On the impact of energy pricing on low energy design of buildings

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ABSTRACT

Implementing low energy design principles and measures in buildings depends on a series of architectural, structural and legal parameters. A building's design, as well as its operational patterns, has increasingly to comply with tightening comfort, health and aesthetic requirements. And all this in view of the fact that the application of techniques like natural and evaporative cooling, sun protection and hybrid energy production systems based on renewable energy sources, are not always easily applicable in the densely built and environmentally burdened urban ambient.

Still, possible the most crucial parameter for the implementation of low energy design principles, at least on a broader scale, is their economics. The feasibility of such schemes is subject to the retail prices of natural gas, oil and electricity, but the pricing policies applied by utilities are becoming more and more complicated, as a result of the liberalisation in the European energy sector during the last decade.

1. INTRODUCTION

The influence of microclimatic conditions on the energy behaviour of buildings began to constitute a major research field in the last decade. The enhanced urbanisation, 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 characterised by a dense and often continuous development 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. Furthermore, atmospheric pollution, combined with increased awareness about the prevailing indoor air quality conditions due to pollutants emitted from building materials and the presence of residents, influence the demands set on ventilation and air-conditioning in a dominant way.

Buildings however, have the goal of providing protection to human beings from the weather conditions and of supporting human activities, when they are used either for residential or for working purposes. As buildings consist major capital investments and human health is invaluable, the possibility of poor indoor air quality (IAQ) and/or poor thermal comfort conditions prevailing in their interior, does contradict the afore mentioned basic goal. Especially in the case of office buildings several studies link indoor environmental quality (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). However ventilation is achieved, 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. Still, 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.

2. COSTING AND PRICING OF AIR-CONDITIONING

The lack of air-conditioning, in buildings designed without any particular bioclimatic features, leads to poor conditions. But even in buildings retrofitted with split-unit types of air-conditioning systems, the situation is not always better, as these do not enable the ventilation of the interior, underlining the point that increased energy consumption does not necessarily result in a respective improvement of indoor environmental conditions (Papadopoulos et al., 2002; Avgelis and Papadopoulos, 2003). 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. It also becomes clear, that the impact of increasing IEQ standards on energy consumption is expected to become even more important in the years to come.

Final energy consumption in buildings in the EU reaches approximately 385.6 Mtoe, which represents about 40% of the total energy consumption. This energy consumption means that the building sector is responsible for about 20% of the total CO_2 emissions (Santamouris et al., 2001). Although in many countries the primary energy consumption of buildings is being reduced because of the effective energy conservation measures adapted, this refers mainly to the heating loads. In Southern Europe, but recently also in Central and Northern Europe, the primary energy consumption continues to increase, mainly due to the propagation of air-conditioning appliances (Freedonia Group, 2002). At the same time, the Coefficient Of Performance (COP) value of the air-conditioning units is reduced by up to 25% due to the higher ambient air and surface temperatures. Room Air-Conditioners (RAC) have become a major success story in the HVAC branch winning market shares from central AC systems. RACs have the typical form of split-unit devices, with the compressors placed externally and the evaporators in the building's interior, with only the refrigerator circulating between the two units. The use of such systems 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 COP of the air-conditioners, thus creating a vicious circle in terms of cooling and electricity demand.

As a result of these developments RAC sales have increased dramatically. Whilst global air-conditioning sales are increasing at 4% annually, sales of RACs increase by almost the double. In Greece the total installed 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 wave 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).

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 for the years 1995-2000 the increase in peak load demand reached 3,500 MW, from 5,000 to 8,500. It has to be noted that peak load demand rose by no more than 1,200 MW from 1985 to 1995, whilst, until 1985, peak load demands were recorded during winter (PPC, 2001). The additional capacity 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. 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 AC, 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 same example indicates that economics are taken into account, leading to peak electricity retail prices 3, 5 or even 10 times higher than base load prices. And whilst lessons have been learnt on how to manage the energy pool and 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 cost for covering the peak summer time demand does well exceed 150 Euros/MWh, compared to approximately 42 Euros/MWh for base load production. 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 passive and low energy design of buildings, as well as of the various passive and active cooling and refrigerating systems should carried out with respect to this threshold and 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.

3. STRATEGIES TOWARDS LOWER COOLING ENERGY LOADS AND DEMANDS

Cooling loads in a building can be dealt in three ways: (a) Avoiding or reducing in the first place their generation, by applying the basic principles of energy design of buildings. 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 minization of internal thermal gains production (b) Postponing their impact on the building's interior presupposes a solid comprehension of the specific building's physics. Only then one can try to capitalise on the building's shell thermal storage capacity, and therefore its thermal inertia, in order to help delay the occurrence of high indoor air temperature values, in order to cope with them late in the evening, when, on the one hand, the ambience is cooler whilst, on the other, base load electricity tariffs are valid. Though, urban buildings, especially the contemporary ones are light-weight constructions with very low thermal capacity and it is hardly possible to utilise 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 way (c) was the pet-child of mechanical engineers, traditionally with an industrial background. Still, the feasibility of the last approach depends, to a good extent, on the successful implementation of the first two options, and the integrated 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 to the prevailing wind conditions (very low wind speed) as well.

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 and 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. In that sense, one has to differentiate two possible situations.

In buildings with a conventional, central HVAC system, the impact of the peak demand on the capital expenses is rather law. Once the decision for such a system is made, a difference of some 10 or 20% on the rating of the system's compressors and chillers is rather small compared to the overall cost of the system and, what is even more important, to the overall cost of the building. Operational expenses, on the other hand are more important, as can be seen from a case study of a 9.000 m^2 office building, commissioned in 1999 in Thessaloniki, Greece (Avgelis et al., 2004). In that sense, the reduction of the building's cooling load, and also demand, lies in the interest of the building's user, the former property rather than the latter, as this is to be his main point of concern throughout the building's life-time. The data presented in the table are based on the current flat rates for electricity retail prices of 72 Euros/MWh. The analysis, however, of the demand's diurnal distribution indicated that in June, July and August approximately 70% of the load and the demand are used between 12:00 and 15:00. Furthermore, these loads represent more than 40% of the total annual cooling loads. Assuming the introduction of a modest peak load tariff of 95 Euros / MWh (i.e. by 32%), this would lead to an increase of the annual operational expenses by 2,657 Euros or 13,1%. If some more drastic pricing policies were to be adapted, i.e. adopting the actual marginal cost of peak electricity production as mentioned in paragraph 2, the additional operational expenses would be 20,760 Euros, i.e. they would be more than double the initial annual expenses. Exaggerated such a scenario though it may seem, it would reflect very much the California experience. The option of passive and active technologies for low energy design of buildings should be considered under such a perspective

4. SOLAR REFRIGERATION

The option of solar refrigeration is not a new one. 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. Still, and despite the progress monitored, 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 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, because of the increasing use of air-conditioning. The reasons for this lie in higher thermal comfort expectations, in lower initial costs for air-conditioning equipment and in the heat island effect in urban areas, which leads to microclimatic changes. On the other hand 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 be well used for solar cooling purposes. Finally, solar assisted refrigeration appears as a promising alternative to the conventional electrical driven air conditioning units also from an environmental point of view, since it results to decreased CO_2 emissions and, in the case of the prevailing solar cooling technologies, in the elimination of CFCs and HCFCs. The latter has become a major aim of the European Union's policy and, combined with the aims set by the Green Book on Energy, is expected to influence the developments in the air-conditioning sector significantly. Still, there are important barriers that have to be overcome, calling for a co-ordinated and focused cooperation of state authorities, industries and the public. The action should aim at improved marketing of the branch's products, increased environmental awareness, better standardisation of the products and establishment of environmental labelling schemes and the introduction of 'tailor-made' financing schemes, like leasing, particularly for big customers, who will act as 'opinion-shapers' for the whole building sector. In that sense, and if such a series of strategies will be adopted, solar sorption refrigeration technologies can definitely be regarded as the prevailing option for the utilization of solar energy in air conditioning. This applies to adsorption and absorption but also to desiccant cooling.

5. CONCLUSIONS

Solar cooling, exclusively or assisted, is still, mainly due to its economics, a comparative option to compete with the conventional air conditioning systems. On the other, hand solar air conditioning potentially offers an elegant model of a clean, sustainable technology, which is consistent with the international commitment to sustainable development. The increasing effort in the research side though, and several collateral advantages of solar cooling technologies indicate a high potential for a wider applicability of solar assisted air conditioning. Particularly, the main advantages of solar air conditioning technologies concern:

- the reduction of summer peak loads of electricity utilities,
- the close seasonal and hourly coincidence of solar radiation and buildings cooling loads profile,
- the use of zero ozone depletion impact refrigerants,
- the decreased primary energy consumption and furthermore,
- the decreased global warming impact.

The above features of solar assisted air conditioning present an alternative way in the comparison with the conventional electrically driven cooling systems. This way includes the consideration of ozone depletion potential, global warming potential, primary energy ratio and finally, the widely acceptable method for evaluating renewable energy sources of life cycle analysis. Under the perspective of these analysis. Under the perspective of these methods the option of solar cooling acquires a more attractive approach. In addition, the disadvantage of low financial feasibility can, in a great percentage, be cancelled if both electric and gas utilities prepare and launch demand side management actions concerning air conditioning.

Furthermore, the installation of solar collectors provides to a building with an all year round energy source suitable for space heating in winter time and domestic hot water supply throughout the year as well. Thus, a global strategic management program treating the implementation of solar air conditioning is a priority action to verify the current and future technological, economical and social aspects and parameters needed to be fulfilled for acceptance and wide penetration of solar energy in the air conditioning business.

On the other hand there is still a large research activity to be done for the utilization of solar energy in the air conditioning systems. Research, which mainly focuses either to solar collectors or the sorption cooling technologies. But the optimization of solar air conditioning systems concerns as well the cooling loads side. A cooling load profile is a product of a building's characteristics and its occupants' behavioral patterns. Passive or natural cooling techniques are proven to be very efficient in reducing significantly a building's cooling load. The challenge here is the integration of passive and natural cooling techniques with solar cooling technologies resulting either to independently cooled buildings free of any environmental load or to limited, and thus financially more viable, solar collectors arrays. The more electricity markets will swift towards higher peak load tariffs, a trend that seems rather inevitable, the more the application of such integrated concepts will become feasible.

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