PRESTAZIONI EDILIZIE E CONTENUTI ENERGETICI GLOBALI DI PARETI PERIMETRALI
BUILDING PERFORMANCE AND GLOBAL ENERGY CONTENTS OF CURTAIN WALLS

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SOMMARIO. In relazione ad alcuni aspetti fondamentali della "teoria della qualità" in edilizia viene individuato il "valore energetico" di un repertorio di pareti perimetrali in base al rapporto tra i livelli prestazionali complessivamente offerti da tali pareti ed i relativi costi, considerati sia in termini monetari che in termini energetici (energie dirette e indirette spese per la costruzione, energie dissipate nella gestione e energie coinvolte nella manutenzione.

ABSTRACT. In relation to a number of basic aspects of "quality theory" applied to the field of building, the authors identify the "energy value" of a repertory of curtain walls, on the basis of the ratio existing between the overall performance levels offered by said walls and related costs, viewed in terms of both monetary and energy expenditure (direct and indirect energy used up in the building process, energy taken up by handling and energy involved in maintenance interventions.

1. INTRODUCTION.

One of the basic aspects of "quality theory" in the building sector is represented by the formulation of a "balance" (that is, a ratio) between the "benefits" stemming from a particular building intervention and the "costs" to be paid for its implementation: "benefits" that can be identified with the overall performance levels attained and "costs" which may be assessed both from the standpoint of actual expenditure and from that of the global energy requirements to be met over the entire period of utilization (or life span) of the building unit.

In this perspective, a research project currently under way, commissioned by the RDB company of Piacenza (Italy) to SI.TE. RICERCHE of Turin (Italy), set out to analyze and assess the levels offered in relation to a series of building performance features regarded as most significant by a repertory of curtain walls built with a variety of construction techniques. At the present stage of the investigation, for the same repertory of curtain walls, an in-depth study of the global energy contents is being performed, with the aim of determining:

- the direct and indirect energy used up during the phases of components manufacturing and building execution,
- the energy dissipated through heat dispersion and involved in the handling of the building's heating system,
- the energy required for the maintenance operations scheduled to take place over the entire life span of the building unit.

The ratio between the overall performance level attained, or the "quality of a building and its global energy content, a ratio that may be termed for brevity's sake as "energy value", can provide fruitful indications on the optimal utilization conditions for the various types of curtain walls in relation to possible prefigurations of building environments, as well as point the way towards solutions capable of suboptimizing the external shielding system with respect to the building's global economy or with respect to the effective attainment of a range of performances.

In this report we shall therefore illustrate a number of results, albeit still partial, obtained so far in the course of the investigation.

2. REPERTORY OF CURTAIN WALL TYPES UNDER CONSIDERATION.

The repertory of curtain walls to be examined has been defined on the basis of specific criteria of "interest" and "threat" exerted by each individual building solution on the brickwork, seen both as factors which might impair the "image" of the masonry (as a material capable of solving certain problems of strength, insulation, etc.) and as the attention to be paid to the consolidation and development of specific fields of utilization (corresponding to the sectors covered by the market). As a consequence, we have included in the repertory the following outer wall types:

- no. 7 types of single-layer brickwork with blocks of varying dimensions and characteristics (denoted by the letters Lm);
- no. 11 types of hollow brickwork, built with bricks and/or blocks, and comprising a cavity which may or may not be thermally insulated (L);
- no. 3 types of walls consisting of a brick layer and a layer of plasterboard panels or gypsum blocks (Lg);
- no. 5 types of walls built with concrete panels or concrete blocks (either lightweight or ordinary), in either single or multilayer solutions (C);
- no. 3 types of walls consisting of a layer of facebricks and a layer of concrete or small lightweight concrete blocks (LC);
- no. 3 types of walls built with different materials, such as timber, sandwich panels of either asbestos cement or aluminium, indicated by letters B, F and A respectively, selected in order to provide references to widely diversified technologies.

3. ASSESSMENT OF THE PERFORMANCE VALUES (OR OF THE QUALITY OFFERED).

As is known, the "quality" of a building unit is understood as the balanced and adequate response, offered by overall product technology, to the overall performance demands stemming from users' needs. This is why the assessment involves tackling a few methodological problems, concerning the definition of significant "performance features" with respect to the various environmental settings, the expected interventions and the establishment of related parameters.

3.1 DEFINITION OF THE SIGNIFICANT PERFORMANCE FEATURES.

On the basis of the knowledge acquired in the field of habitual users' needs and of the requirements emerging from other facets of the construction process,

at times not taken into due consideration (but still exerting a considerable influence on the optimization potential), the following performance range has been selected, including the factors that can be regarded as most significant:

1) Adaptation to take interior fittings;
2) Adaptation to take external fittings;
3) Strength against collisions with soft bodies;
4) Sound insulation;
5) Control over thermal bridges;
6) Ease of cleaning;
7) Duration of the exterior finish, from the aesthetic viewpoint;
8) Strength against concentrated impact;
9) Resistance against deformations;
10) Evolution potential;
11) Integration potential;
12) Noise absorption;
13) Fire resistance;
14) Sensory aspects;
15) Ease of maintenance;
16) Alterability;
17) Disturbance caused by upkeep operations;
18) Emission of fumes, odours, dust, etc.;
19) Supply of "spare performances";
20) Bearing capacity;
21) Visual features;
22) Control over condensation in the mass;
23) Thermal inertia;
24) Emissivity;
25) Flexibility of utilization;
26) Performance continuity.

It should be pointed out that "heat insulation" is not included in this performance list as, in keeping with the methodological premises discussed at section 1, we deemed it best to classify it under the item "costs of handling" rather than under "performance features".

3.2 ESTABLISHMENT OF PERFORMANCE PARAMETERS.

The establishment of parameters aimed at selecting the appropriate magnitudes for measuring the behaviour of the building elements in presence of different phenomena (hygrothermal, acoustic, etc.) as well as identifying the most significant aspects and attributes of the utilization stages of the building spaces and structures, meets with considerable difficulties. Therefore, it was necessary to resort to different approaches in the assessment of performance levels: whilst for some characteristics we were able to avail ourselves of the analytical instruments provided by specific disciplines (such as applied physics, acoustics, etc.), for other types of performance we had to adopt empirical criteria, fixing the distinguishing criteria of performance levels on the basis of personal experience and accepting an inevitable degree of approximation.

3.3 GLOBAL QUALITY

In order to be able to indicate with a summary evaluation (that is, with a mark) the overall quality attained by each individual building solution comprised in the repertory, with respect to different assessment hypotheses, we worked out several correlation scales for the various performance levels, so as to "weigh" each performance feature on the basis of the importance that is attached to it under the following assessment hypotheses:

a) normal hypotheses, reflecting the "weight" attributed on average by the user to the various performance features,
b) hypothesis where greater importance is attached to user safety features,
c) equipotential (same degree of importance) hypothesis for the different performance factors,
d) hypothesis based on the need of adapting to the variability of user needs,
e) hypothesis founded on the requirement of maximum durability of the building elements in time.

Figure 1 shows the quality "marks" assigned to the wall types in relation to each assessment hypothesis, as well as the global quality determined through the summation of these "marks; obviously the latter, that is, global quality, represents an element of judgement obtained as a mean over the five different assessment hypotheses being considered, and therefore it can be used as an approximate yeardstick to identify the solutions best suited for all applications in general.

4. ASSESSMENT OF GLOBAL ENERGY CONTENTS.

In keeping with the general principles outlined in the introduction, the assessment of the global energy contents relating to the curtain wall type repertory under consideration has been carried out through an analysis of the elementary energy investments involved in the entire production process and life span of the building unit, so as to determine:

a) the building energy contents;
b) the handling energy contents;
c) the maintenance energy contents.

4.1 BUILDING ENERGY CONTENTS, CEc.

The examination of the energy consumption relating to the building phase has been performed by establishing two different categories of "energy expenditure":

a) energies used up to produce the building unit, during the transformation stages that go from the extraction of raw materials to the production of finished products and components, also including the placing or assembling stages for the execution of the unit's building elements; these are termed "Direct Energy";
b) energies that are not directly involved in the production and assembly of the building products as items which can be rigrously quantified, but rather concern all those items (goods, services and equipments) that are not physically observable in the finished product and building element, but are nevertheless indispensable for production and execution. These are termed "Indirect Energy".

4.1.1 ANALYSIS OF DIRECT ENERGY CONTENTS.

The determination of Direct Energy Contents, CEd, referred to the curtain wall unit surface, has been performed on the basis of the summation of the product of the Mass P of the materials making up the individual layers of each building solution times the relative Specific Energy Contents ce_S (a concept taken from a previous investigation of the Finalized Energy Project by the Italian National Research Council (CNR) entitled "Exploratory Investigation into possible medium and long term interventions for the promotion of energy saving in the sector of housing construction"):

$$CEd = \Sigma_1^n (P \times ce_S).$$

4.1.2 ANALYSIS OF THE INDIRECT ENERGY CONTENTS.

In view of the great difficulties encountered in quantifying the Indirect Energy Contents by means of an analytical procedure, we had to resort to an estimated appraisal, founded on a number of operational assumptions and observations. In fact, having ascertained a rather strict correlation between the price of building components and their overall energy contents (i.e., direct plus indirect energy contents), we thought of the possibility of translating this price into the corresponding energy content and then determine the Indirect Energy Content as the resulting difference, using the following relationship:

$$CEi = (\alpha \times Pr \times CELT) - CEd.$$

It should be noticed that in this formula, reflecting a calculation procedure suggested by the investigation mentioned at the previous paragraph:

- the symbol α stands for the component's"coefficient of technological complexity", for which, at a stage of first approximation, we set three values, corresponding to as many degrees of complexity,
  - α = 1.2 for a high complexity level,
  - α = 1.5 for medium complexity,
  - α = 2.7 for low complexity;
- the symbol Pr, as we have said, denotes the price of the component, calculated according to the usual methods of market price analysis, referred, as usual, to the curtain wall unit surface;
- the symbol CELT stands for the "Lira's energy content", that is, the equivalence between monetary units and the energy units, and it can be quantified by means of the ratio between the Itálian 'Gross Domestic Product" expressed in monetary terms and the Italian "Gross Domestic Energy Consumption" over the same period of time, expressed in terms of energy.

4.2 HANDLING ENERGY CONTENTS.

The assessment of Handling Energy Contents, CEg, has been obtained as an approximation, on the basis of the calculation of the quantity of heat dispersed per unit surface of the curtain wall along the entire heating period in the winter, correlating this dispersion (by means of the simple relationship shown below) with the actual energy consumption in the boiler by introducing the various

efficiencies of the plant/building system:

$$CEg = (K'm \times D \times 24) / \rho^*$$

where:

K'm = unit transmittance of the curtain wall,
D = number of degrees/days in relation to the climatic area,
ρ^* = combustion efficiency that takes into account the global efficiency of the plant in relation to:
- intermittent operation,
- efficiency of the distribution network,
- efficiency of thermal adjustment.

Needless to say, in this procedure that has been necessarily expressed in a simplified form for brevity, account has been taken of the various features of the building's technological system (ratio of glazed areas, incidence of thermal bridges, etc.) as well as of the reference climatic conditions, so as to obtain a more significant correlation with the Italian situation.

4.3 MAINTENANCE ENERGY CONTENTS.

Finally, the assessment of Maintenance Energy Contents, CEm, also required the definition of an appropriate calculation methodology, a task even harder than the establishment of the procedures outlined in the previous paragraphs, owing to the great diversification of possible maintenance interventions (as a function of the different materials and techniques used) and to the variety of deterioration phenomena affecting the building units (also as a consequence of users' behaviour). The crucial problem to be solved was the definition of the types of maintenance operations to be performed, and the relative implementation cycles required to preserve, as we had assumed, the mean level of performance, form the aesthetic viewpoint, round 80% of the initial value.
Thus it was necessary to rely on the experience acquired by the research group and on the existing literature (albeit limited) in order to eventually define (as is shown in the abstract in figure 2) a list of types of maintenance interventions, their implementation cycles and relative prices (determined through the customary analyses), referred to a building life span of 90 years.

At the current phase of the investigation we are therefore engaged in transforming the overall maintenance costs into energy costs, following a procedure similar to the one described at para. 4.1.2; this transformation also meets with remarkable difficulties, due to the complexity of the operations required to fix an equivalence between the monetary measuring units of maintenance (i.e., Lire spent on maintenance) and the measuring units of energy.

4.4 ENERGY CONTENTS AND RESULTING COSTS.

In relation to the current state of the investigation, we are able to list partial results obtained for the Building Energy Contents CEc of the curtain wall repertory being considered (see Figure 3), whilst in the case of handling and maintenance, as the energy contents cannot yet be expressed, it was deemed of sufficient significance to present the handling and maintenance costs expressed in monetary terms over the 90 year period being taken into account (see figure 4).

The investigation also covered a series of additional evaluations with respect to different utilization contexts of the curtain walls in the repertory, and additional relationships linking the variables involved; these evaluations, although they could not be dealt with in this report for reasons of space, have led to the formulation of a number of final indications and to the identification of current production and utilization trends, which will be illustrated in the following paragraphs.

5. OPERATIONAL LIMITATIONS AND POSSIBILITIES OF THE PROPOSED ASSESSMENT PROCEDURE.

The analysis carried out in keeping with the methods illustrated above is subjected to some limitations stemming from the randomness and indeterminacy factors which can be summed up as follows:

a) the calculation of the direct and indirect energy contents, carried out with the formulas given at paras. 4.1.1 and 4.1.2, is based on the values of the variables denoted by and CELT, which entail a considerable degree of randomness, affecting the individual variables to different extents. A similar consideration also applies to the price, Pr, which can undergo market fluctuations particularly difficult to analyse.

b) quality has been defined as a function of 26 performance features whose quantification, in several cases, cannot be defined univocally, and the same is also true of the hypothesis advanced to determine the scales of correlation between performances (i.e., mutual weight).

c) the classification of the different parameters defining the environmental conditions is impaired by randomness factors which influence the subsequent findings, to a greater or lesser extent.

d) it is important to point out that our knowledge is not exhaustive, especially because the available data are limited; for example, the incidence of labour charges could be taken into account only for building component placing operations and not for the production of the components and materials.

With these limitations in mind, however, it can still be believed that the work done not only represents one of the first attempts made in Italy to arrive at the definition of comparative indications between quality, energy contents and costs on the basis of appraisals that are not restricted to a few parameters, and that it makes available the information necessary to identify major trends in the building sector as well as indications as to the building solutions which may be viewed as optimall all-round, with respect to any environment, or as optimal solutions with respect to specific conditions and/or partial objectives (i.e., individual parameters of assessment).

6. CORRELATION BETWEEN QUALITY AND ENERGY CONTENTS (AND COSTS).

In order to provide an overview of the results that have emerged so far from the research effort and to formulate a few conclusions, we have shown in figures 5 and 6, respectively, the ratio between the global quality and the building energy contents of the various curtain wall solutions (that is, the partial energy value) and the ratio between global quality and total costs (that is, building,

handling and maintenance costs).

Keeping in mind that, as we have already pointed out, reference to global quality necessarily leads to identifying optimal solutions suited to all cases, the following considerations may be expressed:

a) Global quality to total costs ratio (see figure 6). Whilst we find ranking first and second two LC solutions (that is, walls of brickwork and concrete) immediately followed by five L and Lm solutions (that is hollow and single layer brickwork, see the identification letters at section 2), it is observed that the majority of hollow walls examined generally obtains a ranking quite lower than average and is surpassed by concrete solutions. Even though this indication is not uniform for all walls, the comparison between hollow and single layer brickwork leads to a more favourable judgement on the latter: as can be seen in figures 1 and 4, compared with all the remaining types, these display a global quality which is higher, on average, as well as lower average total costs.

b) Ratio between global quality and building energy contents (or building energy value). In connection with this ratio, we again find at the top an LC solution and find two C walls ranking in the leading positions. At the same time, while the building energy values of Lm and C are on average equivalent, attention must be called to the decline in ranking of most L solutions, that is of hollow brickwork: this can be ascribed to their higher building energy contents (see figure 3) and their global quality values, lower on average. Finally it is of some significance that we find at the very bottom the aluminium sandwich panel type walls, obviously determined by their high energy contents and not too high global quality (a situation which is shared by the other two types of panel walls, of timber and asbestos cement).

7. INDICATIONS EMERGING FROM THE INVESTIGATION.

The considerations developed in the previous section, combined with other observations made in the course of the study, point to a significant interest to be attached to the utilization of brickwork together with concrete, either as an external finish element or as building blocks for single layer masonry. This indication, applying, as we have said, to all-round optimal solutions (since it is connected with global quality) should be verified for each solution of interest, both in view of the differences always encountered in similar solutions where particular factors are concerned, and because of the possibility of variations in materials and techniques (and hence of optimization) inherent in each solution.

As concerns instead the identification of optimized solutions for partial objectives, it is possible to state that:

a) in general, all concrete solutions, all single layer masonry solutions (except one) and some Lg and LC types display lower building costs;

b) on the other hand, the objective of lower total (building, handling and maintenance) costs is met by a couple of single layer brickwork types and a couple of LC types, one Lg solution and the asbestos cement and aluminium solutions;

d) finally, the evaluation of quality expressed in relation to the various assessment hypotheses (see figure 1) allows the identification of sub-optimized solutions with respect to special requirements stemming from specific utilization environments.

By way of conclusion we should like to underline a general tendency that seems to emerge from the results obtained so far. In fact, we feel the investigation has confirmed that brick format optimization should not be regarded as the only basic objective nor the only fundamental aspect of a correct methodology of product design. To the contrary, the design procedure should take into consideration, correlate and suboptimize all the operational and handling aspects bearing upon the construction and service life of the building elements. We base this conclusion on the requests currently emerging in our sector and the production strategy indications they provide.

This realization entails the need of envisaging new production lines for both materials and components, through an integrated study covering the needs of quality, construction and economy, rather than designing individual products which may very well be optimized with respect to specific prerequisites, but are not suited to wider and more diversified market prospects.

Within this framework it seems that two alternative hypotheses lie ahead, for a new approach to production: one would be based on the understanding that brickwork offers a performance surplus with respect to its present fields of utilization, and the other would be based on the realization that brickwork still offers untapped possibilities as concerns its performance, construction and application features vis-à-vis specific environmental conditions.

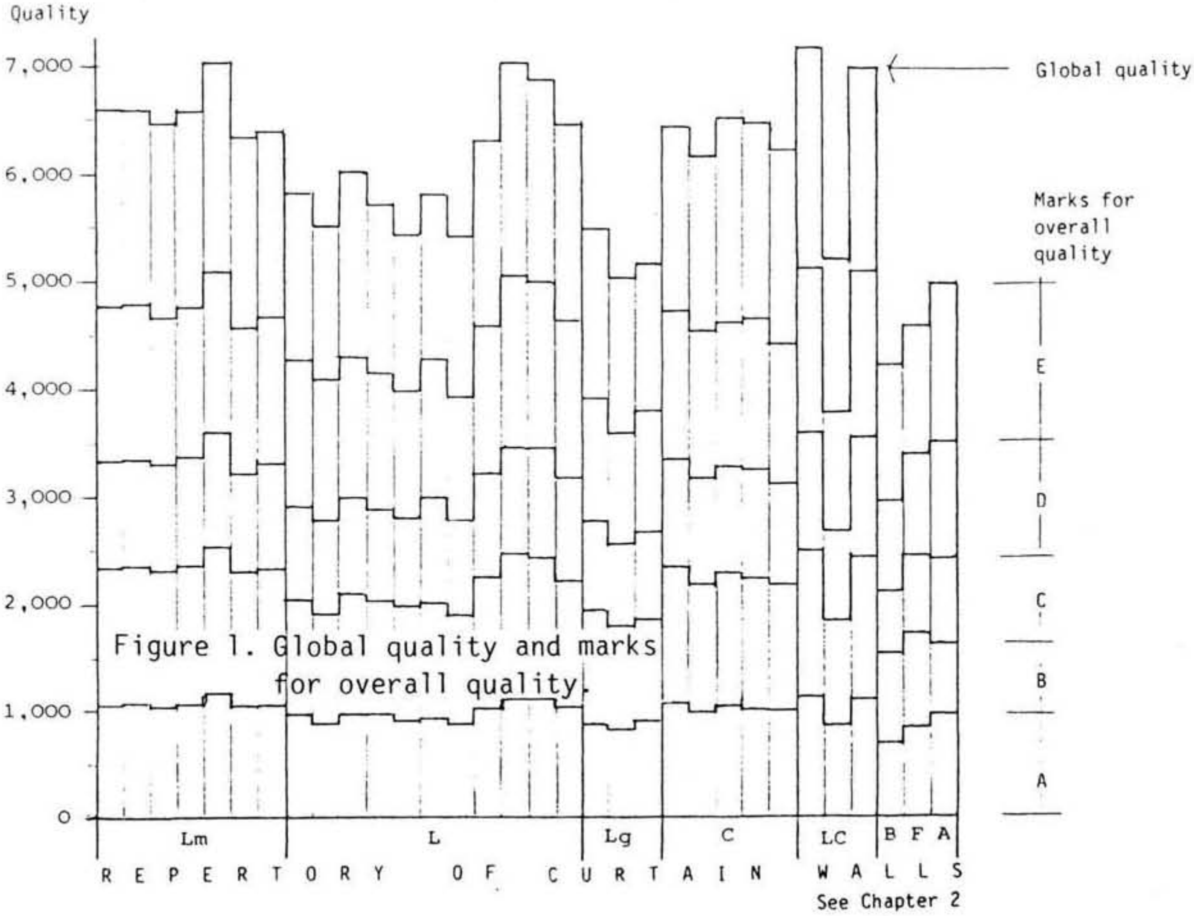


Figure 1. Global quality and marks for overall quality.

Figure 2. Abstract from the programming table of types of intervention and maintenance cycles in relation to environmental situations

		External masonry surface of plastic plaster, including cladding solutions — Type of intervention			External masonry surface of facing brick — Type of intervention		
		Plaster scraping, replastering (15% of total surface), not including scaffolding costs	Plaster scraping, replastering (5% of total surface), not including scaffolding costs	Washing with high pressure water jets and vegetable fibre brushes, not including oleodynamic tower costs	Vapour blasting with siliceous sand	Dust removal and acid washing	Plain washing with high pressure water jects
ENVIRONMENTAL SITUATIONS		MAINTENANCE CYCLES					years
Urban Areas	Continental and mountain climate	24	21	12	27	24	15
	Low Po Valley and mild climates	21	18	9	24	21	12
	Mediterranean and insular climate	24	21	12	27	24	15
Decentralized Areas	Continental and mountain climate	24	21	15	27	24	15
	Low Po Valley and mild climates	24	21	15	27	24	15
	Mediterranean and insular climate	24	21	15	27	24	15

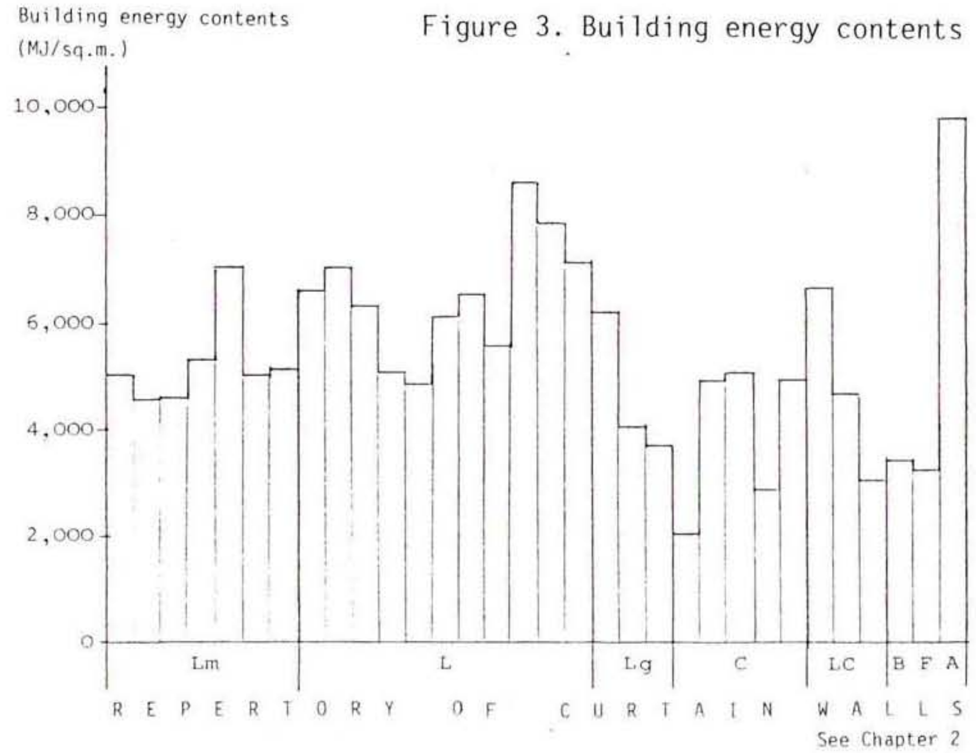


Figure 3. Building energy contents

Figure 4. Total cost
(Building, handling and
maintenance costs)

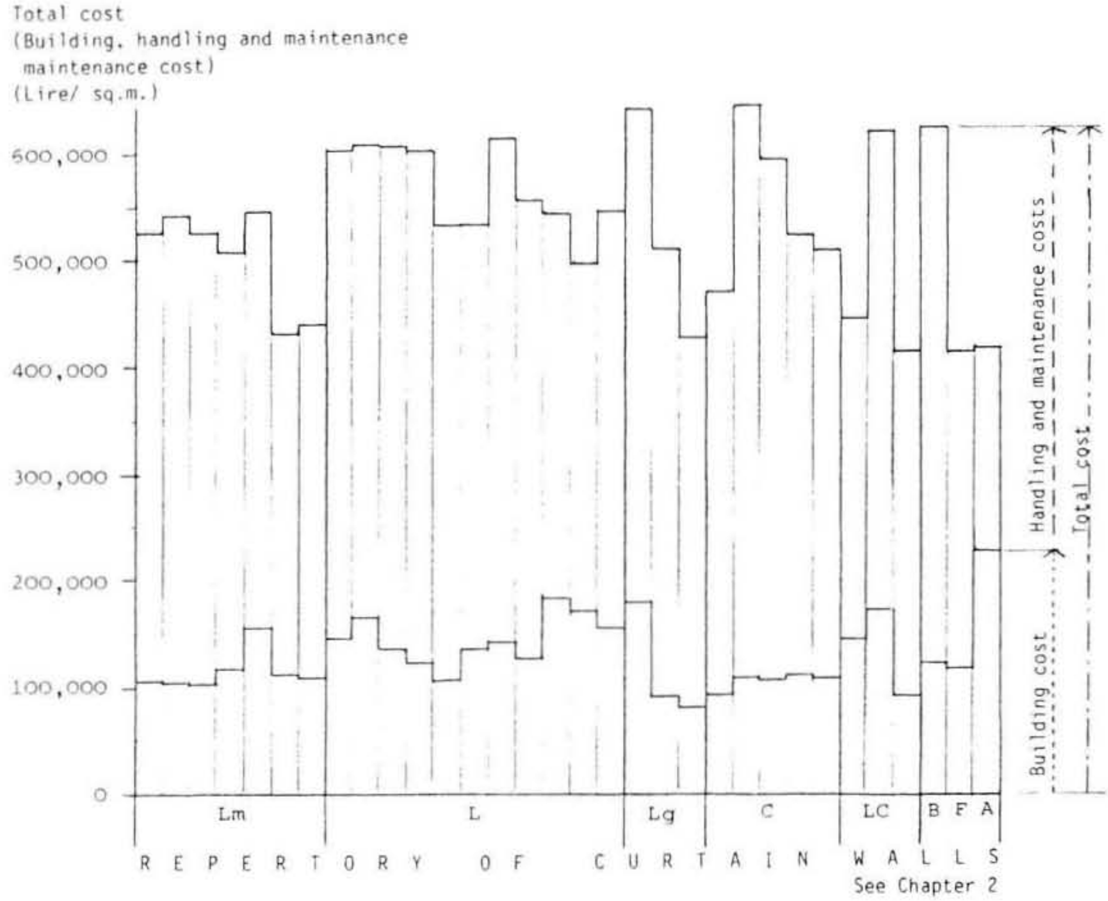


Figure 5. Ratio between global
quality and building
energy contents (or
building energy value)

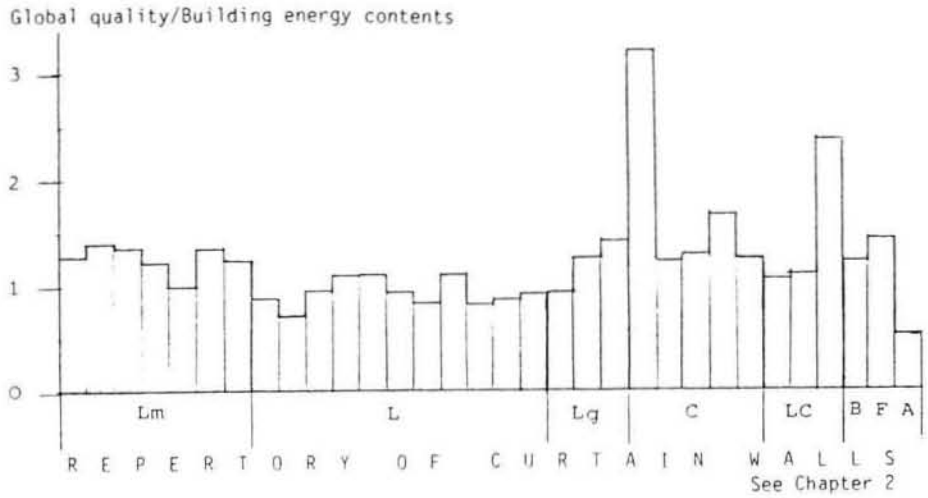
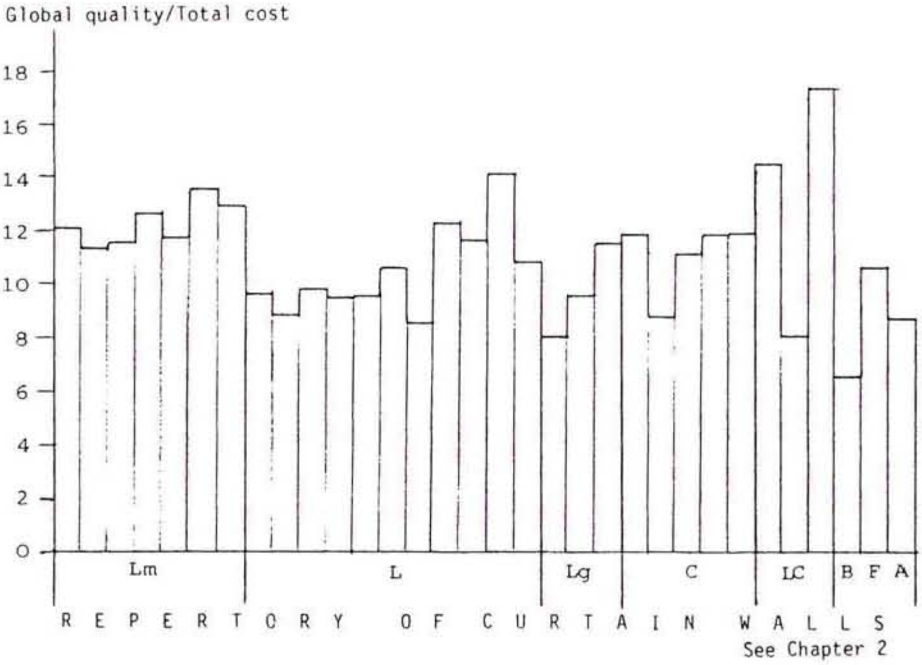


Figure 6. Global quality to total cost ratio



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