The Design of Energy-Efficient Envelopes in Mediterranean-Type Climates

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ABSTRACT

A novel set of building thermal regulations is presented. This is the first set of thermal regulations ever drafted in Portugal, where the climate is mild both in winter and summer, as is characteristic of Mediterranean climates.

This set of regulations is only concerned with the building envelope, aimed at creating natural indoor environments in the buildings that might be acceptable to their occupants year round. Heating needs should be low and air-conditioning systems should be avoided in most cases as a result of the applications of these regulations.

Maximum target nominal heating and cooling needs are established, as well as individual maximum U-values and minimum shading coefficients.

In addition to a detailed description of this set of regulations, there is also a thorough discussion of the constraints and objectives that guided the formulation of these regulations.

INTRODUCTION

When designing a new set of building thermal regulations, a number of factors should be taken into account. In Portugal, three are paramount:

- first, the set of regulations should lead to progress. To achieve this, it is necessary to have a clear picture of the technological status of the building industry, both nationally and regionally;

- second, the climate has a major influence upon buildings, both in the technologies that are used and in the habits of its occupants. The way people live and how they use buildings have a strong impact upon architecture and building materials, glazings, etc., with all their inherent thermal consequences;

- third, it is necessary to clearly set the goals of the regulations in terms of energy, occupant comfort, and quality of construction. Defining the goals of a set of new regulations depends on many variables, e.g., the socio-economic consequences of the new requirements and the technical constraints placed upon the new construction. If the goals are too ambitious, the new regulations may have to be abandoned soon afterward; if they are too modest, the regulations may be meaningless and it may not be worthwhile to upset the existing balance.

Portugal has been studying its first set of building thermal regulations for a few years, and these factors are even more important than if it were simply an update of an existing set of thermal regulations. In the following pages, there is a discussion of the constraints

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placed upon such a set of regulations and the goals that were defined, and a summary of the basic requirements and methodologies that were selected.

CURRENT STATUS OF BUILDINGS IN PORTUGAL

As in many other countries, most modern buildings in Portugal have a concrete structure and an exterior envelope made of ceramic materials, such as is shown in Figure 1. Typically, the walls are single-layered (about 20 cm thick) in the warmer, southern regions and double-layered (10-15 cm thick, separated by a 5 cm air gap) in the colder, wetter northern regions. As a result of a relatively mild climate, both in winter and summer (see Table 1), insulation was never used up to a few years ago, and only now is it starting, albeit rarely, to be used in selected better-quality buildings.

Insulation is also conspicuously absent in roofs, which, except for a few terraces in large buildings, are mostly inclined and covered by ceramic tiles or sheets of asbestos-cement. Traditionally, ceramic tiles are red, but other colors, black in particular, are also being used now for aesthetic reasons, with the corresponding worsening of the thermal characteristics of such roofs.

This type of building, brought about by the industrialization of the last few decades, can be found in every corner of the country, regardless of the local climate. Although it is a small country, three different climatic zones, according to UEATC's criteria (UEATC 1966), can be found in Portugal, as shown in Figure 2. In the past, buildings presented specific characteristics according to their climatic zones - Figure 3 (E. de Oliveira Fernandes et al. 1986): in the colder northern zones, buildings had larger, south-facing window openings, while in the warmer southern zones, where summers pose more problems than winter, buildings had only small, well-shaded openings. Moreover, traditional buildings all over the country were quite massive, more than those now being built; today's buildings mostly use lighter, perforated bricks, while traditional buildings used solid, heavier ceramic bricks, granite, limestone, etc., whatever natural materials were available locally.

Due to the mild climate, there is no tradition of centralized heating or cooling systems in Portugal. Indeed, except in large modern offices or other similar building, where centralized heating and cooling systems have been installed, only fireplaces and small portable heaters are usually used by building occupants for temperature control in winter. Thus, for them to be comfortable, the building itself must be responsive to changes in the outdoor climatic condition to keep the indoor environment within minimally acceptable limits. While this was reached, to a certain degree, in the regionally diverse traditional buildings, modern buildings are less responsive and, therefore, have lower indoor temperatures in winter and higher indoor temperatures in summer. This has led to either more discomfort or to higher energy consumption, both undesirable consequences of modern building construction trends.

Parallel to this mainstream tendency and in the absence of any thermal regulations, other construction techniques, which offer better or worse performance, abound. Of particular concern are buildings with walls consisting of single layers of usinsulated conductive materials such as concrete or concrete blocks, which produce highly uncomfortable environments and rapidly deteriorate.

Another major problem in most buildings is the presence of thermal bridges. Figure 1 clearly shows that a thermal bridge will occur near all the concrete elements of the façades unless an exterior homogeneous layer with high thermal resistance is added to the existing envelope. Since this is not current practice, thermal bridges occur in most buildings, leading to indoor condensation. This is aggravated by the lack of minimum temperature control, i.e., low indoor temperatures and high relative humidities are common indoors, thus creating favorable conditions for condensation. Condensation often leads to mildew growth and degradation of building materials, with its implicit health and economic consequences.

Thus, the situation can be characterized by the buildings not being adequate for the climate. Since the climate is mild, a certain complacency has set in, leading to discomfort or to relatively high auxiliary energy needs for obtaining comfort conditions on a specific (kWh/m^2.degree-day) basis.

REGULATION OBJECTIVES

Faced with the situation that was briefly summarized in the previous section, the major objective of any set of regulations must be to improve the natural climatic response of the buildings. This would have two major consequences:

- to increase the amount of time that comfortable indoor conditions can be naturally obtained in the buildings, both in winter and in summer; and
- in doing so, keeping the tradition of not installing centralized auxiliary heating or cooling systems in buildings, and reducing the energy consumed by the small portable units now in use.

This objective must, however, be reached within the framework of two important constraints:

- Since this is the first set of regulations to be drafted, there must not be a shock for the building industry. Although a step forward must be made, it cannot have large consequences upon construction costs or demand major technological changes, with all implications upon skills required from available industry workers. Cost considerations are particularly important, as there is a current need for several hundred thousand new dwellings and cost increases might upset the already strained balance between current costs and the purchasing power of the population at large.
- The regulations should not be too rigid, i.e., they should allow for a wide range of architectural and technical solutions. Indeed, it is through architecture, during the design phase, that improved building thermal performance can later be reached. Building form and orientation, window selection and placement, and selection of the type of envelope, to mention just the most important factors, have a decisive influence upon thermal performance and can be selected with a certain latitude during the design phase but cannot be changed easily once the building is already built.

The regulations should thus have more effects upon the design phase than on building construction techniques. An effort, however, must be made to correct the most obvious deficiencies in current building construction techniques, namely thermal bridge correction and lack of insulation where it is most useful, e.g., on roofs.

Setting actual numerical requirements in the regulations is further complicated by the difficulty in assigning an economic worth to occupant comfort. As there is little more than "potential energy savings" resulting from the conservation measures to be required, not "real savings" because there is little consumption now, a conventional cost-benefit analysis is not possible.

Finally, a balance between winter heating and summer cooling must be carefully established. No measure that might cause overheating in summer, even if it might have a positive contribution for heating in winter, should be encouraged. It is more important to avoid the need for summer cooling systems, because the Portuguese climate in summer allows for natural indoor temperature control whenever internal loads are not too important. Indeed, as was shown in Table 1, natural nocturnal cooling cross-ventilation is available most of the time, as daily low temperatures are below the 23°C to 26°C range almost every day in summer. If enough mass is provided and cooling loads are controlled within an acceptable magnitude, little or no discomfort will occur.

STRUCTURE OF THE ADOPTED THERMAL REGULATIONS

There are two main types of requirements that can be made in a set of building thermal regulations:

- either specific maximum limits are placed upon the thermal transmittance or individual elements of the envelope, e.g., walls, roofs, windows, etc., or
- a global target for admissible loads is established, allowing designers some leeway in selecting a particular solution for a particular building.

Given the goals and constraints listed in the previous section, both approaches offered positive and negative points:

- specifying minimum requirements for a number of individual building elements would allow for correction of the previously cited deficiencies in current building practices, such as thermal bridges, lack of insulation, etc., but it could lead to too much uniformity in building design;

- specifying a global target would allow the desired design flexibility and would be the best means to promote imaginative and diverse architectural solutions, but might not resolve all the trouble spots in an envelope because some might be relaxed through overcompensation in others.

For this reason, a twofold approach was selected: two maximum global targets for nominal energy needs, one for the winter and another for the summer, with which every building should be in compliance through any combination of architectural and technical solutions its designer chooses, provided that the thermal characteristics are within rather permissible limits. These limits only attempt to rule out the possibility of application of particularly bad solutions, which would, in all certainty, cause serious problems to the building or to its occupants.

Each global target value was established on the basis of good acceptable current building practices, with corrections to overcome the two already cited major problems: thermal bridges and lack of insulation on the roof. The latter item was made mandatory for its low cost, ease of installation, and positive thermal consequences. Insulation in all other parts of the envelope requires more sophisticated and costly solutions and is, therefore, optional.

WINTER REQUIREMENTS

The target value, i.e., the maximum nominal annual heating needs per m^2 of useful floor area (N_I - $kWh/m^2.yr$) is defined by Equation 1:

$$N_I = \left[\frac{1.3\ U_v A_v + U_h A_h + U_w A_w}{A_f} + 0.34\ h\right] (0.024).(DD) \qquad (1)$$

where:

A_v - area of opaque walls (m^2)

A_h - area of the opaque roof plus pavement in contact with outdoors (m^2)

A_w - area of all glazed surfaces (m^2)

A_f - useful floor area (m^2)

h - floor to ceiling height (m)

DD - local degree-days, based on 15°C

Reference U-values for use in Equation 1 are defined for each part of the envelope according to the local climatic zone (as per Figure 2), as indicated in Table 2.

Window U-values correspond to single glazing ($U=5.8\ W/m^2{}^\circ C$) for buildings occupied mainly during day time hours, e.g., offices and stores, and to single glazing with nocturnal protection by a roller blind ($U=4.2\ W/m^2{}^\circ C$) for those buildings with occupancy at night, e.g., residences, hotels and hospitals. Maximum allowable window area (in the equation only) is 15% of the floor area.

U-values are established on the basis of the predominant type of wall construction, i.e., they do not take thermal bridges into account. For this reason, an allowable corrective factor (1.3) is introduced into Equation 1, affecting the selected wall U-values. This factor is based on a normal proportion of wall and concrete beams in a façade, and on a protective layer with a thermal resistance of $0.06\ m^2.{}^\circ C/W$ (e.g., a layer of perforated bricks 25 to 40 mm thick) covering the concrete beams.

These requirements mean that any building designed with this set of construction specifications will automatically be in compliance with the regulations. Other sets of building construction specifications or window areas can be selected as long as the corresponding nominal annual heating needs (N_{IC}) do not exceed those defined by Equation 1. N_{IC} is calculated through a standard procedure in which envelope and infiltration losses as well as useful solar gains, are taken into account. Envelope and infiltration losses are calculated through conventional procedures, and tables of U-values for a variety of walls, roofs, and windows are provided. Also provided is a set of thermal bridging corrective factors, ranging from 1 (complete insulation on the outside) to 2 (insulation placed in the gap of a double-cavity wall with no protective layer on the concrete beams and columns), which must be chosen according to the actual selected construction technique.

Useful solar gains area calculated through the concepts of vertical south-projected area (Balcomb 1980) and solar utilization factor (see Figure 4) (Uyttenbroeck et al. 1986). Thus, a designer can take advantage of orientation, where possible, to relax insulation requirements if enough solar gains are available. A minimum quality must, however, be maintained; maximum permissible U-values are listed in Table 3.

SUMMER REQUIREMENTS

Similar to the winter requirements, a target value for nominal cooling needs per m^2 of useful floor area (N_V - $kWh/m^2.year$) is also defined, as given by Equation 2:

$$N_V = \frac{0.36\ (\sum 1.3\ \Delta T_V\ U_V\ A_V + \sum \Delta T_h\ U_h\ A_h) + 0.7\ G\ A_W}{A_f} .M \qquad (2)$$

where:

ΔT_V, ΔT_h - allowable effective cooling-load temperature differences (7.5°C and 3°C, respectively, for zone V2; add 1.5°C for zone V3 and subtract 2.5°C for zone V1).

G - allowed effective solar gains (see Table 4).

M - average length of the local cooling season (months), defined as the equivalent total clear sky period which would result in the same average incident radiation on a horizontal surface as during a whole average cooling season.

The allowed solar gains were established on the basis of the average clear-sky accumulated solar heat gain factors (SHGF) from 10 a.m. to 10 p.m., as calculated by ASHRAE's CLTD method (ASHRAE 1985) (see Table 5), multiplied by a shading coefficient of about 0.12, 0.30, and 0.35, respectively, for buildings with low, average, and high inertia. It is assumed that gains during the other half of the day are removed by free nocturnal cross-ventilation.

The values of ΔT_V and ΔT_h were derived from ASHRAE's CLTD tables (ASHRAE 1985) (see Tables 6 and 7) with the same criteria.

The U-values are as defined for Equation 1, and the factor 0.7 affecting solar gains represents the average shading effects upon the gross glazed area.

Designers can select buildings with the reference characteristics and be automatically in compliance, or use any other set of solutions and prove that the nominal cooling needs, calculated through a standard method based on Tables 5 to 7, is equal to or lower than the value defined by Equation 2. Additional tables providing typical shading coefficients for various types of glazings are also provided.

As it happens with the winter requirements, there is also a minimum quality that must be met for summer protection. In summer, the major concern is the provision of shading to every glazing that does not face north (NW-NE). Maximum shading coefficients are as listed in Table 8, i.e., no dark-colored internal shading is allowed (if shading is external, there is no such limitation). Furthermore, if the building has a light inertia, only very low values of the shading coefficient are allowed, which correspond to the best internal shading solutions only.

CONCLUSION

The set of regulations that has just been described, like any other set of regulations, contains many compromises, in terms of both goals (or numerical values that were selected) and calculation methods (which must be simple enough to be used by an average person with a minimum of technical knowledge and precise enough to yield meaningful results). The actual numerical goals that were set forth result from the experience of the committee members, on the basis of detailed surveys of the existing building stock, and of results from experimental buildings, either by measurement or by simulation (Maldonado 1986; E. de Oliveira Fernandes and Maldonado 1988; C. den Ouden 1989). Only through future experience can data be gathered to evaluate its success in detail and make the necessary adjustements.

Meanwhile, some conclusions can tentatively be drawn:

- While most existing regulations are focused only upon winter protection (Uyttenbroeck et al. 1986), these Portuguese regulations clearly aim at both winter and summer protection. In mild climates, such as Mediterranean climates, and which occur in selected parts of almost every continent, it is fundamental not to forget that, unless summer protection is available, energy consumption for mechanical cooling will tend to increase as the population demands higher comfort levels along with improved purchasing power.

- The use of nominal heating and cooling loads as target parameters is particularly critical in this type of region. While the calculated needs are never equal to the actual consumption, even in severe climates, due to the influence of occupant usage patterns, the patterns of occupant use in regions with mild climates such as Portugal are very distinct from the assumed thermostatic control. For example, in summer, air conditioning is not even evailable most of the time. But it is felt that the evaluation of a particular building on the basis of a nominal pattern of use yields a good qualitative means of comparison and, as such, "nominal needs" is a useful parameter for the purpose of regulations. It is, for example, the target parameter that was selected for the proposed winter-based European Community Eurocode for the Rational Use of Energy in Buildings (Uyttenbroeck et al, 1986).

It is hoped that this first version will be updated in three to five years, and possibly then expanded to include more restrictive energy targets and to introduce new elements such as infiltrration (and its dependance on the quality of window frames in particular) and daylighting. A companion set of regulations on HVAC systems is also being prepared, which should closely follow the principles described in this report.

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Table 1 - Characteristics of the Portuguese Climate

	Winter Climatic Zones (UEATC 1966)		
	I_1	I_2	I_3
Heating Degree-Days* (°C)	400	800	1600
Design Temperature (°C)	3	0	-3
Available Solar Radiation (kWh/m^2)[x]	400	500	700

	Summer Climatic Zones (UEATC 1966)		
	V_1	V_2	V_3
Design Temperature (°C)[+]	28	32	35
Design-day amplitude (°C)	10	13	16
Average Humidity (g/kg)	12	11	10
Length of "cooling season" (months)	2	3	4.5

* Base 15°C.
\+ Defined on the basis of 97.5% of occurrence in a particular year.
x Integrated value during the heating season.

Table 2 - Reference U-values ($W/m^2.°C$)

Climatic Zone	I_1	I_2	I_3
U_v	1.4	1.2	0.95
U_h	1.1	0.85	0.75

Table 3 - Maximum Permissible U-values ($W/m^2.^oC$)

Climatic Zone	I_1	I_2	I_3
U_v	1.8	1.6	1.45
U_h	1.25	1.0	0.9

Table 4 - Allowed Effective Solar Gains (kWh/m^2.month)

Building Thermal Inertia	Climatic Zone		
	V_1	V_2	V_3
Low*	9	9	7.5
Average	22.5	22.5	18
High+	35	25	20

* $M<100\ kg/m^2$

\+ $M>300\ kg/m^2$

Table 5 - Average Monthly Solar Gains (kWh/m^2.year)

	Orientation								
	N	NE	E	SE	S	SW	W	NW	Hor
G*	26	37	67	75	67	83	77	43	135

* Values apply to average building inertia only. Multiply by 1.2 for low inertia and by 0.9 for high inertia.

Table 6 - Effective Cooling-Load Temperature Differences for Vertical Walls* (°C)

	Low	Average	High
N	5.5	3.5	2
NE	10.5	9	5.5
E	12.5	10.5	8
SE	11.5	9.5	7.5
S	8	6	5.5
SW	11.5	6.5	6.5
W	10	7	7
NW	5	4.5	4.5

* For zone V1 subtract 2.5°C and for zone V3 add 1.5°C.

Table 7 - Effective Cooling-Load Temperature Differences for Roofs* (°C)

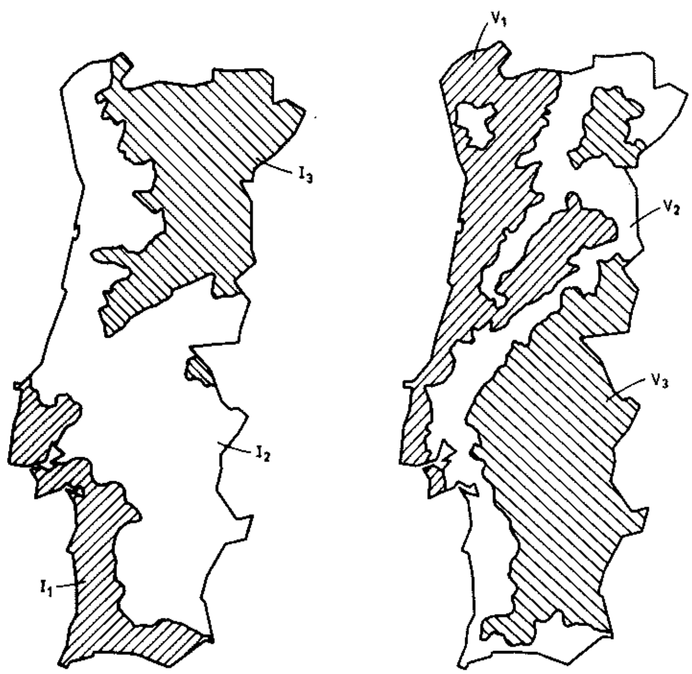
Color	Terrace without suspended ceiling	Terrace with susp.ceiling or nonventilated inclined roof	Ventilated inclined roof
Light	4	3	3
Dark	11.5	10	7.5

* For zone subtract 2.5°C and for zone V3 add 1.5°C

Table 8 - Maximum Allowable Shading Coefficients

Building Thermal Inertia	Climatic Zone		
	V_1	V_2	V_3
Low	0.15	0.15	0.10
Average	0.56	0.56	0.50
High	0.56	0.56	0.56

Figure 1. *View of a typical building structure in Portugal*



a) Winter zones:

Zone	Heating Degree-Days (Base 15°C)	Outdoor Design Temperature (°C)
I1	400	>2
I2	400-800	-2 to 2
I3	800	<-2

b) Summer zones:

Zone	Outdoor Design Temperature (°C)
V1	<31
V2	31-34
V3	>34

Figure 2. *Climatic zones in Portugal*

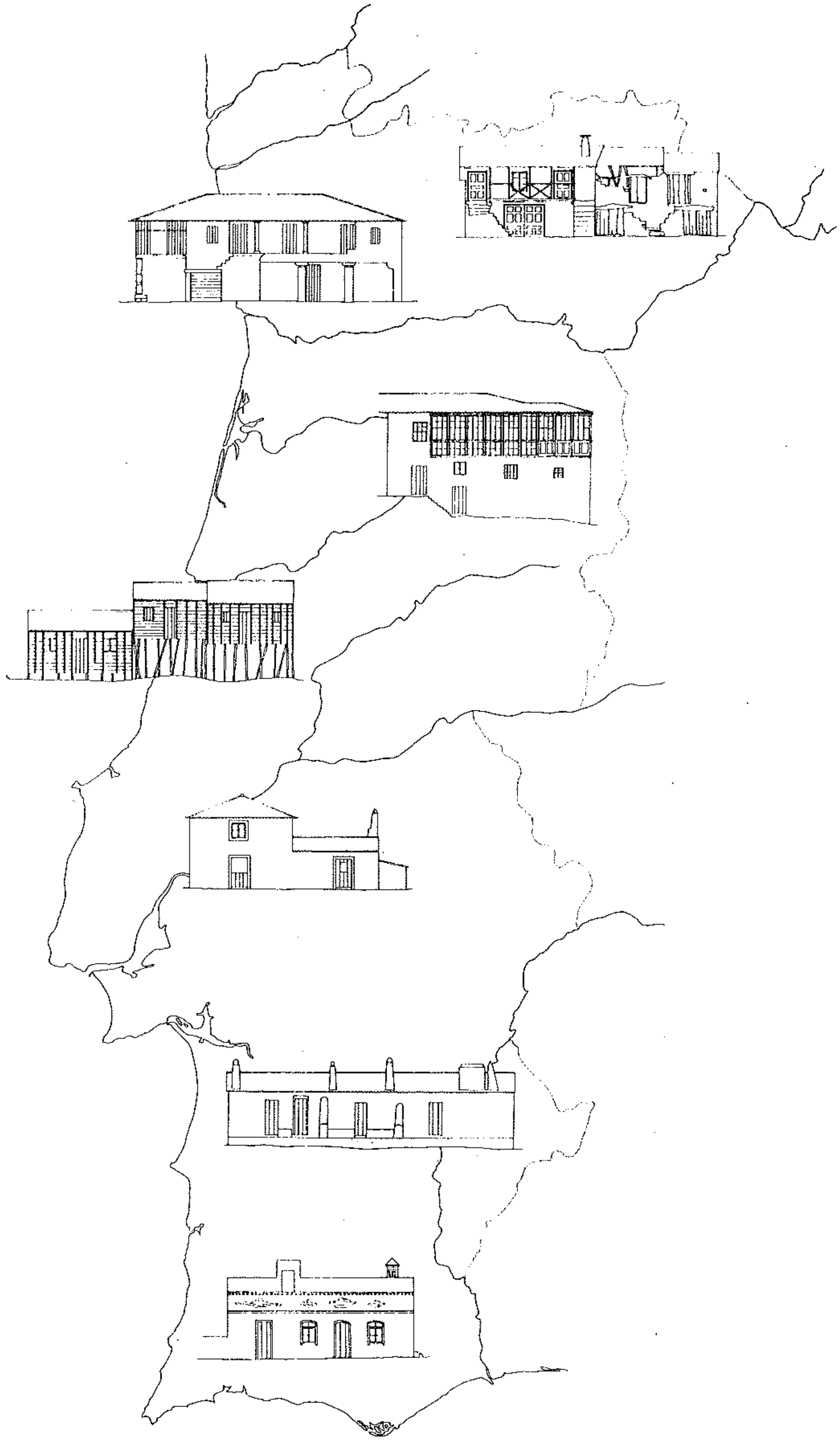
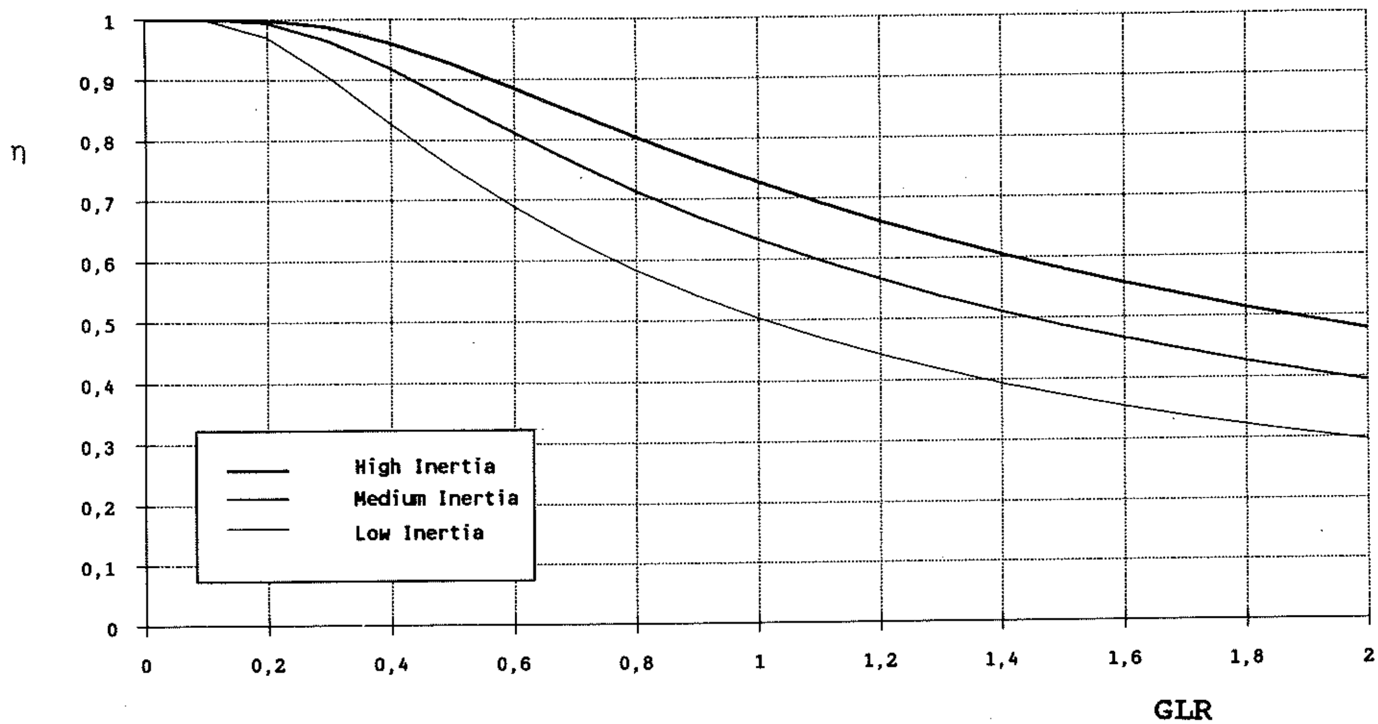


Figure 3. *Types of traditional buildings and their locations in Portugal (E. de Oliveira Fernandes et al, 1986)*



$$\eta = 1 - \exp\left[- \frac{K}{GLR}\right]$$

$$\text{with } K = \begin{cases} 0.7 - \text{Low inertia} \\ 1.0 - \text{Medium inertia} \\ 1.3 - \text{High inertia} \end{cases}$$

Figure 4. Solar utilization factor (Uyttenbroeck et al, 1986)