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Forty years of regulations on the thermal performance of the building envelope in Europe: Achievements, perspectives and challenges

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A R T I C L E I N F O

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The necessity to improve the buildings' energy behaviour became peremptory as a consequence of the two oil crises in the 1970's, and was expressed primarily in the effort to reduce the demand for heating, ventilation and air-conditioning, whilst improving the rather modest indoor environmental conditions standards of that time. It has been quite a long way from those days to the Zero and Nearly Zero Energy Buildings required by contemporary regulations. The way has been paved by intensified, systematic developments, of an advanced, and experimentally well validated, interdisciplinary theoretical background, by its incorporation in the syllabi of most engineering and architectural university courses and by a legislative framework that transcended national regulations and standards offering European directives and harmonized European standards.

There is a bi-directional relationship between the aforementioned development and the progress made in the field of building materials and systems. The successive, ever tightening regulations act as driving forces for the development of effective insulating materials, airtight buildings and smart façades, not to mention the HVAC and predictive BAC systems. It is the availability of those building elements and materials that enables the implementation of ambitious and innovative designs, ensuring that fewer limitations are imposed on the architects' work.

After all, one has to keep in mind that forty years after the implementation of the first thermal insulation regulations and more than ten years after the establishment of the first Energy Performance of Buildings Directive, thermal loads still account for almost two third of the buildings' loads. The further reduction of those loads becomes a more challenging task, the lower the loads become in absolute terms; it is this challenge that calls for new, more advanced building materials and elements but also for a more sophisticated, integrated regulatory approach.

1. Introduction

The history of the building envelope is dominated by features and attributes that govern appearance, proportion, choice of materials and cultural aspects. Its primary function, though, apart from its aesthetics and representative value, is to protect the building against cold, heat, precipitation, wind and solar radiation. As energy efficiency requirements have grown, almost in parallel with the rise in indoor environmental quality standards, the building envelope has taken on a more complex, climate regulating function. In that sense, numerous demands are placed on the building envelope, as it is the interface between the ambient conditions and the internal climate. Meeting those demands is a complex and truly interdisciplinary problem, since it requires the cooperation of architects, engineers and building physicists, and it certainly cannot be discussed in the limited spaced of a paper. It is, however, of interest, to address certain key aspects, on how some of the major features of the building envelope have been regulated by European legislation, before arriving at the latest European Directive on the Energy Performance of Buildings (2010/32/EU), which imposes the Nearly Zero Energy Building goal by 2019 for public and by 2021 for all buildings, and is the most recent in a long series of regulatory actions in the last fifty years or so, aiming at the improvement of building's energy behaviour in Europe.

A review of such actions demonstrates that few regulations can be found on energy efficiency in buildings before the oil crisis of 1973. Those found, mainly in northern European countries, did not really aim at energy efficiency, but at ensuring adequate heating conditions. They did so by promoting the use of tradi-

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tional architectural features that helped to increase the envelope's thermal resistance, like the air layer in the cavity of the double brick wall or in the double layer wooden floor. The first thermal insulation requirements, mentioning explicitly U-values, R-values and specific insulation materials or multi glazing, date back to the 1950s and 1960s: the German DIN 4108 published in 1952 foresaw measures to protect the building envelope, whilst in Scandinavian countries, the Swedish building code BABS of 1960 foresaw component specific U-values and double pane windows, so as to fulfil comfort and economic requirements [1].

After the two oil crises in the 1970s, however, the necessity to improve the building's energy behaviour became peremptory and was expressed in the effort to reduce the energy requirement, by introducing mandatory thermal insulation requirements for the building's envelope, by reducing mechanical ventilation, by improving air-tightness and, of course, the efficiency of heating and of air-conditioning systems. Regulations were introduced at an accelerated pace where there were none, whilst in those countries already enforcing efficiency regulations the requirements were raised.

The effect of this effort became evident in the 1980s, with energy consumption both in residential and in non-residential buildings being reduced significantly, yet not entirely without problems. In the shocked 1970s the issues concerning indoor air quality (IAQ) were temporarily brushed away and the trend in constructions was marked by increasingly airtight buildings and reduced ventilation rates, as low as 2,5 l/s and person [2]. The increased air-tightness, the reduced ventilation rates, together with a lack of the complete understanding of the thermal insulation's hygrothermal behavior, lead to comfort and health problems, both in naturally ventilated residential buildings and in air-conditioned commercial and office buildings [3]. It became clear, that a consideration of the building envelope's thermal transmittance, by means of the U-value alone, did not necessarily result in improved design if achieved without considering the transient hygrothermal behaviour of the whole building [4].

Furthermore, the surface of a building's openings was reduced, in order to reduce transmittance losses, as windows and glass façades of the day rarely had U values better than 3,5 W/m^2 K, with the side-effect that natural lighting was reduced and the estrangement of the building's user to the environment could become a problem, especially in northern European countries [5].

As the first epidemiological studies became available, and one needs to keep in mind that it takes quite a long time to obtain reliable data on problems of this order of magnitude, it was concluded that the sick-building syndrome (SBS) was an increasingly common and important problem, with symptoms uncomfortable or even disabling, eventually running the danger of rendering whole workplaces non-functional. As the study of Redlich et al. concluded [6]: "On-site assessment of buildings is extremely useful. Treatment involves both the patient and the building. Whenever possible, changes such as ventilation improvements and reduction of sources of environmental contamination should be initiated even if specific aetiological agents have not been identified."

During the 1980s and the 1990s, energy efficiency requirements were reviewed and revised, albeit in front of new background, namely to meet the goals set by the Kyoto Protocol (1997), as well as other, national or EU-wide targets to reduce CO_2 emissions. The introduction of the first Energy Performance of Buildings Directive (EPBD, 2002/91/EC) was a quantum leap: for the first time a common legislative approach was adopted in Europe, aiming at achieving energy efficiency in the building sector in a methodologically unified way, whilst also foreseeing mechanisms to monitor and enforce it in practice.

Today, the Zero Energy Building is an accepted short-term goal, which the European construction sector has accepted and

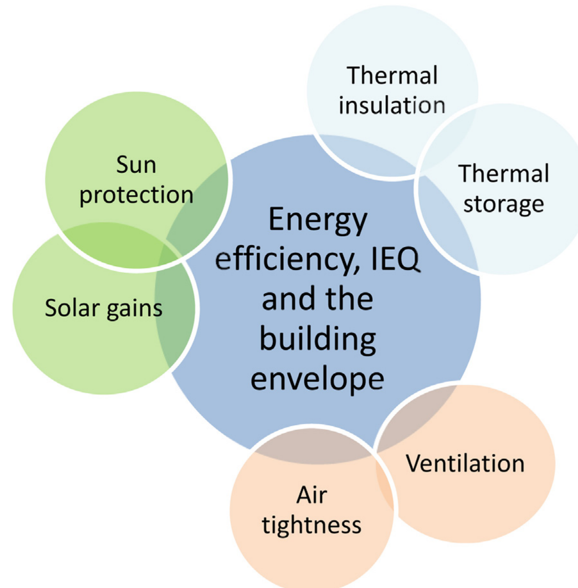

Fig. 1. Parameters of the building envelope that determine energy efficiency and indoor environmental quality.

embraced. At the same time, mandatory minimum energy efficiency requirements in the form of building codes or standards exist in nearly all other OECD countries, even if with substantial differences across the various states' legislations and occasionally even across one country's regions [7].

It is within this line of approach, that one should examine the way in which regulations address the function and the overall optimization of the building envelope's performance. The influential parameters can be grouped in various ways, one of which is depicted in Fig. 1.

There are in principle two ways in which those parameters are regulated in the design and construction of buildings:

(1) Directly, through dedicated energy regulations.
(2) Indirectly, through general building regulations, which foresee requirements in different areas like structural safety, fire and electrical safety, acoustics, comfort conditions etc.

It is not easy to detect which approach is met in each country. According to a report produced by the Concerted Action on the EPBD, the former approach has been adopted by 13 whilst the latter by 16EU member states [8]. The difference in the approach can have an impact during the phases of the design but also of the control and auditing. According to the same report, but also to results of other studies [9,10], it is more difficult to enforce energy performance requirements if they are part of the general building regulations: in some cases it falls within the terms of reference of the design coordinator, i.e. as a rule the architect, and not the energy consultant. In other cases the responsibility lies in the authority responsible for controlling all the building requirements and therefore no particular emphasis is given on the energy aspects.

Still, the reality is more complicated, as pieces of legislation that affect energy efficiency can be found in general building regulations, even in countries that have adopted the dedicated energy regulation approach. In order to clarify this, some examples can be mentioned: (a) referring to the size of windows, which is of paramount importance with respect to solar gains and hence both to passive solar gains and to air-conditioning loads, it is regulated in countries as different as Greece and Latvia,