Energy cost and its impact on regulating the buildings' energy behaviour

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Abstract

The necessity to improve the buildings' energy behaviour was born out of the price shock caused by the oil crises in the 1970's. The respond was expressed by national legislative acts regulating the demand for heating and ventilation. The results were important, though not always without side-effects, for example in the field of indoor air quality. Furthermore, economic and environmental considerations played an important role in determining the policies applied, the latter particularly in the 1990's and as a result of the Kyoto and Montreal protocols. Finally, new problems, like the increasing demand for air-conditioning and its impact on the national electricity systems began to influence the way in which a building's energy behaviour is considered. The enforcement of the European Directive on the Energy Performance of Buildings (2002/91/EC) seems to provide for the first time an integrated regulatory tool, enabling the simultaneous consideration of the energy, environmental and economic parameters of building's design. Its implementation, which is still facing delays, will prove the degree of its efficiency. The paper discusses the evolution of these developments, as it was expressed in the framework of the energy regulations over the last thirty years, on the hand of specific examples in Europe. The discussion focuses on the thermal insulation of the building's envelope, the requirements for indoor air quality and the use of air-conditioning, in order to narrow the subject which is too broad to be covered in its entirety. The development from the first regulations in 1976 to the Directive 2002/91 was neither straight-forward nor solely driven by the rise of energy costs. It is rather based on the quest for an energy conscious, environmental friendly and financially feasible building, which has also to be friendly to its human users.

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1. Introduction

The European Directive on the Performance of Buildings (2002/91/EC), the implementation of which has become mandatory for all member states since January 2006, is the most recent in a long series of regulatory actions, aiming at the improvement of building's energy behaviour. This necessity to improve the buildings' energy behaviour became peremptory during the two oil crises in the 1970's, and was expressed in the effort to reduce the demands for heating, ventilation and air-conditioning, without endangering the living standards of the day. However, the phenomenon is neither new nor one-dimensional. In the recent, but deceptively easily forgotten first half of the 20th century, drastic energy conservation measures were applied affecting the economic and social life in most European countries. As a result of two world wars, but also the great depression between them, energy became a precious commodity, though the building sector depended on coal rather than oil in those days. At the end of the 20th century, and especially during the rather careless at least as far as energy prices were concerned 1990's, most of the energy conservation actions taken, both on a national and on an international level, had their origins rather in environmental than in purely energy saving motives, an approach that is being reviewed due to the sharp increase in energy prices after 2003. Finally, the impact of establishing satisfactory indoor air quality conditions had, throughout the 20th century, a tight relation to the ventilation of buildings, and hence to their energy behaviour. The main conclusion to be drawn from this brief and rather incomplete list of events and developments is that regulating the energy behaviour of buildings has been a goal certainly predating the volatility of the energy markets, which is depicted in Figure 1 and has become the driving force behind all actions taken after 1973.

In these thirty years of intensified, systemic development in the field of energy design of buildings, a new, interdisciplinary scientific field was developed, reaching a stage of maturity in a fairly brief time period. It is characterized by an advanced, and experimentally well validated, theoretical background, by its incorporation in the syllabi of most engineering and architectural departments of Universities and, at least in many countries, by a flexible and fairly effective legislative framework. At the same time, the architects, engineers and constructors active in the field have access to powerful computational codes, to new generations of insulating materials, building components, such as glazing, and HVAC systems, all of which enable the implementation of progressive solutions, besides having the side-effect of ensuring that less limitations are imposed on the architectural design. These developments are exemplified in the evolution of the buildings' energy behaviour in countries like Denmark or Germany, where average specific annual consumption dropped, from between 300 and 400 kWh/m^{2}a in 1970 to less than 50 kWh/m^{2}a, according to Gertis's five steps classification, which is depicted in Figure 2. (Gertis, 1999) At the same time, in other European countries developments were not so spectacular. Taking the average thickness of insulation enforced by national regulations in walls as a good indicator, one can notice that there are two groups of countries: the first one includes those that have progressively increased the required thickness by a factor of 2, the Nordic countries and Germany being good examples of it. The second includes countries like Italy, Greece and Spain, where little has changed after the introduction of the first generation of regulations in the 1970's. This evolution, which is depicted in Figure 3, will be discussed using the developments in Germany and Greece as examples. Still, whatever the motive of conservation actions may be, despite the progress made, and probably because this progress had not the same pace throughout Europe, energy consumption in the building sector continues to constitute a major part of the worldwide annual final energy use. In the European Union alone it exceeds 40% (European Commission, 2005).

2. From energy conservation to building physics: Coping with the heating demand

The first oil crisis led in 1973 to an increase of crude oil price by more than 300%, within less than two years. Given the fact that the importance of coal in the building sector had been steadily declining since the 1950's for thermal use and that the use of electricity and that the use of natural gas was still rather negligible in Europe, though this was more popular in the USA, the explosion in the retail price of heating oil was affecting almost entire societies. (Hirst et al, 1976) Reacting to this development, most European governments imposed regulatory policies in the building sector, aiming especially at new constructions, mainly by means of setting tight limitations for the thermal transmissivity values of the buildings' envelopes, of reducing the ventilation rates and of increasing the minimum efficiency values to be achieved by new boilers. In that sense, the first German thermal insulation regulation from 1977, the WSVO '77, is a good example of imposing limits to the thermal losses through the building's envelope and reducing the ventilation/infiltration losses, by setting a maximum k-value with respect to the building's typological features, aiming at the reduction of values that were theretofore higher than 1,2 W/m^{2}K. (Papadopoulos, 1977) The aspect under which a building's energy balance was considered was to a great extent solely the thermal one. These policies applied were, at least quantitatively, successful and buildings constructed in the late 1970's and early 1980's showed significantly lower energy consumption values than their predecessors. In terms, however, of what is nowadays known as indoor environmental quality (IEQ) the results were not so encouraging. In the shocked 1970's 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. This trend resulted in ventilation requirements as low as 2.5 l/s and person (Janssen, 1999). In northern European countries, with harsh winter climate and very strict regulations, this led to impressive, albeit also dangerous, results as IAQ deteriorated respectively to the energy consumption reduction (Batty et al, 1984; Ihle, 1996). Still, similar trends were monitored even in countries with mild Mediterranean climate, as the analysis of typical Greek buildings demonstrated (Papadopoulos et al, 2002). That the minimization of ventilation rates would lead to worsening IAQ was inevitable, but it was considered to be an acceptable risk, at least until the 1990's. Furthermore, the surface of a building's openings was reduced, in order to reduce transmissivity losses, as windows of the day rarely had k values better than 3.5 W/m^2K, 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. (Schittich, 2003)

A second generation of regulations was produced in the 1980's. On the one hand it featured tighter transmissivity values than the previous regulations, but on the other it enabled higher ventilation rates and, most important, it considered the building's envelope not only a cause of thermal losses, but also a medium for possible thermal gains. It hence signaled the transition from the enclosed, defensive building towards an open one, or what became known as the approach of building physics or bioclimatic architecture. Capitalizing on the expertise gained from the first experiences mentioned afore, and from results obtained from large scale applications in advanced settlements, like in Milton Keynes in the UK, in Solar Village III in Greece, or in Horsens in Denmark, a systematic, more holistic approach was adopted towards the utilization of solar energy, natural lighting, natural ventilation, as well as the thermal storage properties of the building itself. Building Physics became an autonomous, interdisciplinary academic field, the first computational codes became available to architects and engineers and new materials and techniques came on the market. Continuing to monitor the developments in Germany, the first thermal insulation regulation was updated in 1984, so that no building element was allowed to have a k-value exceeding 0,7 W/m^2K. In that way, and as the 1990's emerged and passed, the problem of coping with the heating loads of buildings was considered as a manageable one. A third update of the German thermal insulation regulation took place in

1995, limiting the k-values of the various building's elements to 0.5 W/m^2K. When combining the tighter legislation with the progress made in the field of thermal insulation materials, glazing and heating systems, then the good results monitored in most of the European countries can be considered as a good example for the implementation of a sound energy conservation policy. (Papadopoulos, 2005; Nadel et al, 2004)

The introduction of the CEN standard EN832, on the "Thermal Performance of Buildings - Calculation of Energy Use for Heating - Residential Buildings", in 1998, marked a significant change of attitude, as for the first time the term "thermal performance" was used, instead of "thermal protection" or "thermal insulation", whilst the standard was not only limited to a static consideration of thermal losses, but instead it proceeded to the determination of the final use of energy, in order to cover the building's demands. The respective change in German regulations epitomized this approach, replacing the term "thermal protection" used up till that time to describe the legislative act with the "energy saving" one. (Reiss et al, 2002) Hence, one could argue, that the parties involved in the building sector were provided with an advanced, yet fairly comprehensible and flexible methodology to determine the thermal performance of buildings. Combined with the regulations applicable in most European countries, which enforced high standards of as it can be seen in Figure 4, the building sector could be satisfied with results, both in terms of energy savings achieved and with respect to the macroeconomics of the measures. (Petersen et al, 2001; Miguez et al, 2006) Still, since the mid-1990's new challenges begun to emerge.

3. Facing a 'new' problem: Air-conditioning

In the beginning of the 21st century it became apparent that a new set of problems have become to be dominating the field of building physics. Cooling loads began in the 1990's to be a major component of a building's energy balance and, at the same time, a problem for the whole electricity generation, transmission and distribution systems. An increased awareness in matters of indoor air quality, due both to indoor and outdoor sources of pollution, led to the re-consideration of limitations imposed on ventilation. (Vine, 2003) This interesting development in the minimum requirements imposed on ventilation is most clearly expressed in the changes of the respective ASHRAE standards; it is depicted in Figure 5. Finally, with emphasis given on the environmental quality of the building, not only in terms of living quality but with respect to its whole life cycle, the application of the Life Cycle Analysis concept started to become attractive. (Casals, 2006) Out of these three problems, coping with the cooling loads has become definitely the most important one, though it is closely linked to the other two.

3.1. Establishing good indoor environmental quality in a hostile environment

The influence of microclimatic conditions on the energy behaviour of buildings began to constitute a major research field in the 1980's. The enhanced urbanization, occurring both in developed and developing countries, led to a drastic change of the geographical distribution of population and production activities and consequently to a ubiquitous regional concentration of raw materials and energy consumption (UNESCO, 1992). The urban environment characterized by a dense and often continuous layout of buildings, as well by as the use of materials with high thermal storage properties, leads, amongst other reasons, to the appearance of the "heat island" phenomenon, notably known for the air temperature increase in the urban areas (Oke et al, 1991). The operational demands of buildings are both determined by these conditions and contribute to their enhancement.

In that sense, the anthropogenic changes in urban microclimate and the atmospheric pollution, combined with the increased awareness about the prevailing indoor air quality conditions due to pollutants emitted from building materials and anthropogenic activities, influence the demands set on ventilation and air-conditioning in a dominant way, leading to much higher energy loads than this was the case until the 1970's. It becomes therefore clear, that the whole concept and design of a building's HVAC system has to be considered on the basis of climatic and atmospheric conditions prevailing in contemporary urban areas, and not those that were measured at sub-urban airports some decades ago. (Santamouris et al, 2001) Buildings however, have ultimately the goal of providing protection to human beings from the prevailing ambient conditions and of supporting human activities, when they are used either for residential or for occupational purposes. In that sense, and however ventilation is carried out be it naturally or mechanically, it has to achieve three main tasks: a) to remove air pollutants, generated by anthropogenic activities, from the interior by replacing the existing indoor air with fresh ambient air, b) to dilute the air pollutants in the interior by mixing the old and fresh indoor air and c) to supply in the cooling period air for maintaining a good sense of thermal comfort either by introducing colder air or by featuring the necessary velocity to achieve the evaporative effect on the inhabitants. These three tasks are the basic design characteristics of any contemporary central HVAC system and can be achieved by any state of the art system, however at a certain cost. The acceptance of this cost is based on two facts: (a) buildings constitute major capital investments and especially in office buildings several studies link IEQ not only to human health problems, but also to decreasing productivity, highlighting indoor air climate as an essential quality these buildings have to feature (Wargocki et al, 1999). (b) human health is invaluable and the possibility of poor indoor air quality and/or poor thermal comfort conditions prevailing in their interior contradicts their raison d' être. Finally, one has to keep in mind that the overwhelming majority of buildings in Europe feature neither mechanical ventilation nor a central air conditioning system, leaving natural ventilation the only way to comply with IAQ requirements and, to a certain extent, to control indoor thermal comfort conditions. The implementation therefore of the proposed and published CEN standards, prEN 15242, prEN 13779, EN 13791 and EN 13792, which accompany the European Directive on the Energy Performance of Buildings and assess thermal comfort and IAQ in order to evaluate and classify both mechanically and naturally ventilate buildings, constitutes a major step into the future. (Railio, 2006)

3.2. On the market and economics of air-conditioning

For the reasons discussed in the previous paragraph, since the late 1990's it became common conviction that the lack of air-conditioning, in buildings designed without any particular bioclimatic features, leads to unacceptably poor comfort conditions; an attitude that led to massive retrofitting of split-unit types of air-conditioning systems, also known as room air-conditioners (RACs). But even in buildings retrofitted in that way, the situation has not always improved in terms of IEQ. As RACs do not enable the ventilation of the interior, the concentration of air pollutants may as a matter of fact increase in such buildings, underlining the point that increased energy consumption does not necessarily result in a respective improvement of indoor environmental conditions (Avgelis et al, 2003). The solution to this problem lies in natural ventilation carried out simultaneously with the operation of the RAC, leading obviously to even higher energy consumption values.

Considering these conditions, and however buildings are air-conditioned, it becomes clear that the impact of increasing IEQ standards on energy consumption is expected to become even more important in the years to come, frequently exceeding the "traditional" thermal losses occurring in the heating period through the building's envelope. This has become fairly clear in Southern Europe, but is also beginning to show in Central and Northern Europe, as the propagation of air-conditioning appliances is becoming the primary reason for increasing energy consumption in buildings, after the latter had declined to the afore mentioned policies reducing their heating demand (Freedonia Group, 2002). Room Air-Conditioners (RAC) have become a major success story in the HVAC branch winning market shares from central AC systems. Whilst global air-conditioning sales are increasing at 4% annually, sales of RACs increase by almost the double. In Greece the total installed electrical capacity of RACs is estimated to more than 3,500 MW, while approximately 200 MW are installed every year. Similar developments can be monitored with respect to central or semi-central units: their capacity is estimated to be more than 1,500 MW with an annual growth of about 250 MW, considering only the last five years statistics. The development in Southern Europe is in line with the Greek example. A high penetration of room air-conditioners and their wide effect on the energy system is evident. According to the EERAC study, (EERAC, 1999) the penetration of RACs in Southern European countries will increase by more than 10% annually in the next years, adding more loads to the electricity system and resulting in higher CO_2 emissions. Furthermore, the heat waves that hit Western and Northern Europe in 2003 acted as a catalyst for increased sales of RACs in markets that were rather reluctant to adopt this technology so far. Combined with the decrease in the prices of mainly Asian produced RACs, sales are expected to increase by more than 20% annually in Western Europe, compared to the 8% for the year 2002 (RAC, 2003). The use of such systems, however, enhances the street canyon phenomena, a major factor in the development of the heat island in densely built urban areas, as the compressor units, which constitute emission points of rejected heat, are usually suspended on the buildings' facades or place on the flat roofs. This rejected heat enhances, on a micro scale level, the street canyon effect increasing even more the cooling demand of the buildings. At the same time, it further reduces the coefficient of performance (COP) of the air-conditioners by up to 25% due to the higher ambient air and surface temperatures, thus creating a vicious circle in terms of cooling and electricity demand. (Hassid et al, 2000; Papadopoulos, 2001)

These developments lead to an increase in electricity consumption that is concentrated in the two or three summer months, and become therefore a dominant element in the energy balance of every power supplier. As an example, the summer peak load in Greece during the years 1999-2000 showed an annual increase of 16% or 1,163 MW, while the annual growth rate for load was approximately 4.1%. As the same time, and for the years 1995-2000 the peak load demand increased from 5,000 to 8,500 MW. It has to be noted that until 1985 peak load demands were recorded during winter and not summer (PPC, 2001). The additional capacities needed to cover those peaks are obtained either by expensive generation facilities with low utilization factor like hydroelectric plants and gas turbine plants, or by electricity imports from neighbouring countries. In recent years, the Greek electricity utility faced several times the treat of black outs on hot summer days, both due to limitations in production capacities and in the overburdened distribution networks. Similar same difficulties were experienced in countries like Italy, Germany and France during the summer of 2003, despite the fact that on an annual base these countries show moderate growth rates in the use of electricity, as it can be seen in Figure 6. It is evident, that such peaks, occurring only for a few weeks a year, cannot be covered at a reasonable cost as the additional investments needed in infrastructure cannot be justified. In order to face the summer load peaks, without affecting the demand side, new power generation plants should be built close to the consumption location, i.e. in the major urban areas, at a high economic and environmental cost. If the utility uses a time-dependent tariff or demand charge to cover the additional cost of the capacities needed, the operational cost for air-conditioning would be much higher for customers. Such an alternative, which would also discourage the extensive use of air-conditioning, can on the long run be efficient only if it is accompanied by the introduction of energy conservation techniques, aiming at the reduction of cooling loads. But even if one would choose to neglect the economics of such a policy, there are certain technical barriers one meets, when attempting to cover a steeply increasing energy demand. The example of California in 2000 demonstrates that there are clear limits to the increase of consumption that can be covered in a liberated energy market, even when demand side management tools are applied (Faruqui et al, 2001). The Californian example also indicates that when the total economic costs of covering the peak loads are taken into account, this may well lead to peak electricity retail prices 3, 5 or even 10 times higher than the respective base load prices; a cost that could not be carried even by the wealthy state of California. Whilst lessons have been learnt on how to manage the energy market, in terms of an energy pool with typical commodity market’s features, and at the same time on how to implement medium and long-term capacity planning schemes, the necessity for reducing peaks in demand inevitably leads to adapting a reasonably differentiated pricing policy. According to studies made during the preparations for the Greek Olympic Games of 2004, the actual marginal cost for covering the peak summer time demand does well exceed 150 €/MWh, compared to approximately 42 €/MWh for base load production and 73 €/MWh for the summer period (RAE, 2004; CEPD, 2006) The results of these studies were, unfortunately one could state, verified in the years 2004 and 2005 (RAE, 2005) One has also to notice that environmental, or any other sort of externalities, are not included in these figures, though the may very well have to be considered, with respect to the obligations arising from the Kyoto protocol and the impact the latter has on power generation. The evaluation of the energy design and behaviour of buildings, as well as of the conservation measures and/or various passive and active cooling and refrigerating systems should be carried out with respect to this threshold. The main goals can only be to avoid or reduce the generation of cooling loads, to postpone the burdening of the building's interior on a diurnal base and, finally, to try to produce refrigeration in a sustainable way.

4. Non-energetic aspects of air-conditioning

The widespread use of air-conditioning, however, is not only an energetic or economic problem. Neither are environmental problems limited to the CO_2 emissions due to energy consumption. Prior to the Montreal Protocol of 1987, the refrigeration and air-conditioning market was dominated by the use of CFC and HCFC refrigerants. Their properties, like zero flammability and toxicity, make it relatively easy to design safe refrigeration systems that can be used in locations where untrained members of the public may be in the vicinity of a refrigeration plant. The European Commission's Regulation on ozone layer depleting substances, (2037/2000/EC), which was implemented on October 1st 2000, treats the whole spectrum of control and phase out schedule of all ozone depleting substances. Given the fact that a threat to the ozone layer from CFCs and HCFCs occurs only when these substances are released into the atmosphere, the EU regulation includes specific measures aimed at minimizing CFC and HCFC emissions, which have already lead to an increase of the owning and operational cost of refrigeration systems using HCFCs and therefore support the penetration of either alternative refrigerants or alternative refrigeration technologies. There are numerous new refrigerants on the market that have been specifically developed to address the phase out of CFCs and HCFCs. On the long run, however, only five important global refrigerant options remain for the vapour compression cycle, on which almost every contemporary air-conditioning systems is based, as well as for the various non-vapour compression methods including sorption, steam jet, gas cycle cooling etc or passive and natural cooling methods. These are: hydrofluorocarbons (HFCs, HFC-blends with 400 and 500 number designation), ammonia (R-717), hydrocarbons and blends (HCs, e.g. HC-290, HC-600, HC-600a etc.), carbon dioxide (CO_2, R-744) and water (R-718). None of these refrigerants is perfect. For instance, HFCs have relatively high global warming potential (GWP), ammonia is more toxic than the others and both ammonia and hydrocarbons are flammable. Interest in ammonia and hydrocarbons is stimulated, at least in part, by the fact that HFCs are greenhouse gases which will be, according to the Kyoto agreement, subjected to control measures. However, safety aspects also imply stringent emission controls for ammonia and hydrocarbons. Although these aspects are not covered by the Montreal Protocol, they nevertheless form criteria in the ongoing "environmental acceptability" debate. Appropriate equipment design, maintenance and use can help to reduce these concerns, though at the cost of greater capital investment or lower energy efficiency. Respectively, energy efficiency research is partly encouraged by the contribution of energy production to CO_2 emissions (UNEP, 2001). All these aspects transform the future strategies on selection of refrigerant technologies into a delicate optimization procedure, at least on a medium and long-term basis.

So far, the existing legislation on ozone depleting substances has placed increasing pressure on CFC and HCFC end users to start using alternative working media and technologies. It has resulted in the extended use of HFCs, which are highly attractive for cooling applications. Despite the fact that all pure HFCs and most HFC blends require synthetic lubricating oils, instead of the more conventional mineral oils used with CFCs and HCFCs, the use of HFCs to replace CFC or HCFC in refrigeration plants is currently the option with the lowest cost for many users. On the other hand, whilst they have zero ODP, HFCs have a significant global warming potential (GWP). This is typically in the range of 1,000 to 3,000 times the GWP of CO_2. At the 1997 Kyoto meeting, HFCs were included as one of six global warming gases being targeted for emission reductions. It is of high interest to note that in 1995 the air-conditioning and refrigeration market was responsible for HCF's emissions of 4.3 Mt of CO_2 equivalent, a figure corresponding to about 11% of the total HCF emissions. This figure has been predicted to increase to 28.2 Mt of CO_2 equivalent by the year 2010 equaling approximately 43% of the total HCF emissions (March, 1998).

Considering the alternative refrigeration technologies, one has to mention the option of solar refrigeration, though this is not a new technology as such. Thermal driven absorption and adsorption technologies have been in use since the 1930's, whilst the use of solar driven sorption systems for the cooling of buildings has been studied systematically since the early 1970's. Despite the progress monitored, however, no commercial major breakthrough has been achieved in the building sector, with the exception of desiccant systems, mainly in the USA. Sorption systems are referring either to open or closed cycles. Open cycles are mainly desiccant systems, while closed cycles are adsorption or absorption systems. Absorption systems are the oldest and most common heat driven systems and are for many years commercially available. In the low-pressure side an evaporative refrigerant is absorbed by the absorbent formulating a weak absorbent solution. Adsorption involves the use of solids for removing substances from either gaseous or liquid solutions (Papadopoulos et al, 2003). Both phenomena of absorption and adsorption are used to provide thermal compression of the refrigerant instead of mechanical compression in the case of vapour compression cooling systems. In desiccant systems, sorbents are used for the dehumidification of the incoming air, which in that sense is strictly not a refrigeration process, though it is certainly part of air-conditioning.

By assessing the potential for solar energy refrigeration by means of a SWOT analysis, one can draw the following results (Papadopoulos et al, 2004): Peaks in electricity demand occur, more frequently in recent years, in most developed countries during the summer period, for the reasons discussed afore. The close coincidence of the maximum insolation with both the cooling loads and the peak electricity demand indicates that solar assisted refrigeration may be an interesting option to handle successfully these two issues. Furthermore, the solar thermal market has gained momentum in Europe since the mid-1990's, leading to a satisfactory propagation of hot water systems, which may well also be used for solar cooling purposes. In terms of approaching a new market, this is a main argument for the possibility of partially solar powered cooling using alternative technologies like sorption or steam ejector cooling. Increasing the annual utilization factor of solar thermal systems, which is so far limited because of their use for hot water production and in some cases space heating, can counterbalance the lower efficiency of solar sorption systems, and make them financially feasible options. At the same time they can be considered as the most environmental friendly cooling option from every aspect, including ozone depletion potential, global warming potential and primary energy consumption. The most suitable combinations of solar thermal technologies and sorption systems are depicted in Figure 7.

5. Towards the reduction of cooling loads and demands

When determining a strategy, cooling loads in a building can be dealt with in three ways: (a) Avoiding or reducing their generation in the first place, by applying the basic principles of building physics. This implies the implementation of sound sun-protection schemes, the use of thermal insulation, the use of reflective and low-absorbing materials on the building's interior, the practice of reasonable ventilation patterns and the reduction of internal thermal loads production (b) Postponing their impact on the building's interior. This presupposes a solid comprehension of the specific building's physics in order to capitalize on the building envelope's thermal storage capacity so as to delay the occurrence of high indoor air temperature values. In that way one can cope with them late in the evening, when, on the one hand, the ambience is cooler and, on the other, cheaper load electricity tariffs are applying. Still, urban buildings, especially the contemporary ones are often light-weight constructions with low thermal storage capacity and it is difficult to apply this technique (c) The third way is the use of alternative sources and systems to produce the refrigeration necessary to cope with the cooling demand. This becomes necessary when ways (a) and (b) have been exhausted, or when they are impractical and, in any case, in order to solve the problem of dehumidification, which can hardly be solved without mechanical air-conditioning.

Typically the "passive" options (a) and (b) have been the fields favoured by architects and civil engineers, whilst the "active" option (c) was the pet-child of mechanical engineers, traditionally with an industrial background. Still, the feasibility of the last option depends, to a good extent, on the successful implementation of the first two ones, and, in that sense, on the integrated energy design of the building. On the other hand, the idea of an exclusively naturally cooled building, located in the densely built urban environment may seem attractive, but it is hardly realistic. This is not only due to restrictions on the building architecture but also to the prevailing environmental conditions, i.e. very low wind speeds and vortices in street canyons, high level of noise due to traffic, increased air pollution etc. In terms of thermodynamics, i.e. thermal processes and systems' design, the relationship between passive and active strategies can be expressed as one between covering the arising thermal load and ensuring the necessary installed power to cope with the maximum demand. In terms of economics this relationship can be described as the search for the minimum life-cycle cost of the building, whilst at the same time trying to balance the capital and the operational expenses in a way appealing to the building's owner or/and user. The approach adopted by the European Directive on the Energy Performance of Buildings, with the inclusion of renewable energy gains in the building's energy balance and the implementation of typified consumption values to be stated by the buildings' energy certificate, is an important step in that direction. It will enable the consideration of future operational expenses by the building's possible user, increasing the pressure on the constructor to abandon the typical criterion of minimizing the capital expenses, by building an energy wasting building.

5. Concluding remarks

The impact of increasing energy prices on the regulation of buildings' energy behaviour has been the major driving force behind most of the legislative measures implemented by national governments and international organizations and institutions, at least in the aftermath of the turbulent 1970's. In the 1990's interest shifted towards facing environmental problems, both in the sense of reducing atmospheric pollution and ensuring sustainability and in that of establishing satisfactory indoor environmental conditions for the buildings' users. This was to some extent due to falling energy prices, but also in order to counterbalance some of the evolutions of the 1970's, when the effort to reduce energy consumption caused some serious drawbacks in the indoor environmental quality of buildings. The dilemma, however, that for some years seemed to occur between energy consciousness and high standards of living quality is a false one, as developments since the mid 1990's proved. Buildings can be energy conscious, comfortable, healthy and environmental friendly simultaneously. At the same time, they can also be feasible investments, especially when considering the latest developments in the prices of oil, natural gas and electricity. In that sense, a building's Life Cycle Cost and its environmental Life Cycle Analysis' indices can be both minised, whilst at the same time ensuring high quality of living or working environment.

In order to achieve this complex and ambitious goal the regulatory approach used hitherto, with elaborated and strict, but fragmented, acts of legislation does not suffice. Three decades of intensive research in the field of building physics have proven that progress can only be achieved if the 'problem building' is considered in a holistic approach. The same philosophy has to be adopted in the regulatory approach, a philosophy that governs the new European Directive on the energy performance of buildings which provides, in that sense, a useful background for enforcing developments in the building sector. Key issues for its effective application are the use of state of the art know-how, expertise and technology, the imposition of a firm set of standards and regulations in practice and the elaboration of a new attitude amongst the market players. In that sense, the successful adoption by the market of the new Directive depends to a good extent on the adaptation of its philosophy in accordance with the local needs, but also in the efficient training and re-education of those who will be asked to apply it. This need becomes more important, as a frequently vented criticism about the new Directive with its 31 accompanying standards, is that it forms a complex problem for architects, engineers and constructors. This may be to some degree true, in particular when considering further regulations that already apply, like the one on refrigerants, or such that are in the stage of discussion, like the one on the minimum use of certain percentages of renewable energy sources directly for heating and cooling. On the other hand, complex problems can rarely be solved by simplifying tools.

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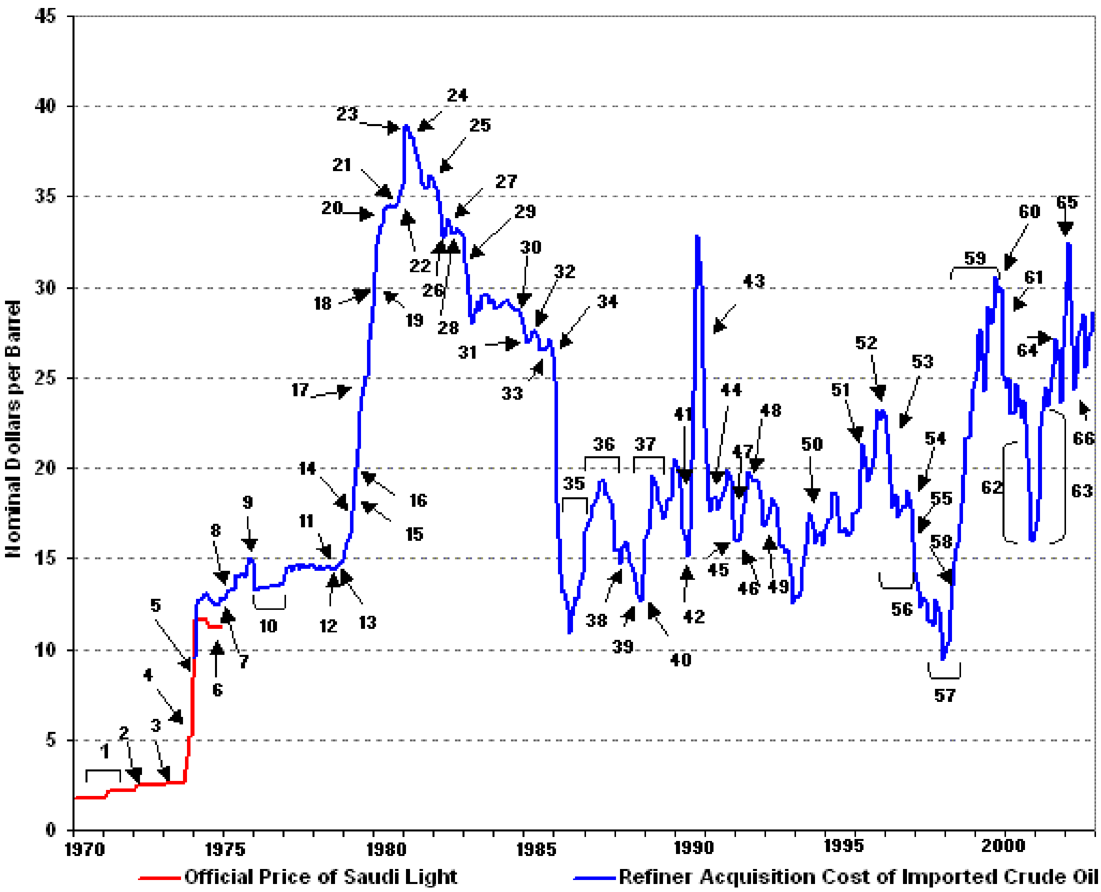

Figure 1. Development of oil price since 1970 [Source: EIA, 2006]

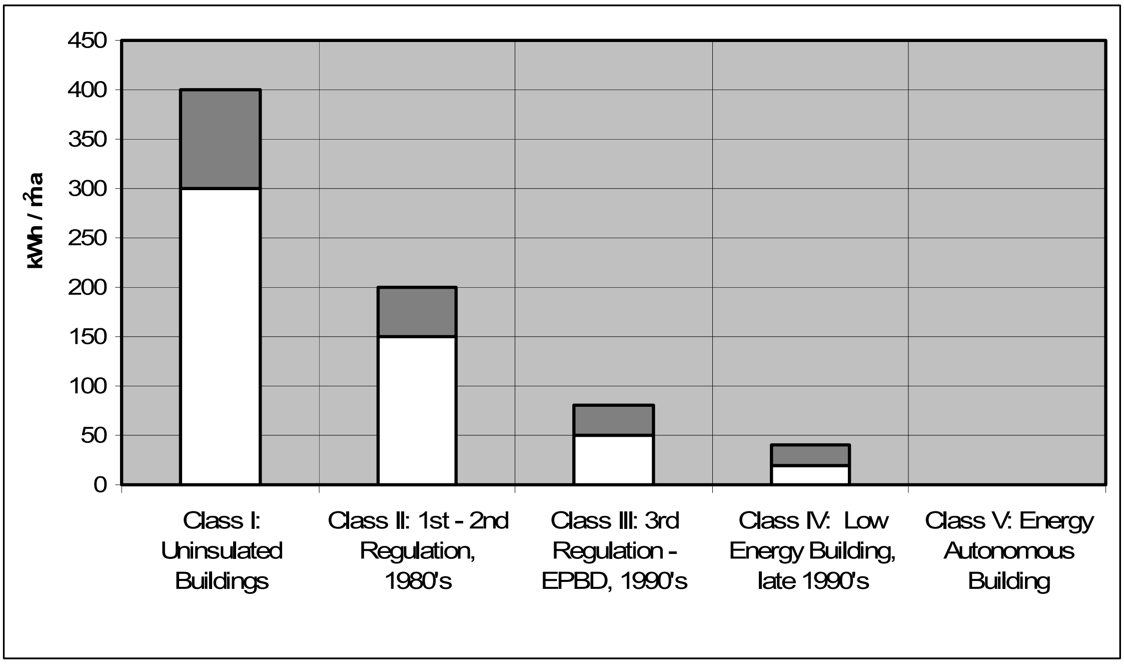

Figure 2. Evolution of heating energy consumption in German buildings, according to the 5 steps approach by Gertis

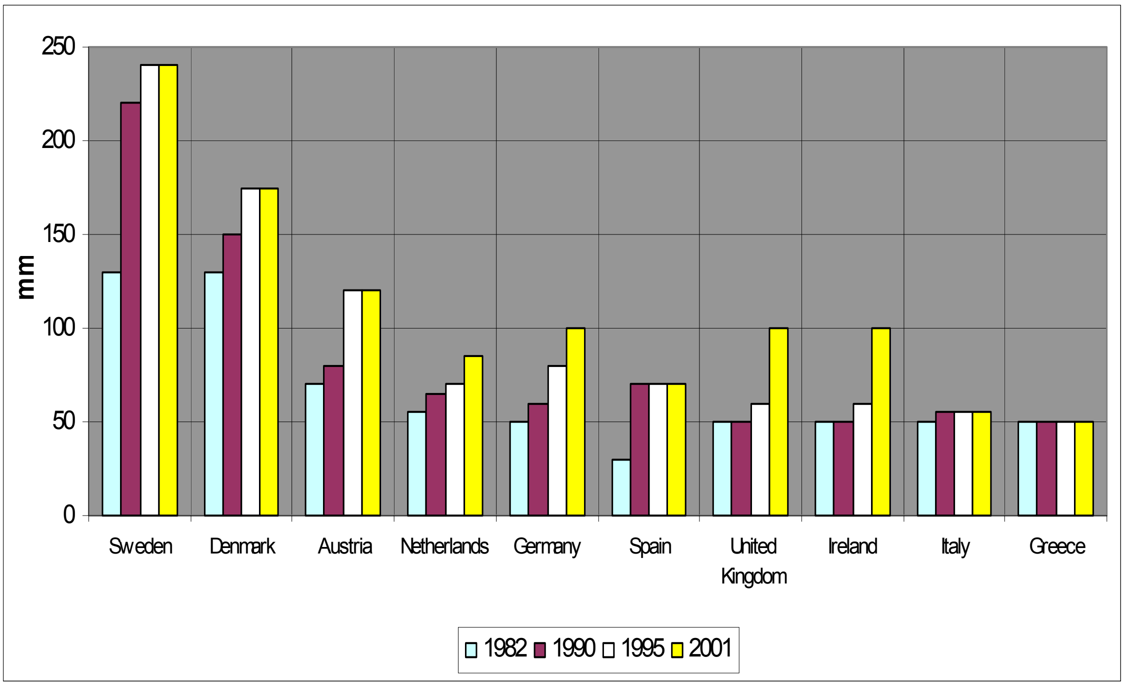

Figure 3. Development of average insulation thickness for walls, as foreseen by national regulations, in European countries [Data sources: EURIMA, EUMEPS]

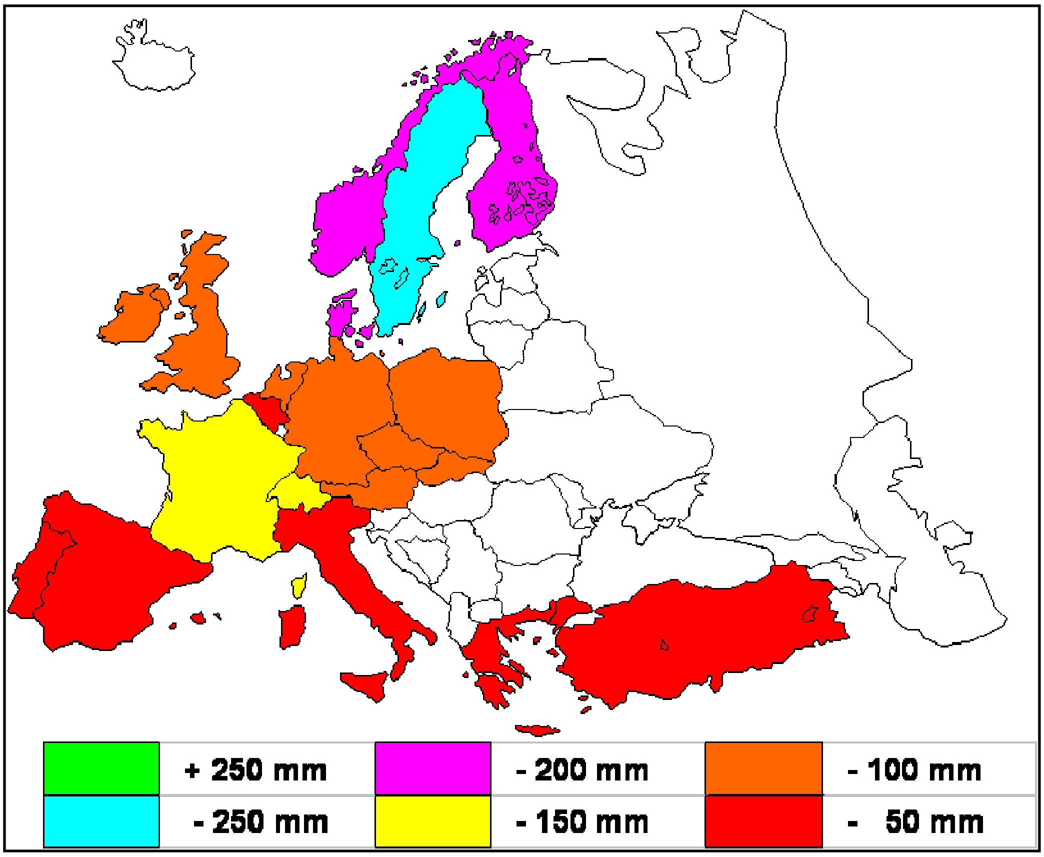

Figure 4: Insulation thickness in walls, as foreseen by national regulations in European countries in 2003 [Source: EURIMA, 2003].

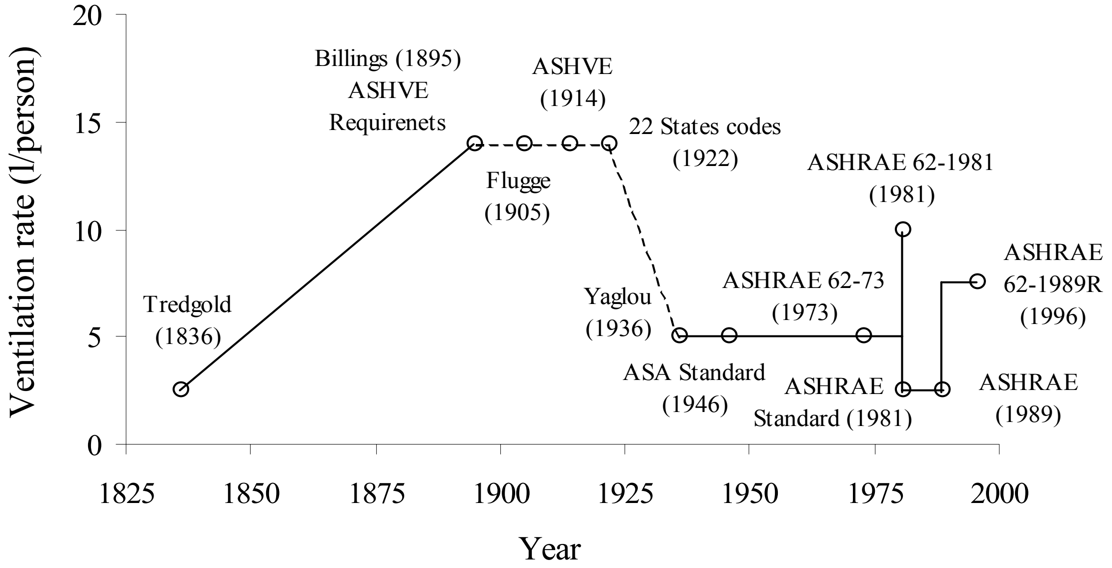

Figure 5. Development of minimum ventilation rates in USA [Source: Awbi, 1998]

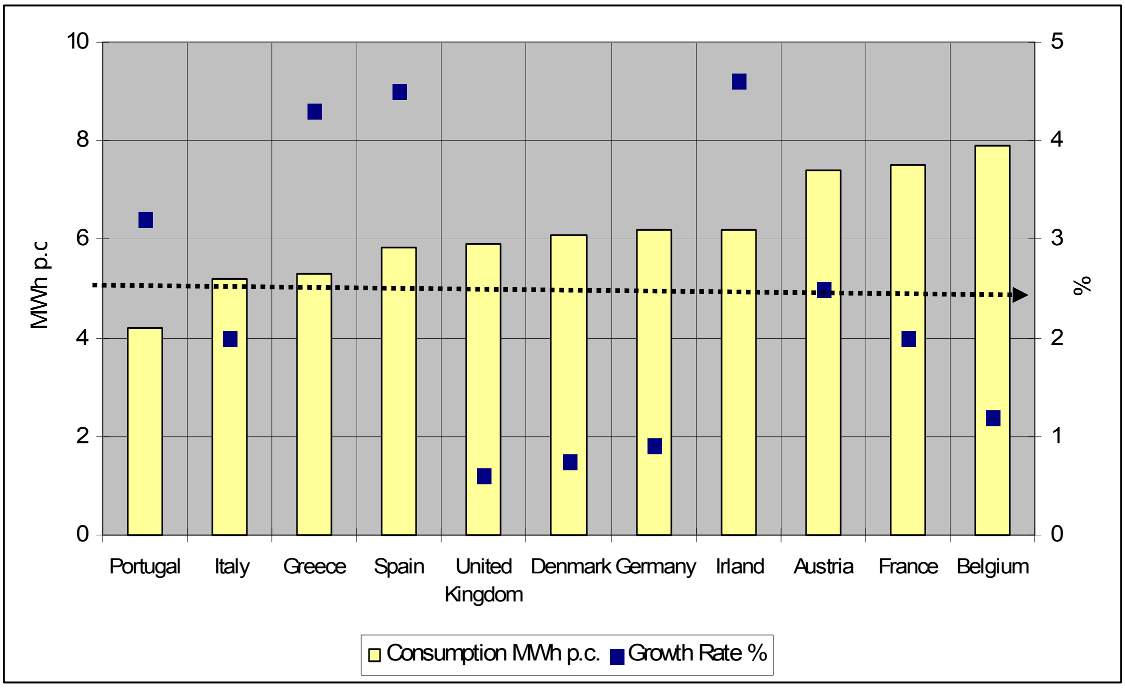

Figure 6. Development of electricity consumption and its annual growth rate in European countries [Data source: Economist Intelligence Unit, 2006]

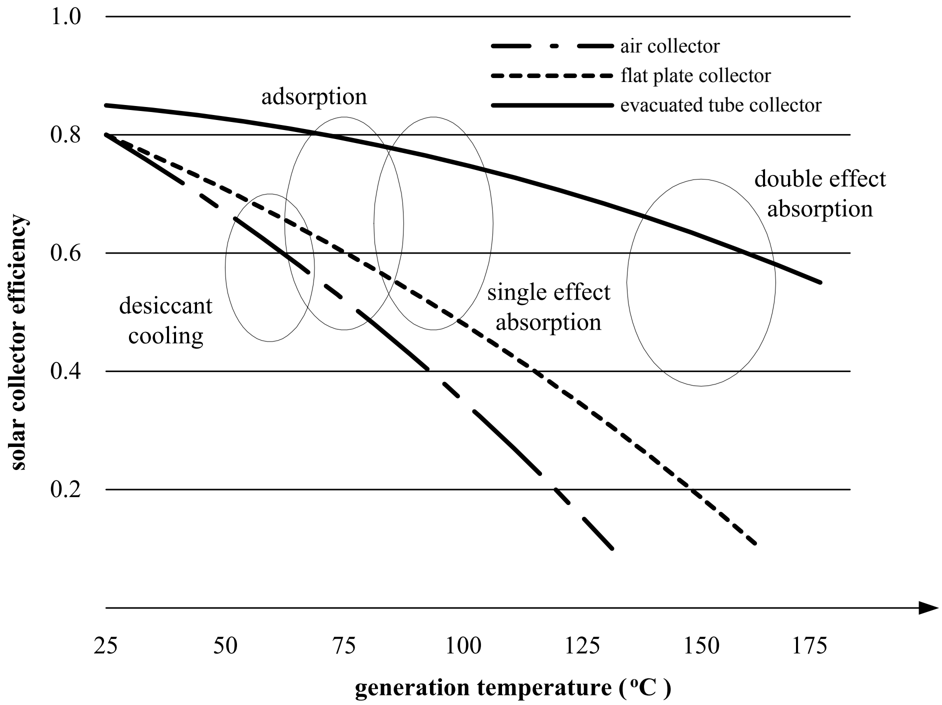

Figure 7. Possible combinations of solar thermal and sorption refrigeration technologies [Source: Henning, 2000]