ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

2001-29

LESO-PB

Van der Maas J., Roulet C.-A., Flourentzou F.

Measurement of Airtightness with the Stack Pressurisation Method - Application to Two Buildings

CISBAT 2001

3 - 4 octobre

MEASUREMENT OF AIRTIGHTNESS WITH THE STACK PRESSURISATION METHOD - APPLICATION TO TWO BUILDINGS

Jacobus van der Maas[1], Claude-Alain Roulet[2] and Flourentzos Flourentzou[2]

[1] *Service Cantonal de l'Energie, ScanE, CH-1204 Genève*
[2] *Laboratoire d'Énergie Solaire et de Physique du Bâtiment, École Polytechnique Fédérale deLausanne, CH-1015 Lausanne*

ABSTRACT

The new Swiss standard SIA 180 requests that building envelope leakage be limited to low values. Therefore commissioning the new or retrofitted buildings should include air tightness measurement. The application of the usual fan pressurisation method to measure air tightness of buildings requires substantial equipment and personnel, and is especially expensive for large enclosures. A solution is provided by making use of the pressure gradient resulting from stack effect. It is demonstrated how the air leakage area of buildings can be estimated quickly and at low cost by making explicit use of the concept of the neutral pressure level. The method is validated by comparison with pressurisation measurements. Software to help with the planning and interpretation of the measurements is free available.

INTRODUCTION

The airtightness of the building envelope has an influence on comfort and the energy performance of buildings. It is measured by determining the airflow rate through the envelope for a given pressure difference. In Europe, reference is usually made to the airflow rate at a pressure difference of 50Pa, in terms of an airchange rate, $n_{l,50}$ [1/h], with respect to the interior volume. For example, to avoid accumulation of air pollutants, odours and humidity, national standards recommend for naturally ventilated buildings that the value for $n_{L,50}$ is in the range 2 to 4,5 [1/h] [1,2].

For a full control of air infiltration, the building envelope should be made with care and fully airtight leaving only purpose provided ventilation openings. The new Swiss building standard SIA 180 requests a strict control of the building envelope leakage, and commissioning the new or retrofitted buildings will more and more often require air tightness measurement.

The classical procedure to measure airtightness is to install a sufficiently powerful fan in the building envelope (a blower door), to increase the pressure to a level in excess of 50Pa, and to measure the airflow rate then as a function of pressure difference. For large volumes however, this can be problematic. For example for a 10'000 m^3 space, the maximum airflow rate provided by the fan should then be around 40'000 m^3/h at 50Pa. Also, this technique does not give information on the location of the air leakage paths. It is interesting to note that in the frame-work of a research project of the International Energy Agency (IEA ECB&CS Annex 26), large enclosures of more than 100'000 m3 have been studied [6].

To reduce the measurement error in pressurisation techniques, the measurements should be performed when stack and wind pressures, which add to the fan pressure, are negligibly small (low or non-heated buildings, low wind velocity).

Fan-pressurisation data are expressed empirically [1,2,3,8] as a power law between the airflow rate, Q [m^3/s], and the differential pressure, Δp [Pa] :

(1) $$Q = nV/3600 = K(\Delta p)^n$$

where the exponent n varies over the range 0.5 et 0.7 and K is the leakage coefficient. The value n = 0,5 corresponds to flow through a large opening [1,2].

If the effective opening area is $A_0 = C_d A$ (where C_d is the discharge coefficient which is approximately 0.6) :

(2) $$Q = A_0\sqrt{2\Delta p / \rho} = A_0 u; \qquad u = \sqrt{2\Delta p / \rho} \approx 1{,}3\sqrt{\Delta p}$$

where u is a velocity and $\rho \approx$ 1.2 kg/m³ is the air density. For a pressure difference of Δp = 50 Pa, the maximum air velocity in the opening is then 9 m/s.

It is interesting to determine a direct correspondence between the airtightness given in terms of $n_{L,50}$ [1/h] and an equivalent leakage area in [m^2].

For an exponent n = 0.6±0.1, one derives from equation (1) an estimate for the leakage area :

(3) $$A = (0.5 \pm 0.15)\, n_{L,50}\, V.\, 10^{-4}\ [\text{m}^2]$$

This expression, applied to a volume of 10'000m^3 and for example a value of $n_{L,50}$ = 2 [1/h], gives a leakage area of 1 m^2, with an uncertainty of 30%.

The stack pressurisation method allows the height of the leakages to be determined, as long as openings are available and accessible at different heights of the building façade.

It is possible to localize the air leakage pathways, by following smoke movement, or in the case of fan.pressurisation thermography can be used when the indoor-outdoor temperature difference is significant.

STACK PRESSURISATION

To estimate the air leakage distribution in buildings of significant height it is possible to study separately the airtightness of the bottom, center and top of the building [2,4,8]. Depending on the availability and accessibility of openings in the façade, the information on the leakage distribution can be more or less detailed.

Figure 1 shows schematically the variation of the differential pressure with height for three base cases with a large opening at roof level (i) at half facade height (ii) at ground level (iii). It is assumed that all internal doors are open (single zone condition), and that the windspeed is sufficiently small so that the wind pressure can be neglected when compared to the stack pressure. Finally, it is assumed here that the temperature outdoors is lower than indoors. Air flow is visualised using small smoke puffs [9] and both the velocity profile and the NPL are easily made visible.

For each of these cases, the pressure distribution is known and the net air flow rate (resulting from the air infiltration through the envelope) can be measured in the large opening. By applying equation 2 using the mean stack pressure, a leakage coefficient K can be determined for the three configurations. The NPL software module [7] allows to évaluate a wide range of single zone configurations.

The original method [2,4,7] has been improved in order to make its application simple and fast. Details of the theory are given in [8]. Two approaches are distinguished.

A.-Starting from the case where the NPL is observed near half opening height, the width of the vertical opening is decreased and measured when the NPL is just visible at the top or bottom. The net airflow rate can be calculated using the theory for airflow through large openings [7,8] and the leakage area follows from eq. 1 or 2.

B.- Starting from a case where the NPL is observed somewhere in the opening, the width is reduced until the neutral level is not longer visible. The air velocity is measured in the opening at two reference heights, e.g. at 10 and 90% of the opening height. The width of the opening is subsequently reduced and the velocity is measured at varying width (the width is changed by covering part of the opening with fitting wood board), and the position of the NPL is deduced for each opening.

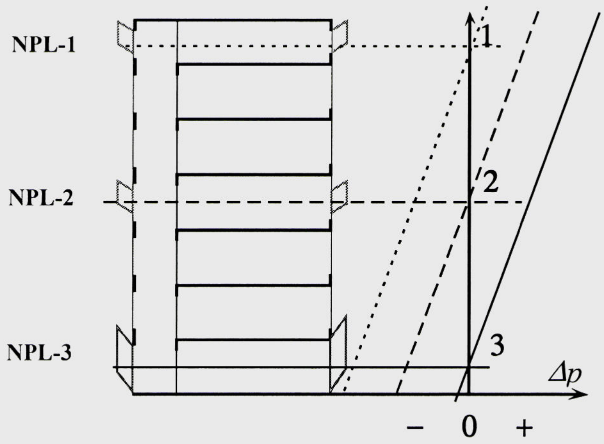

Figure 1 The multi-level building is represented with 3 openings at the left. To the right, the stack pressure distribution is given for three cases with single opening in the facade at the level of the 1) roof 2) middle and 3) ground.

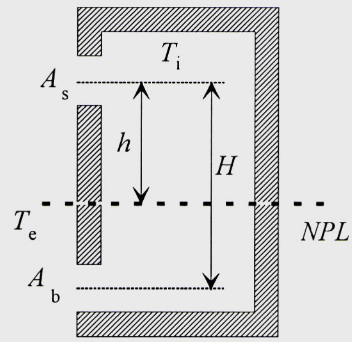

Figure 2. The neutral pressure level (NPL) is easily calculated for a space with two openings [5,7]

CASE STUDIES

The stack pressurisation method has been applied to two test cases, the three-level LESO building [3] and the atrium of an administrative building [6]. The measurement conditions are :

- full control of, and access to the openings in the building envelope (windows, doors, flaps), as well as of the internal doors of the investigated building area. Possibility to shut down the mechanical ventilation system.
- sufficiently low wind velocity and sufficiently high inside-outside temperature difference

The latter conditions require

(4) $\Delta T\, H >> 20\, v^2$

which can be realized on buildings higher than H=5 m and wind velocity v < 1m/s.

The measurement equipment comprises an air-thermometer, an anemometer, a smoke source and a meter. The software [8] allows direct interpretation of the observations.

Case study 1 : LESO building

The LESO is an interesting building to test the new method because all the parameters K and n for the local leakages between inside and outside and in-between offices are known [3]. These values were obtained with a fan pressurisation method over the range 20 et 80 Pa [3].

The equations [8] used in the NPL software [7] have been tested in several configurations, and agreement within 20% was found between measured and calculated flow rates. This precision is sufficient when it is realised that the leakage values of a building can vary over an order of magnitude.

The fan-pressurisation data for the whole building are given by [3]

(5) $$Q = K(\Delta p)^n = (0{,}21 \pm 0{,}07\%)(\Delta p)^{0{,}6} m^3 / s / Pa^n$$

which implies for a volume of 2165m^3 that $n_{L,50}$ = (3,6 ±1,2) [1/h].

To compare with the stack-pressurisation, the method was applied to the lower part of the building. All doors and windows in the building facade where closed with the exception of one door (H = 1,98 m, W = 0,9 m), at roof level. The NPL in the open door was observed at a height z_n= 0,8±0,1 m from the bottom of the opening. Given the inside-outside temperature difference of ΔT= 6,7±0,4 K, the air infiltration through the ground level part of the building, is calculated to be Q_b= 0.13± 0,03 m^3/s, for a maximum stack pressure difference of 2,3 Pa (eq. 4, H = 10m).

Given that only half of the building is pressurized and assuming a uniform leakage distribution, it is assumed that the leakage air flow rate for the whole building is double this value, Q_{tot} =2 $Q_b \approx$ 0.26 m^3/s. From equation (1) it follows that the value at 50Pa, $n_{L,50}$ $\approx$ (3±1) [1/h] for a volume of 2165m^3. The difference between the two methods is not found to be significant given the measurement uncertainty of 30% .

Case study 2 : Atrium in Zug

To measure the air leakage area of an 8000 m³ atrium in Zug (the eastern part of three atria interconnected at ground level), approach B of the stack pressurization method was used. For a temperature difference of 13 K and a stack height of 21 m, the maximum stack pressure was 11 Pa. Stable and reproducible velocity profiles and consistent values for the NPL were found, while the wind velocity was less than 1 m/s.

During a first measurement campaign to measure the leakage area of the top part of the atrium, the three atria were still interconnected. The air velocity in an open door at ground level (A_b = 1,9 m^2) was measured to be high (> 2 m/s), corresponding to an airflow rate of more than 4 m^3/s. The size of the leakage area at rooflevel was calculated to be (3 ± 0,5) m^2 . Afterwards, roof windows in the central atrium, blocked in the open position, were found with a total opening area of 3 m^2.

During the second measurement campaign, east and central atrium were separated. The NPL was observed in a groundfloor door at 1,6 m from the bottom of the door (A_b =3,8m^2), and at 20,5 m from ground in an open window (A_s =1,8 m^2). The air velocity was measured for varying opening size. The upper leakage area was determined equivalent to an opening of A_s = (0,5±0,1) m^2 situated at H = 21 m from groundlevel.

Using a roofwindow for the known opening area A_s, a groundfloor leakage area of A_b = 0,1 ±0,03 m^2 was determined. After removing the separation between the atria, the increase of the velocity in the roofwindow was consistent with a groundfloor leakage area of A_b = (0,4 ±0,1) m^2.

From the total leakage area ($A_s + A_b$ = 0,6, respectively 0,9 m^2), the ventilation rate at 50 Pa is determined with equation (3), giving $n_{L,50}$ =1,5, respectively 2,2 [1/h]. This value compares well with the Swiss standard SIA 180.

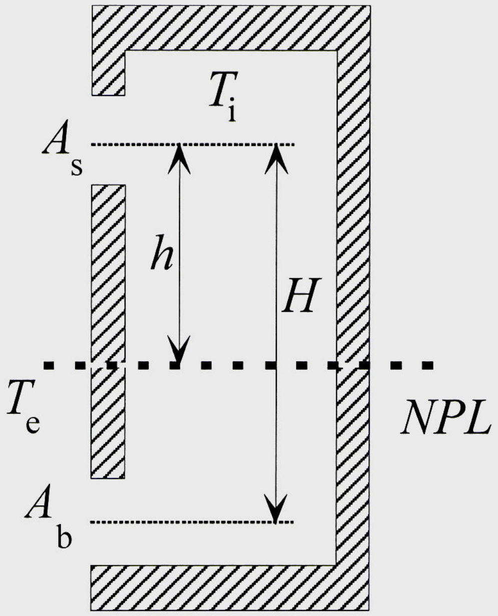

Figure 4a : Two opening model

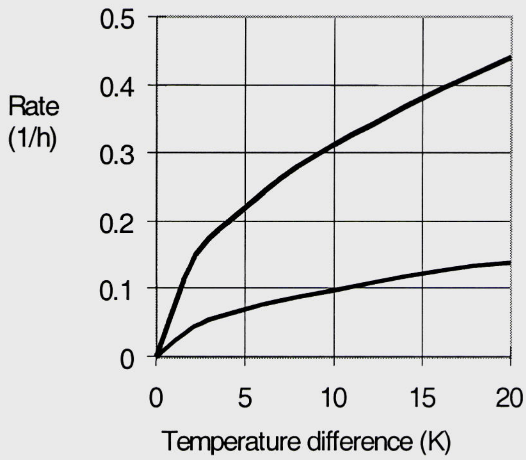

Figure 4b: Infiltration rate as a function of temperature difference for leakage areas A_s=0.5m^2 at 21m, and at groundlevel A_b=0.1 m^2 (lower curve) and A_b=0.4 m^2

Figure 4 shows air infiltration rates as a function of temperature difference, showing that the ventilation rate for a typical temperature difference in winter (10 K), is situated between 0.1 et 0.3 volumes par heure. This ventilation rate is relatively important due to the fact that the distance between the two openings is 20 m. It is interesting to note that for a case where the leakage areas are not distributed but nearly at the same level, the stack ventilation rate can be much smaller.

CONCLUSIONS

Buildings must be more and more air-tight to conform to new building standards. Therefore commissioning the new or retrofitted buildings will more often include air tightness measurements. The measurement of the air-leakage area with the classical fan-pressurisation method is rather cumbersome and costly, the more so when large building volumes are concerned. Alternatively, the stack pressurisation method is described which has been applied to two buildings with success. Software is available to simplify the interpretation of the results [7]. For very large volumes, stack pressurisation is the only practical way to determine leakage areas. The method is simple and has the potential to be used as a quick and cheap test by architects and building owners, to check the airtightness of an enclosure either qualitatively or quantitatively.

RÉFERENCES

1. Sherman, M. : The use of blower-door data, Indoor air, N°5, pp 215-224, 1995.
2. Roulet, C.-A. and Vandaele L.: Airflow patterns within buildings - Measurement Techniques, AIVC technical note 34 and Report of the IEA ECB&CS Annex 20 program, Air Infiltration and Ventilation Centre, Coventry, 1991.

3. Fürbringer, J.-M., C.A. Roulet, Compagnon, C. and Scartezzini, J.-L.: Validation de programmes de calcul des échanges d'air à l'aide de mesures expérimentales, Projet NEFF 339.1, Rapport Final, LESO Lausanne, 1990.

4. Hajakawa S. and Togari S. : Simple test method of evaluating exterior tightness of tall office buildings. Air change rate and air tightness in buildings (M.H. Sherman, Ed.) STP 1067, pp 231-248, ASTM, Atlanta, 1990

5. ASHRAE Handbook - Fundamentals.

6. Schaelin A, Moser A., Van der Maas J. and Aiulfi D. : Application of air flow models as design tools for atria, Roomvent '96, Yokohama, Japan, July 17-19, 1996.

7. The software LESOCOOL (downloaded at lesowww.epfl.ch), contains a fully operational NPL-module.

8. Van der Maas J., Flourentzou, F., Roulet, C.-A. : Mesure simple de l'étanchéité d'un bâtiment par effet de cheminée: la méthode du niveau neutre, 9.Schweizerisches Status Seminar, Energieforschung im Hochbau, Zürich, 1996

9. Dräger air flow tester (www.prod.draeger.com) or cold cigarette smoke (passed through a small diameter tube)