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Paper 13

**THE USE OF A GUARDED ZONE PRESSURIZATION
TECHNIQUE TO MEASURE AIR FLOW PERMEABILITIES
OF A MULTI-ZONE BUILDING**

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SYNOPSIS

In the past few years, research efforts have been made to acquire accurate knowledge about infiltration and ventilation in multi-zone buildings. By this way, a wide variety of modelling techniques have been developed which suffer of a lack of satisfactory validations.

The purpose of this work is to set up a data bank of high quality measurements which will serve to carry out an empirical validation of multi-zone air infiltration programs. Among other data, a complete set of air flow permeabilities of a well known experimental midsize building will be included to this bank.

We use the guarded zone pressurization technique for the purpose of measuring this set. The system is made of two computer controlled fans which automatically pressurize the different rooms of the building. Pressures and air flows are sampled and gathered during the overall experiment which runs generally over one night. Values of the corresponding permeabilities are calculated from these data through a mean square fit.

An overview of the procedure used to measure these permeabilities as well as a description of the experimental equipment developed for this purpose, is presented in this paper. The measured permeabilities and a discussion of their values, are also be given.

LIST OF SYMBOLS

Q_M	:	measured air flow, [$m^3 h^{-1}$]
Q_E	:	air flow to outside, [$m^3 h^{-1}$]
Q_{Lj}	:	lateral flow, that is air flow to neighbouring zone $j = 1$ at east and $j = 2$ at west, [$m^3 h^{-1}$]
Q_I	:	airflow to the staircase
ΔP_i	:	pressure difference across a given element, [Pa]
$\Delta P (IA)$:	pressure difference between the guarded zone and the guarding zone, [Pa]
(M)	:	experience matrix $M_{it} = 1$ if flow i is measured in experience t
C_{s-ext}	:	exfiltration coefficient connecting room s and the outside node, [$m^3 h^{-1} Pa^{-n}$]
C_{s-int}	:	exfiltration coefficient connecting room s and the staircase node, [$m^3 h^{-1} Pa^{-n}$]
$C_{s-s'}$:	exfiltration coefficient connecting room s and room s'
n_{s-ext}	:	exponent, [-]
Q_{50}	:	leakage at 50 [Pa], [$m^3 h^{-1}$]
A_L	:	leakage area, [cm^2]

1. INTRODUCTION

Any detailed thermal analysis of a building should include inter-zone coupling in particular considering inter-zone air movements. While single zone description of the building seems to be satisfactory for static modeling, the prediction of thermal dynamic behaviour requires a multizone description of air movements [1].

The recently developed codes of air infiltration process take into account the permeability distribution and need an empirical validation with appropriate sets of measurements [2]. For this purpose we have decided to constitute a data bank for validation [3].

External and internal climate conditions and tracer gas measurements are taken simultaneously on the LESO building [4]. In addition, we present in this paper some pressurization measurements on the principal elements of the envelope and internal walls of this building.

For these measurements, we have used a guarded zone technique for which we have developed the Mage automatic measurement System.

This work is part of the Swiss ERL-project (Energierrelevante Luftströmungen in Gebäuden) which is an important air infiltration research project [5].

2. THE GUARDED ZONE TECHNIQUE

The simple pressurization of a single room in a multiroom structure (fig. 1a) requires, at a given pressure difference ΔP_i , a measured air flow Q_M so that :

$$Q_M (\Delta P_i) = Q_E (\Delta P_i) + \sum_{j=1,2} Q_{Lj} (\Delta P_i) + Q_I (\Delta P_i) \quad (1)$$

The guarded zone technique consists on pressurizing the contiguous rooms (The guarding zone) with a second fan. In this manner the lateral pressure difference ΔP (IA) is kept to zero and the lateral flows Q_L are canceled (fig. 1b). Then, we get for the same pressure difference :

$$Q_M (\Delta P_i) = Q_E (\Delta P_i) \quad (2)$$

In a second step, opening the window and closing the door in one of the contiguous rooms (fig. 1c) let us use the following equation :

$$Q_M (\Delta P_i) = Q_E (\Delta P_i) + Q_{Lj} (\Delta P_i) \quad (3)$$

Repeating this procedure for all the contiguous rooms and a series of pressure differences, we get for each pressure difference the easily solvable equation system :

$$\begin{pmatrix} Q_{M1} \\ Q_{M2} \\ Q_{M3} \\ Q_{M4} \end{pmatrix} = \begin{pmatrix} 1 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} Q_E \\ Q_{L1} \\ Q_{L2} \\ Q_I \end{pmatrix} \quad (4)$$

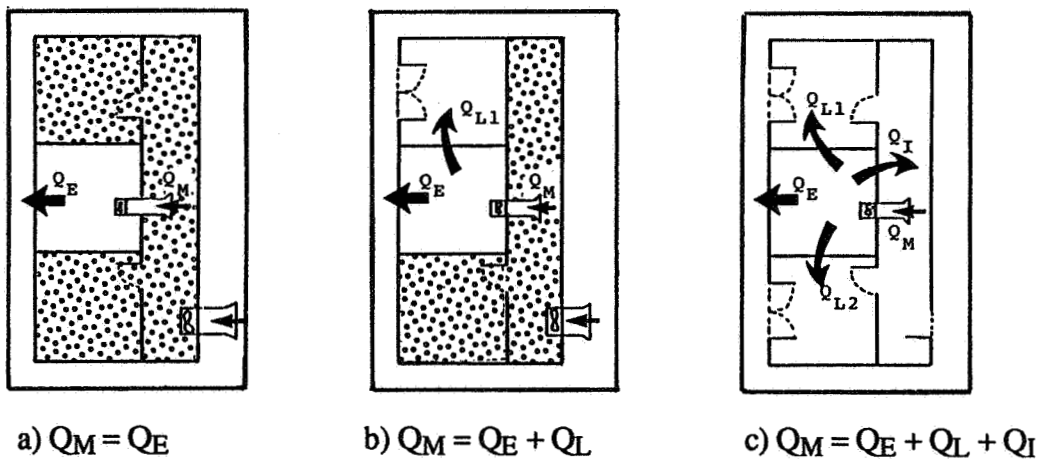


Figure 1 : Strategy of the guarded zone technique.

The resolution of the system (4) for several pressure differences :

$$\vec{Q} = M^{-1} \vec{Q}_M \quad (5)$$

gives sets of $\{Q_S (\Delta P_i)\}$ which will be fitted to this relation

$$Q_S = C_S \Delta P^n \quad (6)$$

in order to get the C_S and n_S exfiltration characteristics of the walls of the guarded zone.

3. DESCRIPTION OF THE MAGE MEASUREMENT SYSTEM

3.1 Generalities

The MAGE System (Mesure par Anneau de Garde de l'étanchéité) is a complex system which pressurizes buildings, controls the pressurization and measures the pressure differences between the inside and the outside of the building as well as outside conditions and exfiltration flows.

To know the permeability distribution, numerous measurements are needed. These measurements shall be all taken at given fixed pressure differences (e.g. 10, 20, , 50, 60 [Pa]) to be used in equation 4. Moreover, to avoid the inconveniences of the measuring (noise, drafts) for the occupants, the experimentations are made during the night. For all these reasons, an automatic system has been developed. Figure 2 shows the structure of this system process.

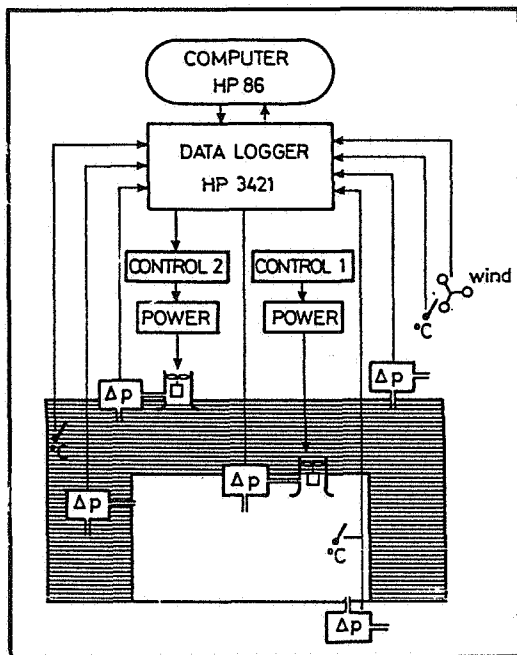


Figure 2 : MAGE - Structure.



Figure 3 : MAGE - System.

3.2 Instruments and Procedure

Figure 3 shows the MAGE equipment, constituted of four electronic manometers, two electronic fan controllers, two voltage sources and a data logger. The system is controlled by a small desktop computer.

The program gives the set points to the fan controllers and controls if the target are reached within the tolerances (usually 5 %).

Then the measurement can begin. The data logger measures all the data and the program tests them for stability and no excessive wind conditions to control the confidence in the measurement.

If all the tests are passed then the values are stored, if not, they are rejected. Then the program repeats this procedure several times for different pressure differences according to the starting values.

3.3 Air flow measurements

Two different methods of air flow measurement have been used because in such an experimental building, the permeabilities are very different from one room to another. The air flows to be measured range from about 15 [m³/h] for the air tightness element at 10 [Pa] to 1500 [m³/h] for the worst at 60 [Pa].

For the small flows, a nozzle with flow velocity measurement was used while for the largest flows, a nozzle with pressure measurement was chosen.

4. THE LESO - BUILDING

The LESO - Building is a mid-sized administrative building constituted by nine south oriented cells with solar façades, few differently oriented rooms, and a staircase as shown on figures 4 and 5. On Figure 4 you can observe the complexity of the permeability structure.

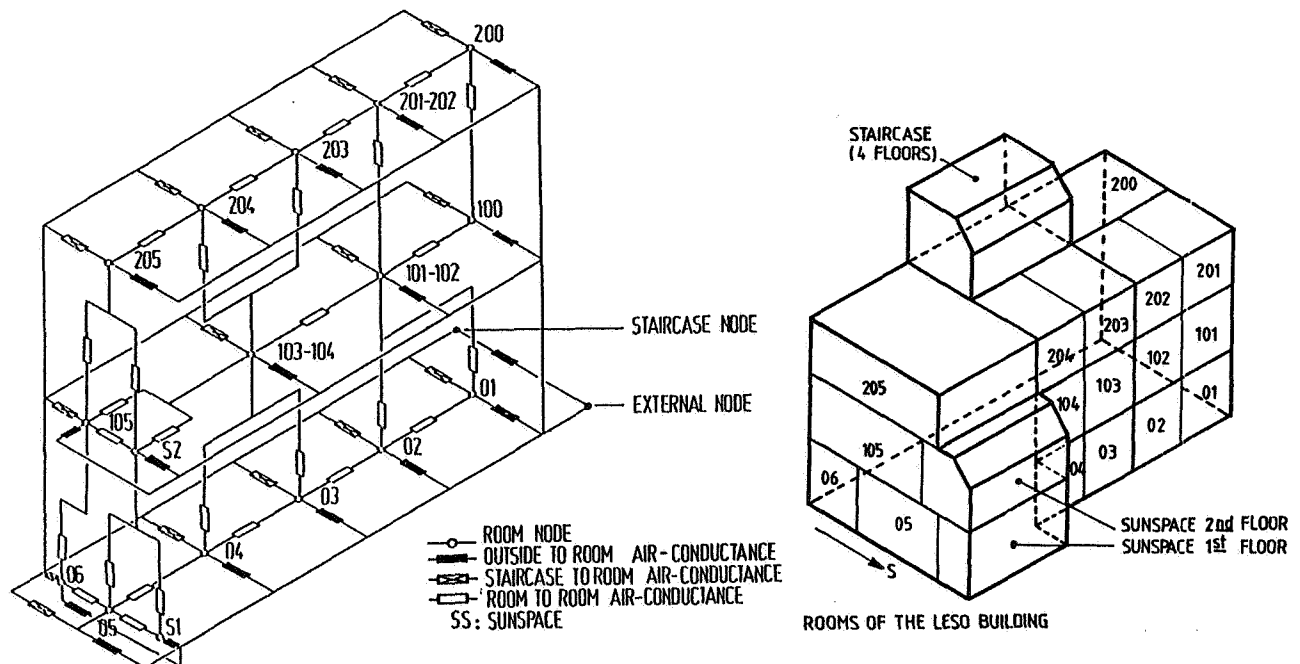


Figure 4 : Perspective of the LESO - Building (top) and corresponding conductances net (bottom).

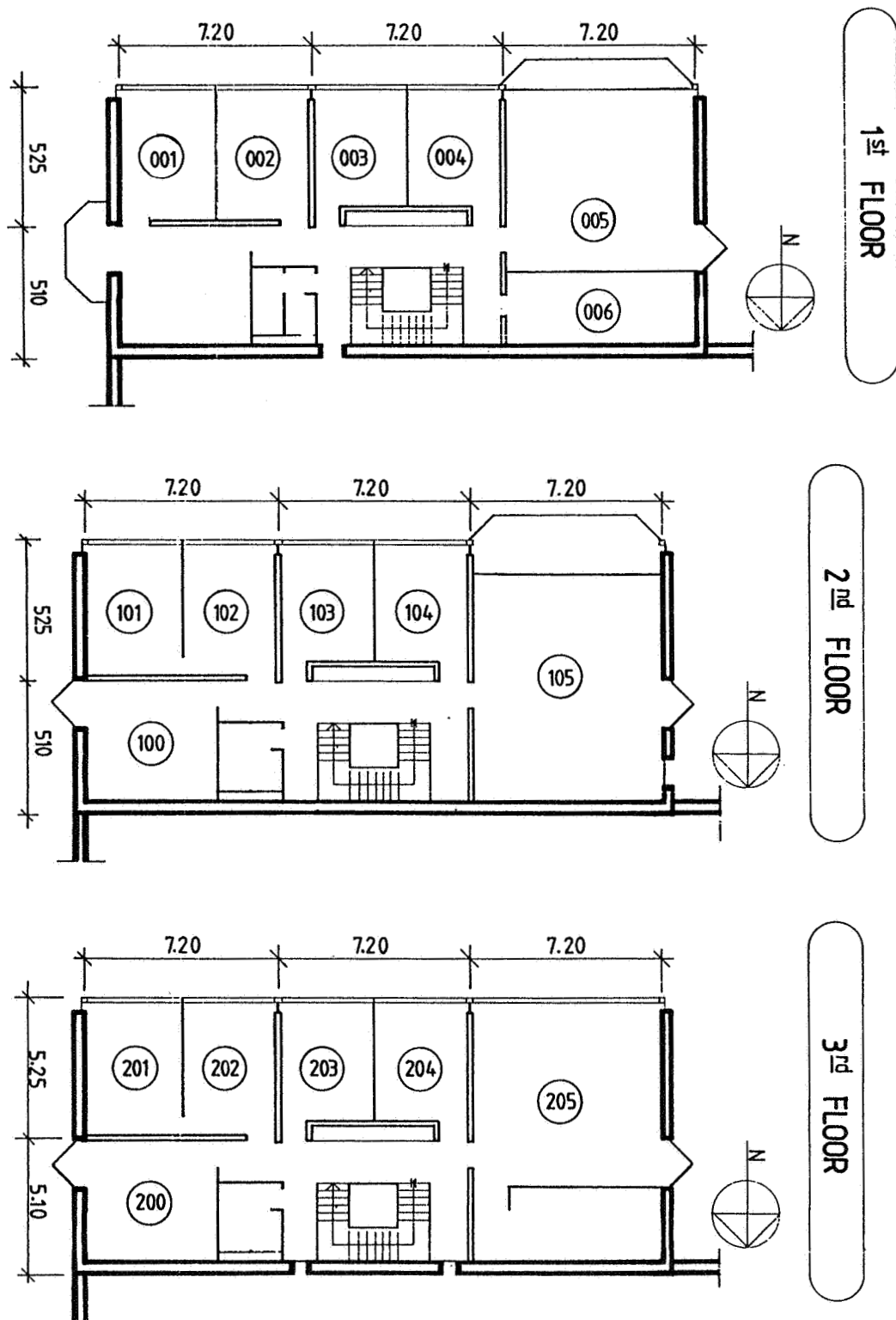


Figure 5 : Plans of the three floors of the LESO - Building.

From room to room there are 61 conductances. The vertical ones (13) have been neglected. The greenhouse has been considered as a façade and some rooms got together with the staircase node.

Finally, the measured structure has 11 nodes with a total of 28 conductances to be measured.

The limitation of the node number comes from the limits of the CESAR, the equipment used for tracer gaz measurements [6].

The results presented in this paper have been obtained from 50 experiments which have needed three months of measurement.

6. RESULTS

6.1 Rooms Pressurization

The results of the pressurization of the LESO - Building are presented here on floor plans and bar charts.

The floor plan representation shows the localization of the C-values and the exponents n (fig. 6, a, b). There are presented each in different drawings for better understanding but they must be considered as a whole.

The bar charts present the C-values, the exponents and so the leakage at 50 [Pa] and the leakage area for a reference pressure of 4 [Pa] for the walls (fig. 9) or the rooms (fig. 10).

The leakage at 50 [Pa] is defined in the equation 7 and the leakage area in the equation 8 [7]

Leakage at 50 [Pa]

$$Q_{50} = C 50^n \quad (7)$$

Leakage area at the reference pressure 4 [Pa]

$$A_L = C \sqrt{\frac{\Delta P}{2}} 4^{(n-.5)} \quad (8)$$

The results presented here are calculated for the following experimental conditions :

$$960 \text{ [mbar]} < P_{\text{atmospheric}} < 980 \text{ [mbar]}$$

$$20 \text{ [}^\circ\text{C]} < T_{\text{inside}} < 24 \text{ [}^\circ\text{C]}$$

The correction factor for standard conditions (20 [°C] and 1.013 x 10⁵ [Pa]) is lower than 2 % [7].

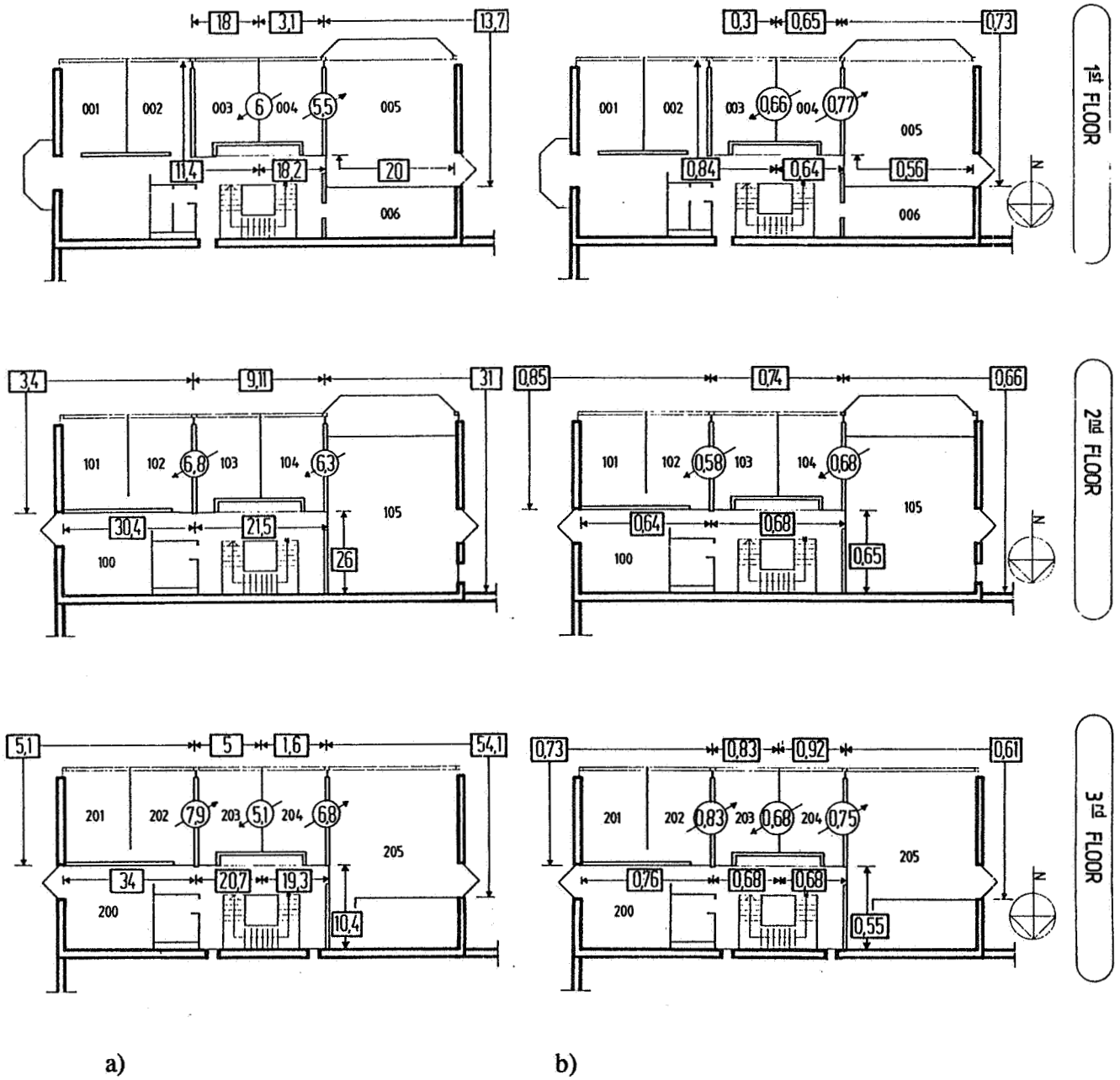


Figure 6: a) C-values of the LESO - Building [m³/h Paⁿ]
 b) Exponents. n[-]

□ -values for exfiltration from a room to outside or staircase.

⊘ -values for exfiltration from a room to another room with the sense of measurement.

LEAKAGE AT 50 [Pa]

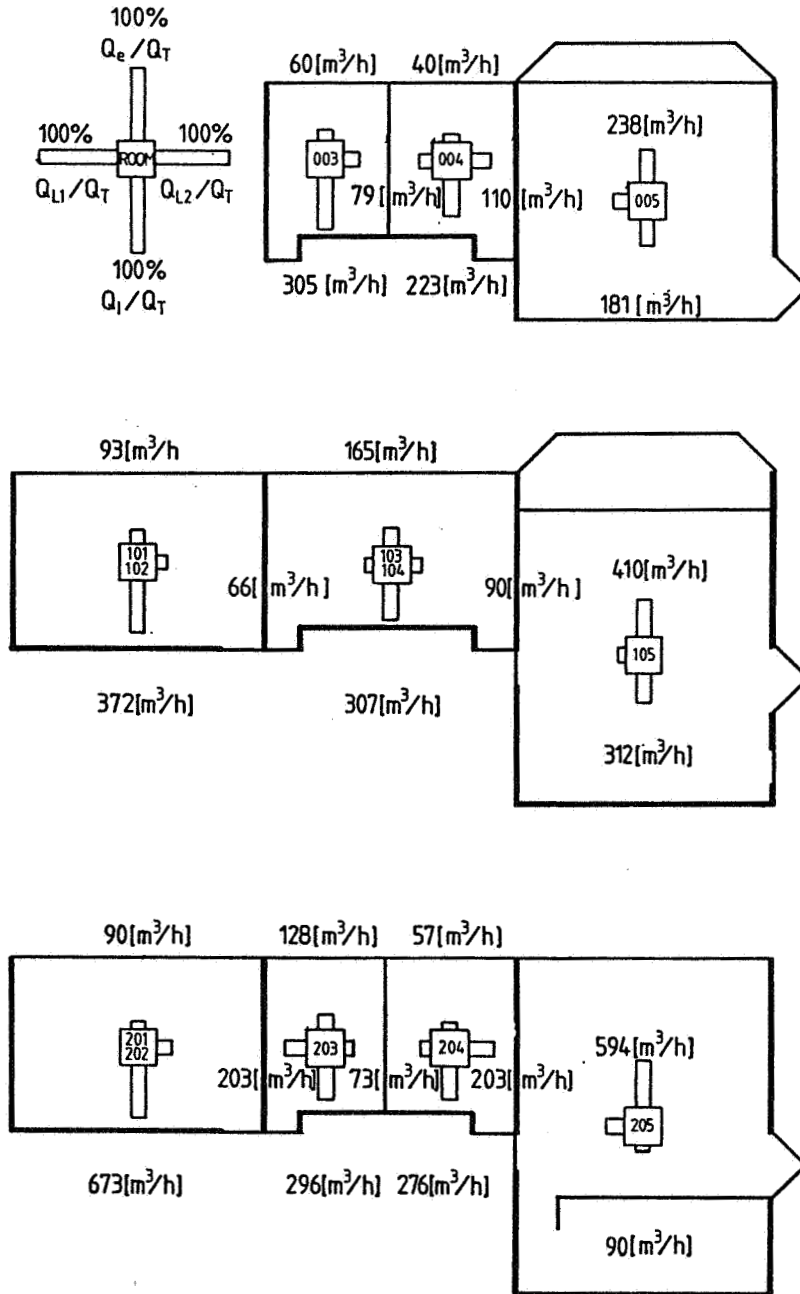


Figure 7 : Leakage at 50 [Pa]

The values correspond to the flows from a room to outside (up), to staircase (down), to a contiguous room (lateral side).

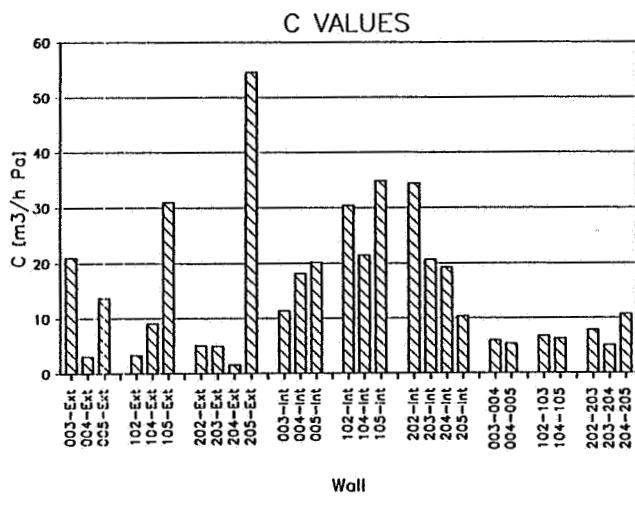


Figure 8 : The measured C-values [m³/h Paⁿ] for the walls. (confidence < 10 % except for C_{203-E}, C_{204-E}, C_{205-I}, C₁₀₄₋₁₀₅, C₂₀₃₋₂₀₄ where 20 % < confidence < 30 %)

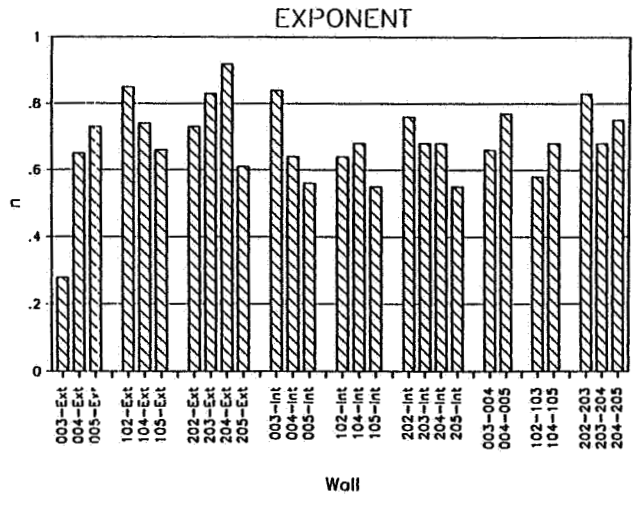


Figure 9 : Measured exponent. (confidence < 10 %)

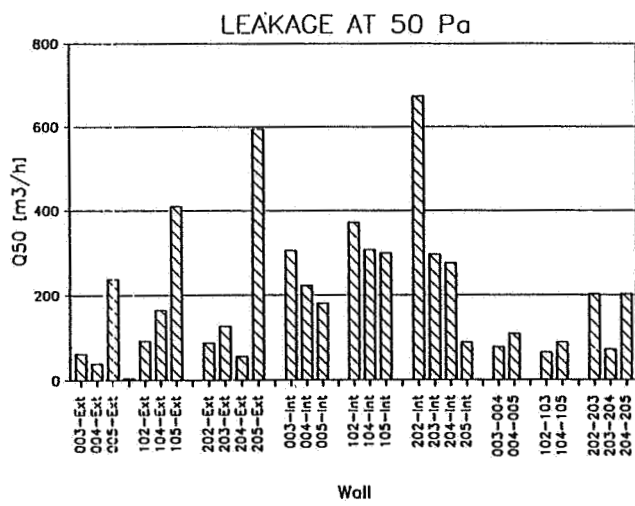


Figure 10 : The leakage at 50 [Pa] in [m³/h] (confidence around 10 %)

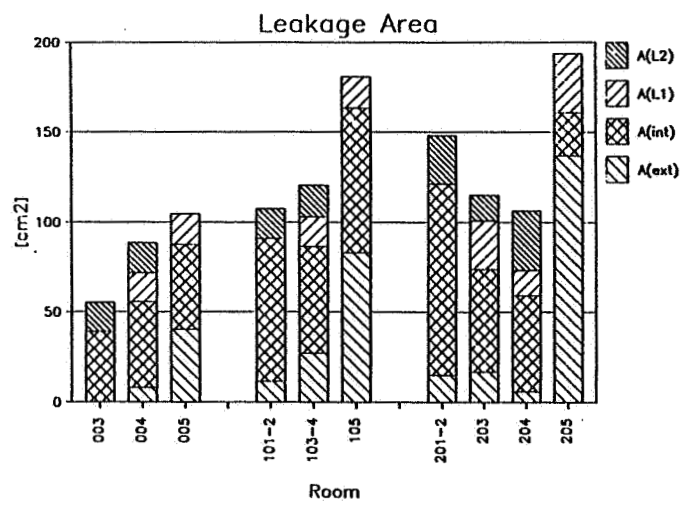


Figure 11 : Leakage area [cm²] for the rooms for a reference pressure of 4 [Pa] (confidence around 10 %)

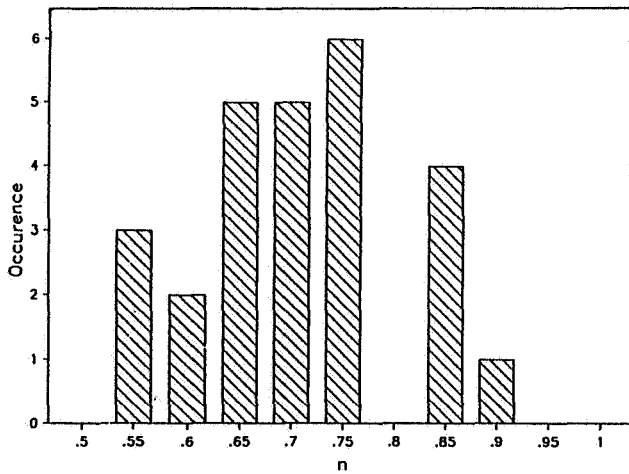


Figure 12 : Histogram of the rooms exfiltration exponents
 $N = 26$ $\bar{n} = 0.70$ $\sigma = 0.10$.

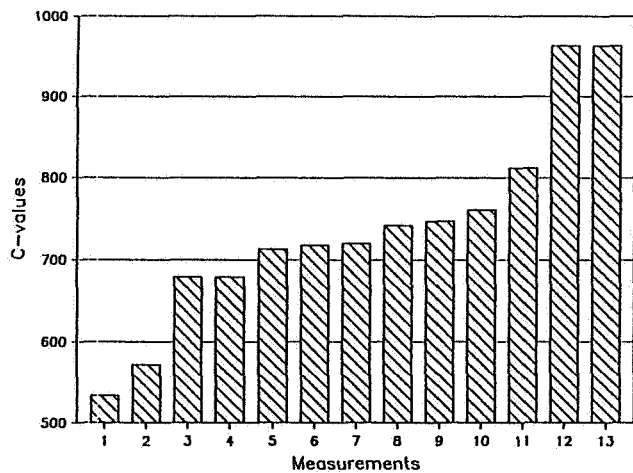
6.2 LESO - Building Pressurization

Exfiltration flow for the whole building has been measured simultaneously with the rooms pressurization, since it was necessary to pressurize the building as a guarding zone.

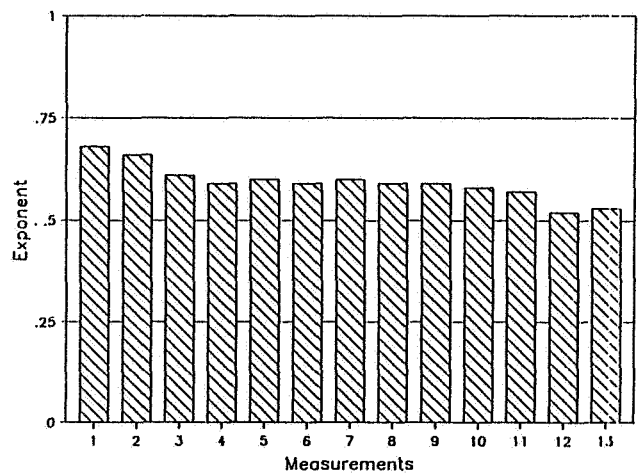
Results from 13 measurements are presented here. They are sorted following increasing C-values (fig. 13).

LESO - Building measurements		
V	:	2165 [m ³]
\bar{C}	:	740 ± 250 [m ³ /h ⁻¹ Pa ⁻ⁿ]
\bar{n}	:	0.6 ± .1 [-]
\bar{Q}_{50}	:	7400 ± 480 [m ³ h ⁻¹]
A _L	:	1760 [cm ²]
n _{L.50}	:	3.43 [h ⁻¹]

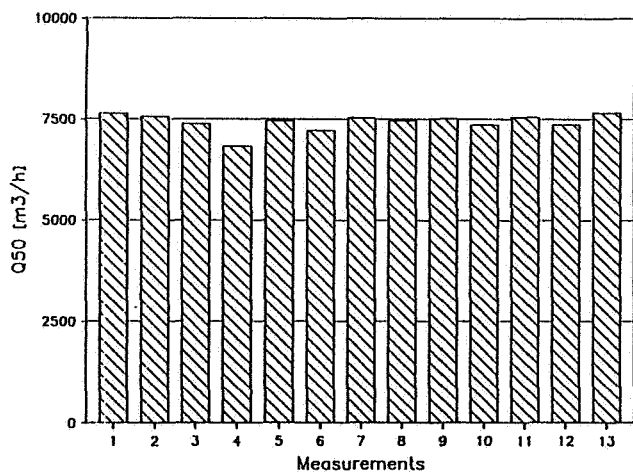
The average result of \bar{C} and \bar{n} are calculated with Q_{50} and Q_{10} .



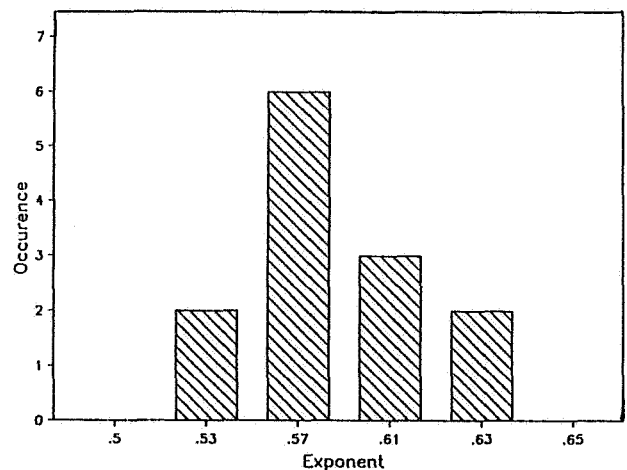
a) C-values [$\text{m}^3 \text{h}^{-1} \text{Pa}^{-n}$]



b) exponents sorted according to the increasing C-values



c) Q50 [m^3/h].



d) Histogram of the whole building exfiltration exponent

$N = 13$ $\bar{n} = 0.59$ $\sigma = 0.04$.

Figure 13 : Measurements on LESO - Building

7. INTERPRETATION

Here are commented the results presented in figures 8 to 10. The most interesting as well as the most constraining problem has been the large range in the air tightness of the rooms. The reasons are that the rooms have different façades and several room-to-room walls are masonry walls without rendering.

Confidence intervals are calculated for 95 % probability that they contain the true value [8].

7.1 Room-to-outside conductance

The untightness of room 205 ($C_{205-ext} = 54.6 [m^3 h^{-1} Pa^{-n}]$) comes from an opening skylight kept closed by its own weight.

Room 105 and 005 have both a sun-space as a south façade. The difference of air tightness (table 1) can be explained by the different separation wall between the sun space and the room. In room 005, there is a normal external façade while in room 105 there is an internal window with two doors, which are no so airtight [9].

Room	C_{i-ext}	n	Q_{50}	A_L
-	$[m^3 h^{-1} Pa^{-n}]$	[-]	$[m^3 h^{-1}]$	$[cm^2]$
005	$13.7 \pm .3$	$.73 \pm .005$	238 ± 24	41 ± 1
105	31 ± 1	$.66 \pm .01$	410 ± 40	83 ± 3

Table 1 : Air tightness comparison in rooms 005 and 105.

Rooms 203 and 204 have the same industrial façade. This façade has an integrated ventilation system which can be open or closed.

So room 204 has been measured in the closed position while room 203 in the open one (table 2).

Room	C_{i-ext}	n	Q_{50}	A_L
-	$[m^3 h^{-1} Pa^{-n}]$	[-]	$[m^3 h^{-1}]$	$[cm^2]$
203	5.0 ± 0.3	$.83 \pm .02$	128 ± 13	17 ± 1
204	1.6 ± 0.3	$.92 \pm 0.4$	57 ± 6	$6.2 \pm .1$

Table 2 : Air tightness comparison in rooms 203 and 205.

Room 003 shows an exponent of $n_{003-Ext} = 0.3$. This can be explained as follows : the wall between room 003 and room 002 (cf fig. 4) is crossed through by a waste water duct surrounded by an important hole. This hole is so badly situated that it has been impossible to seal it. With such a big hole the pressure difference control between the guarded and the guarding zone is not accurate enough to get satisfactory results.

7.2 Room-to-staircase conductances

The leakage between one room and the staircase depends on the wall surface and door cracks. The wall are all masonry walls without renderings and their air tightness depends on the workmanship. The door air tightness depends mainly on cracks between elements and holes for electrical wires (The LESO - Building is an experimental building and counts numerous probes connected to a central data logger).

However, three rooms 004, 203, 204 which are in the same situation with the staircase present very similar results as it is shown in table 3.

Room	C_{i-int}	n	Q_{50}	A_L
-	$[m^3 h^{-1} Pa^{-n}]$	$[-]$	$[m^3 h^{-1}]$	$[cm^2]$
004	18.2 ± 1	$.64 \pm .03$	223 ± 22	48 ± 3
203	$20.7 \pm .8$	$.68 \pm .02$	296 ± 30	57 ± 2
204	$19.3 \pm .5$	$.68 \pm .01$	276 ± 28	53.3 ± 1.4

Table 3 : Room-to-staircase airtightness comparison.

7.3 Room-to-room conductances

Those conductances depends mainly on the wall composition. For example, the wall between rooms 203 - 204 on the third floor is a thin plaster board wall with a door and wall 202 - 203 or wall 204 - 205 are masonry walls without renderings.

7.4 Exponents

Figure 9 shows the exponents for each measured wall. The case of the wall 003-Ext has been commented in chapter 7.1. The other values are distributed around the mean value of 0.70 with a standard deviation of 0.10 (fig. 12).

There is a relation between the C-values and the exponents n which is apparent when comparing the values for the walls 202-Ext to 205-Ext. The walls 005-Ext, 105-Ext, 205-Ext with the largest C-values have the smallest exponents. This is not a rule however. The exponent depends on the flow characteristics (Laminar flow : $n \rightarrow 1$, turbulent flow : $n \rightarrow .5$) and there for on the cracks dimension.

7.5 Air tightness distribution

Figure 7 shows how the leakage is distributed for each room. The bars represent the ratio of a given flow at 50 [Pa] (Q_{ext} , Q_I , Q_{L1} , Q_{L2}) and the total flow of the room ($Q_T = Q_{\text{ext}} + Q_I + Q_{L1} + Q_{L2}$).

For each room, except the rooms 005, 105 and 205, the wall with the largest leakage is the north wall connected to the staircase. This is mainly due to leakage through the doors. Rooms 005, 105 and 205 have very untight façades as well as much larger surfaces of the external walls than of the wall in contact with the staircase.

Figure 11 shows the total leakage areas for every room, except for room 003 where the external wall leakage area cannot be calculated since the measured exponent of this wall is inferior to .5 (see chapter 7.1).

7.6 LESO - Building air tightness

The pressurization of the whole LESO - Building shows a relation between C-value and the exponent n. 13 measurements was obtained for different situations and they are shown in fig. 13.a and 13.b.

The stability of Q_{50} is evident when looking at fig. 13.c since the C-value change with a ratio of 1 to 2 from the minimum to the maximum value.

The dispersion of results have many possible causes, like the mixed influence between the permeability and wind direction, the position of probes, the fact that peoples live in the building and change its state, etc. But this shows overall that the monozone pressurization of a large volume is not a precise measurement to estimate the leakage at low pressure. The air leakage at 50 [Pa], Q_{50} , and the corresponding air renewal $N_{L,50}$ are anyhow interesting values because of their stability.

8. CONCLUSION

The results given here show the Mage usefulness. It would have been tedious and even impossible to measure elements permeability of such a complicated structure by sealing walls or with advanced single fan pressurization [10].

Mage results are high quality results when the leakage between the measured and the guarding zones is not too large. They have confidence intervals around 10 % while usual results have confidence around 25 % [1]. They will serve as input data in order to validate air flow simulation programs.

Mage results quality could be increased by using one or two more manometers, in order to have a better control on the outside pressure of the corner rooms. Better flow meter with a very large range (15 [$\text{m}^3 \text{h}^{-1}$] to 1500 [$\text{m}^3 \text{h}^{-1}$]) would allow to pressurize every rooms up to 80 [Pa] and to use an experimental planning of better quality.

9. ACKNOWLEDGEMENTS

The LESO inhabitants had to accept noise, obstructed stairs and passages and even closed doors sometimes. The authors will here apologize them and acknowledge for understanding.

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10. REFERENCES

- [1] A. Roldan, F. Allard, G. Achard, "Influence des infiltrations et des transferts aérauliques entre pièces sur la charge thermique d'un bâtiment multizone" ICBEM'87 Proceedings, vol. III, EPFL, Lausanne, Switzerland, 1987
- [2] H.E. Feustel, J.-L. Scartezzini
"Development and validation of a simplified multizone infiltration model" ICBEM'87 Proceedings, vol. III, EPFL, Lausanne, Switzerland, 1987
- [3] J.-L. Scartezzini, J.-M. Fürbringer, C.-A. Roulet
"Data needs for purpose of air infiltration computer code validation" 8th AIVC Conference Proceedings, Uberlingen, RFA, 1987
- [4] R. Compagnon, J.-M. Fürbringer, C. Roecker, C.-A. Roulet
"Nouveaux développements de deux méthodes de mesures aérauliques dans les bâtiments" Energieforschung im Hochbau, ETH-Zurich, Switzerland, 1988
- [5] Status Seminar "Forschungsprogramm :
Energierelevante Luftströmungen in Gebäuden"
Winterthur, Switzerland, 1987 (in French and German)
- [6] J.-L. Scartezzini, C.-A. Roulet, O. Jolliet
"Continuous air renewal measurements in different inhabited buildings" 6th AIC Conference, proceedings, 1985
- [7] Norme ISO (Draft)
"Measurement of building air tightness using fan pressurization"
Lausanne, Switzerland, 1987
- [8] A.K. Persily, R. Grot
"Accuracy in pressurization data analyzis"
ASHRAE Technical Bulletin, Infiltration air leakage, June 1985
- [9] J.-L. Scartezzini, A. Faist, J.-B. Gay
"Experimental comparison of a sunspace and a water hybrid solar device using the LESO test facility". Solar Energy, vol. 38 N° 5, pp 355-366, 1987
- [10] P. Wouters, D. L'Heureux, P. Noordecker
"Advanced single fan pressurization" CSTC Brussels, Belgium, 1988