Economic evaluation for the technical performances of the building shell components: doors and windows

LAMBERTO TRONCHIN, ILARIA DURVILLI, KRISTIAN FABBRI and VALERIO TARABUSI

DIENCA – CIARM, University of Bologna, Italy

Abstract: -
Soundproofing and heat insulation of a building façade depend on the performances of each element, which forms it. Glass surfaces, which could be considered the "weak" elements of a façade, have to be studied with attention in order to avoid more heat dispersions, thermal and acoustical bridges.
The Italian Decree DLgs of 2005 August 19th n° 192 "Accomplishment of the Directive 2002/91/Ce about the energetic output in building" with Enclosure C fixes the thermal transmittance values of the transparent locks, determined on the bases of the Climatic Area.
Regarding the acoustical performances, the DPCM of 1997/12/05, "Determination of the passive acoustical requirements of the buildings" defines the evaluation indexes measured *in situ* following the ISO 140 and ISO 717 standards, which refer the evaluation index of the façade to the reverberation time ($D_{2m,nt,w}$), which is influenced by the presence of doors and windows.
The aim of this work is the study of the thermal and acoustic performances of doors and windows, considering a real case of a terraced building. The study is carried out analysing the total performances of four door and window typologies, according to the 2000 UNI EN 12207 and the 2005 UNI 11173.
Finally, the evaluation of energetic costs is presented.

Key words: - Sound insulation; thermal insulation, Economic evaluation, Energy Performance.

INTRODUCTION

A right planning of the building shell, according to the DLgs 2005 August 19th "Accomplishment of the Directive 2002/91/CE about the energy performance in building" and DPCM 1997/12/05, "Determination of the passive acoustical requirements of the buildings", has to involve an economic-performance evaluation of the thermal-physical and acoustical features of each element which forms it. In particular doors and windows, which are the "weak" elements of the shell, have to respect, from 2006/01/01, the values of the thermal transmittance for the transparent locks, including frames, on the basis of the Climatic Area, defined in DLgs 192/5, Enclosure C, which introduces more restrictive limits from 2008/01/01, and then from 2010/01/01; while DPCM of 1997/12/05 defines an evaluation index of the façade sound proofing, $D_{2m\ nt\ w,}$ which has a value strongly influenced by doors and windows presence, that very often damage its efficiency.
This work deals with the global study of the doors and windows thermal and acoustical performances of a terraced building, utilized as house that is going to be realised.

Fig. 1 - Outside layout

THE CASE STUDY

The object of the simulation is the front flat of a terraced building situated at Lugo (Ravenna), in the north-centre of Italy. Five terraced houses compose the building with two levels out of ground, with the following building typology: reinforced concrete frame, tile cement floors and empty case padding walls.

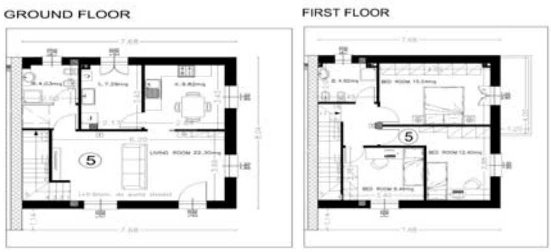

Fig. 2 - Plans of terraced houses: ground floor and first floor

The building packages are formed as follows:

- Outside wall with 29.5 cm thick (from indoors to outdoors): 1,5 cm plaster, 8 cm hollow brick, 1.5 cm plaster, 5 cm rock-wool insulator, 12 cm brick, 1.5 cm plaster;
- Wall among flats: 41 cm thick (no heated rooms), composed by hollow tiles brickwork, with plaster on two sides and thermo-acoustical insulator among flats;
- Concrete floor with airy loose stone foundation 70 cm thick;
- Covering floor with pent roof in insulated tile 40.5 cm thick.

The glass studied surfaces, may be composed by an aluminium frame with a thermal cutting shutter and two glass typologies:

- Type 1 glass: stratified sheet 6 mm+1.52 mm (PVB) +4 mm;
- Type 2 glass: double-glazing 8 mm+12 mm (air) + 8 mm.

For each glass typology, then, two different dimensions of windows and French windows have been considered, totally four examined cases (see table 1):

Case	**Door and window**	**Dimensions [m^2]**	**U [W/m^2K]**	**R'w [dB]**
1.a	window glass Type1	1.20 x 1.60	4.52	37
	French window glass Type 1	1.00 x 2.60	4.52	37
1.b	window glass Type 1	1.40 x 1.60	4.52	37
	French window glass Type 1	1.20 x 2.60	4.52	37
2.a	window glass Type 2	1.20 x 1.60	2.40	42
	French window glass Type 2	1.00 x 2.60	2.40	42
2.b	window glass Type 2	1.40 x 1.60	2.40	42
	French window glass Type 2	1.20 x 2.60	2.40	42

Table 1 Thermal transmittances and index of the apparent soundproof power of the studied glass surfaces

THERMAL SIMULATION

The object of the simulation consists on the analysis of two kinds of doors and windows for two dimensions of windows and French windows, with aluminium frame with a thermal cutting shutter (U= 2,8W/m^2K):

- Case 1.a: window dimensions, 1.20 m x 1.60 m, and French windows 1.00 m x 2.60 m, as in the plan, with aluminium and glass type 1 doors and windows;
- Case 1.b: window dimensions, 1.40 m x 1.60 m, and French windows, 1.20 m x 2.60 m, 20 cm enlarged compared to the plan, with aluminium and glass type 1 doors and windows;
- Case 2.a: window dimensions, 1.40 m x 1.60 m, and French windows 1.00 m x 2.60m, as in the plan, with aluminium and glass type 2 doors and windows;
- Case 2.b: window dimensions, 1.40 m x 1.60 m, and French windows, 1.20 m x 2.60 m, 20 cm enlarged compared to the plan, with aluminium and glass type 2 doors and windows.

In order to check the thermal behaviour of the façade, it has been calculated the dispersant glass and opaque surfaces of the building shell (see table 2) using, for each structural packages, the following thermal transmittances:

- Outside padding wall with a global transmittance U = 0.59 W/m^2k;
- Tile cement floor with airy loose stone foundation U = 1.06 w /m^2k;
- Covered floor with pent roof in insulated tile U = 68W/m^2K.

Description	Sur.Case1 [m^2]	Sur.Case2 [m^2]	Volume [m^3]
North-East wall	42.38	41.86	384.31
South-East wall	41.30	39.55	384.31

South-west wall	43.90	43.26	384.31
Wall of a no heated room	49.91	49.91	384.31
Tot. Dispersant Vertical Sur.	127.58	124.67	384.31
Glass surface	21.24	25.04	384.31
% glass surface	16.65 %	20.08 %	384.31
S/V [m^{-1}]	0.33	0.32	384.31

Table 2 Calculation of opaque and glass surfaces

Thermal software

In order to simulate and calculate the dispersions during the wintertime and the need of energy for the winter air-conditioning, the BestClass software has been used. The Energy Department of Milan Province and the "BEST" Department at Milan Polytechnics developed it. The BestClass software calculation model represents the Recommendation CTI R03/3 derived by the EN 832.
To evaluate the building thermal behaviour, for the glass and opaque surfaces, the following parameters have been considered:

- Energetic dispersions through transmission (kWh/year);
- Sun contributions of transparent surfaces (kWh/year);
- Energetic need of the shell (kWh/year);
- Winter air-conditioning need (kWh/year);
- Specific primary en. need (kWh/m^2 year).

The results obtained with the BestClass software are reported in tables 3 and 4.

Simulations cases	Case 1.a	Case 1.b	Case 2.a	Case 2.b
Transmission En. [kWh/year]	16.018	16.716	13.869	14.228
Sun contributions of transparent surfaces [kWh/year]	183	219	183	219
Shell energy need [kWh/year]	17.825	18.190	15.378	15.707
Shell specific need [kWh/m^2 year]	157	163	138	141
Primary En. need winter air-cond. [kWh/year]	19.293	20.022	16.926	17.288
Specific Primary En. need winter air-cond. [kWh/m^2 year]	173	179	152	155

Table 3 Results of the simulations of the building thermal behaviour expressed in kWh

Simulation cases	Case 1.a	Case 1.b	Case 2.a	Case 2.b
Transmission En. [kWh/year]	0.00%	4.36%	-13.42%	-11.2%
Sun contributions of transparent surfaces [kWh/year]	0.00%	19.67%	0.00%	19.7%
Shell energy need [kWh/year]	0.00%	2.05%	-13.73%	-11.9%
Shell specific need [kWh/m^2 year]	0.00%	3.78%	-12.27%	-10.4%
Primary En. need winter air- conditioning [kWh/year]	0.00%	3.78%	-12.27%	-10.4%
Specific Primary En. Need winter air-conditioning [kWh/m^2 year]	0.00%	3.78%	-12.24%	-10.4%

Table 4 Results simulations of building thermal behaviour expressed in percentage

Comments on the results of thermal simulation

From the simulations of the shell thermal behaviour it can be noted that:
about the thermo- physical parameters:

- Decreasing door and window transmittance (see case 1 and 2) there is a reduction of the shell energy need of 13.7% for the case 2.a and 11.9% for the case 2.b;

about the variation of door and window dimensions:

- There are not significant changes on sun energy contributions (36 kWh/year cases 1.b-2.b)
- Increasing the transparent surface it raises the shell thermal dispersion, even if in a minimal way, being counterbalanced by greater sun contributions;

about the connection between the transmittance variation and the transparent surface variation:

- The decisive element to reduce the shell energy need is the transmittance; see variation between cases 1 and 2 (table 4).

ACOUSTICAL SIMULATION

In the acoustical simulation, as in the thermal one, four cases have been examined, deriving from considering two doors and windows typologies for two windows and French windows dimension, with aluminium frame and a thermal cutting shutter: Case 1.a, Case 1.b, Case 2.a, Case 2.b.

During the development of the acoustical calculation for each façade element, the following evaluation indexes of the sound insulation index (R'_w) have been considered:
Outdoor padding wall, as reported in laboratory certification (R_w = 57): R'_w = 54 dB, m' = 250 Kg/m^2:

- windows (Case 1.a:1.2 x 1.6, Case 1.b: 1.4 x 1.6) and French windows (Case 1.a: 1 x 2.6, Case 1.b: 1.2 x 2.6) with aluminium and glass type1: R'_w = 37 dB, m'= 25 Kg/m^2 door and window;
- windows (Case 2.a:1.2 x 1.6, Case 2.b: 1.4 x 1.6) and French windows (Case 2.a:1 x 2.6, Case 2.b: 1.2 x 2.6) with aluminium and glass type 2: R'_w = 42 dB, m'= 46 Kg/m^2 door and window.

To analyse the modification of the apparent insulation index when the doors and windows dimensions and the typologies change, for each room the following paramenters have been calculated:

- Indoor volume [m^3];
- Indoor surface of the façade bordering on the outdoor [m^2]:
- Indoor surface of the façade bordering on the outdoor after the holes [m^2]:
- Glass surfaces [m^2], calculated for each case.

Acoustical software

In order to calculate the sound insulation index compared to the reverberation time, (e.g. D_{2mnTw}) the Echo software, realised by TEP S.r.l. for ANIT, has been used. The Echo software calculation model enables to check the conformity of the passive acoustical requirements as required by DPCM 1997/12/05.
The façades are the most important element of the buildings to obtain suitable airborne noise insulation from outside. Accordingly to the outdoor sound source, it provides a variable directly measurable parameter on the level of the insulation performance.
The calculation of the façade sound-proofing for each room of the terraced house has been performed, in order to evaluate in which rooms and which door and window typologies and dimensions, could guarantee the value of 40 dB of sound insulation as required by DPCM 1997/12/05.

In this first phase, it has been used an worksheet calculation table, because Echo does not provide decimal values, and so it does not allow to check the variation of soundproofing index D_{2mnTw}, when doors and window typologies change. The calculation has been carried out applying the Equations (1) and (2):

$$R' = -10\log\left[\sum\frac{Si}{S}10^{-Ri/10} + \frac{A_0}{S}\sum 10^{-Dn,e,i/10}\right] - C_l \quad (1)$$

$$D_{2mnTw} = R' + 10\log\left(\frac{V}{6T_oS}\right) \quad (2)$$

As a result, the less favourable rooms resulted the living room and the laundry (Table 5):

Description	Case 1.a-Class 0 [dB]	Case 1.b-Class 0 [dB]	Case 2.a-Class 0 [dB]	Case 2.b-Class 0 [dB]	DPCM 5/12/97 [dB]
Living room	42.5	41.8	46.9	46.3	40
Laundry	41	40.3	45.8	45.1	40

Table 5 Calculation D_{2mnTw} living room and laundry - Excel -

They have been evaluated the values about living room and laundry because in the first case (living room), it is the room with the most glass surface, while in the second case (laundry), it is the only room where in the case 1.b the limit of the rule is reached, due to the relation between opaque surface and the transparent one.
To compare the acoustical performances to the thermal one, made by means of Echo software, the calculation of the sound-proofing has been extended to the whole façades which bound the shell, putting itself in class 0 of air permeability (see tables 6,7,8,9):

Description	Opaque Sur. [m^2]	Glass Sur. [m^2]	D_{2mnTw} ECHO [dB]	DPCM 5/12/1997 [dB]
S-W Facade	37.97	6.44	45	40
S-E Facade	30.58	8.36	44	40
N-E Facade	39.57	4.84	46	40

Table 6 Case 1.a -Calculation D_{2mnTw} -ECHO-

Description	Opaque Sur. [m^2]	Glass Sur. [m^2]	D_{2mnTw} ECHO [dB]	DPCM 5/12/1997 [dB]
S-W facade	36.81	7.60	44	40
S-E Facade	29.1	9.84	43	40
N-E Facade	39.05	5.36	45	40

Table 7 Case 1.b -Calculation D_{2mnTw} - ECHO-

Description	Opaque Sur. [m^2]	Glass Sur. [m^2]	D_{2mnTw} ECHO [dB]	DPCM 5/12/1997 [dB]
S-W Facade	37.97	6.44	49	40
S-E Facade	30.58	8.36	48	40
N-E Facade	39.57	4.84	50	40

Table 8 Case 2.a -Calculation D_{2mnTw} - ECHO-

Description	Opaque Sur. [m^2]	Glass Sur. [m^2]	D_{2mnTw} ECHO [dB]	DPCM 5/12/1997 [dB]
S-W Facade	36.81	7.60	48	40
S-E Facade	29.1	9.84	47	40
N-E Facade	39.05	5.36	49	40

Table 9 Case 2.b -Calculation D_{2mnTw} -ECHO -

Description	Case 1.a- Class 0 D_{2mnTw}%	Case 1.b- Class 0 D_{2mnTw}%	Case 2.a- Class 0 D_{2mnTw}%	Case 2.b- Class 0 D_{2mnTw}%
S-W Facade	0,00%	-2,22%	8,89%	6,67%
S-E Facade	0,00%	-2,27%	9,09%	6,82%
N-E Facade	0,00%	-2,17%	8,70%	6,53%

Table 10 Results of simulations of the shell acoustical behaviour expressed in percentage

Comments on the acoustical simulation

From the simulations of the shell acoustical behaviour (table 6,7,8,9 and 10) it can be noted that:

-About the façade sound proofing:

- R'_w and the opaque component surface being equal, cases 1.a - 2.a and cases 1.b - 2.b with the increase of doors and windows R'_w it raises the façade sound-proofing of 4 dB (see tables 6-8 and 7-9);

-About the variations of opaque and glass door and window dimensions:

- R'_w of each door and window typology being equal, cases 1.a - 1.b and cases 2.a - 2.b, with the increase of the glass surface there is a reduction of the façade soundproofing index of 1 dB.

-About the relation between variation of thefaçade sound proofing of each outdoors surface of the shell and the relevant variation of the transparent surface (in percent):

- The variation of transparent surface of doors and windows, which are in the façade, has a small effect, as average 2.2%, on the façade sound-proofing variation (see the comparison between the case 1.a and 1.b and the case 2.a and 2.b, table 10);
- The element which effectively affects the façade sound-proofing increase is the sound insulation of the glass components, with an average increase of 8.9% in the case 2.a and 6.7%, case 2.b, compared to case 1.a, taken as a reference (see per cent variation between cases 1 and 2, table 10);
- The façade with the best performance from the sound proofing point of view, is the northeast façade, because it has an inferior numbers of doors and windows compared to the other tables.

ENERGETIC COSTS

In addition to acoustical and thermal simulations, an economic evaluation for the winter air-conditioning, linked to building energetic features, for the four study cases, has been carried out.

In order to evaluate the energetic costs the cost of the energy bill has been taken as a reference, i.e. the cost of gas cubic metres used on the basis of the energy need for the winter air-conditioning.

To determine the costs, the natural gas cheap rate in €/mc, for the town of Lugo, provided by Hera, a Company service has been used. The cost is 0.63 €/mc, with a calorific power higher than 37.56 MJ/mc. From the thermal simulation data expressed in kWh/year and from the energetic rate the annual costs of the charge for the winter air-conditioning expressed in €/year, have been calculated.

Comments on the energy costs simulation

From the simulation of the energy costs it can be noted that:

- When the dimensions of doors and windows increase, the dispersions and the energy costs increase,

- When the transmittance decreases, the energy costs decrease too.

In conclusion it can be affirmed that the decisive element to reduce the energy costs is the door and window transmittance, since among the cases 1 and 2 the variation due to the transmittance reduction is at least of 10% (see table 11 and 12).

Description	Case 1.a	Case 1.b	Case 2.a	Case 2.b
Energy Cost	1165 €	1209 €	1022 €	1044 €

Table 11 Results of simulations of the energy cost

Description	Case 1.a	Case 1.b	Case 2.a	Case 2.b
Energy Cost %	0.00%	12.27	10.39	0.00%

Table 12 Results of simulations of the energy cost

CONCLUSIONS

From the simulations, doors and windows clearly constitute the weak element of the building shell, either for the thermal aspect or the acoustic one. Moreover, the thermal transmittance and the sound insulation index determine the door and window performance. For this reason there are main differences between cases 1 and 2, with a greater variation between the base case 1.a and case 2.a.

Improving one of the two performances, thermal or acoustical, there is a reduction of the energy costs.

The national and international normative, involved in the thermal, acoustical and luminous performances of the building, clearly rule each building component. However, by means of the results of simulations, it is likely that there are some relations which link the door and window dimensional, thermal and acoustical parameters.

To satisfy the requirements of the luminous, thermal and acoustical wellness of the rooms, the enhancement of the performances, even just one of these parameters which characterize door and window, produce a greater internal comfort. It needs to be studied which are the minimum parameters and the relations among the door and window performances, in order to satisfy the several legislative and normative measures.

REFERENCES

[1] European Directive 2002/91/Ce "Directive 2002/91/EC of the European Parliament and of the council of 2002 december 16 on the energy performance of buildings"

[2] Legislative rule 2005 n.192 "Attuazione della Direttiva 2002/91/Ce relativa al rendimento energetico nell'edilizia"

[3] DPCM 1997 December 5th "Determinazione dei requisiti acustici passivi degli edifici" (G.U.n.°297 del 22/12/97)

[4] Recommendations CTI R03/3 "Prestazioni Energetiche degli edifici. Climatizzazione invernale e preparazione acqua calda per usi igieni sanitari"

[5] UNI EN 832 "Thermal Performance of Buildings – Calculation of Energy Use for Heating residential buildings"

[6] UNI EN ISO 140-5:2000 "Acoustics - Measurement of sound insulation in buildings and of building elements. Field measurements of airborne sound insulation of façade elements and façades"

[7] UNI 11173 "Criteri di scelta in base alla permeabilità all'aria, tenuta all'acqua, resistenza al vento, trasmittanza termica ed isolamento acustico"

[8] UNI EN 12207: 2000 " Permeabilità all'aria – Classificazione"

[9] UNI EN ISO 6969 "Componenti e elementi per edilizia-resistenza termica e trasmittanza termica" - Metodo di calcolo

[10] "BestClass" Procedure operative Tavolo Energia & Ambiente Provincia di Milano.

[11] Software ECHO 4.0 "Verifica dei requisiti acustici passivi degli edifici ANIT"

[12] Software BestClass "Certificazione energetica degli edifici versione BETA1.02 Sacert"