INFLUENCE OF TURBULENT WIND ON AIR CHANGE RATES AN APPLICATION WITH CLIM2000 SOFTWARE PROGRAM

G. GUYON*-P. GIRAULT*-S. DELILLE**-D. HOAREAU***-J. VILLAIN****
* Electricité De France, Pôle Industrie, Division R&D, Site des Renardières
F-77818 Moret sur Loing Cedex, FRANCE - E-Mail : G.Guyon@edf.fr
** ILM Technologies, 6 Rue St-André, F-72000 Le Mans, France.
*** Universite de La Reunion, Dept Physique-Mécanique, F-97715 St Denis. Cedex 9, France
**** CSTB Nantes, 11 Rue Henri-Picherit , F-44071 Nantes Cedex, FRANCE

ABSTRACT

In the framework of a collaboration between EDF and CSTB, we carried out a specific experimental protocol in Bouin house (CSTB site, house completely dedicated for infiltration and air change measurement) with different configurations to study the wind fluctuations. These experimental data are used to validate the pressure elementary models available into CLIM2000 software and especially the infiltration models. The agreement between experimental data and simulated results is acceptable taking into account the difficulty of this kind of experiment. Different ways of improvements and of analysis are still under treatment. Nevertheless, we have found that specific air inlets give lower ventilation rate than classical ones.

1 - INTRODUCTION

Infiltration and interzonal airflow are important heat and mass transfer mechanisms in buildings but not well understood. Many sources, experimental and regulation, indicate that heat losses due to infiltration represent 30 to 40% of the heating energy requirements of the buildings. The quality of building envelopes increasing due to reinforced insulation and as a consequence the heat losses through opaque walls and windows decreasing, it is very important to know precisely the losses related to ventilation. At the present time, air infiltration and interzonal flow rates cannot be confidently predicted. Although some predictive tools exist for such problems, there is few empirical data available to verify their precision and validity.

The CLIM2000 software allows to model air flows problems especially infiltration, intrazonal and interzonal exchanges. The two state variables, temperature and pressure, are solved at each time step. A short description of CLIM2000 is given in a companion paper.

In the framework of a first collaboration between EDF and CSTB (Centre Scientifique et Technique du Batiment), we studied with CLIM2000 the influence of turbulent wind perpendicular to the wall on the air change. Then, the measurements were recorded with a frequency of 0.1Hz in order to exhibit the wind fluctuations. We compared the air change rate obtained in such conditions with the ones obtained with typical climate date in which such fluctuations are completely smoothed. The difference can reach 20% in air change rate **[3]**.

To continue in that way, still in collaboration with CSTB, we prepared a specific experimental protocol in Bouin house (CSTB site, house completely dedicated for infiltration and air change measurement) with different configurations to study the wind fluctuations.

The experimental data are applied to CLIM2000 software program to validate the air/pressure elementary models.

2 - TEST SITE

2-a - Bouin experimental house characteristics

This house is owned by CSTB. It is located in Bouin on the coast of Atlantic Ocean (50 kms South-West from Nantes city). This site has been chosen because of its important characteristics in terms of wind. It has a clear view, no obstacles nearby and it is 2kms far from ocean. The prevailing winds are West (200-280°) and North-East (40-60°). The compass card (Figure 1) gives the average value of the wind speed measured over 2 years period on the site at 28.5m high **[8]**.

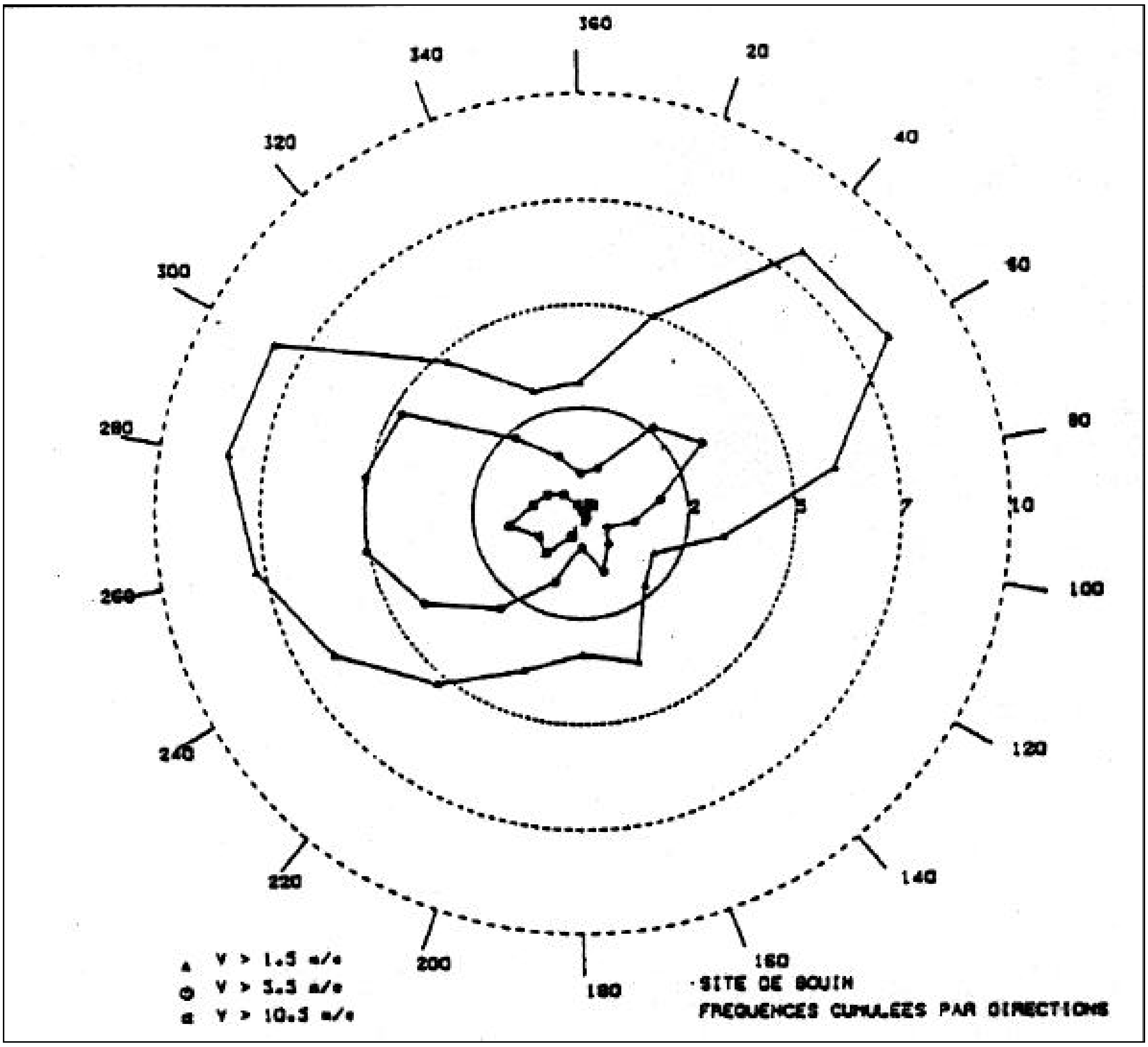

Figure 1 : Compass card of Bouin house

The average value of wind speed is 5.5 m/s. The turbulence intensity is low. At 17m high, I_u and I_v (turbulence intensity) **[2]** are equal to 0.122 and 0.083 resp.. At 30m high, I_u and I_v are equal to 0.112 and 0.075 resp.. In order to characterize the spatial importance of whirlwind, one uses the scale of turbulence. The scale is calculated on the basis of the average value of wind speed and on x, y and z axis from the correlation coefficients of u' speed longitudinal fluctuations. For Bouin site, we have L_{u-x}=160m and L_{u-y}=L_{u-z}=30m (L_u : actual length of an upwind slope ; subscripts x, y, z alongwind, crosswind and vertical direction). The main conclusion is that the wind is well established in terms of direction and magnitude.

It is equipped as laboratory. It presents the particularity to be oriented by the users in a given wind direction (Figure 2).

Figure 2 : Bouin experimental house

Due to its shape and dimension, it is representative of a small house (length 9m, width 4.8m, volume height 2.08 m and ridge capping height 4m, slope of 30°, volume to be used 89.5m^3). Three windows and one French window are on the different façades.

2-b - Preliminary work

The preliminary work consisted in eliminating all parasitic infiltration in order to not pollute the air-exchange rates coming from air inlets created for the rest of the experimental protocol. Leaks were stopped by applying polyurethane foam and silicone weather-strips. The airtightness was checked with the concentration-decay method by using tracer gas (ethane). The permeability is very close to zero (0.0015 ac/h). After this checking, some defaults were created to represent the classical infiltration value given by the French thermal regulations **[5]**. To achieve that, holes were created on each vertical façade and on the roof. Each hole was qualified (power law) by the mean of a precise air flow meter up to a 50Pa pressure difference.

We have also characterized the global U-value and the first time constant of the house by a power step test.

2-c - Experimental protocol

We prepared a step by step experimental protocol in order to examine the effect of turbulent wind in different conditions and to identify the weight of each parameter in the global ventilation rate of the house. For each configuration, we tested 7 orientations of the house in relation to the wind (0, 30, 60, 90, 120, 150 and 180°).

The **Configuration 1** is the simplest one. It consists in measuring the ventilation rate of the house vs the external pressure field.

The **Configuration 2** introduces a heat source inside the house in order to maintain a 21°C constant temperature. The air is stirred in order to achieve a good homogeneity of temperature. It consists in measuring the ventilation rate vs the external pressure field and the temperature difference between exterior and interior.

The **Configuration 3** is introduces in addition to heat source, a mechanical extraction unit which produces an air change rate of 0.7 ac/h and French classical air inlets (auto adjustment of the air flow). Off course, the pressure characteristics of each air inlet is well known and checked experimentally. The aim of this experiment is to evaluate the parasitic ventilation rate.

The **Configuration 4** is exactly as the Configuration 3 but introduces different air inlets. A flexible strip was introduced into the air inlet so that the air can come in but not come out. This kind of air inlets are used in France to save energy. With these air inlets, the air can come in the room through infiltration and air inlets, and come out through the mechanical extraction unit and infiltration, not through air inlets. The aim of this configuration is to evaluate the impact of such air inlets on air flow rates and then, on energy savings.

The **Configuration 5** consists in separating the volume into two different volumes. The first represents a living room and the second one represents a kitchen. The extraction unit is installed in the kitchen. Each air inlet of the kitchen was sealed. The door between separating the two zones is closed. This experiment allows us to evaluate the parasitic air flow in a configuration close to the reality. Each zone is heated at 21°C constant temperature.

The **Configuration 6** is exactly as the Configuration 5 except the close is open. By comparison with the previous one, this case pertains to the influence of a closed door on the operation of the mechanical extraction unit.

In order to take into account the turbulent component of the wind, the acquisition system frequency is 5Hz i.e. every parameter is recorded every 0.2 second. Many parameters are measured : wind speed, wind direction, atmospheric pressure, external temperature, external relative humidity, internal pressure, internal temperature, internal relative humidity, global ventilation rate with tracer gas system, energy consumption, differential pressure of air inlets and infiltration.

At the end of each experiment, the tracer gas measuring apparatus was recalibrated. So that, the best experimental data to compare is the ventilation rate given by tracer gas.

3 - MODELLING ON CLIM2000

The house is modelled into CLIM2000 software program. We used the temperature/pressure modelling available into CLIM2000. The infiltration and air inlets are modelled by the mean of power law elementary models. The power law used is as follows : $Q = K.\Delta P^n$

The effect of wind on each facade in terms of dynamic pressure is calculated by the following equation : $Pv = \frac{1}{2} r \cdot cp \cdot U_{ref}^2$ in which ρ, cp and U_{ref}^2 are air density, pressure coefficient and wind speed measured at the ridge capping of the house. There are different possibilities available into CLIM2000 for cp values. We can choose the Fauconnier & Al. Values **[3]** or the Liddament & Al. Values **[7]**. We will present hereafter the influence of these values on the calculated global ventilation rate. U_{ref}^2 is based on the following expression : $U_{ref} = U_{met} \cdot (\frac{Z_{fait}}{Z_{met}})^N \cdot K_V$ where U_{met} is the measured wind speed at z_{met} height, z_{fait} is the ridge capping height of the house, N is a coefficient dependent on the environment which takes different values function of sea, land, forest, suburbs or city environment and K_V is an obstruction coefficient which takes different values in land and cities.

For each configuration, we compare the ventilation rate measured by the gas tracer method with the value calculated by CLIM2000. In the first time, we use the elementary models as commonly used i.e. with typical cp values given by **[3]**. After, we make a short sensitivity analysis on cp values and on the coefficients used in the power law describing the infiltration holes and air inlets.

4 - RESULTS

Only the results related to the four first configurations will be presented hereafter. The two last configurations were completed in the first week of March 99, so that we are not able to produce any analysis by the papers submission deadline.

3-a - Configuration 1

The comparison between experimental results and simulated results is given on Figure 3. We can see that CLIM2000 ever underestimates the ventilation rate of the house. The difference between measurements and simulation can reach 37% for the 0 degrees orientation. In some cases like 30, 90, 120, 150 and 180 degrees, this difference is not so high and the agreement is quite good. Due to the fact that the uncertainty of tracer gas measurement apparatus is close to 15%, we can say that the CLIM2000 are good enough. The difference could come from the pressure coefficient used into CLIM2000 which are based on the values given in the references **[3,7]**. We tried to recalculate the exact values of the pressure coefficient by using these experimental data. In the average value considered, the difference between the calculated values for each façade and the values used previously can reach 25%. This difference can explain the disagreement for the orientations 0 and 60 degrees. For the others orientations in which the agreement is good, the calculated pressure coefficients are closed to the ones used into CLIM2000. Another possible source of disagreement could come form the power law coefficients used for infiltration and air inlets. Indeed, they were calibrated under certain conditions of temperature different from the ones observed during the experiment. This point is under verification.

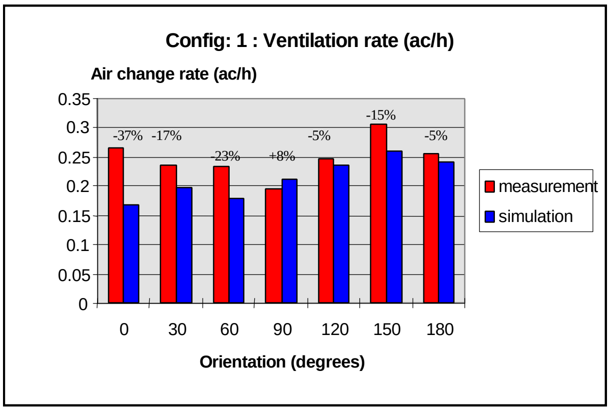

Figure 3 : Config. 1 (comparison simul./meas)

3-b - Configuration 2

The comparison between experimental data and calculated results for the Configuration 2 is given on Figure 4. Once again, CLIM2000 underestimates the global ventilation rate of the house. The difference can reach 32% in certain cases. The same explanations as in 3-a can be stated here. One point of interest here is the fact that the influence of temperature field is negligible in regard to the pressure difference generated by the wind. Even if we compare only the measured values in both configurations, there is no fundamental differences between them. We should have expected an impact of temperature on the ventilation rate because in the configuration 2, the internal temperature is equal to 21°C whereas the external temperature is close to 10°C. The air density difference due to the temperature difference should have produced an extra ventilation rate. It is not the case. Nevertheless, we are still analyzing the discrepancies between simulated results and measured data to find a definitive explanation in order to improve the models.

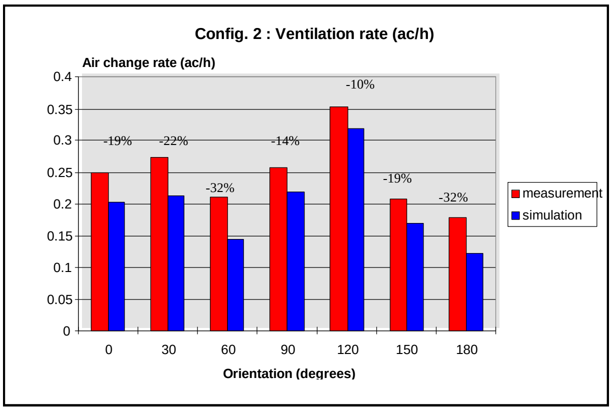

Figure 4 : Config. 2 (comparison simul./meas.)

3-c - Configuration 3

The comparison between experimental data and calculated results for the Configuration 3 is given on Figure 5. Except the orientation 180 degrees in which it seems that the experimental data are not precise enough, the agreement is not so bad and the difference is around 16%. Due to the fact that the air change rate given by the air extraction unit is close to 0.7 ac/h, we have a good homogeneity between Configurations 2 and 3. Indeed, we can observe a « translation » of the ventilation rate values. The Configuration 3 values are 0.7 ac/h higher than the Configuration 2 values. This point is interesting because the parasitic ventilation rate is close to the ventilation rate observed into the Configuration 2.

Nevertheless, we will rerun this configuration after finding an explanation of discrepancies between experimental data and simulated results observed in the Configurations 1 and 2.

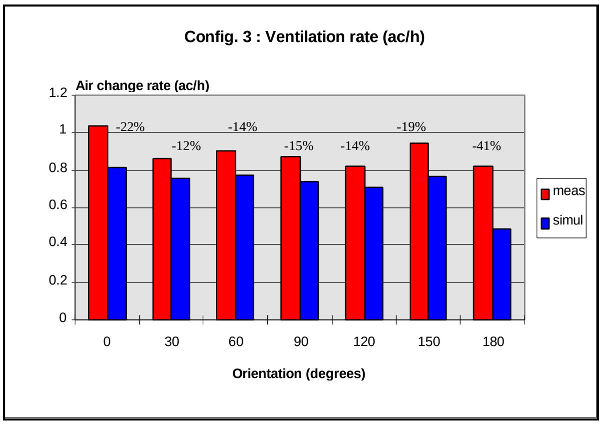

Figure 5 : Config. 3 (comparison simul./meas.)

3-d - Configuration 4

The comparison between experimental data and calculated results for the Configuration 4 is given on Figure 6. The agreement between experimental data and simulated results is good enough for this kind of experiment. We can see that the special air inlets (air can come in but not come out) installed for this configuration gives lower ventilation rate for certain orientations than the ones installed for the configuration 3.

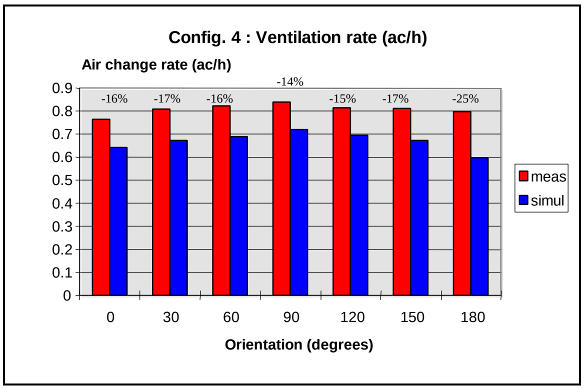

Figure 6 : Config. 4 (comparison simul.meas.)

The comparison between these two configurations in terms of ventilation rate is given in Table 1.

Table 1 : Comparison Conf.3 vs Conf.4

Conf. 3 (meas.) (ac/h)	Conf. 4 (meas.) (ac/h)	Difference 3-4 (%)
1.035	0.765	+35.3
0.864	0.809	+6.8
0.906	0.824	+10
0.875	0.84	+4.2
0.825	0.816	+1.1
0.943	0.812	+16.3
0.822	0.798	+3

The comparison is available because the weather conditions for these two configurations are close to be identical. Indeed, the configuration 4 was carried out just after the configuration 3. It seems to be interesting to use the special air inlets into house because the consequence in terms of energy consumption is not negligible.

We will rerun this configuration after finding an explanation of discrepancies between experimental data and simulated results observed in the Configurations 1 and 2.

3-e - Sensitivity analysis

We made a short sensitivity analysis to study the influence of cp values on the calculated ventilation rate and the influence of the coefficients of the power law describing the air flow coming through infiltration and air inlets.

For cp values, we have rerun the simulations by using Liddament cp values instead of Fauconnier cp values. The comparison between these two kinds of cp values in terms of ventilation rate difference between simulation and experimentation for three orientations (0, 60 and 120 degrees) of Configuration 1 is given in Table 2.

We can see that the use of the second set of cp values does not improve the results each time. In two orientations, the improvement in terms of agreement between experimentation and simulation is obvious. In the last orientation, there is no improvement. This due to the fact that in this angle of wind attack, the cp values are quite the same in both references. Nevertheless, this point is interesting and needs to be focused on. In a next future, we will try to determine the real cp values of the Bouin house by the use of experimental data. These real cp values will be included into CLIM2000 in order to see the if the agreement between experimentation and calculation is better.

Table 2 : Comparison cp values for Config. 1

Orientation (degrees)	Fauconnier cp values **[3]**	Liddament cp values **[7]**
0	-37%	-34%
60	-23%	-23%
120	-7%	-5.2%

The second short sensitivity analysis we made consists of the study of the influence of the power law coefficients driving the air flow coming through infiltration and air inlets. We think that they are dependent on the temperature. So that, we have made a 10% perturbation on K (see Section 3) ; then after, a 10% perturbation on n (see Section 3) and then after a 10% perturbation on K and n simultaneously. The results for the orientation 0° of Configuration 1 are given in .

Table 3 : Influence of power law coefficients (Config1 0°)

Perturbation	Meas. (ac/h)	Simul. (ac/h)	Difference (%)
base case	0.267	0.169	-37%
K	0.267	0.183	-31%
n	0.267	0.182	-31%
K and n	0.267	0.201	-25%

Off course, as an expected result, the influence of the power law coefficients is important on the ventilation rate. With just a 10% perturbation, we can have an improvement of 12% in terms of ventilation rate.

By these two light sensitivity analyses, we have found different ways to explain the discrepancies between experimental data and simulated results. Nevertheless, the agreement is not so bad due to the difficulty of such experiments.

In the next study which is under treatment, we will try to find the real cp values and their influence on the simulated results. We will add also the uncertainty of measurements to see if the simulated results are included in the uncertainty band of the measurements.

CONCLUSION

A very important experimental sequence was carried out in the framework of a collaboration between EDF and CSTB in order to study the influence of a turbulent wind on the ventilation rate of a house. The experimental data are compared to the simulated results obtained from CLIM2000 software program. The agreement is not so bad due to the fact that this kind of experiments is difficult to carry out.

The comparison between Configuration 3 and Configuration 4 gives the conclusion that the special air inlets which allow the air to come in but not to come out, produce lower ventilation rate than the others.

Nevertheless, some ways of extra analysis have been found. We are continuing the analysis especially on the determination of the real cp values of the Bouin house and on the influence of temperature on the power law coefficients. The results of this next analysis will be reported in a new paper when ready.

These results are preliminary. The next analysis will be based on the differences observed between experimental results and standard value of air change rates given by the French thermal regulation. If these differences exist, then we will try to develop a specific model to take into account the turbulent effect of wind by using the classical recordings of wind speed and wind direction.

AKNOWLEDGEMENTS

The authors would like to Mr Hervé BREBION from CSTB, who took part to the experiments in Bouin house.

REFERENCES

[1] Etheridge D. W., « A note on crack flow equations for ventilation modelling », Building and Environment, Vol.33, N°5, pp. 325-328, 1998.

[2] Eurocode 1 : Basis of design and actions on structures - Part 2.4 : Actions on structures-Wind actions », European Comittee for Standardization, May 1995

[3] Fauconnier R., «Energétique des bâtiments », PYC Edition, vol.2, pp71-90.

[4] Girault P., « Etat des lieux sur les modèles d'infiltration d'air de CLIM2000 », EDF report HE-14/96/040, Dec. 1996.

[5] Moyé C., « La perméabilité à l'air des bâtiments d'habitation », Cahiers du CSTB 2019, Sept. 1985.,

[6] Nagda N. L., « Air infiltration, energy use, and indoor quality in EPRI test houses/ Part I-Infiltration and energy use », Proc. Indoor air quality seminar, Atlanta, Georgia, USA, January 1985.

[7] Liddament M., Allen C., « The validation and comparison of mathematical models of air infiltration », Technical Note AIC N°11 September 1983.

[8] Villain J., « Etude expérimentale relative aux infiltrations d'air dans le laboratoire expérimental de Bouin », CSTB/EDF private report, Déc. 98.

[9] Villain J., « Champ de pression induit par le vent sur la maison expérimentale de Bouin (Vendée)-Banque de données expérimentales », CSTB report EN-SC 92.05 L, 1992.

[10] Walker I. S. and Al., « A comparison of the power law to quadratic formulations for air infiltration calculations », Energy and Buildings, 27, pp293-299, 1998.

[11] Wortman D. N. and Burch J., « System analysis on two-tracer-gas, two-zone airflow measurements », SERI/TR-254-2249, Feb. 1984.