressurization technique can be used to measure air leakage distribution within buildings. Two types of experimental plans can be defined, which leads to different confidences in the results depending widely on the situation of the measured leaks.

After a description of the representation of each experimental plan, the estimators of the leakage parameters are exhibited and discussed.

Some indicative confidence limits are given by assuming some inaccuracies on the measured parameters in typical situations.

It is important to remember that some plans may not be available in buildings because of the limited range of the flowmeters and expected disparity of air tightness.

The leakage coefficients are obtained the following way :

a) for at least two pressure differences through the elements, the flow distribution is measured using a proper planning of experiments, as shown below

b) for each element, the sets (Q, ΔP) obtained are used to fit an empirical law which is most frequently

$$Q = C\,\Delta P^{n} \qquad (1.1)$$

or :

$$\Delta P = a\,Q + b\,Q^{2} \qquad (1.2)$$

Depending on the number of measured points (or measured pairs Q, Δp) two methods can be used.

If there is an absolute confidence in one of these models, the best experimental plan [5] is to measure Q (ΔP) at only two extreme pressures : the lowest and the highest possible and compatible with the instruments and the measured building. These measurements will give two pairs of results : Q_{min}, ΔP_{min} and Q_{max}, ΔP_{max}. The coefficients are then obtained by solving a pair of equations (1.1) or (1.2), which gives :

to get C and n

$$n = \frac{\ln(Q_{min}/Q_{max})}{\ln(\Delta P_{min}/\Delta P_{max})} \qquad (1.3)$$

$$C = Q_{min}\,(\Delta P_{min})^{-n} = Q_{max}\,(\Delta P_{max})^{-n}$$

and to get a and b :

$$a = \frac{\Delta P_{min}\,Q_{max}^{2} - \Delta P_{max}\,Q_{min}^{2}}{Q_{min}Q_{max}\,(Q_{max} - Q_{min})} \qquad (1.4)$$

$$b = \frac{\Delta P_{min}\,Q_{max} - \Delta P_{max}\,Q_{min}}{Q_{min}\,Q_{max}\,(Q_{min} - Q_{max})}$$

If more than two points are measured, the usual least square fit method is used.

2. REPRESENTATION

Figure 2.1 presents the typical situation for a room with three neighbours measured with a two-fans technique. The flows will be all along this chapter referred to in the same way :

Q_e flow between the given room and outside

Q_2, Q_4 flow between the given room and a lateral neighbour

Q_3 flow between the given room and the hall

Q_m measured flow

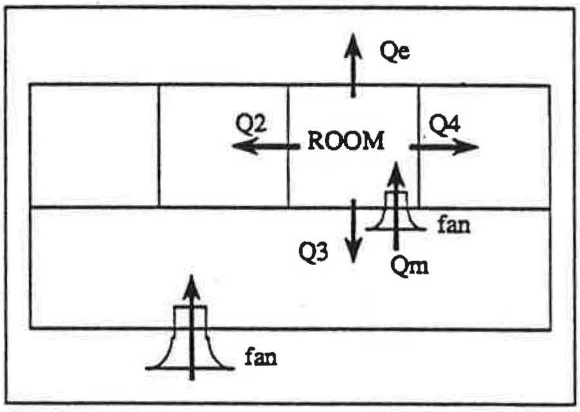

Figure 2.1: The flow during a pressurization test.

Figure 2.2 allows to define the use of the terms *"pressure ring"*, *"room"* and *"outside"* for a better understanding.

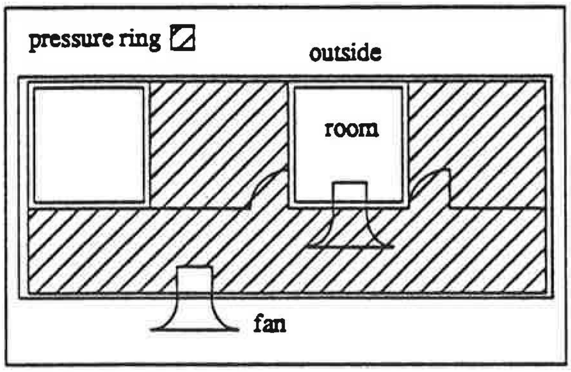

Figure 2.2: Measurement situation

The two experimental plans which can be used to measure the leakage distribution in this case are the so called "deduction method" and "guarding zone method". It is shown below how to use these methods to measure the leakage distribution in buildings.

3. DEDUCTION METHOD

The deduction method consists on varying the pressure p_m in the **pressure ring**, keeping a constant pressure p_r in the room as schematized in figure 3.1 so that :

$$P_r - P_m = \Delta P \qquad (3.1)$$

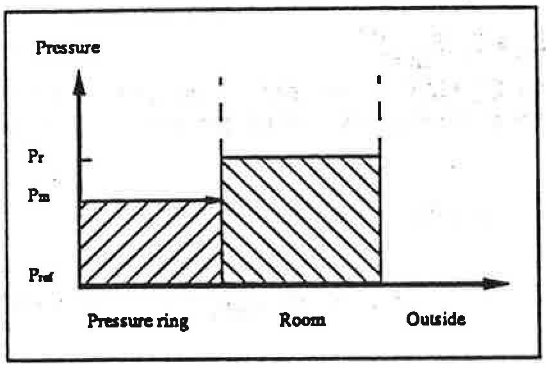

Figure 3.1: Pressure level in pressurization test with deduction method.

By using this method it is possible to measure all the flows Q_e, Q_2, Q_3, Q_4 directly or indirectly, as described hereunder [4].

3.1 *Room-to-hall flow estimation*

The flow $Q_3(\Delta P)$ is available directly from two measurements in the same experiment: by opening windows and closing doors in adjacent rooms, the **pressure ring** is limited to the hall . The experiment is shown in figure 3.2.
The estimator of $Q_3(\Delta P)$ is then :

$$Q_3(\Delta P) = Q_{D1}(P_r - P_m) - Q_{D1}(P_r - P_r)$$

$$Q_3(\Delta p) = Q_{D1}(\Delta P) - Q_{D1}(0) \qquad (3.2)$$

Where P_r is the constant pressure in the room and $Q_{D1}(\Delta P)$ is the result of the experiment D1 at the pressure difference ΔP between the ring pressure and the room.

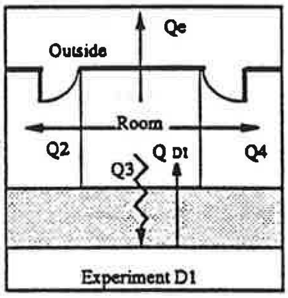

Figure 3.2: Experiment to obtain Q_3 (ΔP) (The zig-zag arrow represents the step-by-step varying pressure).

3.2 *Lateral flow estimation*

It is necessary to perform two experiments D1 and D2 to obtain the lateral flow Q_2 or Q_4..The plan adapted for the measurement of Q_2 (ΔP) is shown in the figure 3.3

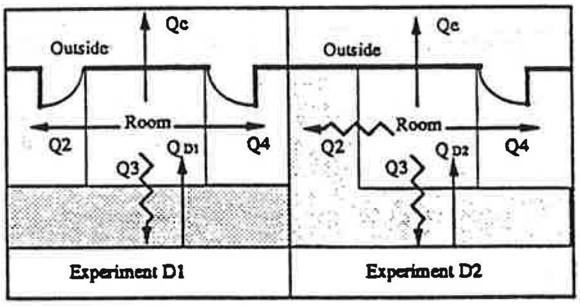

Figure 3.3: The two experiments necessary to obtain a lateral flow with the deduction method.

The estimator of Q_2 (ΔP) is then :

$$Q_2(\Delta P) = Q_{D2}(\Delta P) - Q_{D2}(0) - Q_{D1}(\Delta P) + Q_{D1}(0) \qquad (3.3)$$

3.3 *External flow estimation*

This flow $Q_e(\Delta P)$ also needs two different experiments (figure 3.4). In the first one, D3, the **pressure ring** is constituted by all the adjacent rooms and the second one, T, consists on pressuring only the **room**, keeping the hall and the adjacent rooms at the outside pressure by opening doors and windows.

The estimator of Q_e is then :

$$Q_e(\Delta P) = Q_T(\Delta P) - [Q_{D3}(\Delta P) - Q_{D3}(0)] \quad (3.4)$$

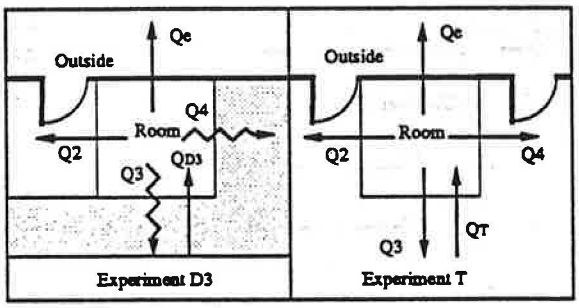

Figure 3.4: The two experiments necessary to obtain the external flow Q_e using the deduction method.

3.4 *Estimation of the errors occurring in flows $Q_i(\Delta P)$*

Now let us look out the error analysis through the deduction process. The preceeding items have shown how to obtain the flows $Q_i(\Delta P)$ of the wall i at the pressure difference ΔP by summing or subtracting flows Q_{Di} from at most 4 measurements at pressure difference ΔP or ΔP_r.

These flows $Q_i(\Delta P)$ are fitted on power law (1.1) in order to obtain the coefficients C_i and the exponents n_i.

This will be made in two steps studying first the relative error $E(Q_i(\Delta P))$ on the flows and using then the general theory on the error propagation for linear regression (3.6)

$$\ln(Q_i) = \ln(C_i) + n_i \ln(\Delta P) \quad (3.5)$$

At this point we are interested to have a confidence limit for the flows Q_i:

$$Q_i = Q_{i,meas} \pm t(P,N)\, S(Q_i) \quad (3.6)$$

The theory of error estimation gives the following estimate of $S(Q_i)$ as function of the deviation of its parameters [1].

$$S^2(Q_i) = \sum \left[\frac{\partial Q_{Di}}{\partial \Delta P_j}\right]^2 S^2(\Delta P_j) + \sum S_Q^2 + \sum \partial q_i^2 \quad (3.7)$$

where S_Q is the own standard deviation of the volumetric measurement obtained during the calibration with a given flowmeter accuracy (5%), δq_i is an additional flow through the conductance i produced by slight pressure differences through conductances where this Δp should be zero.

Applying this at flow Q_3, taking into account that

$$Q_{3,meas} = Q_{D1}(\Delta P) - Q_{D1}(0) \quad (3.8)$$

we have :

$$S^2(Q_3) = S^2(Q_{D1}(\Delta P)) + S^2(Q_{D1}(0)) + \Sigma S_Q^2 + \Sigma \delta q_i^2 \quad (3.9)$$

The standard deviation of that zero pressure difference being $S_{\Delta po}$, we have:

$$\delta q_i = C_i (S_{\Delta po})^{ni} \quad (3.10)$$

As $Q_{D1}(\Delta P)$ is the sum of the flows through several conductances i, its standard deviation is given by :

$$S^2(Q_{D1}(\Delta P)) = \sum \left[\frac{\partial Q_i}{\partial \Delta P_j}\right]^2 S^2(\Delta P_j)$$

$$= \sum n_i^2 q_i^2 \left(\frac{S_{\Delta Pi}}{\Delta Pi}\right)^2 \quad (3.11)$$

and finally

$$s^2(Q_{D1}) = \sum_{i \neq 3} n_i^2 q_i^2 \left(\frac{S_{\Delta Pr}}{\Delta Pr}\right)^2 + n_3^2 q_3^2 \left(\frac{S_{\Delta P}}{\Delta P}\right) \quad (3.12)$$

Table 3.1 shows the relative error $S_{\Delta P}(Q_i)/Q_i$ caused by pressure instabilities and assuming a constant exponent n for every element, while table

$$E_{D,\Delta p}(Q_e) = \{ n^2 \frac{s_{\Delta p}^2}{\Delta p^2} \left[2 \sum_{i=2}^{4} \frac{C_i^2}{C_e^2} + 2\left(\frac{\Delta p_r}{\Delta p}\right)^{2n} + 1 \right] + \left(\frac{s_{\Delta po}}{\Delta p}\right)^{2n} \sum_{i=2}^{4} \frac{C_i^2}{C_e^2} \}^{1/2}$$

$$E_{D,\Delta p}(Q_2) = \{ n^2 \frac{s_{\Delta p}^2}{\Delta p^2} \left[2 \frac{C_3^2}{C_2^2} + \left(\frac{\Delta p_r}{\Delta p}\right)^{2n} \left[4 \frac{C_e^2 + C_4^2}{C_2^2} + 2\right] + 1 \right] + \left(\frac{s_{\Delta po}}{\Delta p}\right)^{2n} \left[2 \frac{C_3^2}{C_2^2} + 1\right] \}^{1/2}$$

$$E_{D,\Delta p}(Q_3) = \{ n^2 \frac{s_{\Delta p}^2}{\Delta p^2} \left[2 \left(\frac{\Delta p_r}{\Delta p}\right)^{2n} \sum_{i=1}^{4} \frac{C_i^2}{C_3^2} + 1 \right] + \left(\frac{s_{\Delta po}}{\Delta p}\right)^{2n} \}^{1/2}$$

$E_{D,\Delta p}(Q_4)$: like $E_{D,\Delta p}(Q_2)$ but permutating C_2 and C_4

Table 3.1: Relative errors $s_{\Delta p}/Q_i$ occuring in the deduction method for flow Q_i and caused by the pressure instabilities,being assumed: a perfect flow measurement, a constant relative error $s_{\Delta p}/\Delta p$ on the pressure differences Δp_i and Δp_r, a constant exponent n and a standard deviation $s_{\Delta po}$ for zero pressure differences.

$$E_{D,Qm}(Q_e) = E(Q_m)\{ 2\left(\frac{\Delta p_r}{\Delta p}\right)^{2n} + 2\left[\left(\frac{\Delta p_r}{\Delta p}\right)^{n} + 1\right] \sum_{i=2}^{4} \frac{C_i}{C_e} + 2 \left[\sum_{i=2}^{4} \frac{C_i}{C_e}\right]^2 + 1 \}^{1/2}$$

$$E_{D,Qm}(Q_2) = E(Q_m)\{ \left(\frac{\Delta p_r}{\Delta p}\right)^{2n} [4\chi^2 + 4\chi + 2] + \left(\frac{\Delta p_r}{\Delta p}\right)^{n} [2\chi(1 + 2\zeta) + 2\zeta] + 2\zeta^2 + 2\zeta + 1 \}^{1/2}$$

where $\chi = (C_e + C_4)/C_2$ and $\zeta = C_3/C_2$

$$E_{D,Qm}(Q_3) = E(Q_m)\{ 2\left(\frac{\Delta p_r}{\Delta p}\right)^{2n} \left(\sum_{i\neq 3} \frac{C_i}{C_3}\right)^2 + 2\left(\frac{\Delta p_r}{\Delta p}\right)^{n} \left(\sum_{i\neq 3} \frac{C_i}{C_3}\right) + 1 \}^{1/2}$$

$E_{D,Qm}(Q_4)$: like $E_{D,Qm}(Q_2)$ but permutating C_2 and C_4

Table 3.2: Relative errors s_Q/Q_i occuring in the deduction method for flow Q_i and caused by errors in the flow measurements. A constant exponent n is assumed.

3.2 shows the part S_Q/Q_i of the error coming from the errors in flow measurements. The total error is the geometrical average of these two elements:

$$S(Q_i) = \sqrt{(S_{\Delta P}(Q_i))^2 + (S_Q(Q_i))^2} \quad (3.13)$$

More synthetically it is to be understood that the flow Q_i looked for is obtained by difference between large flows, which may have acceptable absolute errors, but this error will be large when compared to the small difference. The disadvantage of this method is the number of flow measurements needed to obtain some individual flows.

It is also easily understood that the tightest the measured element is, the worst will be the confidence in the result.

4 GUARDING ZONE METHOD

In the guarding zone method the pressure in the **pressure ring** (guarding zone) is always the same as that of the **room** (guarded zone) as illustrated in figure 4.1

In the experimental schemes the guarded walls are indicated as hatched zones as in figure 4.2.

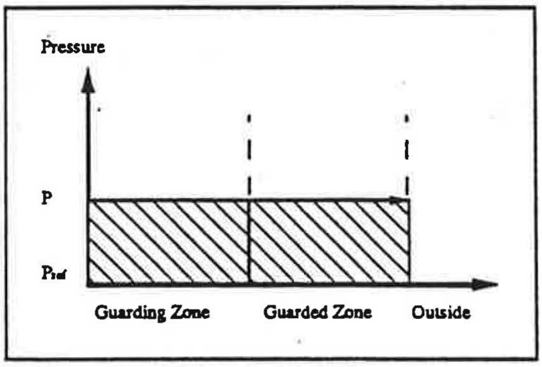

Figure 4.1: Pressure levels in pressurization test with guarding zone method.

4.1 External flow estimation

External flow $Q_e(\Delta P)$ is available in one experiment G1 presented in figure 4.2

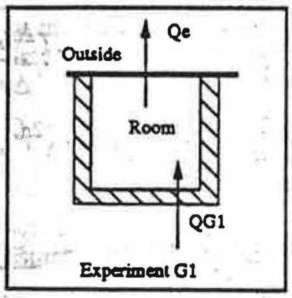

Figure 4.2: The experiment necessary to obtain the external flow Q_e using the guarding zone method.

The estimator is the simplest one :

$$Q_e(\Delta P) = Q_{G1}(\Delta P) \quad (4.1)$$

4.2 Lateral flow estimation

Using the same type of experimentation plan as previously, e.g. changing the guarding zone by opening windows and closing doors, it is possible to measure the lateral Q_2 or Q_4 (figure 4.3).

$Q_2(\Delta P)$ or $Q_4(\Delta P)$ is given by :

$$Q_2(\Delta P) = Q_{G2}(\Delta P) - Q_{G1}(\Delta P) \quad (4.2)$$

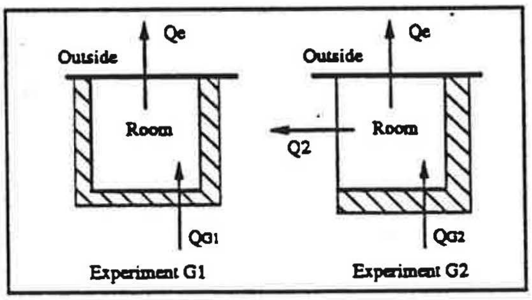

Figure 4.3: The experiments necessary to obtain the lateral flow Q_2 (ΔP) using the guarding zone method.

4.3 Room to hall flow estimation

The plan presented in figure 4.4 give the following estimator for $Q_3(\Delta P)$

$$Q_3(\Delta P) = Q_T(\Delta P) - Q_{G3}(\Delta P) \quad (4.3)$$

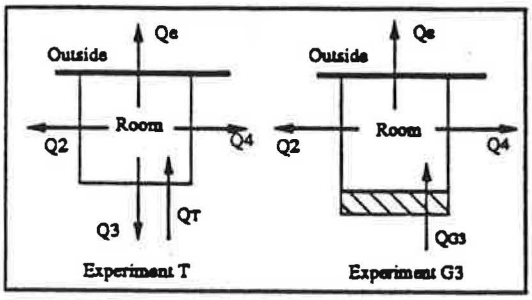

Figure 4.4 : The experiments necessary to obtain the flow Q_3 (ΔP) using the guarding zone method.

4.4 Estimation of the errors occurring in flows $Q_i(\Delta P)$

Using the same hypothesis as previously for the deduction method, we obtain for the guarding zone method the relative errors listed in table 4.1 and 4.2 obtained using (3.9).

In next chapter, the error of the two methods will be estimated assuming some simplifications in order to be compared.

4.5 Errors on the coefficients

The error $\delta y = t\,(P, N)\, S(x_i)$ on the results $y = y(x_1, ..., x_i, ...)$ can be deduced from the standard deviations of the measurements $s\,(x_i)$ using the following relations :

$$S^2\,(y) = \sum \left(\frac{\partial y}{\partial x_i}\right)^2 S^2\,(x_i) \qquad (4.4)$$

As an example, let us apply the equation (4.4) to the formulas (1.3). Calculating $\partial n/\partial Q$ and $\partial n/\partial \Delta p$, we find finally :

$$S^2(n) = \frac{1}{D}\left[\left(\frac{S(Q_{min})}{Q_{min}}\right)^2 + \left(\frac{S(Q_{max})}{Q_{max}}\right)^2 + n^2\left(\frac{S(\Delta P_{min})}{\Delta P_{min}}\right)^2 + \left(\frac{S(\Delta P_{max})}{\Delta P_{max}}\right)^2\right] \qquad (4.5)$$

where : $D = \ln\left(\frac{\Delta P_{min}}{\Delta P_{max}}\right)^2$

and for C :

$$S^2(C) = C^2\,[(S(Q_{min})/Q_{min})^2 + (n\,S(\Delta P_{min})/\Delta P_{min})^2 + (\ln \Delta P_{min})^2\,S^2(n)] \qquad (4.6)$$

or, depending on the measurement point used to calculate C :

$$S^2(C) = C^2\,[(S(Q_{max})/Q_{max})^2 + (n\,S(\Delta P_{max})/\Delta P_{max})^2 + (\ln \Delta P_{max})^2\,S^2(n)]$$

And the error on any further estimate Q obtained using the equation (1.1) with the estimated coefficients C and n will be :

$$S^2(Q) = Q^2\,[(S(C_i)/C_i)^2 + (n\,S(\Delta P_i)/\Delta P_i)^2 + (\ln \Delta P_i)^2\,S^2(n)] \qquad (4.7)$$

$$E_{G,\Delta p}(Q_e) = \left\{ n^2 \left(\frac{s_{\Delta p}}{\Delta p}\right)^2 + \left(\frac{s_{\Delta po}}{\Delta p}\right)^{2n} \left(\frac{\sum_{i \neq e} C_i^2}{C_e^2}\right) \right\}^{1/2}$$

$$E_{G,\Delta p}(Q_2) = \left\{ n^2 \left(\frac{s_{\Delta p}}{\Delta p}\right)^2 \left(2 \left(\frac{C_e}{C_2}\right)^2 + 1\right) + \left(\frac{s_{\Delta po}}{\Delta p}\right)^{2n} \left(2\,\frac{C_3^2 + C_4^2}{C_2^2} + 1\right) \right\}^{1/2}$$

$$E_{G,\Delta p}(Q_3) = \left\{ n^2 \left(\frac{s_{\Delta p}}{\Delta p}\right)^2 \left(\frac{2}{C_2} \sum_{i=1}^{4} C_i^2 - 1\right) + \left(\frac{s_{\Delta po}}{\Delta p}\right)^{2n} \right\}^{1/2}$$

$E_{G,\Delta p}(Q_4)$: like $E_{G,\Delta p}(Q_2)$ but permutating C_2 and C_4

Table 4.1: Relative errors occurring in the guarding zone method for the estimation of the flow $Q_i(\Delta_p)$, being assumed a constant relative error on the pressure difference Δp_n and Δp_r, a constant exponent n for every elements and a standard deviation $s_{\Delta po}$ for the pressure difference $\Delta p = 0$, s_m comes from the flow meter inacurracy.

5. STUDY AND COMPARISON OF ERRORS OCCURING IN FLOW ESTIMATIONS

Looking at equations in table 3.1, 3.2, 4.1 or 4.2, it is obvious that the evaluation of the effects of parameters variation on the errors is not simple. For this reason a sensitive study was performed on the six functions S_{Q_i} to extract the most important influences. The seven parameters listed in table 5.1 have served to test the sensitivity of the variance functions. The table presents also the highest, the medium and the lowest values of these parameters taken into account in this study for each variables. These values are choosen in accordance with the measurement performed in the LESO-building [3].

The variation of the exponent from an element to another was not considered.

The parameters have been screened by fitting a linear model on the results of a factorial planning (estimation of 128 cases of the function with every parameters taken alternatively at the lowest and highest level) [5].

The model has the form (5.1)

$$S(Q_i) = b_0 + \sum b_i X_i + \sum_{i \neq j} b_{ij} X_i X_j + \sum_{\substack{i \neq j \\ i \neq k \\ j \neq k}} b_{ijk} X_i X_j X_k + \dots\dots\dots + b_{1234567} X_1 X_2 X_3 X_4 X_5 X_6 X_7 \qquad (5.1)$$

for parameters X_i.

The largest coefficients identify the major parameters and interactions. Care should be taken on parameters which could have a very non linear and non monotonic influence as the exponent n.

5.1 Study of S_{Q_e}

The result of the screening for S_{Q_e} is presented in figure 5.1.

N°	Name	Symbol	Lowest	Medium	Highest
1	External conductance	C_e [$m^3/h\ Pa^n$]	2	6	10
2	Lateral conductance	C2 [$m^3/h\ Pa^n$]	0	5	10
3	Internal conductance	C3 [$m^3/h\ Pa^n$]	10	15	20
4	Exponent	n [-]	.5	.75	1.0
5	Press. diff. accuracy	S (ΔP)/ΔP [%]	2	6	10
6	Zero press. diff. accur.	S (ΔPo) [Pa]	.05	.275	.5
7	Flow meas. accuracy	E (Q) [%]	2	6	10

Table 5.1 Studied parameters with the considered levels.

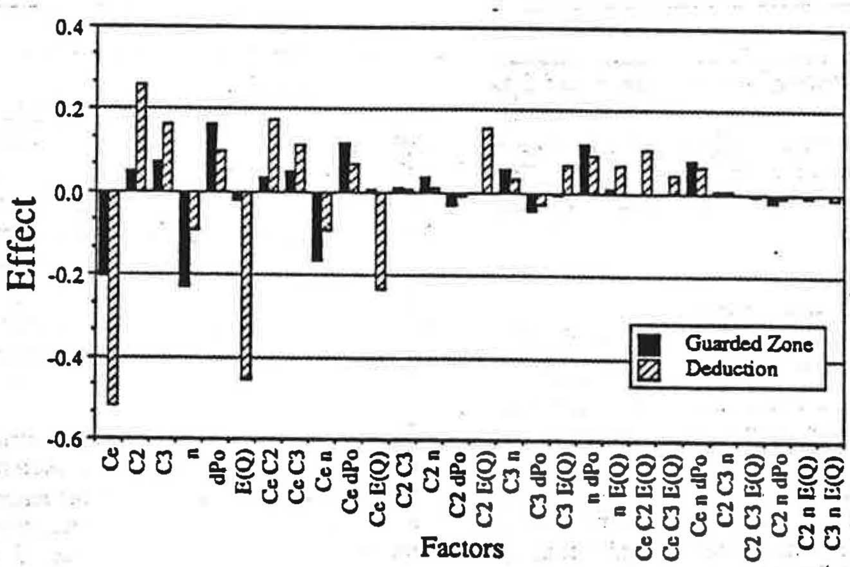

Figure 5.1 : Major effects in the error for Q_e. The unlisted effects are negligible. The sign indicates the direction of the effect.

The major effects are clearly seen : the errors in the guarded zone technique are sensitive to the variation of C_e, n, S(ΔPo) while the errors in the deduction method are sensitive to the error in the measurement of the flows. E (Q) and the conductances themselves. The interaction two by two of the major effects are often important. It is the case for the interaction C_e-n, C_e-S(ΔPo) , n-S(ΔPo) for guarding zone technique and C_e-C_2, C_e - E(Q), C_2- E(Q) for the deduction method.

It is interesting to note the difference of sensitivity of the two methods for the same factor. The most typical case are the factor n and the factor E(Q).

5.1.1 Exponent influence

The influence of the exponent n, shown in figure 5.2 (and calculated from the functions of table 3.1, 3.2, 4.1 and 4.2) is not trivial at all and can illustrate perfectly how to integrate the coefficients of the linear model.

In the guarded zone method $\delta(Q_e)$ is strongly influenced by the value of the exponent (every other parameters are taken at medium level) and has a monotonic evolution since in the other method the influence is not important but the error, depending on the other parameters is larger and is not monotonic.

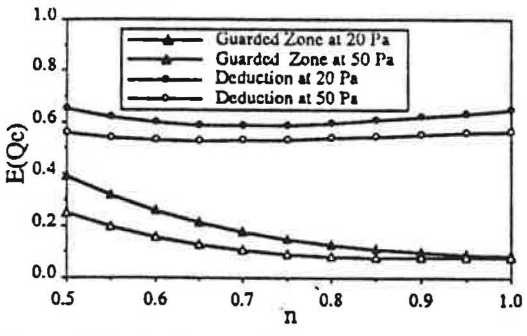

***Figure 5.2 :** Influence of the exponent n and S_{Q_e} / Q_e (see tables 3.1, 3.2, 4.1, 4.2) for the two methods when the pressure difference ΔP through the measured element is taken at 20 [Pa] or 50 [Pa] and other Parameters are taken at medium levels (see table 5.1).*

5.1.2 External conductance influence

A strong influence of the external air-conductance is expected. The figure 5.3 shows a hyperbolic behaviour, the error going down when C_e is growing. This result is a conjugated consequence of the facts that the unmeasured conductances have an influence on the error and that the external wall is the tightest one. The measurement usually consists to measure a small flow in presence of undesirable additional flows which may easily be important (also for little zero pressure defect) because they occur through untighter walls.

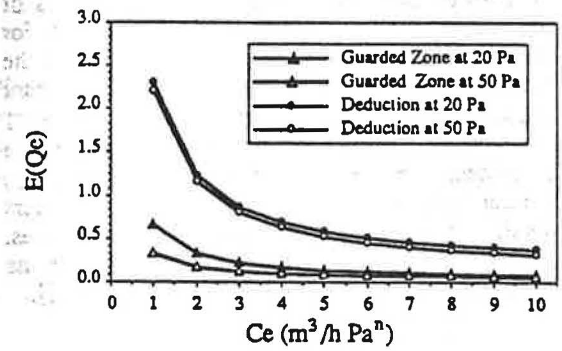

***Figure 5.3** Influence of the external conductance C_e on S_{Q_e}/Q_e (see tables 3.1, 3.2, 4.1 and 4.2) when the pressure difference ΔP through the measured element is taken at 20 [Pa] or 50 [Pa] and other parameters are taken at medium levels (see table 5.1).*

5.1.3 Zero pressure difference influence

The influence of the zero pressure difference deviation S(ΔPo) on S_{Q_e}/Q_e is linear for the two methods as shown in figure 5.4. In accordance with the result of the screening method (fig. 5.1) the guarding zone technique is more sensitive to this parameter than the deduction technique.

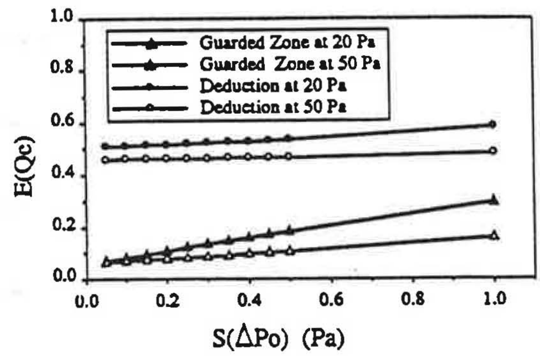

***Figure 5.4 :** Influence of the zero pressure deffect S(ΔPo) on S_{Q_e}/Q_e for the two methods when the pressure difference ΔP through the measured element is taken at 20 [Pa] or 50 [Pa] and other parameters are taken at medium levels (see table 5.1).*

5.1.4 Flowmeter accuracy effect

The influence of the flowmeter accuracy is a problem mainly for the deduction method. This is because in this method the desired flow Q_i is obtained by difference of larger flows Q_{Di} (see chapter 3.3) and the error, which is proportional to the measured flow, has a critical influence on the smaller flow estimations.

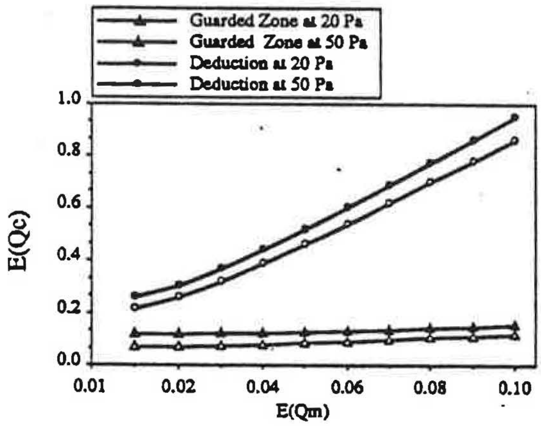

***Figure 5.5** : Influence of the flowmeter precision E(Q) on S_{Qe}/Q_e for the two registered methods when the pressure difference ΔP through the measured element is taken at 20 [Pa] or 50 [Pa] and other parameters are taken at medium levels (see table 5.1).*

The study of major effects have shown a clear advantage for the guarded zone method and the conjugated effects are not important enough to change this fact. In chapter 6 the two methods are compared in realistic situations and herein after the result for internal and lateral flow are commented.

5.2 Study of S_{Q2} and S_{Q3}

The measurement of Q_2 and Q_3 have more or less the same behaviour than Q_e concerning the errors with sometimes an attenuation or an accentuation with the increase of pressure ΔP. But it can be noted, for example, that S_{Q2} is generally of higher magnitude and that the sensitivity of Q_3 to parameter C_3 is smoother than Q_e and Q_2 with their respective conductances C_e and C_2 (fig. 5.6). The latter is probably explained by the fact that the explored range of C_3 is higher than the ranges of C_e and C_2.

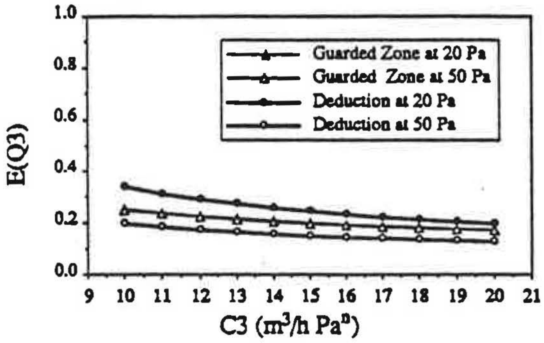

***Figure 5.6** : Influence of C_3 on S_{Q3}/Q_3 for the two registered methods when the pressure difference ΔP through the measured element is taken at 20 [Pa] or 50 [Pa] and other parameters are taken at medium levels (see table 5.1).*

6. COMPARISON OF THE TWO METHODS

In accordance with the previous chapters we have choosen some interesting points to compare the two methods.

The parameters can be sorted in two series : the room parameters depending on the building to be measured and the technical parameters as the accuracy of the instruments.

Table 6.1 describes the evaluated situation taking into account what is met in the field [3].

	Building parameters				Technical parameters			
Situation	Ce [m³/h Paⁿ]	C2 [m³/h Paⁿ]	C3 [m³/h Paⁿ]	n [-]	E(ΔP) %	S(ΔPo) [Pa]	E(Q) %	Comment
1	10	10	10	.65	2	.5	5	Uniform conductance
2	5	10	10	.65	2	.5	5	Medium conductance
3	2	10	20	.65	2	.5	5	Extreme conductance
4	2	10	20	.65	1	.1	2	Very good instruments

***Table 6.1** :* Comparison situations.

6.1 Error on Qi estimation

The results are exibited in the table 6.2. The bar charts 6.1 to 6.4 present a comparison of the two methods.

20 Pa	GUARDING ZONE			DEDUCTION		
CASE	ε(Qe)	ε(Q2)	ε(Q3)	ε(Qe)	ε(Q2)	ε(Q3)
1	.17	.23	.32	.40	.57	.44
2	.32	.22	.28	.67	.48	.37
3	1.12	.31	.18	1.95	.54	.20
4	.39	.11	.07	.75	.21	.08

50 Pa	GUARDING ZONE			DEDUCTION		
CASE	ε(Qe)	ε(Q2)	ε(Q3)	ε(Qe)	ε(Q2)	ε(Q3)
1	.11	.16	.31	.36	.35	.26
2	.21	.14	.27	.60	.30	.22
3	.71	.18	.17	1.73	.36	.13
4	.25	.06	.07	.68	.14	.05

Table 6.2 : Relative error for registered situation (table 6.1) at 20 [Pa] and 50 [Pa].

In the uniform situation, where the leakage is the same for every element, the relative error at 20 [Pa] is between 17% and 32% for the guarding zone method while it ranges from 40% to 57% for the deduction method. The error diminishes with the increase of the pressure difference. In figure 6.1 it is also possible to observe the difference between the two methods for each conductance.

At this point it is important to notice the magnitude of the relative error.

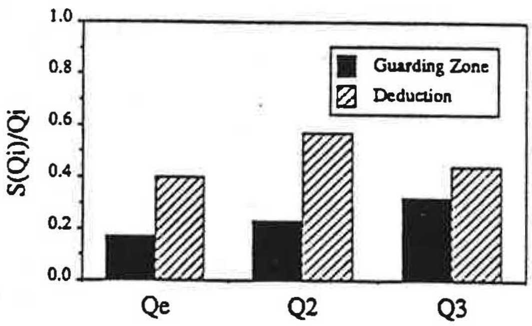

Figure 6.1 : Comparison of the standard relative errors S_{Qi}/Q_i at 20 [Pa] when the leakage is uniformely distributed (see table 6.1).

In situation 2, qualified as medium, the external conductance is tighter than in the previous case. It is the case of a field situation with a relatively leaky façade. When the conductance C_e is the half of the previous one, the error has doubled, but the error on the other elements are smaller (table 6.2).

Figure 6.2 shows clearly that now the error on Q_e is the largest and its magnitude is becoming critical (67%) for the deduction method.

However the critical point is clearly passed in the case 3 by the two methods (fig. 6.3).

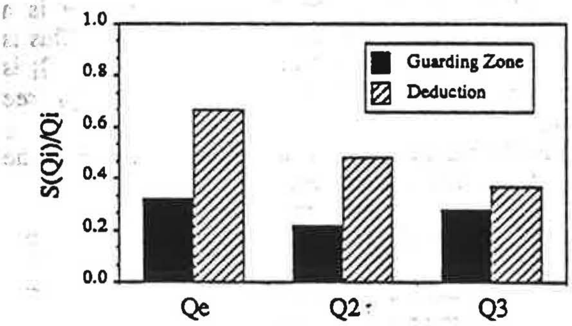

Figure 6.2 : Comparison of the standard relative errors S_{Qi}/Q_i at 20 [Pa] the leakage is distributed as usually in the field (see table 6.1).

The error on Q_e reaches 100 % and the error on Q_2 overpass 50%. And this leakage distribution is not extreme at all : it represent the situation very common in the field of a tight façade with leaky internal walls, as in some rooms of the LESO building [3].

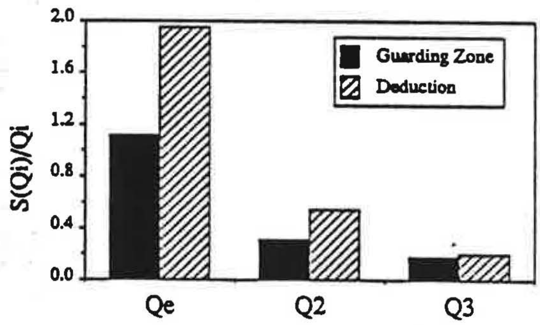

Figure 6.3 : Comparison of the standard relative errors S_{Qi}/Q_i at 20 [Pa] the leakage distribution is typical for a tight façade (see table 6.1).

Case 4 (fig. 6.4) shows the influence of a technical improvement in the instruments. The flowmeter has an accuracy of 2% and the pressure measurement is accurate to 1%. The results, which are not much better than before, show how it is difficult to improve the result.

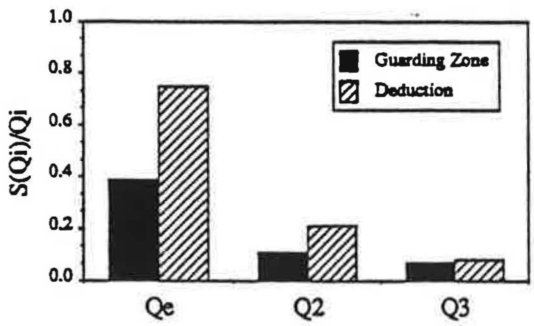

Figure 6.4 : Comparison of the standard relative errors S_{Qi} (Q_i at 20 [Pa] if a special effort is put on the accuracy of instruments (see table 6.1).

6.2 *Error on coefficients C_i and n_i estimation*

Applying equations 4.5 and 4.6, the standard deviation on the coefficients C_i and n_i are obtained for the four situations. The results are shown in tables 6.3 and 6.4 The conficence are then an order of magnitude larger because of the propagation of errors in non linear equation.

	GUARDING ZONE			DEDUCTION		
CASE	E(Ce)	E(C2)	E(C3)	E(Ce)	E(C2)	E(C3)
1	1.03	1.44	2.26	2.75	3.40	2.58
2	1.94	1.32	2.00	4.57	2.90	2.22
3	6.74	1.82	1.26	13.23	3.29	1.23
4	2.37	.65	.49	5.15	1.29	.49

Table 6.3 : Relative error S_{ci}/C_i for registered situations C_i being estimated from measurement at 20 [Pa] and 50 [Pa].

	GUARDING ZONE			DEDUCTION		
CASE	E (ne)	E (n2)	E (n3)	E (ne)	E (n2)	E (n3)
1	.34	.48	.75	.91	1.12	.85
2	.64	.44	.66	1.51	.95	.73
3	2.22	.60	.42	4.37	1.08	.41
4	.78	.21	.16	1.70	.42	.16

Table 6.4 : Relative error S_{ni}/n_i for registered situations n_i being estimated from measurement at 20 [Pa] and 50 [Pa].

7. CONCLUSION

It is obvious, in front of the large confidence limits exhibited for typical cases, that the error analysis is of great importance in multizone pressurization techniques, mainly when the results of these measurements are to be introduced into multizone infiltration models in order to validate them.

The main instrumental source of error in the guarded zone technique is the control of the zero pressure difference between the guarding and the measured zones, when it is the accuracy of the air flow measurement which is critical in the deduction method.

For the conditions usually encountered in the field, the guarded zone technique is generally more accurate than the deduction method.

The confidence intervals of the results are broad, and may be of the same order of magnitude as the results themselves. These large error domains are usual, even for the optimal experimental plans presented above. They may be even larger e.g. if the flows for a given pressure difference are not measured directly but interpolated from other measurements.

It seems hard to believe that the confidence intervals are so large, since in most experiments, the measured points are well aligned on a logarithmic flow-versus-pressure diagram. It should be remembered here that the logarithmic diagram precisely hides the variations and linearizes many functions. This fact may explain why it was not possible, till now, to decide which crack flow model (equations 1.1 or 1.2) corresponds best to the reality.

Since errors can be large and depend on the effective values of the measured conductances, a great effort is needed to improve the accuracy of the instruments. As a consequence, it seems hopeless to plan multi-fan measurements with inaccurate instruments, such as blower doors, without examining carefully, before the experiment, the errors to be expected.

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