CRITERIA TO DEFINE LIMITS FOR BUILDING AIRTIGHTNESS

Airtightness of some Portuguese dwellings

Armando Pinto

Building Components Division, National Laboratory of Civil Engineering LNEC

Lisboa 1700-066, Portugal

ABSTRACT

The increasing concern on energy conservation in buildings and the increasing insulation level of buildings, lead to the introduction of limits for building airtightness, to minimize building heat losses. In some countries the recommended limits are very strict and could be difficult achieved with standard construction practices. Usually the limits are established according construction (best) practices and in some countries it takes in account the building type, ventilation system and weather. Usually those limits don't take in account the air flow rate for background ventilation.
In Portugal the concern about building airtightness is limited to air permeability of windows. In the study curried out it was assessed the importance of whole building airtightness, versus window air permeability and the importance of whole building airtightness to define limits that take in account, energy losses, indoor air quality and ventilation requirements and the action that promote the pressure difference across building envelope (wind actions, thermal buoyancy and ventilation systems).

KEYWORDS
Airtightness, Air permeability, Ventilation, Energy conservation, Natural ventilation, Mechanical ventilation

BUILDING AIRTIGHTNESS VS WINDOWS AIR PERMEABILITY

In Portugal since 1987 there are limits to windows air permeability Mimoso (1987). The air permeability of windows could have a relatively large range. For aluminium windows tested at LNEC (Pinto, 2002), the sliding windows on average belong to class 2 of air permeability (EN 12207: 1999), and the side hung casement on average belong to class 3.

If we suppose that the glazed area is 20% of the floor area, the air permeability of windows corresponds to n50 of 0.6 for sliding windows and 0.3 for side-hung, on average.

The airtightness of Portuguese buildings was first studied at FEUP by Afonso et al (1988), where it was measured the airtightness of 7 buildings (6 dwellings and 1 detached single family house), using the blower door test method (ISO 9972: 1996). In other study, it was measured the air tightness of 12 detached single houses, Silva (1991).

In the previous studies it wasn't assessed the importance of the air permeability of different components of building shell. To try to address the importance of windows in whole building airtightness, in this study, in four buildings, the airtightness was measured sealing windows and sealing the roller shutters boxes, the two major discontinuities in building shell. The results of those 4 tests show that the window air permeability is responsible for only 5 to 11% of building air leakage and that crack around roller shutters could be responsible for 15% to 50% air leakage, figure 1. In one building, with one anemometer, some of the remaining leaks were identified in joints between floors and walls and electric pipes. This results are similar to other obtained in other countries, Wouters (1986), Moyé 1985), or obtained by extrapolation Orme (1999), ASHRAE (1997).

These results show that to minimise air leakage in building, it will be necessary to recommend limits to whole building airtightness and not only to some components, such as windows.

The air tightness of 23 Portuguese buildings is represented in figure 2. For apartments the n50 on average belong to the range 2 to 4, and in the detached dwellings n50 belong to the range 4 to 10, which mans an airtightness classified as average according to EN ISO 13790, but over some limits imposed in some European countries, justifying the studied of reasonable limits for airtightness of Portuguese buildings.

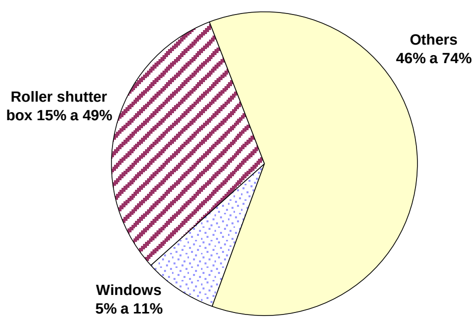

Figure 1 – Average leakage distribution in four buildings

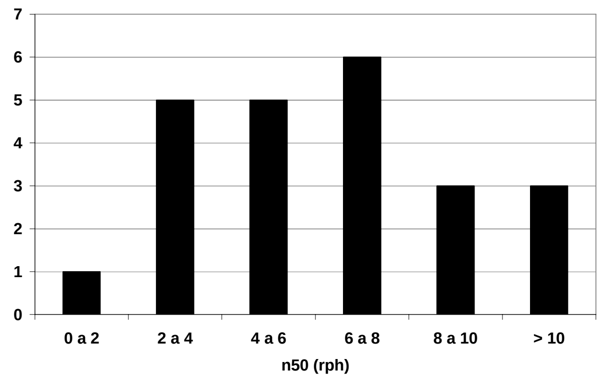

Fig.2 – n50 of 23 Portuguese buildings

CRITERIA TO DIFINE AIRTIGHTNESS OF BUILDINGS

In Portugal and other countries, the intake of fresh air for ventilation of residences usually is done directly from outdoor, using small opening, trickle ventilator. One first approach to define limits for building airtightness could be that the building air leakage should be less than the background ventilation rate (Q_b in m^3/h) at 10 Pa for building with natural and hybrid ventilation systems and 20 Pa for building with centralised mechanical ventilations systems, eqn 1 (**Criteria I**). The 10 Pa and 20 Pa, pressure difference are based on standards to design ventilation system (NP 1037-1:2000, NF XP P 50-410: 1995). This criteria when applied, gives very stringent airtightness limits for buildings, table 1.

$$\begin{aligned} n50 &\leq Q_b \times (50/20)^{0.67} && \text{for buildings with mechanical ventilation} \\ n50 &\leq Q_b \times (50/10)^{0.67} && \text{for buildings with natural or hybrid ventilation} \end{aligned} \qquad (1)$$

The criteria I, doesn't take into account the action that promote air infiltrations so, another criterion could be: <u>the limitation of air infiltration (total air flow rate) to the double of background flow rate under strong wind action, for example, for wind speed with a probability of being exceeded only on 5% of time, in one year</u> (**Criteria II**) This criteria focus on the major concern of airtightness which is air infiltration in buildings, conservation of energy and thermal comfort. This second criteria lead to different limits according to building wind exposure and ventilation system.

To get wind effect on buildings, it was analysed the data of the test reference years of Lisbon and Paris (table 2), where we can see the larger difference in air temperature.

Since building have different exposure to wind, it was considerer 3 types of terrain, and 5 height, which gives the wind Reduction Factor ($U = RF \times U_{meteorological}$) presented in table 3 (BS 5925:1991). With this wind Reduction Factor and the wind speed exceeded only in 5% of the time (assure reasonable air infiltrations in 95% of the time) we can calculate the dynamic pressures of wind and define 8 classes of exposure to wind, table 3.

To define and appreciate the impact of building airtightness it was considered the four buildings indicated in table 1, and it was studied in more detail two buildings (table 4): one apartment building with two opposite façades exposed to wind (the most stringent) and one detached dwelling with four façades exposed to wind (the less stringent).

AIRTIGHTNESS FOR BUILDINGS WITH MECHANICAL VENTILATIONS SYSTEMS

To define the limits for "over ventilation" in buildings it was used a simple air flow network with one internal node and one node for each façade exposed to wind. In the simulations of mechanical ventilations system it was considered the 8 wind classes, continuous extraction of Q_b, the intake of fresh air trough trickle ventilator with the performance shown in figure 3 and the air infiltrations trough each façade given by the power low, eqn 2 (nfac, is the number of façades exposed to wind). For wind pressure coefficient it was adopted the data for the low-rise building (table F1, Orme, 1999) and the wind angle 0º.

With the results of the simulation (table 5), it was concluded that the limits for airtightness of buildings could be calculated by eqn 3, which is equivalent to limit the air flow trough crack around building envelope to Q_b. The limits obtained by eqn 3, are 6% lower than the limits obtained by the air flow network for P_{dyn}=80Pa and 25% lower for P_{dyn}=10Pa. The constants 47 and 63, are calculated by: $47 = 50^{0.67} \times 2/[(C_p0º-C_p180º)/2]$, $63 = 50^{0.67} \times 4/[C_p0º-(C_p0º+ C_p90º+ C_p180º+ C_p270º+)/4])$.

$$Q = n50/nfac/50^{0.67} \times \Delta P^{0.67} \qquad (2)$$

$$n50 \le 47 \times Q_b/Vol \times (P_{dyn})^{0.67} \quad \text{for buildings with 2 exposed facades}$$
$$n50 \le 63 \times Q_b/Vol \times (P_{dyn})^{0.67} \quad \text{for buildings with 4 exposed facades} \qquad (3)$$

The application of these limits to case studies (table 4), gives the results presented in table 5, where we see the decrease of the requirements of building airtightness as wind exposure decrease. To test the validity of these limits, the two case studies were evaluated in more detail with ESP-r, for wind classes 1, 2, 5 and 8. For the wind class 5, it was studied four scenarios: 1, zero airtightness, only air intake devices; 2, air intake devices and criteria I of building airtightness; 3, air intake devices and n50 respecting criteria II; 4, air intake devices and n50 comply with criteria flow rate fourth of the background ventilation in no more than 5% of the time. In scenarios 5, 6, 7 air intake devices and n50 comply with criteria II.

From ESP results (table 6) we can conclude:

- It is reasonable to recommend limits that depend of wind exposure and depend on the number of façades exposed to wind;
- The limit of the air infiltration to the double of background ventilation in less than 5% of the time seems reasonable, because if we admit 4 times the background ventilation (case 4) we have a large increase on heating demand (internal air temperature of 20ºC);
- If we compare criteria I (case 2) with the other cases satisfying criteria II we observe a slight increase on heating demand. But this slight increase could be overcome if the number of air intake devices is reduced proportionally to the airtightness;

AIRTIGHTNESS FOR BUILDINGS WITH NATURAL VENTILATIONS SYSTEMS

The limit for airtightness in building with natural ventilations systems is relatively more cumbersome to achieve, because in a first stage we must assure the background ventilation rate in more than 50% of the time between November and April (the heating season) and we should also limit the over ventilation because of thermal comfort, and energy consumption.

To limit air leakage it was considered the trickle ventilator (figure 3). To calculate the number of trickle ventilator to assure the background ventilation rate it was used the model ESP-r. The air flow trough chimneys was evaluated using the model ($m=C.\rho.\Delta P^{0.5}$) with a stack height of 5 m, where the values of C comply with NP 1037-1 (C=46 for chimney in kitchen and 21 for chimney in bathroom). In the detached dwelling it was considered a larger chimney in kitchen with C of 110 and C of 21 for the 3 bathrooms. The cowl was simulated with the model of Gonzales (1984), (∅300mm, C_p=-0.55, ζ=1.22, B=0.8, n=0.18).

In ESP-r were analysed four scenarios: case 1, determination of the number of air intake devices to get background ventilation in 50% of the time between November and April, with zero building airtightness; case 2, determination of the n50 required to assure the background ventilation in 50% of the time with zero air intake devices; case 3, simulations with 75% of the air intake devices and 25% of n50 of case 2; case 4, simulations with 25% of the air intake devices and 75% of n50 of case 2. The results are presented in table 7, and we can conclude:

- In buildings with natural ventilations systems we need much more air intakes than in mechanical ventilation systems to assure the background ventilation rate in a reasonable period of time, stated here as 50% of the time between November and April, period when we have the lowest outdoor temperatures, and the greater stack effect. This number is much higher than the one obtained with the 10 Pa criteria. The analysis of whole year show that these air are enough to assure the background ventilation in 50% of the time of the year in Lisbon and only 30 to 50% in Paris.
- This larger air permeability required for background ventilation agrees with the results obtained by the simple model proposed by Perino et all (2002), which require a slightly higher air permeability.
- Because we need much more air intakes in natural ventilations system, it seems reasonable to admit a larger air leakage to building envelope, than in buildings with mechanical ventilations systems. But, from the results of wind class 8 it is recommended to limit n50 to 25%, which gives a value near criteria II, eqn 3.
- Another interesting result is that, buildings with natural ventilation have a heating demand larger than buildings with mechanical ventilations system, because of the greater variability of air flow rates; in Lisbon, the air flow rate is higher than $2\times Q_b$ in 20% of the time. This value could compensate partly the energy consumption of fans.
- Because of the higher air temperature in Lisbon, than in Paris, the air permeability required for background ventilation in Lisbon is higher than in Paris.

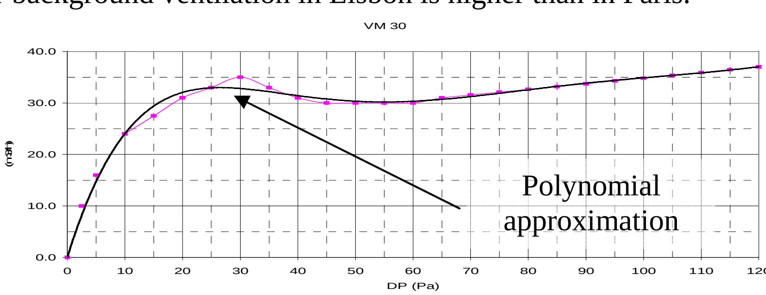

Figure 3 – Performance of auto-regulate air intake device with module 30 m^3/h at 20 Pa

CONCLUSIONS

In this paper it was presented some data about Portuguese building airtightness. The values measured in 23 building, show good agreement with the proposed requirements for sheltered buildings, but these values could be excessive for more exposed buildings.

The leakage distribution of Portuguese buildings agrees with measurements made in other countries and show that we should limit the whole building airtightness and not only some of their components.

From the study done it is proposed that the building airtightness for mechanical and natural ventilated buildings should be limited to double the background ventilation in less than 5% of the time, which could be obtained by eqn 3, taking into account wind exposure (table 3) and background ventilation.

To get better building behaviour the airtightness of the building should be measured, to verify the compliance with criteria and to decrease the number of air intake devices proportionally to the air flow rate across cracks in building shell.

With these limits it could be expected a decrease in the heating demand and a negligible reduction in cooling loads.

The method for the calculations of air intake for buildings with natural ventilation systems should be revised because the values obtained with 10 Pa criteria are insufficient.

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Table 1 – Application of criteria I to some buildings types

Typology	Apart 1 bed	Apart 2 bed	Apart 3 bed	Apart 4 bed	DSFH
Floor area (m^2)	53	65	82	105	135
Q_b (m^3/h)	86	130	180	235	285
n50 Nat. Venti.	1.9	2.3	2.6	2.6	2.5
n50 Mec. Ven.	1.2	1.5	1.6	1.7	1.6

Table 2 – Weather data

	v (m/s) > 50% time	v (m/s) > 5% time	T_{air} (ºC) < 50% time	DD_{20}	Heat. Seas. (month)	I_{sul} kWh/m^2.month
Lisbon	3.6	8.9	11.5	1750	6	90
Paris	3.6	8.9	5.5	2890	8	28

Table 3 – Wind effect class

Terrain / H (m)	Reduction factor RF			P_{dyn} (Pa) exc. 5% time			Wind effect Class		
	Open flat	City	Urban	Open flat	City	Urban	Open flat	City	Urban
5	0.89	0.89	0.52	40	10	10	4	1	1
10	1.01	1.01	0.62	50	20	10	5	2	1
18	1.11	1.11	0.72	60	20	10	6	2	1
28	1.20	1.20	0.81	70	30	20	7	3	2
60	1.36	1.36	0.97	80	50	30	8	5	3

Table 4 – Data of the two detailed case studies

	Floor (m^2)	Volume (m^3)	Q_b (m3/h)	Uwall (W/m^2K)	Uwin (W/m^2K)	Uroof (W/m^2K)	A_{win}/A_{floor}
Apartment	53	135	86	0.78	3.5	-	20%
Detached	135	340	286	0.78	3.5	0.50	20%

Table 5 – Limits of building airtightness for two case studies according wind exposure class

Typology	V (m^3)	Q_b (m^3/h)	Nº air intake	n50							
				1	2	3	4	5	6	7	8
Dwelling	135	86	3	6.4	4.0	3.1	2.5	2.2	1.9	1.7	1.6
DSFH	340	285	10	11.3	7.1	5.4	4.5	3.8	3.4	3.1	2.8

Table 6 – Heat demand (kWh) and over ventilation with mechanical ventilation

Case	Wind Class	Apartment (3 air intake)					Detached Apartment (3 air intake)				
		n50	Lisbon		Paris		n50	Lisbon		Paris	
			Heat	Q>2Q	Heat	Q>2Q		Heat	Q>2Q	Heat	Q>2Q
1	5	0	90	0.0%	1 865	0.0%	0	3 554	0.0%	13 174	0.0%
2	5	1.2	103	0.1%	1 914	0.0%	1.0	3 607	0.0%	13 373	0.0%
3	5	2.2	115	0.4%	1 999	0.3%	3.8	3 920	1.7%	14 450	2.7%
4	5	5.1	220	17.0%	2 575	10.0%	9.2	4 986	20.7%	17 819	20.6%
5	1	6.4	105	0.2%	1 911	0.1%	11.3	3 644	0.1%	13 489	0.3%
6	2	4.0	126	2.0%	2 042	1.2%	7.1	3 916	2.1%	14 419	3.0%
7	8	1.6	135	2.2%	2 122	1.3%	2.8	4 054	3.3%	14 922	4.0%

Table 7 – Heat demand (kWh) and over ventilation with natural ventilation

Wind Class	Apartment 2 exposed façades								Detached dwelling 4 exposed façades							
	Lisbon				Paris				Lisbon				Paris			
	N	n50	Heat	%	N	n50	Heat	%	N	n50	Heat	%	N	n50	Heat	%
1	130	0	559	26%	58	0.0	2,351	12%	260	0	4,566	14%	92	0	13,711	2%
1	98	8.4	486	25%	44	4.7	2,314	11%	195	7.6	4,462	13%	69	3.4	13,688	1%
1	33	25	358	23%	15	14	2,288	8%	65	22.9	4,269	9%	23	10.3	13,629	1%
1	0	34	295	20%	0	19	2,239	7%	0	30.6	4,172	7%	0	13.7	13,602	1%
5	18	0	241	25%	12	0.0	2,141	15%	60	0	4,325	18%	36	0	13,755	3%
5	14	2.2	265	25%	9	1.5	2,179	15%	45	2.8	4,394	18%	27	1.7	13,913	6%
5	4.5	6.7	314	24%	3	4.5	2,295	15%	15	8.3	4,498	17%	9	5.2	14,187	9%
5	0	9.0	331	23%	0	6.0	2,318	14%	0	11.1	4,537	17%	0	7.0	14,311	9%
8	12	0	181	24%	8	0.0	1,871	0%	40	0	3,988	10%	27	0	13,345	0%
8	9	1.5	219	24%	6	1.0	1,993	4%	30	1.9	4,148	14%	20	1.2	13,616	3%
8	3	4.5	307	25%	2	3.1	2,229	14%	10	5.7	4,410	30%	7	3.6	13,980	9%
8	0	6.0	344	25%	0	4.1	2,319	17%	0	7.6	4,521	19%	0	4.8	14,170	12%

% - percentage of time between November and April when Q>2 Q_b; N- nº of air intake devices