Original Article

Performance-based diagnosis applied to the rehabilitation of residential buildings

Received (in revised form): 24th July 2009

João G. Lanzinha

is Assistant Professor since 2006 at UBI – University of Beira Interior, Portugal. Graduate in Civil Engineering (1983) at FEUP, Faculty of Engineering of the University of Porto, Portugal; and PhD in Civil Engineering (2006) at UBI – University of Beira Interior, Portugal. President of Scientific Commission and Head of Civil Engineering and Architecture Department, UBI, Portugal. Member of Research Centre C-MADE – Centre of Materials and Buildings Technologies, UBI, Portugal (www.cmade.ubi.pt). Member of Editorial Board, Building Pathology Studies Group – PATORREB (www.patorreb.com), Editor Professor Vasco Freitas, FEUP, University of Porto, Portugal. Qualified Expert for RCCTE building certification by ADENE – Portuguese Energy Agency, managing body of EPBD implementation. Senior Member of Ordem dos Engenheiros (Portuguese Engineers Order).

Vasco P. de Freitas

is Full Professor since 2001 at DEC, FEUP, Porto University, Porto, Portugal. Graduate in Civil Engineering (1982), PhD in Civil Engineering (1993) all at FEUP, Faculty of Engineering of the University of Porto, Portugal. Present post: full professor in the Civil Engineering Department of FEUP, since 2001; Director of Building Physics Laboratory LFC at FEUP, since 1990; Director of Advanced Studies in Building Rehabilitation at FEUP; Joint Coordinator of CIB-W86 Building Pathology and Coordinator of CIB-W40 Heat and Moisture Transfer in Buildings. Main research fields: building physics, hygrothermal behaviour, building pathology and building retrofit. Supervisor of 21 PhD theses and Master theses, co-author of two books, various chapters in other books and of over 100 articles published in international refereed journals and conferences.

Correspondence: João G. Lanzinha, Civil Engineering and Architecture Department, University of Beira Interior, R. Rua Marquês d'Ávila e Bolama, s/n, 6201-001 Covilhã, Portugal

ABSTRACT A lack of investment in maintenance and conservation has resulted in the decay of the housing stock in Portugal, a situation exacerbated by a failure to define and implement public policies designed to encourage landlords to preserve the constructed heritage in our cities (which is of incalculable economic and cultural value). When the decision is taken to intervene in a building that shows significant signs of pathology, rehabilitation work should not go ahead until a detailed diagnostic study has been performed. The resulting report should clearly identify problems encountered, establish their causes and suggest an intervention method designed to ensure that certain basic requirements are met. This article aims to contribute to the preparation of such diagnoses by presenting the outline of a method known as Performance-based Diagnosis Applied to the Rehabilitation of Buildings, supported by a computer application called MEXREB. It also analyses the results of a validation study in which this methodology was applied to a series of 39 buildings (498 individual households containing a total of 1086 residents).

Journal of Building Appraisal (2009) 5, 133–148. doi:10.1057/jba.2009.26

Keywords: rehabilitation of buildings; diagnostic methods; performance-based assessment

PRELIMINARY REMARKS

The constructed heritage in Portuguese cities reveals noticeable signs of decay, particularly in the historic centres. Older buildings (that is those constructed before 1960) are the ones most obviously affected, and there are many unoccupied properties, confirming statistical evidence that testifies to the vacation of thousands of residential units in urban buildings. This situation is largely owing to landlords' lack of financial resources, due in turn to the policy of 'rent-freezing', which has made it difficult to carry out repairs and maintenance on this type of building.

Moreover, many 'recent' buildings (that is constructed in the 1990s), like those from the 1960s and 1980s, are already in a worrying state of decay, as a result of insufficient investment in maintenance. A factor contributing to this is certainly the burden of mortgages, which leave owners with few funds left over for maintenance operations.

When a building shows signs of significant pathology, rehabilitation work should not go ahead until a detailed diagnostic study has been performed, which clearly identifies the problems, establishes their causes and suggests an intervention method. This, however, is only the 1st Phase of a Rehabilitation Project. Ideally, the rehabilitation of residential buildings should be approached as an integrated process, involving diagnosis, the decision to intervene, estimation of costs, the preparation of a plan of intervention, the monitoring of the work and subsequent maintenance.

Given the notorious state of decay of the housing stock, and the need for technical support tools, this article aims to present a performance-based method of diagnosis and intervention called *Performance-based Diagnosis Applied to the Rehabilitation of Buildings* (Lanzinha, 2007). As well as delimiting the method's sphere of application, defining the concept of the 'envelope' and establishing the requirements to be met, it also describes the method used for assessing and quantifying those requirements. The method was then applied to 39 multi-family housing blocks, containing a total of 498 households and 1086 residents.

ASSESSMENT OF DIAGNOSTIC SUPPORT TOOLS AVAILABLE

Tools to aid diagnosis for use in residential buildings are available in some European countries. They are applicable to different types of building, have predefined procedures and, in the most recent cases, are supported by computer applications.

As regards the building envelope, these methods basically divide the building into its various component parts, attribute a qualitative grade corresponding to the degree of deterioration, and then provide an estimate of repair costs. Four methods, all with these characteristics, were studied in order to assess their respective spheres of application, operating principles and applicability, and advantages/disadvantages, indicating some possible ways in which each one might be developed. The methods were:

- MER HABITAT – Méthodes d'Evaluation Rapides (Merminod and Vicari, 1984; Marco *et al*, 1996);
- TEST HABITATGE (Casademont *et al*, 1989);
- EPIQR – Energy, Performance, Indoor environmental Quality and Retrofit (EPIQR, 1999); and
- CLAU, 2000 (CLAU, 2000).

It is not easy to arrive at an overall assessment of these methods, as there are significant differences between them as regards design, assessment criteria used and backup available. These are shown in Table 1.

Table 1: Overview of diagnostic methods

	<i>MER HABITAT</i>	<i>TEST HABITATGE</i>	<i>EPIQR</i>	<i>CLAU 2000</i>
Multimedia backup	—	—	•	•
Breakdown into task-related chapters (no.)	9	6	—	6
Number of building parts described	291	55	50	29
Codes indicating degree of decay (no.)	4	5	4	4
No. of residential units to be visited in the building	3 or 5	Min. 3	Min. 3	n/s
Description of the state of decay using exclusively textual means	•	•	—	—
Description of the state of decay using text and illustrations	—	—	•	—
Calculation of repair costs				
Index based	•	•	—	•
Using costing databases	—	—	•	—
Survey of residents	—	—	•	—
Establishment of decay level of the building as a whole	—	•	—	—
Thermal assessment and optimisation of energy consumption	—	—	•	—
Environmental assessment	—	—	—	•
Assessment of complexity conditions affecting the work to be carried out	—	•	•	—
Comparison with model building	•	—	—	—
Appendix giving description of the functioning and behaviour conditions of the building	—	•	—	—
Appendix giving description of current anomalies found in buildings	—	•	—	•
Publication of building maintenance handbook	—	—	—	•
Documents to aid the preparation of reports	—	—	—	•

Notes: • - Existing in the method; Min. - minimum; n/s - not specified.

These methods all involve a standardised, systematic technical diagnosis of various parts of the envelope and interior spaces. However, the comparative approach used may encourage subjectivity (that is conclusions that are based more on opinion than upon tests or measurements).

All of these tools estimate the probable degree of decay and respective repair costs without undertaking any kind of test or check. Consequently, the results obtained may diverge a great deal, in accordance with the interpretation made by the expert responsible for the work.

The graphic appearance, multimedia backup and commercial presentation of these methods have developed significantly, making them appealing to potential users. However, despite this, there does not appear to be large-scale use of these new tools. This may reveal their inability to adapt to the needs of the various public and private organisations operating in the market, and to the different features of the buildings concerned.

According to our analysis and weighing-up of different factors under appreciation, the following aspects should be taken into account in the development of new methods:

- an emphasis on the envelope, as this contributes decisively to the interior comfort of the residential units;
- importance given to the residents' opinions in the choice and implementation of intervention decisions;
- the calculation of cost estimates that are close to reality, achieved by organising dynamic databases for the purpose; and
- the treatment of each building as a unique entity, rather than merely comparing them with model buildings.

Table 2: Classification of buildings in accordance with characteristics and period of construction

A. <i>Historic buildings/monuments</i>	Buildings representing a particular historic period of a nation or continent, with unique aesthetic characteristics, marked cultural references or a particular symbolic system.
B. <i>Old buildings</i>	Buildings over 50-year-old, at the end of their useful life, with mixed masonry and wooden structures.
C. <i>Recent buildings</i> (less than 50-year-old)	<i>1st Phase</i> – Residential buildings with porticated structure in reinforced concrete (between 30- and 50-year-old) <i>2nd Phase</i> – Residential buildings designed after the oil crisis of the 1970s, incorporating thermal insulation and energy consumption solutions (between 5- and 30-year-old).
D. <i>New buildings</i>	Very recent buildings which have not yet exceeded their legal guarantee period, but which may already present early signs of pathology (less than 5 years).

THE PERFORMANCE-BASED METHOD FOR THE PREPARATION OF DIAGNOSTIC STUDIES (MEXREB)

Applicability

Buildings may be classified in accordance with their characteristics and period of construction, as shown in Table 2.

The method suggested here was designed to be applied to multi-family residential blocks. It is not applicable to old or historic buildings, as the rehabilitation process is not compatible with methodological regulations in place for the preservation of the historical heritage or with the high costs of ensuring that those buildings comply with present-day standards.

As regards more recent buildings, the method may be applied to buildings over 30-year-old and to new buildings (under 5 years), but only on the basis of carefully selected criteria. This is because the former are likely to require interventions with greater impact, while the latter, which are more recent, may have a misleadingly ‘good appearance’.

The optimum age interval is recent buildings of the 2nd Phase (that is 5–30-year-old). It is recommended that this be subdivided into the following groups in order to assess homogeneous samples and make adequate comparisons when necessary: Buildings aged 5–10 years; Buildings aged 10–20 years; and Buildings aged 20–30 years.

The envelope and requirements to be met

Concept of the outer envelope

The envelope is the barrier that separates the interior and exterior environments. It may be divided into two main parts: the vertical parts (which may be opaque or glazed) and the roof (where the main focus is rainwater drainage and connections with projecting parts).

Requirements for the envelope of buildings

The envelope needs to satisfy a wide range of different demands. Let us look at the example of the external wall. This provides a barrier between the exterior and interior environments in order to create comfortable living conditions. Therefore, we need to assess its stability and durability over time, and its ability to provide a protective barrier against the wind, rain, sun, heat, noise, fire, solid materials, insects, animals and even human intruders. However, we should be aware that the external wall not only acts as a protective barrier, it also has to provide adequate illumination for the interior, frame the building aesthetically, and (less importantly) satisfy certain specific demands such as

Table 3: List of requirements

<i>Part of the envelope</i>	<i>Zone</i>	<i>Requirement</i>
Vertical parts	Opaque	Thermal insulation
		Fire resistance
		Noise insulation
		Waterproofing
		Control of vapour permeability
		Wall/structure compatibility
		Treatment of thermal bridges
		Waterproofing
		Control of air permeability
		Thermal insulation
	Glazed	Noise insulation
		Wind resistance
		Control of light transmission
		Control of condensation
		Maximum solar factor
Roof	Common zone	Waterproofing of roof cover
		Control of air permeability
		Control of vapour permeability
		Thermal insulation
	Connections with projecting parts and capping	Flashing impermeability
		Efficient drainage
	Rainwater drainage	

colour, texture and porosity. All these aspects contribute to the various requirements defined for the performance of external walls.

It is also important to point out that these factors are all interconnected and interdependent, and that their behaviour is multifaceted. For example, although thermal insulation must be provided, it is also important to ensure that sunlight can penetrate in winter (solar factor) and that there is minimum need for cooling mechanisms in summer. Similarly, the building must also be airtight, while simultaneously guaranteeing the air quality inside and facilitating ventilation so that unwanted heat gains are properly removed, particularly in the summer.

The Performance-based Diagnosis Method defines a series of requirements to be met by various parts of the building, which then enables the quality of the building to be assessed. The list is based upon legal provisions and regulations in force, and upon codes of good practice, available in technical and scientific publications. Twenty-one main requirements were chosen, listed in Table 3.

Quantification and characteristics of requirements

The requirements were defined in accordance with criteria established by the authors in the light of their experience and contact with the building industry. The whole area to be assessed was taken into account, as was the relative importance of the different zones of the envelope, and all requirements were considered to have equal weight in the overall assessment of the envelope.

This is not, therefore, a static list. At any given moment, requirements may be altered, eliminated or added; the classification system and intervals may be changed, or another series of requirements may be defined.

During the course of the research (Lanzinha *et al*, 2002, 2003, 2006), a series of 21 charts were prepared, one for each of the requirements selected. These describe the requirement in question, its mode of expression, complementary aspects to be checked, the assessment and quantification method to be used, and the quality levels attributed.

The requirement charts were defined over a particular period and within the context of the regulations that were in force at that time. As nothing is immutable, particularly in the domain of building regulations, it is natural that these requirements may change to accompany progress made in other domains.

THE STRUCTURE OF THE PROPOSED METHODOLOGY

The Performance-based Diagnostic Method applied to the Rehabilitation of Buildings is organised into the following phases:

- 1st Phase – Contact with the customer/definition of objectives;
- 2nd Phase – Consultation and study of available documentation;
- 3rd Phase – Visual inspection to assess the general state of conservation of the building;
- 4th Phase – Survey of residents,
- 5th Phase – Performance-based assessment; and
- 6th Phase – Assessment report.

The performance-based assessment should always be understood as the main objective. The visual inspection is no more than a simple observation of the building, without the use of any complex instruments, and the results will inevitably depend upon the experience and ability of the engineer involved. Thus, it should be viewed merely as a preliminary phase to the assessment process.

Figure 1 shows the diagnostic procedure proposed.

Performance-based assessment

The performance-based assessment is the core of the methodology proposed, and therefore warrants special attention. The aim is to quantify the performance of various parts of the envelope. The assessment is based upon the functional requirements established in regulatory documents, and technical analyses, calculations, measurements and *in situ* tests will be conducted wherever possible. The performance of various parts of the building will be assessed for different situations, and the results will be compared with the requirements stipulated.

This type of assessment is essentially technical in nature and must be carried out by experts with appropriate training in planning, construction and conservation of buildings, in order to ensure that the data is properly introduced. These experts must also have in-depth knowledge of the applicable regulations, the functional requirements of building parts, construction rules and processes, the technical basis of the functioning of various components of buildings, measuring and gauging instruments and so on. Hence, less experienced professionals, or those with only basic training in construction science, may not be up to the task.

MEXREB computer programme

The computer programme, MEXREB, was designed to facilitate the assessment procedure. After the relevant data has been fed into the programme (see example in Figure 2), it generates a profile of the building being studied as regards the 21 requirements. For each of the requirements defined, charts are provided containing all the information necessary for the analysis.

The final outcome of the whole assessment process is the generation of a performance-based Diagnostic Profile (see Figure 3), which, when compared with the desired profile, indicates the aspects most in need of attention. That is to say, the performance-based

Figure 1: Diagram of the diagnostic procedure proposed.

The screenshot shows a software interface for calculating thermal transmittance for an opaque zone (Zona Opaca: Fachada Norte). The form is divided into several sections:

- Elementos Construtivos**: Options for 'Parede Simples' or 'Parede Dupla'. For 'Parede Dupla', it specifies exterior and interior panels with materials like 'Bloco de Betão Normal' and 'Tijolo Furado'.
- Isolante**: Options for 'Sem Isolante', 'Exterior', 'Interior', or 'Entre Paredes'. It includes fields for material (e.g., 'Poliestireno Expandido') and thickness ('Espessura').
- Revestimento**: Options for 'Contínuo' or 'Descontínuo' with material choices like 'Alvenaria/Cantaria', 'Elementos Cerâmicos', or 'Monomassa'.
- Factor de Concentração de Perdas**: A field for F_c (set to 1.3).
- Base das Paredes**: Options for 'Pedra Natural' or 'Reboco e Pintura'.
- Portas**: Options for 'Material' (e.g., 'PVC') or 'Não Tem'.
- Área da Zona Opaca**: A field for area in m^2 .
- Acabamento**: Options for 'Tinta' (e.g., 'Plástica') or 'Próprio Material'.

On the right side, the 'mexXREB' logo is displayed above the calculated 'Coeficiente de Transmissão Térmica' of $0.62 \text{ W/m}^2 \text{ C}$. At the bottom right are 'Ok' and 'Cancelar' buttons.

Figure 2: 'Opaque Zone' form (legend in Portuguese).

diagnosis gives a clear idea of the parts of the envelope that require intervention in order to achieve the quality level desired.

It should be noted that there must be compatibility between the various actions required to rehabilitate different parts of the envelope. In fact, whenever a rehabilitation intervention is carried out on part of the envelope, it may bring implications for the performance-based classification of other parts. For example, reinforcing the thermal insulation of an external wall may simultaneously improve the level of waterproofing and

Diagnóstico Exigencial e Grau de Satisfação das Exigências

Fechar Imprimir

12345

Elementos Verticais: Zona Opaca

Resistência Térmica				
Resistência ao Fogo				
Isolamento Acústico				
Estanquidade à água				
Controle de Permeabilidade ao Vapor				
Compatibilidade Parede / Estrutura				
Tratamento das Pontes Térmicas				

Elementos Verticais: Envidraçados

Estanquidade à água				
Estanquidade ao ar				
Resistência Térmica				
Isolamento Acústico				
Resistência ao Vento				
Controle de Transmissão Luminosa				
Controle da Condensação				
Factor Solar Máximo				

Cobertura: Comum

Estanquidade à água do Revestimento				
Controle de Permeabilidade ao Ar				
Controle de Permeabilidade ao Vapor				
Resistência Térmica				

Cobertura: Ligações com Elementos Salientes e Capeamentos

Estanquidade das Ligações				
---------------------------	--	--	--	--

Cobertura: Drenagem de Águas Pluviais

Escoamento Eficaz				
-------------------	--	--	--	--

Figure 3: ‘Performance-based Diagnosis’ window (legend in Portuguese).

even reduce its reaction to fire. When a certified window is installed, this will also make the building more watertight and improve thermal and acoustic insulation, and wind resistance. It may also reduce the ventilation flow if specific mechanisms are not installed to counter this.

APPLICATION OF THE MODEL

Characteristics of the sample

To assess the functioning of the proposed method, a sample of 39 multi-family buildings was selected. All the buildings were analysed and 370 questionnaires were made to the 498 households, which covered a total of 1086 residents (see Table 4).

Table 4: Characteristics of the sample

No. of buildings studied	39
No. of residential units	498
No. of questionnaires made realizados	370
No. of residents	1086
Buildings over 30-year-old	2
Buildings aged 20–30 years	3
Buildings aged 10–20 years	11
Buildings aged 5–10 years	14
Buildings under 5-year-old	9

Of the surveys carried out, there was a predominance (58.15 per cent) of T3 (three-bed roomed) units, followed by T2 (21.3 per cent), T4 (12.03 per cent), T1 (7.77 per cent) and T5 (0.75 per cent). These percentages seem to be in accordance with the predominant distribution of types.

The questionnaires were made in 74.3 per cent of households, which guarantees the reliability of the results. We should remember that in some of the methods studied and applied in other countries, only three questionnaires were made per building. In our case, 9.48 households were analysed per building on average (out of a total number of 12.77 households per building), three times more than the figure studied in the methods cited. In seven of the buildings, it was even possible to carry out all the surveys, as had been hoped.

As for the type of occupancy, of the 498 units surveyed, 62.05 per cent were owner-occupied, 36.29 per cent were rented and 1.66 per cent did not fall into either of these categories. The type of occupancy seems to be in accordance with typical residency patterns in Portugal, with most units occupied by their owners. Nevertheless, there were a significant number of rented units (over a third).

Overview of results obtained

The buildings were divided into age intervals (less than 5-year-old, 5–10, 10–20, 20–30 and over 30 years). The results of the visual inspection were compared to those yielded by the MEXREB performance-based assessment for each age interval, and overall. The MEXREB performance-based assessment results were assessed globally and according to area of the envelope. Finally, the influence of occupancy type on the MEXREB results was also considered.

The 370 surveys made to residents were also analysed to find out the extent to which certain situations (such as excessive noise) posed an inconvenience for the residents. The questionnaires also yielded important information concerning the residents' interest in undertaking rehabilitation work and their priorities.

Visual inspection versus MEXREB performance-based assessment – Classification by building

Assessment by age interval of buildings

Figures 4–8 show the comparative results of the visual inspection and performance-based assessment according to age interval of buildings:

- Buildings less than 5-year-old (9 buildings);
- Buildings aged 5–10 years (14 buildings);
- Buildings aged 10–20 years (11 buildings);

Figure 4: Visual inspection versus MEXREB (Buildings less than 5-year-old).

Figure 5: Visual inspection versus MEXREB (Buildings aged 5–10 years).

Figure 6: Visual inspection/MEXREB (Buildings aged 10–20 years).

- Buildings aged 20–30 years (3 buildings); and
- Buildings over 30-year-old (2 buildings).

In conclusion, it can be seen that the scores awarded by visual inspection are considerable better than those achieved using the MEXREB performance-based assessment. This suggests that the buildings tend to appear to be in a better condition than they actually are. The data supplied by the performance-based assessment are considered to be

Figure 7: Visual inspection versus MEXREB comparison (Buildings aged 20–30 years).

Figure 8: Visual inspection versus MEXREB (Buildings aged +30 years).

more reliable, as it reflects the performance of different parts of the envelope from the perspective of building physics.

Assessment of the whole sample

After the age interval analysis, an assessment of all 39 buildings was carried out in order to gain an overview of the whole situation.

The comparative graph of results (Figure 9) shows that the score obtained from the MEXREB performance-based assessment is always lower than the score obtained from the visual inspection, as we might expect. Moreover, this decreases relative to the age of the building.

As regards the average results of the visual inspection, the study shows that the score decreases with the buildings' age, which is to be expected, given the decay caused by external agents over the course of the building's life. However, there is one age interval (20–30 years) where the score increases, probably because of the reconstruction work carried out in the meantime.

Analysing the scores for the performance-based assessment, we can see that the performance-based quality has increased over the last 30 years, although there was a period when it decreased slightly (in the group of buildings aged 20–30 years). Buildings over 30-year-old, however, present a MEXREB performance-based assessment of 'Sufficient', despite the natural tendency for a decrease in the score with age. This may be explained by the fact that this age interval contained relatively few buildings. Moreover,

Figure 9: Visual inspection versus MEXREB (total sample).

Table 5: Summary of classifications

Age interval of buildings (years)	Visual inspection	Performance-based assessment
<5	Very good	Good
5–10	Good	Sufficient
10–20	Sufficient	Sufficient
20–30	Good	Poor
>30	Sufficient	Sufficient

these buildings may have been more carefully constructed, compared to those aged between 20 and 30 years.

In the series studied, there is one period (buildings aged between 10 and 20 years) in which the score attributed to external appearance appears to have gone down, despite the general tendency for construction quality to increase. However, the visual inspection results are not uniform on this point, which suggests that buildings aged between 20 and 30 years have probably been renovated. In this period, the buildings already presented signs of visible decay, and required conservation work. The owners would have been, by this time, free of the bulk of the mortgage that they had contracted, and were able to make available some funds for these expenses.

From the data analysed, we can conclude that there is a period when the score relative to the performance-based assessment dropped: namely the end of the 1970s and beginning of the 1980s (that is the series of buildings aged 20–30 years). This probably reflects a certain lack of social and economic control experienced in Portugal during the period when the country was in transition to democracy.

We also found that, in buildings aged less than 20 years, the quality had improved and more requirements were being met as a result of the implementation of thermal, acoustic and fire regulations in buildings designed for habitation.

The average scores from the visual inspection and performance-based assessment MEXREB are summarised in Table 5 in the form of a qualitative evaluation.

Assessment of results of performance-based analysis

The results of the performance-based analysis (Figure 10) show that the average score of buildings by age group is generally in 2–3 bands, corresponding to the classification *Sufficient*. This classification evolves positively within this interval and buildings less than 5-year-old now have an average score slightly more than 3, meaning that they fall into the *Good* category.

Figure 10: MEXREB – Overall classification by age interval.

Figure 11: MEXREB – Average classification of walls by age interval.

Figure 12: MEXREB – Average classification of glazed parts by age interval.

The classification scale established in the performance-based assessment methodology seems adequate. However, most buildings are far from achieving the highest grade. If the same analysis is performed on different parts of the envelope (Figures 11–13), we come to similar conclusions as regards the improvement experienced over the years.

It can be seen from this series that the roofs (Figure 13) are the parts of the buildings in best condition; the average classification of the most recent buildings (less than 5-year-old) falls into the *Very Good* category (above 4).

Figure 13: MEXREB – Average classification of roofs by age interval.

Table 6: Relationship between building age/type of occupancy (total Sample)

Total sample	Age of buildings (years)									
	< 5	%	5–10	%	10–20	%	20–30	%	>30	%
<i>Type of occupancy</i>										
Owner	44	62.86	77	62.10	52	55.32	29	65.91	13	81.25
Tenant	24	34.29	46	37.10	40	42.55	14	31.82	3	18.75
Other situation	2	2.86	1	0.81	2	2.13	1	2.27	0	0.00
Total	70	100.00	124	100.00	94	100.00	44	100.00	16	100.00

As regards glazed parts (Figure 12), the development across age intervals is positive, but only buildings aged less than 10 years scored *Sufficient*. We might conclude that the classification structure is too demanding; but the truth is that we all have the notion that glazed parts are one of the parts that most weaken buildings and that they are rarely subjected to regulation or certification.

If there were to be progress in this direction, and if the choice of glazed parts to be installed could take account of functioning and behavioural demands, the classification would improve to *Good* and *Very Good*.

The influence of the type of occupancy on results obtained

It seemed to be of particular interest to assess the effects of the type of occupancy (owner or tenant) upon the scores obtained by visual inspection and performance-based analysis for each of the age intervals of the buildings.

A table was constructed from the sample (Table 6) which shows the values relative to the type of occupancy for each age interval.

In buildings, under 20 years of age the percentage of owners residing in the buildings gradually increases in inverse proportion to the age of the building (Figure 14). The results of the visual inspection have also increased in parallel, which could possibly be related to the recent age of the building and to a greater interest on the part of the owners in preserving the external appearance of buildings, and to the greater availability of funds to carry out maintenance work.

A similar kind of analysis relative to tenant occupiers shows (Figure 15) that, for buildings aged less than 20 years, the percentage of tenant occupants has decreased, moving in the opposite direction to the scores for visual inspection.

Figure 14: Relationship between visual inspection/MEXREB assessment when owner-occupied.

Figure 15: Relationship between visual inspection/MEXREB assessment for tenant-occupied units.

This behaviour may be explained by the fact that a higher percentage of resident owners increase the probability that maintenance work will be carried out on the building. Tenants are not usually expected to make this kind of investment, unless it is in their interest to do so.

This study therefore allows us to conclude that the percentage of resident owners may influence the state of conservation of the envelope of the building. That is to say the more owners reside in the building, the more people there are that are interested in preserving and maintaining it.

CONCLUSIONS

The aim of this work was to define a Performance-based Diagnostic Method Applied to the Rehabilitation of Buildings, based upon the analysis of a series of requirements for parts of the envelope.

After using the application, it was concluded that the visual inspection yields higher scores than the performance-based assessment, and that this difference persists irrespective of the age of the buildings. The visual inspection score assesses the appearance of the building envelope; it should therefore be used with caution when evaluating and defining rehabilitation work. Indeed, in our opinion, it should only be used as a preliminary study.

Performance-based assessment, on the other hand, provides more accurate and concrete data about the quality of construction, as this study shows. Thus, we can

conclude that, in many cases, the external appearance of a building does not correspond to its true state of conservation or degree of functionality, and that it may not comply with the requirements for the various parts making up the envelope. Thus, the performance-based assessment is more reliable.

However, both methods are useful for evaluating the state of conservation of buildings, even though the results of the performance-based assessment will ultimately carry more weight. Thus, the engineer responsible will be better equipped to assess the state of conservation of the building and to take decisions that will result in improved functioning and appearance, thereby contributing to the comfort of the residents.

REFERENCES

- Casademont, P., Casanovas, X., Miracle, M. and Rosselló, M.B. (1989) *MANUAL TEST HABITATGE*. Col·legi D'Aparelladors i Arquitects Tècnics de Barcelona, Spain (in Catalan).
- CLAU. (2000) *Assistente de manteniment – llibre de l'edifici, test manteniment reports*. Col·legi D'Aparelladors i Arquitects Tècnics de Barcelona, Spain (C.D. in Catalan).
- EPIQR. (1999) *Un outil d'aide à la décision pour la réhabilitation des bâtiments d'habitation – Les principes de la méthode*, Paris, France: C.S.T.B. (in French).
- Lanzinha, J.C., Freitas, V.P. and Castro Gomes, J.P. (2002) Development of Exigencial Diagnosis Methodology Applied to Building Rehabilitation, In: Ural, O., Abrantes, V. and Tadeu, A. (eds.) *XXX IAHS World Congress on Housing – Housing Construction – An interdisciplinary task*; 9–13 September. Coimbra, Portugal: FCTUC.
- Lanzinha, J.C., Freitas, V.P. and Castro Gomes, J.P. (2003) Metodologia de Diagnóstico Exigencial Aplicada à Reabilitação de Edifícios de Habitação, In: Freitas, V.P. and Abrantes, V (eds.) *Proceedings of the 1st National Conference on Building Pathology and Rehabilitation – PATORREB 2003*; March, Porto, Portugal (in Portuguese).
- Lanzinha, J.C.G. (2006) *Reabilitação de Edifícios – Metodologia de Diagnóstico e Intervenção*. PhD thesis, University of Beira Interior, Covilhã, Portugal (in Portuguese).
- Marco, D., Hass, D., Willemin, C. and Edelman, P. (1996) *MER HABITAT – Méthode de diagnostic des dégradations, des désordres et des manques et d'évaluation des coûts de remise en état des bâtiments d'habitation*. Office fédéral du logement OFL, Granges, Switzerland. Bulletin du logement, Vol.64 (in French).
- Merminod, P. and Vicari, J. (1984) *Manual MER/Méthode d'évaluation rapide des coûts de remise en état de l'habitat*. Office fédéral du logement, Granges, Switzerland. Bulletin du logement, Vol. 28.