WINDOWS FROM A LISBON PALACE. HERITAGE VALUES FOR SUSTAINABLE CONSTRUCTION

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RESUMO

Windows are an essential element of façades providing building identity. Windows are also an important element for occupant's wellbeing and to decrease energy demand for heating, cooling ventilation and lighting. The recent development of material and technological process changed the shape, size and functionality of windows. This article describe the windows main characteristics from a Lisbon Palace, presenting their technological solutions, performance and heritage value for sustainable construction.

Keywords: Windows / Sustainable development / Energy / Comfort / Life Cycle Analysis

1 INTRODUCTION

Accordingly with the Roman historian Pliny, glass was discovered in an incident in a beach of the river Belus in Síria, when Phoenician sailors used pieces of natron to support their cooking pots over their fire. The fire has melted the natron that reacted with the sand, forming nodules similar to jewels, these jewels were pieces of glass. In spite of the description of Pliny it is not possible to describe where or when glass was discovered (Gonçalves 2004).

The first architectonic applications of glass appeared in ancient Rome, the broad glass was used to close building holes. In the ruins of the cities of Pompey and Herculaneum where found numerous trace elements of glass probably used in the windows of the public baths.

Before the end of the XIII century windows rarely had glass, only some relevant buildings like churches had glazed windows. The windows profiles frequently were mainly built in wood, with shape of a diamond to deflect the light and the wind (Tutton et al. 2007).

The development of windows with mullions and transoms emerged due to the fact that glass was only available in small dimensions, several of the glazes consisted of small pieces of glass glued together by a line of lead or iron and also by the requirement of mechanical resistance to the wind action.

The window has evolved in response to the resources available and the developments on the design and technology. The natural light of space and view to the outdoor has taken the constructors to be even bolder in the search for structural solutions to provide larger windows. Windows are also an integral part in the appearance of the buildings, reflecting the practices and the historical heritage.

The essential requirements of a window are mainly related with three human expectations: daylight, fresh air and the outside view. The integration of these three expectations was only possible with the development of the sash windows at the mid-Georgian era (Tutton et al. 2007).

With the industrial revolution it was possible to obtain glass with larger dimensions that allows a broader use in architecture.

On the XIX century, in England, regardless other factors, the mortality indicators were related with the poor indoor environmental conditions in the buildings, such as humidity and poor ventilation (Tutton et al. 2007). Edwin Chadwick was in charge of finding solutions for the problems that were affecting the working classes, he proposed that the windows should not be heat conductors, it was proposed that the windows should have a second glass to eliminate the moisture in the houses. In order to improve the ventilation, on 1866 it was imposed the use of a sash window that would open in the totality of their width, although the law did not mentioned the minimum size of the windows, so many buildings did not had the acceptable window size for their ventilation.

In the past curtains and shutters were the principal method of heat conservation in the buildings, this is a recommendable method to mitigate the excessive loss of heat in old windows.

2 METHOD

To study and characterize the windows and their influence on wellbeing and immaterial matters, an audit to the building was performed with the following steps:

i. Collection of technical information about the building and windows.
ii. Technical visit to assess and gather information about:
    a. Windows materials, type, size, glass, shutters/blinds
    b. Windows pathologies namely water leakage, openings or cracks, hardware malfunction, state of coatings and profiles.
    c. Detailed analysis of relevant windows solution.
iii. Theoretical analysis of Windows performance: Wind load resistance, air permeability, water tightness, thermal insulation and sound insulation.
iv. Impact assessment of special windows solution for sustainable construction, namely on energy performance, indoor air quality and comfort.

In the flowing section will be presented the main findings.

3 CASE STUDY

3.1 BUILDING

The palace construction dates from the beginning of XIX century, having a gross floor area of 3060 m^2. The building has a floor plan of nearly 58 m x 26 m, with one facade facing NE to the main street and the other facing SW to the garden. The main entrance of the building faces NW. The building has two story high, nearly 4 m floor to ceiling high. One part of attic roof was also converted to useful area.

The building has stone masonry walls and windows apertures have thick granitic stone. The windows have an internal wing shutter, made of wood, coated with white paint. Some window of the second floor facing SW have an external awning shading system

In recent years, some windows were replaced by aluminium windows, PVC windows and in the case of windows facing the NE was applied a second aluminium window from inside. In table 1 is depicted the overall windows characteristics. The share of frame material or replaced window is related with overall window area in that façade. The main building has 109 windows, meaning that 59% of windows were changed from their initial condition.

Currently, the Palace is used as an office building, having a heating system with boiler and water radiators and the offices also have air conditioning units.

Table 1: Windows characteristics

Façade	Units	Area (m^2)	WWR	Frame Material	Window glazed fraction	Replaced or retrofitted
NE (street)	35	105	23%	Wood (64%) Wood double window (36%)	37%	36%
SW (garden)	42	114	25%	Wood (7%) PVC (60%) Aluminium (33%)	46%	93%
NW (entrance)	16	42	20%	Wood (59%) PVC (41%)	62%	41%
SE	16	29	14%	Wood (78%) Aluminium (22%)	55%	22%

3.2 WINDOWS, GENERAL ASPECTS

The building has 109 windows, with an area of 11% of building floor area, that mean higher than the minimum requirement from RGEU, but lower than the usual 15% or 20% in recent constructions. Fifteen of the windows were replaced in 2005 by PVC windows with double leaf, were the main leaf has tilt and turn movement. Those windows have a solar control glass and are mainly exposed to SW. In the 90's windows were replaced by aluminium windows with single glazing. In those aluminium windows facing SW, it was also applied a solar reflective sheet on the inside face of the glass.

It's interesting to stress that the major changes were done in windows facing the garden (SW). In the main façade (NE), facing the street, the outside window remains almost the same, but in the ground-floor a double window was applied from inside (fig. 1), to improve the sound insulation and thermal resistance.

In the first floor the windows facing NE remain simple, but in some of them the single glazing was replaced by a double glass (fig. 2), improving the performance and maintaining the aesthetics. In other windows was applied a glass pane in the inside face of the exiting glass, providing almost a double glass solution. In these two last solutions, the patrimonial value and functionality of the windows was preserved, while in the case shown in fig 1. the functionality of windows (natural ventilation) was partly compromised because of the additional constraint to kept open both windows.

Figure 1: Double window

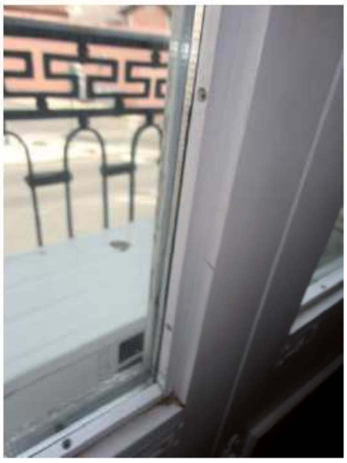


Figure 2: Windows with double glass

3.3 WINDOWS, AIR PERMEABILITY

Air permeability classification of windows products with described product characteristics (table 3) can be obtained without test (EN 14351-1, 2016). The wooden windows of the Palace don't have gaskets in the movable joints (fig. 1a) and have a large (approximately 1 mm) gap between the profiles in the movable parts, meaning that the windows are leaky (REH, 2013 and Silva, 2012), allowing a large amount of uncontrolled air infiltration, but also could be responsible for water leakage and poor sound insulation. The air permeability could be limited for example applying gaskets in the movable joints (fig. 3b), reducing the heat losses in windy days and also providing a slightly higher sound insulation.

Despite the high air permeability of old windows, because the building is in city centre, relatively protected from wind, it's estimated an air flow rate due to infiltration of nearly

0.2 ach[†] (Pinto, 2014), that means, lower than the minimum requirements for the indoor air quality of 2 $m^3/(h.m^2)$ or 0.5 ach (PORTARIA n. 353-A/2013) in this case.

Table 3: Air permeability classification without testing[‡]

Product specification	Classification
External pedestrian doorsets with a continuous weather stripping under appropriate compression	1
Fixed and openable windows with a continuous weather stripping under appropriate compression	2
Fixed lights with seal or sealant to the infilling	3

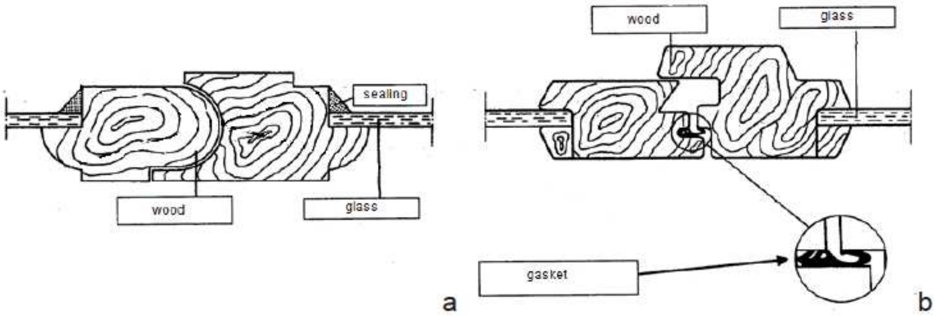


Figure 3: Window movable joint sealing. a) Without gaskets, b) With gaskets

3.4 WINDOWS, NATURAL VENTILATION

Despite the unwanted air infiltration through window gaps and cracks in building envelope that are insufficient to assure the air flow rates required for the indoor air quality, the building has several windows particularly fit to provide natural ventilation and assure indoor air quality when windows are kept open (PORTARIA n. 353-A/2013). In spring and in summer the windows could also provide an important amount (examples 5 air changes per hour) of fresh and cold air, to cool the building and building thermal mass and provide thermal comfort, decreasing the use of air conditioning and the building energy consumption.

To provide natural ventilation all windows in the building have operable leafs. But, to provide natural ventilation the leafs should have a stable position when open and also deflect the air for ceiling, to prevent discomfort for occupants. In fig. 4 are shown some examples of appropriate window types for natural ventilation (PORTARIA n. 353-A/2013). To allow the natural ventilation of spaces, usually several window/openings should be used to allow a proper air distribution inside the rooms and also to give users some control over the total opening area and the air flow rate. To provide natural ventilation the spaces should have windows with an open area of nearly 4% of floor area (400 cm^2/m^2 floor area). In this building, with an average wind speed of 3.6 m/s, to achieve 5 ach, an opening area of nearly 75 cm^2/m^2 of floor area could be enough. To

[†] ach - air changes per hour

[‡] Classification according section 4.14 NP EN 14351- 1:2008+A1:2011 and EN 12207

achieve 0.5 ach for indoor air quality in winter, an area of 7.5 cm^2/m^2 of floor area could be enough if cross ventilation is achieved.

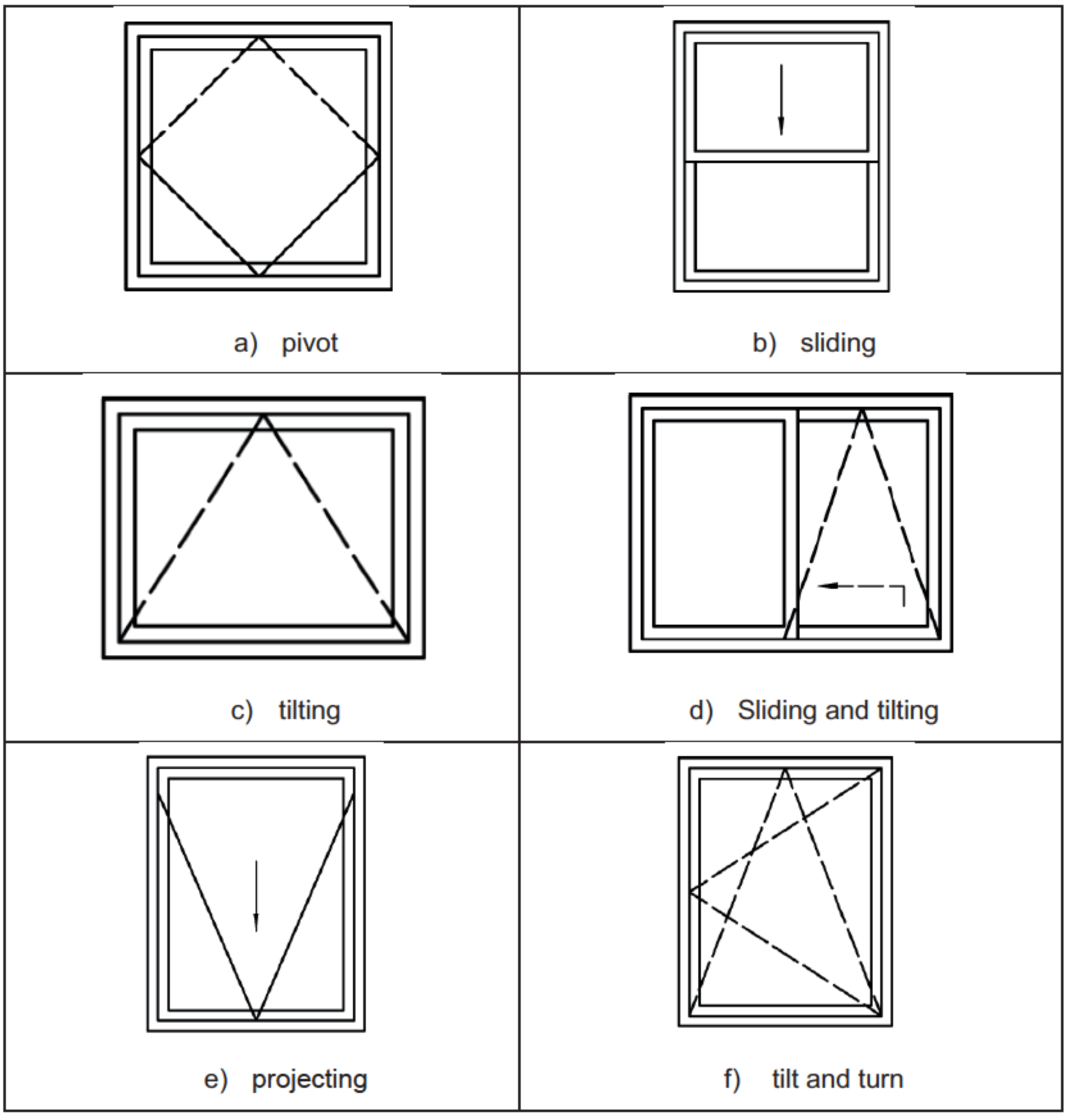


Figure 4: Example of window type proper for natural ventilation of spaces

Because the majority of windows have an open area greater than 50% of window area, the building has enough free open area for natural ventilation. Despite the majority of windows are from side-hung type, due to the weight of leaf, they have a stable position when open. To give user control over open area and natural ventilation this building also have small movable “glasses” inside the leaf (fig. 5b) or small projection windows on the top of the window (fig. 5a).

This kind of window type is today relatively unusual and are well adapted to provide user control confidence to let the window open, because:

- The risk of intrusion is small, because of small open dimensions;

- The risk of water infiltration is also low, since the tilting with small angle decrease that risk;
- The opening at top of the window deflects the fresh air to the ceiling decreasing the air speed in the occupied zone and also allowing a better mixing of fresh outside air with room air, preventing cold draft in winter.


a)

b)

Figure 5: Windows for natural ventilation. a) projecting leaf at top, b) small projecting opening in the leaf

3.5 WINDOWS, THERMAL PERFORMANCE

The windows with single glass panes present a low thermal insulation, having an coefficient of thermal transmittance (U_w) of nearly 5.1 W/(m^2.K), while windows with double glass panes with timber profiles could have thermal transmittance values of 2.8 W/(m^2,K) for 16 mm gap between glass panes. In the 70 period of last century, after the oil crises, several research projects were developed to increase building thermal insulation, namely with double windows and storm windows to increase window thermal insulation (Mimoso, 1987).

In the windows facing NE of the first floor of the Palace is possible to find windows with a double glass pane applied in the inside, were it's interesting to note the hardware to fix the inside glass pane, creating an air layer of nearly 6 mm. This specific solution have also some drawbacks, regarding the metallic contact between hardware and glass that could break the glass. The gaps around the inside glass don't increase the sound insulation of window, despite the extra glass pane.

When the objective is to increase thermal insulation, sound insulation and decrease the air permeability, usually the use of a double window is the best choice, allowing the maintenance of façade aesthetics and increase the performance of the opening with the application from inside of a new window. In this case, because of the large thickness of the walls, it's possible to apply a new window almost 50 cm apart from the original window, reducing their visual impact (fig. 1). In the case of application of double window, it's required to have small ventilation openings between the air space and the outdoor, to reduce moisture problems and condensation in glass panes.

Regarding window size, the WWR is nearly 20%, and the window flor area ratio is 11%, meaning that the wind area is relatively lower than the actual reference values of 15% to 20% for the ratio of windows to floor area and 30% for WWR. This lower window ratio is in line with the restriction in windows size in buildings from XIX century.

3.6 WINDOWS, SOUND INSULATION

According to windows standard EN 14351, the sound insulation of windows (Rw (C; Ctr)) of fixed and openable (top, side, bottom-hung or pivoted) windows could be assessed using table 4, if the windows belongs at least to air permeability class 3 and have at least 1 seal or 2 seals in the case of R_w window of 36 dB.

In the most severe situation defined in the acoustics regulation (DL n.º 96/2008) it is required a façade sound insulation $D_{2m,nT,w}$ of 33 dB. In those cases, if the window has a sound insulation at least of 33 dB, the window will not compromise the sound insulation of the façade. To obtain that value of 33 dB, the sound insulation of the glass should be at least 30 dB, that means a single glass unit of 5 mm thickness, a laminated glass or a double glass 4-(6 to 16)-6 that have values not lower than 32 dB. The use of double windows, typically increase the sound insulation of the aperture at least 3 dB above the best window, meaning, that the use of an airtight (class 3) window with single glass at least 5 mm thick, could be enough to achieve an insulation of 33 dB.

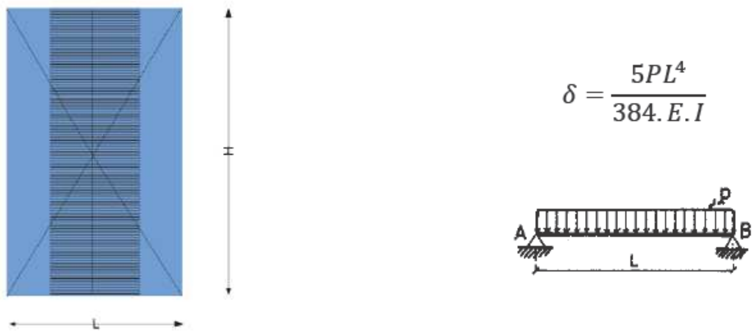
Table 4: Window sound insulation with insulation glass units§

Rw glass (dB)	Rw window (dB)
27	30
28	31
29	32
30	33
32	34
34	35
36	36

3.7 WINDOWS, WIND LOAD RESISTANCE

The wind load resistance of windows should be assessed by testing (EN 14351). For the most deformable profiles, calculations can be performed assuming the elastic behaviour of elements (Veloso, 1976), fig. 6. For the assessment of wind load resistance, the central profiles of the window could be studied like a simple supported beam subject to a uniform load, that has the value P=W.L/2. Where W is the wind load pressure for the serviceability limit state and L is the width of the window with two leafs (fig. 6). For wood, the elastic modules could range between 7 and 17 GPa, and a value of 10 GPa could be acceptable for resinous wood. The maximum deflection of wood window profiles with single glazing should not be greater than H/150 and 15 mm. For

§ Classification according annex B, NP EN 14351- 1:2008+A1:2011 building until 10 m height in urban area (roughness class I or II), the wind pressure load for the serviceability limit state is 1200 Pa (NP 4517: 2015). Using the simple supported beam model, the elastic modulus of 10 GPa, the thickness of the wood profiles could be calculated and are given in fig. 5 for several window height and with 1.6 m width. It's interesting to note, that for small windows, the 35 mm thickness of the windows from the palace have enough inertia and that for windows with 3.5 height the inertia is near the value required, meaning that the old construction procedures were proper to design profiles and takes into account the window size.



$$\delta = \frac{5PL^4}{384.E.I}$$

Figure 4: Wind load calculation

4 CONCLUSIONS

It was analysed the windows from a Palace from XIX century. Despite the technological constraints from that time, it was shown that the building presents several interesting solutions to promote the energy efficiency in buildings, namely to provide natural ventilation for indoor air quality, free cooling and thermal comfort in a sustainable way. To control natural ventilation, some windows have small projecting leafs, inside the major leaf, allowing for small openings that could be interesting to promote natural ventilation in cold seasons regarding the small opening area required. It was also emphasised the care with occupants, because several inaccessible leafs have a mechanical remote control to open and close.

The window area is lower than the reference values for current constructions, but complies with RGEU, allowing for enough opening to promote natural ventilation, but also to gather the solar heat gains and natural light (WWR of nearly 20%).

To increase the windows thermal insulation, in this building there are two well recognise solution in rehabilitation, the use of a double window (to increase also the sound insulation) and the use of a double glass pane. In the first case (double windows) some care should be taken to assure natural ventilation, because the opening of inside windows it's not suitable.

Despite the absence of standards and regulation at the time of construction, the windows with wood profiles presents cross sections that are fit for actual requirements, despite the lower glazes fraction and present better stiffness than new installed windows, that have leafs with lower height (2.5 m) than the old ones (3.4 m).

Despite the technological, historical and immaterial value of old windows and system, almost 59% of windows were replaced to increase the comfort and wellbeing in the building. To preserve those intangible values described, it's important to set a protocol to gather the construction characterises of relevant windows and perhaps require the rehabilitation of some units to preserve those values.

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