Paper No: 698: SUSTAINABLE DESIGN STRATEGIES IN INDUSTRIAL BUILDINGS' REFURBISHMENT: A CASE STUDY IN LISBON

Lurdes Duarte[1]; Manuel Correia Guedes[2]

[1] MSc, Arch., Department of Civil Engineering and Architecture, Instituto Superior Técnico, Lisbon
[2] Professor, Ph.D., Department of Civil Engineering and Architecture, Instituto Superior Técnico, Lisbon
Contact: mcguedes@civil.ist.utl.pt

Abstract

This paper presents a study on the potential use of sustainable design strategies in the refurbishment of industrial buildings in Portugal. A representative case study in Lisbon was analysed through field work, using monitoring and questionnaires, as well as through software simulation.

An overview on the role of architects on industrial buildings' refurbishment is presented. The issue of thermal comfort criteria is also discussed, in the context of passive design application. Various design solutions are proposed, applicable to a number of similar existing situations in Portugal and elsewhere in Southern Europe.

Keywords: Industrial Buildings, Refurbishment, Sustainable Architectural Design

1. Introduction: Previous considerations

In terms of environmental impact, this paper refers to Industrial buildings in terms of:

a) its Architecture and consequent indoor environmental performance, i.e. the workers' comfort conditions, as well as the best design strategies to provide satisfactory comfort conditions, and reduce energy consumption.

b) its impact at the urban level, from the initial location in city centres to the subsequent migration to the urban outskirts.

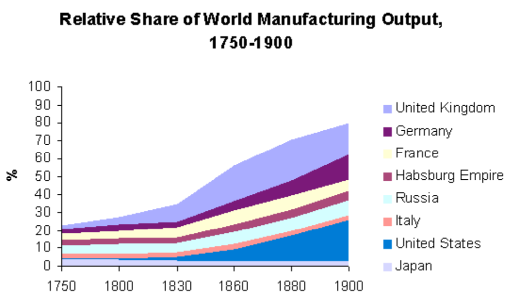
The subject of the environmental impact of the industrial processes, i.e. pollution, depletion of natural resources is outside the scope of this study.

2.INDUSTRIAL BUILDING'S REFURBISHMENT AND SUSTAINABLE DEVELOPMENT

2.1 Conceptual parameters

A significant percentage of the population spends most time of their lives working in Industrial Buildings. In historical terms this reality is, for example, illustrated in figure 1, showing the distribution of the world-wide manufacturing production between 1750 and 1900 (Bairoch, 1981).

Figure 1



However, perhaps because this is an exceptional type of buildings, or because they are perceived as being "lost causes" in terms of green refurbishment, or perhaps Architects had, in most cases, a minor role (if none at all) in their conception, the fact is that this building type is very rarely a subject of study in terms of sustainable refurbishment, or re-use.

This approach must, like in any other cases, integrate ecological, economical, social and cultural considerations, aiming at providing satisfactory working environments and reduce negative impacts on the physical ecosystems.

This theme, namely the evaluation of the life cycle of industrial buildings (LCA), was object of a recent study prepared in the *Institut für Industrielle Bauproduktion*, of Karlsruhe University (*cf.* fig. 2).

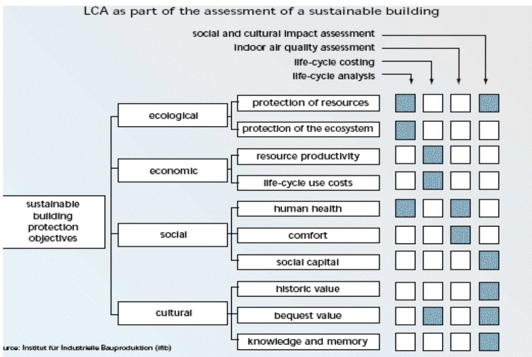


Figure 2 – LCA as part of assessment of a sustainable building (Kohler, 2002).

This evaluation must be carried out when analysing sustainable refurbishment strategies, involving all life cycle phases of the building, from the extraction of raw materials, their production, transport, the building construction and maintenance, and the possibilities of recycling.

2.2 Industrial buildings: the Portuguese case

An important study was published by INETI (Institute of Industrial Technologies, in 1999, called " Industrial Buildings in Portugal ". The study involved a large number of buildings, considering factors such as constructive characteristics, building typologies, year of construction and energy consumption. An example of one of the cases included in the referred studies is the Textile Factory of Vale do Ave, shown in Fig. 3.

Figure 3 – Textile Factory of Vale do Ave, Portugal

In the studied examples, it is noticed that the roof areas of these buildings have no thermal insulation, with significant impact in terms of thermal losses in winter and overheating in summer.
In terms of natural lighting (visual comfort), the situation is, on the contrary, satisfactory in most cases. Most buildings use zenithal lighting (facing North) allowing a natural uniform lighting of the inner spaces.
In terms of the question of the roof areas in industrial buildings in Europe, Brunelli and Simmos Yannas point out that the form of the roof assumes particular importance in the case of single floor buildings, fact that influences both the thermal performance of the building and the penetration and the distribution of natural lighting (Brunelli, 2005).
A good example of rehabilitation is the "Union" factory ("Fábrica União"), in Lisbon, which was converted to housing and commerce. The renovation project preserved the South façade, bringing benefits from the external wall's high thermal inertia, and integrating the ovens and industrial chimneys in the urban set. It also converted the whole inner space of the block in a garden opened to the general public (cf. fig. 4).

Figure 4 – Refurbishment of the "Union" factory, into housing and commerce, in Alcântara, Lisbon

2.3 Energy consumption and GHG emissions

In Portugal, primary energy consumption of buildings is, on average, about 25% of the total energy consumption of the country, representing a total consumption of 3,5 Mtep (million equivalent tons of oil). However, this value tends to increase in time, and already reaches more than 40% in the case of the major cities (Gonçalves, 1999). In terms of global consumption, the Industrial sector is responsible for around 32 % of the primary energy and of 40 % of the electric energy consumed.

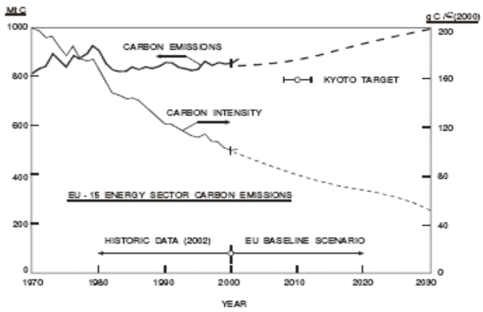


Figure 5 – CO2 Emissions and the energy sector 1970 – 2030 in the EU (EC, 2002)

In agreement with the scenery defined by the European Union, CO2 emissions must be reduced by 8 % of the levels of 1990 until 2012.

2.4 Thermal comfort in Industrial Buildings

From studies carried out in the 1970's involving industrial workers, Thomas Bedford connected the importance of the freshness factor with the variability of air speed in the summer and the effect what this factor has in the improvement of thermal comfort.
On the other hand, Bedford reported that levels of RH% greater than 55 % induce sensations of lethargy.
In another field work, - Jill C. Brown carried out environmental monitoring and questionnaires to the workers of a set of modern industrial buildings, located in the South of England. In his study, Brown reported that that the workers preferred variable thermal environments, instead of uniform environments, using HVAC (Brown, 1995).
These works contributed to the formulation of the Adaptive theory in the 1970's, by Humphreys and Nicol, which resulted from the observations

gathered in hundreds of field works carried out in different climatic contexts, and different building types (in offices, schools or dwellings).

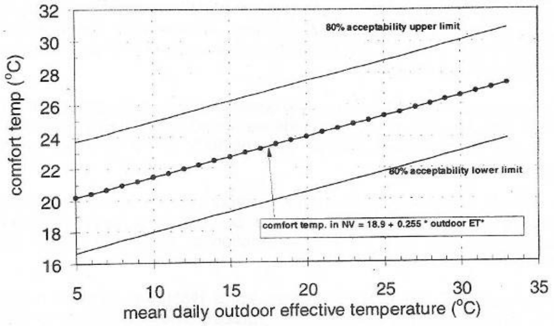


Figure 5 - ASHRAE RP 884 correlations, showing the acceptance limits up to 80% (De Dear, Brager and Cooper, 1987)

2. - DESIGN STRATEGIES

Some examples of good practices can be found in Europe, namely in the Quartier Vauban's Building, in Germany. The external walls made of massive brick, with strong thermal inertia, have a thickness of around 51 cm, with an U-value of 1,5W/m²K. In picture 7 we can observe the difference in thermal performance between lightweight and a heavy weight construction.

Another example of the use of thermal inertia is the "Ecological Construction Centre", also in Germany. It involved the rehabilitation and enlargement of an existent industrial building, built in bricks, with an area of 1731 m ². It is located in an ancient industrial area of the 19th century, in Kolben-Seeger.

Other interesting examples are shown, articulating several strategies, from the application of green roofs, to the use of buried pipes for cooling and fresh air, the use of shading for exposed glazed areas, the use of stack effect for ventilation, etc.

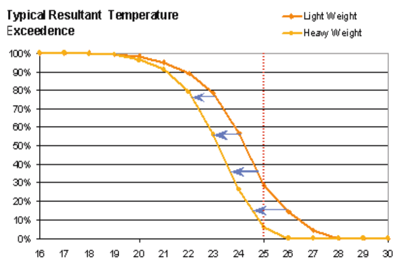


Figure 6 – Difference in thermal performance between light and heavy weight construction.

This set of strategies is illustrated in the project "*Centre for Understanding the Environment*" (*cf..* figs. 8 and 9).

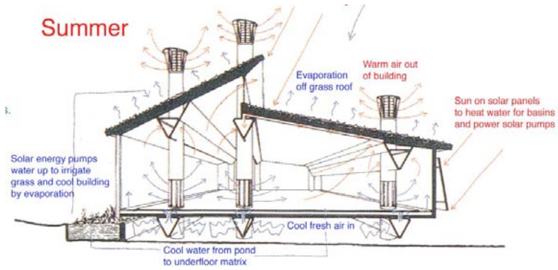


Figure 7 - "Centre for Understanding the Environment", Horniman Museum in Summer (Source: Harrington, 2005)

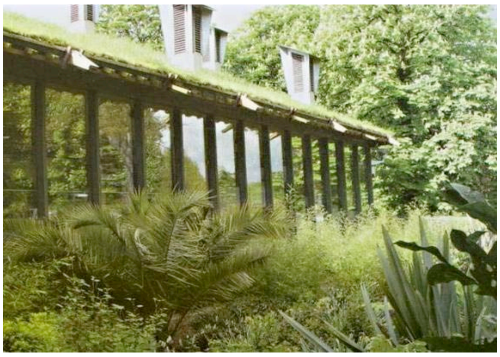


Figure 8 – Green Roof in "Centre for Understanding the Environment", (Source: Harrington, 2005)

Most of the manufacturing interiors are destined to be occupied by persons who have specific needs, in terms of visual accuracy to safely operate machines and equipments. A good solution was used in Nave 1 (the case study), in Lisbon (*cf..* fig 10).

Figure 9 – Zenital Lighting in shed (Nave 1)

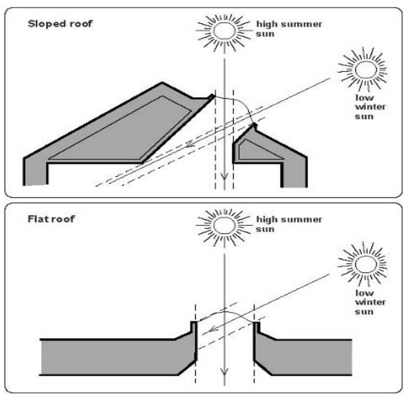


Figure 10 - Influence of the roof lights' form on daylighting (Source: Heschong, 1998).

Relatively to the application of photovoltaic systems in industrial buildings, the example of "Réunion Island", in France, is shown in Fig.12. The power installed in the end of 2005 was around 15% superior to that of 2004, approximately 6 MW (PVPS, 2005).

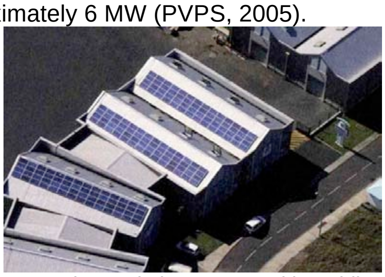


Figure 11 – Photovoltaic system with public network connection, 32 kW – Réunion Island, France.

3. A CASE STUDY IN LISBON

3.1. Objectives

An industrial building was studied in Lisbon (in the context of an M.Phil. dissertation), aiming at:

1. Analyse its environmental characteristics;
2. Identify present comfort conditions
3. Produce design recommendations.

Figure 12 – Case study: the Miraflores Complex – Carris, Nave 1

An environmental monitoring was carried out, measuring temperature and Relative Humidity in the occupied zones of the building (working areas). Simultaneously, weekly questionnaires were made to the workers during the hottest period of the year (August and beginning of September. These results were analysed through the statistical program SPSS.

A software model was also made, using ECOTECT, in order to compare results to those found in the field, and to analyse the efficiency of different design strategies to improve existing conditions.

3.2. Results

The Complex of Miraflores is located in the district of Oeiras and the climatic data was gathered in the Institute of Meteorology,

Temperatura do ar 1974-1990	Precipitação 1961-1990	Humidade Relativa média 1974-1990	Velocidade do vento (km/h) 1961-1990	Insolação 1961-1968
T. média anual 16,0ºC	Média anual 664,8 mm	09H 76 %	Nº dias ≥ 36 5,9	Nº médio de horas com luz solar – 2 567,6
T. mínima média 11,8ºC	Nº de dias ≥ 1mm 78	15H 65 %	Nº dias ≥ 55 0,5	Insolação Média 55 %
T. máxima média 20,3ºC	Nº de dias ≥10mm 21,6			

Table 1 – Climatic data for Oeiras (Lisbon).

About 30 workers completed the questionnaires, during five weeks. The number of workers varied between 29 (2nd week of August) and 33 (1st week of September). Given that we were in the summer period, workers basically used the same pattern of clothing: a T-Shirt and cream-coloured cotton trousers.

acções para aumento de conforto					
semana	+ luz	+ ventilado	+ impermeabilidade ao ar	+ protecção sol	Total
11 a 15/8	4	2	0	1	7
21 a 25/8	0	6	2	1	9
28/8 a 1/9	2	5	0	0	7
4 a 8/9	2	2	4	0	8

Table 2 – Actions carried out by the workers in order to avoid discomfort.

In table nº 2, we can observe that there is significant number of actions performed by the workers in order to improve comfort/ avoid discomfort, involving the improvement of more natural light conditions; more ventilation and fewer drafts.

A simulation on the estimated PPD percentage was also performed using ECOTECT, (cf.. imagine 13), which showed a PPD of nearly 50% in winter (December, January and February).

3.3. ECOTECT simulations

Various scenarios were simulated using ECOTECT, of which 3 were chosen to be the most realistic:

Scenery A: replacement of the uninsulated roof by an insulated one;

Scenery B: Create a double wall (with cavity insulation) on the South façade;

Scenery C: Use external insulation on the existing South façade.

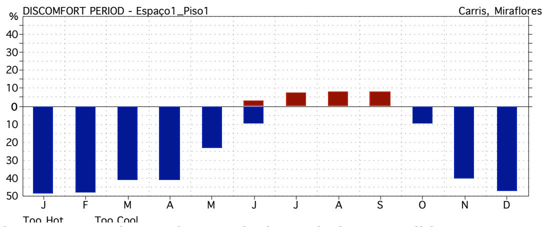


Figure 13 – Discomfort period – existing conditions

Constituição	di (m)	λ (W/m.ºC)	Rj (m2.ºC/W)	Referência
chapa metálica	0,02	50,00	0,00	pag I.9 ITE50 LNEC
isolamento térmico Roofmate 0.08 m	0,08	0,035	2,29	marca CE
TOTAL			**2,29**	
Rse			0,04	
Rsi - fluxo ascendente (perdas)			0,10	
Resistência térmica superficial TOTAL			**0,14**	
			$R_{térmica\ total}$	**2,43**
			U (W/m2.ºC)	**0,41**

Table 3 – U-Value of the insulated roof (scenario A)

The U-value for scenario A, obtained through reference values of the ITE50 (LNEC), was of 0,41 W/m2 ºC, making a big difference relatively to the value obtained for the existent situation - 7,12 W/m2 ºC (the covering without any type of insulation).

Constituição	di (m)	λ (W/m.ºC)	Rj (m2.ºC/W)	Referência
reboco 2x0.02	0,04	1,3	0,03	pag I.7 ITE50 LNEC
Tijolo furado de 11	0,11		0,27	pag I.12 ITE50 LNEC
caixa de ar	0,05		0,11	pag. I.10 ITE50 LNEC
poliestireno extrudido (XPS)	0,05	0,037	1,35	pag I.3 ITE50 LNEC
betão	0,22	1,65	0,13	pag I.5 ITE50 LNEC
Gesso cartonado	0,013	0,25	0,32	pag I.7 ITE50 LNEC
TOTAL			**2,22**	
Rse			0,04	
Rsi			0,13	
Resistência térmica superficial TOTAL			**0,17**	
			$R_{térmica\ total}$	2,39
			U (W/m2.ºC)	**0,42**

Table 2 – U-Value for the double wall (scenery B)

The U-Value obtained for Scenery B – the double wall was 0,42 W/m ².ºC. The inner wall consisted on a gypsum-cardboard plaque. The cavity insulation was constituted by 5 cm of air and 5cm of extruded polystyrene (XPS), with an U-value of 0,025 W/m2 ºC and finally the external brick wall made of perforated 11cm-thick bricks.

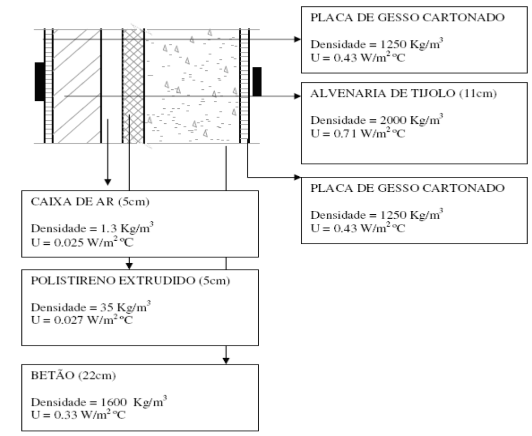


Figure 14 – Constructive system of the double wall.

Results improved for the winter months, relatively to the present situation. A global reduction of the period of discomfort was achieved – though the PPD is still high (42 %).

Constituição	di (m)	λ (W/m.ºC)	Rj (m^2.ºC/W)	Referência
argamassa projectada não tradicional	0.01	1	0.01	pag I.7 ITE50 LNEC
poliestireno expandido moldado (EPS)	0.06	0.042	1.43	pag I.3 ITE50 LNEC
bloco de betão	0.15		0.20	pag I.12 ITE50 LNEC
TOTAL			**1.64**	
Rse			0.04	
Rsi			0.13	
Resistência térmica superficial TOTAL			**0.17**	
			$R_{térmica\ total}$	1.81
			U (W/m^2.ºC)	**0.55**

Table 3 – U-Value for Scenery C (external insulation with EPS).

In this case, the U-value was of 0,55 W/m2 ºC. As for the PPD decreased significantly, being situated between 18 to 26 %. This solution is the one that provides better comfort conditions, for the winter period, though PMV votes for summer did not improve.

Figure 15 - PPD for the month of December, with EPS insulation.

3.4 Design Recommendations

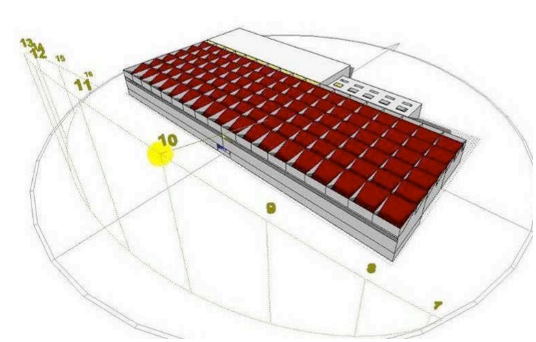


Figure 16 – Sunpath, Ecotect Model of Nave 1.

In order to provide satisfactory comfort conditions, the following aspects must be considered:

- The importance of the roofs in industrial buildings is fundamental, and it should be taken in consideration since the beginning of the refurbishment project. Insulation measures should be studied, integrating winter heating requirements with solar protection in summer and the use of daylight.
- External walls should be insulated, preferably using external insulation.
- Roof glazed areas should be well dimensioned – integrating winter requirements with the need for natural light. Windows should, if possible, face North, in order to provide a cool, uniform daylight and simultaneously protect from Summer overheating.
- The existence of thermal inertia associated to a correct system of ventilation (e.g. night ventilation), can avoid situations of overheating in the Cooling season.
- Part, or even the totality of the energy needs can be fulfilled through the use of renewable energy systems, namely through the application of photovoltaic panels in the roof (cf. image 17).

For the case of Lisbon it is expectable that the system could produce around 1400 kwh for each installed kWp.
Though, if one considers that the efficiency of the modules is of 14 %, one could obtain about 0,140 kWhp for m ² of roof area, with a total area coverage of 60 % (the total roof area is of 5400 m ²). The installed capacity (Nominal) would be of 453,60 kWp and the produced energy 635.040 MWh.

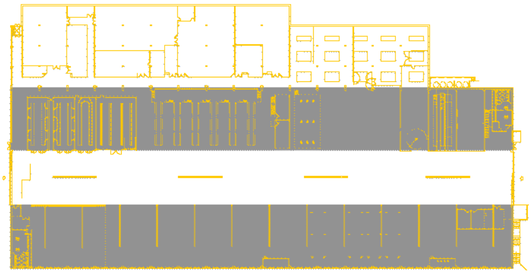


Figure 17 – Floor plan of Nave 1. Roof area is shown in grey.

4. Conclusions

1. Renovation and re-use of industrial buildings is, and must be, gradually becoming a reality;

2. The Architect's knowledge of design strategies is still quite limited, due to the very few existing cases in which these strategies have been successfully applied, by scientific methods.

3. The use of these buildings is changing with time. This is a gradual process depending on market demands. The refurbishment of these buildings, often obsolete, is not only needed but can also be a very interesting challenge and a source of renewed creativity for Architects.

References

BRUNELLI, Gustavo, YANNAS, Simos in "Effect f Roof Shape on the Daylight Performance of Industrial Buildings", vol. 1 e 2, NDU Press, Environment & Energy Studies Programme, Architectural Association Graduate School, London WC1B 3ES, United Kingdom, 2005

FIALHO, João P. Carmo, "Coberturas de Grande Vão – Aspectos da sua evolução recente e metodologias para a concepção arquitectónica das Coberturas Traccionadas", Tese de Doutoramento, 1991

GONÇALVES, Helder, António Joyce, Luís Silva in "Fórum, Energias Renováveis em Portugal – Uma Contribuição para os Objectivos de Política Energética e Ambiental", ADENE/ INETI, ISBN 972-8646-05-4, Lisboa, 2002

GUEDES, Manuel Correia, in. "Thermal Comfort and passive Cooling Design in Southern European Offices", PhD. Thesis, University of Cambridge, Faculty of Architecture, Cambridge, 2000