ON THE INFLUENCE OF THE AIR INFILTRATION HEAT LOSSES ON THE ENERGY PERFORMANCE OF ITALIAN RESIDENTIAL BUILDINGS

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ABSTRACT

It is often discussed about the possibilities that more efficient windows offer to reduce the energy loads in residential buildings. Often such results can be achieved reducing the thermal transmittance or optimising the solar gains, not so often the influence of the air permeability is taken into account. This issue is, on the contrary, very important in countries, as Italy, where the age of the building stock is accompanied by the installation of very old windows, characterised by high air leakage, which causes strong heat losses and discomfort phenomena for users. This paper aims at giving an idea of the achievable heating energy savings coming from the application of more tight fenestration systems at national and dwelling level. This should give also some useful indication for users about the economic savings that can be obtained during the life cycle of the installed product. It is also presented the ENEA experimental building, where testing and evaluation of different fenestration products, concerning the energy and the thermal comfort performances, are scheduled for the next heating season .

KEYWORDS

Windows, air infiltration, residential buildings, space heating.

INTRODUCTION

One of the main issues related to the Italian building stock is its advanced age. The last census showed that, of the 26.5 million of Italian dwellings, around the 25% was built before the world war two and the 80% was built before 1980, that is the period when policies of energy savings started to be taken into account in the building sector. Another important factor is the 65 to 70% of single glazed window actually installed in the Italian building, considering that in commercial buildings more efficient fenestrations systems are installed since several years, it is evident the poor state of the windows stock in the Italian residential sector. Even if new energy regulations were implemented in the past years, their effect was very limited, since the refurbishment aiming at improving the energy performance of existing building growing quite slowly. The residential sector reflect this negative trend, with the heating needs of Italian building among the highest in Europe, considering the climatic conditions.

It is often discussed and indicated, especially at normative level, the importance of the *U* value of the windows to improve the thermal performances of buildings, without considering the influence of the air permeability of such components, in particular in case of old and leaky fenestration systems. In addition, discomfort phenomena may arise close to the windows due to the presence of cold air streams. It must be noted that Italian dwellings are seldom equipped with mechanical ventilation system, this imply that the indoor air exchange and quality relies only on the natural ventilation, which, especially in winter time, does not have an adequate rate and, as a consequence, a limited energy impact. Improving the air tightness of the windows and, as a consequence of the buildings, is necessary to compensate the higher energy loads coming from the application of mechanical ventilation system, bound to be mandatory according to the forthcoming new national energy methodology.

A STUDY FOR AN ENERGY RATING SYSTEM IN RESIDENTIAL BUILDINGS

A self financed study for the implementation of an energy rating system for windows in the Italian residential buildings was carried out at the end of the nineties. the results of the study are largely presented elsewhere, Maccari et al. (2000). Here are summarised the basic principles of that research, while more focused will be the analysis related to the air permeability evaluation. It is also important noting that, even this study was never turned into real policies at standard and normative level, it made arise an important discussion on how and why improve the fenestration stock in the Italian market.

The energy balance of the building depends on the *Uvalue* (thermal losses), *g* (solar gains) and the air infiltration through the fenestration. The main idea to rate the windows was to analyse how a fenestration system, with known properties, affected the building performance. To do this, it was necessary to have a large amount of data and use them for a best fit regression, in order to obtain a simple equation to compare different kind of windows. Hence were selected: 3 type of buildings (row houses, 6 building, with pilotis at ground level, 4 level building), 5 cities (representative of all the climatic zones, but the hotter with not significant settlements); 6type of windows, summarised in table 1. More over the energy performance of buildings were calculated for 8 different orientation. All the simulation were performed with a well known dynamic code fo building energy analyses, TRNSYS (1996). Ad hoc routine can be developed in the code to model some particular system or components. In this case a new routine was implemented to take into account the air infiltration through the windows, property difficult to consider in building simulation program.

At the time the study was performed, the Italian standards, UNI 7979 (1979) (now substituted by European standards, EN 12207 (2000)), consider 4 classes of windows, related to the maximum infiltration rate acceptable as a function of pressure. As an example at 100 Pa it must be: 50 $m^3/h\times m^2$ for class A1, 20 $m^3/h\times m^2$ for A2, 7 $m^3/h\times m^2$ A3, no classification if leak is worse than A1. The routine, developed in the Fortran language allowed to calculate the thermal loads due of not treated outdoor air passing through the fenestration systems, as a function of the climatic conditions (temperature, humidity, solar radiation, wind and so on…). The permeability of a building (*Qo*), as a function of permeability of transparent components, can be evaluated with the following equation, Eqn. 1:

$$Q_0 = \frac{\Delta P}{V}\left[\sum_q (mA)_j + \sum_r (vL)_j\right]$$

where:

q	number of windows	A	windows area [m^2]
r	number of roller-shutter box	L	roller-shutter box length [m]
ΔP	out/indoor gap pressure [N/m^2]	m	permeability of window [$m^3/s\times m^2$]
V	heated volume [m^3]	v	perm. roller-shutter box [$m^3/s\times m$]

The air infiltration rate of the building Q was computed using the following relation, Eqn. 2:

$$Q = \frac{\sqrt{(a_1 \cdot h^{b_1} + a_2 \cdot h^{b_2})}}{75} Q_{075}$$

where:

Q	air infiltration flow rate [m^3/h m^2]
h	building height [m]
Q_{075}	air infiltration rate at 75 Pa [m^3/h m^2]
a_1, a_2, b_1, b_2	numeric coefficients related to location, vertical permeability and wind speed.

Table 1 Characteristics of the reference windows

Code	Glass (mm)	Frame	U (W/m^{2}°K)	g	τ_v
A	Single Glass	Metal w/o TB	6.1	0.87	0.90
B	Clear DGU	Metal w/o TB	4.5	0.76	0.81
C	Clear DGU	Metal TB	3.1	0.76	0.81
D	DGU low-e (0.2)	Metal TB	2.6	0.72	0.73
E	DGU low-e (0.1)	Metal TB	2.4	0.64	0.76
F	DGU low-e (0.1) + argon	Metal TB	2.2	0.64	0.76
G	DGU low-e + solar filter	Metal TB	2.6	0.47	0.71

Considering all the variables, more than 1000 building simulation were performed. By a multilinear regression, the following formula, Eqn. 3, was determined:

$$NHLR = 52 - 9.4 \times U + 32.2 \times g - 0.25 \times Q_{75}$$

This formula calculates the heat load reduction, normalised to the degree days a,nd to the square meters of building, when using windows, whose characteristics are to be inputted in the formula itself, respect to the reference windows (window A in table 1). To be noted that the air tightness of the window now determined according to EN 12207, must be corrected, by means of well known formula, to input the value at 75 Pa in the above formula.

INFLUENCE OF THE AIR PERMEABILITY OF WINDOWS ON THE ENERGY AND ECONOMIC BALANCE OF TYPICAL DWELLINGS

Extrapolating some of the simulation results, it is possible to check in detail the influence of the infiltration rate on the building energy performances. In particular, the attention is focused on 4 cities, corresponding to the climatic zones, where the majority of the population leaves. The presented results refers to the four level building, which represents a diffuse typology on the Italian territory. The graphs in figure 1 and 2 show the heating loads in Turin (2553 degree days) and Rome (1440). As expected, the heating loads decrease improving the *U-val*ue (except for window E, due to a strong reduction of the solar gains) and the air tightness. Focusing the black lines in the two figures, it can be noted the not negligible influence of the air permeability. In fact, the building equipped with a very good window (F) of class A1 can have worse performance if equipped with a normal window (C) but in class A2 or 3. To be noted that the class of air infiltration are those defined in the old Italian standard.

Tables 2 to 5 summarise the percentage reduction of heating loads due to more air tight window, for each window and locality. Beside Turin and Rome, also Olbia, Sardinia (1142 degree days, typical southern peninsular climate), and Palermo (751, hot Sicilian climate), were considered. In Olbia the heating loads are comprised between 98.5 and 21.1 giga joule, in Palermo between 5.29 and 0.83. Window A is not considered, because both in renovation and new building is obsolete. In each table, the first 3 rows show the reduction respect to the not classified window, the 4th row shows the reduction of A3 respect to A1 and the 5th respect to A2. As expected the lower the air permeability, the higher the energy savings. An A3 window, whatever their thermal characteristics are, can reduce the heating loads of the building of 35-50% respect to a window A, the limit is in Palermo where the reduction can reach the 60%. Good improvements are obtained comparing A1 and A3 windows, between 20 and 30%, again the more rigid is the climate, the lower is the energy reduction. And finally, acceptable results are obtained comparing both windows as A2 and A3. In Turin, cold climate, the advantage are limited (5-7%), in Rome they are close to 10% and better results, as expected are obtained for Olbia and Palermo.

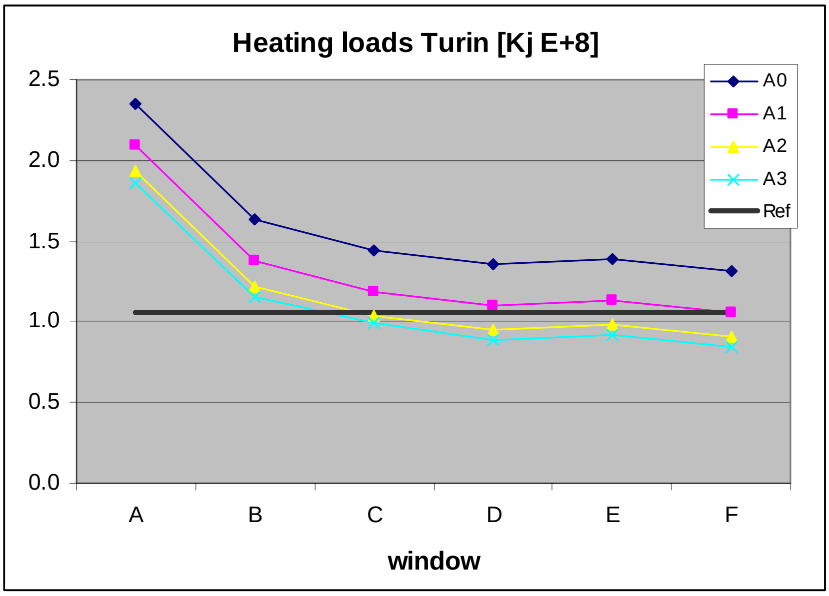

Figure 1 Heating loads of the reference buildings in Turin

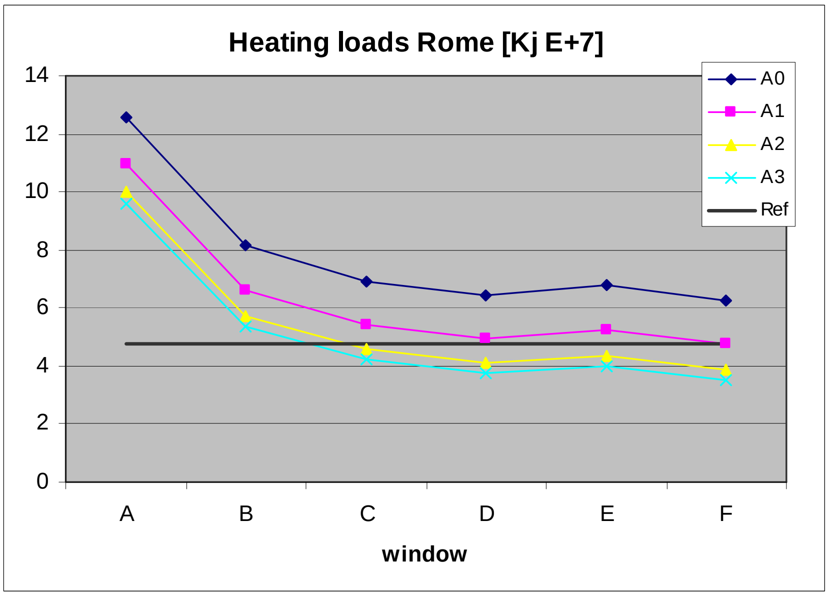

Figure 2 Heating loads of the reference buildings in Rome

Table 1 Percentage reduction of heating loads in Turin

	Turin					Rome				
	B	C	D	E	F	B	C	D	E	F
A0_A1	84	82	81	81	81	81	78	77	78	77
A0_A2	75	72	70	71	69	70	66	64	65	62
A0_A3	71	69	67	66	64	65	61	58	59	57
A1_A3	84	84	81	81	80	81	77	76	76	74
A2_A3	95	96	93	93	93	93	92	91	92	91

Table 2 Percentage reduction of heating loads in Turin

	Olbia					Palermo				
	B	C	D	E	F	B	C	D	E	F
A0_A1	75	71	70	70	69	72	68	66	67	64
A0_A2	61	55	53	54	51	57	51	47	49	46
A0_A3	55	49	46	47	45	51	44	40	42	39
A1_A3	73	69	66	67	65	70	65	62	63	60
A2_A3	90	88	87	88	87	89	87	85	86	84

The application of Eqn. 3 permits the calculation of the energy savings that can be reached when using more efficient windows. It is interesting the economic effect of more efficient windows in case of new and retrofitted building. It is considered an apartment of the reference building, around 120 m2 and with 15 m2 of windows. It is supposed that the building has an gas heating system (70% as efficiency of the whole system) and the price is 0.72 € per cube meter. According to the actual national situation the interest and inflation rates are respectively fixed in 3 and 2.5%. The NPV (net present value) and the PBT (pay back time) are calculated considering a life cycle of 30 years for the product.

Considering new buildings equipped with low emittance double glazing units (U of the window 2.2 $W/m^2°K$). A class A4 (according to the actual EN standards) window costs around 5% more of the same window in class A2 (considering the market price of assembled windows, supplied by the association of wood, PVC and metal frames), with the annual achievable energy savings it comes out a PBT of 2.8 years and NPV of 1300 € in Turin, and 5 years and 640 € in Rome.

The same analysis for retrofitting has, of course different results. In the previous case the investment was only the extra cost of the selected windows, in this case the investments regards the full price of the new products to install. The NPV of new windows, both in class A2 and A4, respect, is very high, more than 13000 € in Turin and 7000 € in Rome, because of the better performance respect to the old installed ones. Of course the relative difference between A2 and A4 gives the same results of the new building case. Concerning the PBT, in Turin it is calculated in 6.1 and 5.8 years for A4 and A2 respectively, in Rome 10.8 and 10.3. In this case the economic analysis does not change very much, even if an added values is always kept. To keep in mind that the energy balance of the building is positively affected and energy and environmental issues are accomplished.

EXPERIMENTAL CAMPAIGN AT THE EXPERIMENTAL BUILDING “CASA INTELLIGENTE”

The experimental building “Casa Intelligente” (Smart House) at ENEA was funded by the Italian Ministry of Industry, in order to carry on experimental researches to improve the energy performance, the safety, security and comfort for users, in residential dwellings. It is a two level building, the two floor are identical: the first one has a not heated basement below, the latte has a flat roof.

Some experiences and monitoring were already performed during the past years. A new campaign on the energy performance of windows is going to take place next winter. During the campaign it will be performed an energy monitoring to analyse the performance of different products at the building level, at the same time a thermal comfort monitoring will be carried out. The aim is to evaluate how less efficient products affect the comfort for occupants, for what concerns infrared thermal exchange of cold surfaces and cold air stream entering in to the build environment because of leaky frames and windows. This activity should be carried on to push the Italian market towards products more energy efficient and already economically competitive on the market. This analysis should also support the new national and international legislative actions with the definition of more performing benchmark in terms of energy efficiency in building.

CONCLUSIONS

The renovation of the Italian stock buildings is a necessary step to be taken in the next year. It will be done by new constructions and by refurbishment of the existing building. Within these actions, great care on the energy and environmental issues will be dedicated. The stock of the installed windows is very poorly performing and lot of chance for energy efficient products are offered by the market. From the above analyses some conclusions can be inferred:

- The air permeability is an important factor for thermal losses, in many cases good thermal and solar properties of windows can be mocked if the product is not adequately air tight.
- In cold areas windows with low permeability (A4) can improve the building performance of 20 to 35% if poor windows are installed (A1 and A2). Minor energy savings, even if not negligible, can be obtained even respect to A3 windows. In milder climates such percentages increase, even if the amount of saved energy is of course reduced.
- Using high class products is also economically convenient, the extra cost for a more tight windows is generally around 5% and the pay back time is of few years. In existing building the pay back time is of course higher, but also the net present value is.
- In order to push the market towards more efficient products, it seems important the implementation of experimental campaigns and the dissemination of collected results in order to stress the advantage that such products give in terms of energy end economy savings, environment safeguard and users comfort and quality of life.

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