ENERGY IN URBAN BUILDINGSCITIZENSHIP

ENERGIA NAS EDIFICAÇÕES URBANAS E CIDADANIA

Santamouris, Mattheos

RESUMO
Este trabalho apresenta a situação européia atual com relação ao consumo de energia e a qualidade ambiental no setor da construção, investigando as principais razões que têm levado ao aumento da demanda energética. Propõe e discute um grupo de medidas que podem contribuir para melhorar a qualidade do ambiente construído, revertendo a tendência atual de aumento do consumo energético e diminuindo o efeito urbano de mudança climática.

PALAVRAS CHAVE: consumo energético, segurança energética, qualidade ambiental urbana, comunidade europeia

ABSTRACT
This paper presents the current EU situation with respect to energy consumption/environmental quality in the built-up sector, analyzing the main reasons for this increase in energy demand. A group of measures is proposed/discussed in order to help improve the quality of the built-up environment, reversing the current trend of increasing energy consumption/mitigating the urban effect on climate change.

KEYWORDS: energy consumption, energy security, urban environment quality, european community

1 INTRODUCTION

Construction is one of the most important economic sectors worldwide. The total world’s annual output of construction is close to $3 trillion and constitutes almost one-tenth of the global economy. About 30% of the business is in Europe, 22% in the United States, 21% in Japan, 23% in developing countries and 4% in the rest of the developed countries. Buildings use almost 40% of the world’s energy, 16% of the fresh water and 25% of the forest timber, while is responsible for almost 70% of emitted sulphur oxides and 50% of the CO2.

Construction represents more than the 50% of the national capital investment. It employs more than 111 million of employees and it accounts for almost the 7% of the total employment, and 28% of the global industrial employment. Given that every job in the construction sector generates 2 new jobs in the global economy, it can be said that the construction sector in a direct or indirect way is linked to almost 20% of the global employment.

The building sector absorbs almost 40% of the energy consumption in Europe and the absolute energy consumption is increasing continuously. Despite European Union has signed the Kyoto agreement, and has put in force very clear legislative policies, aiming to decrease the energy consumption, the actual demand is increasing continuously. In parallel, very important problems of indoor environmental quality and social inequalities related to energy put the emphasis on new priorities and policies related to the building sector.
The present paper aims to present the actual situation in Europe related to the energy consumption and environmental quality of the building sector. In parallel, it aims to investigate the main reasons that contribute to the actual increase of the energy demand. Finally, to propose a group of measures that may contribute to improve the environmental quality in the built environment and decrease the energy demand.

2 ENERGY CONSUMPTION IN EUROPE

The energy consumption of the building sector (services and households) in the 25 countries of EU is close to 472 GToe (2004 data), while the corresponding consumption of the 15 initial countries is close to 412 GToe. Figure 1 shows the annual variation of the consumption for both groups.

In the period 1999-2004 the energy demand presented an increasing trend for both the 15 and the 25 countries. The mean annual increase of the consumption was close to 1.8%. According to, almost all EU countries, except for Belgium and Sweden, presented an increase of the energy consumption (see Figure 2).

Southern European countries presented the highest increase. Spain and Greece increased their energy demand for services and households to about 26% (1999-2004 period), while the corresponding increase for Portugal was close to 21%. In parallel, France and Italy presented an increase of about 10 and 6% in the corresponding period.

Figure 1 - Annual variation of the energy consumption (services and households) in the European Union. Source: Energy, 2005

Increase of the energy demand in Southern Europe is the complex result of social, economic, political and technical issues related to the economic growth of the countries, rapid penetration of air conditioning, inadequate legislation and thermal degradation the urban environment. All the above issues will be discussed in the following chapters.

Most of the energy spent in the building’s sector is coming from conventional energy sources. Only 6-7% of the energy is coming from renewables, while the penetration of non conventional sources in the energy balance of the Member States is not expected to be spectacular.
As a result of the economic growth in Europe and in particular in Southern Europe, the size of dwellings per family is increasing continuously, while the occupied space per person is increasing as well. Table 1 shows the variation of the number of person per household in selected European countries for the period 1980-2003.

Increase of the space per person has a direct impact on the energy consumption of buildings as more space per person has to be heated or air conditioned. In parallel, as a function of the existing economic growth, the mean size of dwellings varies considerably between the various countries (Figure 3).

Southern countries are quite far from the Northern European standards and thus there is a high potential for further social improvements. Thus, it is expected that in many countries and in particular in the European South, the energy consumption of the building sector will continue to increase at least for the above social and economic reasons.
4 RAPID PENETRATION OF AIR CONDITIONING

The market of air conditioning is expanding continuously. According to the data given in, in 1998 the total annual number of air conditioning sales was close to 35,188,000 units, while it has increased to 41,874,000 units in 2000 and to 44,614,000 units in 2002, with a predicted level of 52,287,000 units in 2006. In Europe an increase close to 22% on air conditioning sales is observed between 2002 and 2006, while the corresponding increase of sales is 39.2% for Asia, excluding Japan, 23.2% for Oceania, 13.6% for Africa, 13.3% for South America and 10.5% for Middle East.

In Europe, most of the cooling systems are installed in Southern countries, almost 74% of the total number of systems, according to Table 2. Italy has the highest number of installed units (29%) while split systems are the most common units and represent more than 60% of the appliances.

<table>
<thead>
<tr>
<th>System</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Split</td>
<td></td>
</tr>
<tr>
<td>Multi-split</td>
<td></td>
</tr>
<tr>
<td>Windows</td>
<td></td>
</tr>
<tr>
<td>Single-duct</td>
<td></td>
</tr>
</tbody>
</table>

TABLE 2
Different systems of room air conditioners in Europe (1996).

<table>
<thead>
<tr>
<th>Country</th>
<th>Split</th>
<th>Multi-split</th>
<th>Windows</th>
<th>Single-duct</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>93 400</td>
<td>21 800</td>
<td>16 600</td>
<td>7 700</td>
<td>79 000</td>
</tr>
<tr>
<td>France</td>
<td>752 000</td>
<td>189 850</td>
<td>106 500</td>
<td>218 750</td>
<td>1 259 100</td>
</tr>
<tr>
<td>Germany</td>
<td>198 000</td>
<td>59 800</td>
<td>74 500</td>
<td>193 400</td>
<td>526 100</td>
</tr>
<tr>
<td>Greece</td>
<td>138 000</td>
<td>51 830</td>
<td>555 000</td>
<td>744 690</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>1 504 697</td>
<td>50 177</td>
<td>134 860</td>
<td>582 006</td>
<td>2 111 740</td>
</tr>
<tr>
<td>Spain</td>
<td>972 000</td>
<td></td>
<td>245 000</td>
<td>152 000</td>
<td>1 369 000</td>
</tr>
<tr>
<td>Portugal</td>
<td>267 157</td>
<td>30 143</td>
<td>17 720</td>
<td>7 890</td>
<td>322 620</td>
</tr>
<tr>
<td>UK</td>
<td>516 890</td>
<td></td>
<td>54 887</td>
<td>107 755</td>
<td>674 412</td>
</tr>
<tr>
<td>Others</td>
<td>119 180</td>
<td>31 100</td>
<td>44 700</td>
<td>116 040</td>
<td>315 660</td>
</tr>
<tr>
<td>Total EU</td>
<td>4 501 534</td>
<td>466 000</td>
<td>1 249 747</td>
<td>1 183 451</td>
<td>7 402 662</td>
</tr>
</tbody>
</table>

%       | 61%   | 6%        | 17%     | 16%         | 100%  |

As a result of the rapid penetration of air conditioning in Europe, the energy consumption for cooling purposes has been increased highly. While, in 1990, the energy consumption for cooling in EU countries was close to 1,900 GWh, it is expected to exceed 44,430 GWh in 2020. In parallel, the corresponding carbon dioxide emissions will increase from 516 KT in 1990 to 18.1 MT by 2020 (Table 3).

**TABLE 3**

Carbon Dioxide emissions in selected EU countries because of the air conditioning.

<table>
<thead>
<tr>
<th>Unit</th>
<th>Tonnes CO2</th>
<th>1990</th>
<th>1996</th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>157</td>
<td>1,603</td>
<td>15,749</td>
<td>31,467</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>238,630</td>
<td>266,221</td>
<td>488,957</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>7,645</td>
<td>25,615</td>
<td>159,241</td>
<td>265,983</td>
<td></td>
</tr>
<tr>
<td>Greece</td>
<td>99,235</td>
<td>959,939</td>
<td>2,387,187</td>
<td>3,737,087</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>182,591</td>
<td>2,247,096</td>
<td>2,923,553</td>
<td>3,623,486</td>
<td></td>
</tr>
<tr>
<td>Portugal</td>
<td>147,359</td>
<td>358,099</td>
<td>1,038,841</td>
<td>1,519,546</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>n.a.</td>
<td>1,124,256</td>
<td>4,381,826</td>
<td>7,130,489</td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>47,710</td>
<td>219,640</td>
<td>704,204</td>
<td>1,165,583</td>
<td></td>
</tr>
<tr>
<td>Other E.U.</td>
<td>4,694</td>
<td>153,969</td>
<td>83,545</td>
<td>159,580</td>
<td></td>
</tr>
<tr>
<td>Total E.U.</td>
<td>516,451</td>
<td>6,058,935</td>
<td>11,959,391</td>
<td>18,102,187</td>
<td></td>
</tr>
</tbody>
</table>


Using of air conditioners has a serious impact on electricity demand in most of the countries. High peak electricity loads oblige utilities to build additional power plants to satisfy the increasing demand, and because of the limited use of these plants, the average cost of electricity increases considerably. Southern European countries face a very important increase of their peak electricity load. Figure 4 shows the increase of the peak electricity demand in Greece during the very recent years. It is also characteristic that Italy faced very important electricity problems during the summer of 2003 because of the high electricity demand of air conditioners.

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**Figure 4** - Monthly Peak Electricity Load in Greece for the period 1997-2002.

**5 NON APPROPRIATE LEGISLATION**

Non appropriate legislation in Europe and in particular in Southern European countries was one of the major reasons for the high energy consumption of the building sector. The MURE study has compared
the actual energy consumption for heating purposes of a typical building in each member state against the corresponding consumption of the same building when the Danish regulation is applied.

As shown in Figure 5, appropriate building legislation may decrease the energy consumption of buildings in Southern Europe up to 50%. It is expected that the application of the European Directive on the Energy Performance of buildings will contribute highly to improve the energy legislation and thus decrease the energy consumption of buildings.

![Figure 5](image)

Figure 5 - Comparison of consumption of a typical building applying the building regulation of Denmark in each Member State (climate corrected).

6 THERMAL DEGRADATION OF THE CITIES

As a result of heat positive balance, air temperatures in cities are higher than the temperatures of the surrounding rural country. This phenomenon known as “heat island” exacerbates electricity demand for air conditioning of buildings.

Important research has been carried out in Europe regarding to the heat island effect. Studies have been performed in southern, central and northern cities and it has been documented that the intensity of heat island may exceed 100C. Figure 6 shows the measured intensity of heat island in selected cities all around Europe.

![Figure 6](image)

Figure 6 - Heat island intensity in selected European cities.
Source: Santamouris, 2006

In parallel, as higher ambient temperatures result in lower efficiency air conditioners it is found that the minimum COP values were lower by about 25% in the central Athens. The impact of the London urban heat island on building summer cooling demand has been studied in. It is reported that during a typical hot week a rural reference office has 84% energy demand for cooling compared to a similar urban office.
7 ENERGY CONSUMPTION AND INCOME

It is well known that the energy consumption of households has a strong relation of the income. High income families consume more, while low income households spend a high proportion of their resources in energy.

Fuel poverty is defined as the number of households who need to spend in excess of 10% of their income on energy to achieve a specified heating standard. When expenditure exceeds 20% of the income, the family is defined as suffering 'severe energy poverty'. Statistical data around Europe has shown that fuel poverty is very high in the Southern Europe and according to moderate calculations accounts for about 12% of the households in Italy, 30% in Greece, 26% in Spain and 44% in Portugal.

Analysis of the energy situation in the building sector should always consider the specific conditions of the various income groups. Low income groups live in low quality dwellings and have to spend more energy to keep acceptable indoor conditions. A recent study in 1,100 households in Athens has shown that there is a very clear relation between the income level and the percentage of non insulated dwellings. The higher the income the higher the percentage of insulated buildings. It is found that only 28% of the low income group lives in insulated buildings, while the corresponding value for the richest group is close to 70%. Also, it is found that the higher the income the higher the percentage of buildings with double glazing. For the low income group the percentage of double glazed buildings is 24% while for the high income group the corresponding value is 67%. Insulated buildings with double glazing are quite rare for the lower income groups (8%), while the corresponding percentage increases to 60% for the high income group.

Concerning the mean heating energy consumption per person and area, it is found that the lower the income the higher the cost of heating per person and unit of surface. The cost per person and unit of area for the lower income group is to about 127% higher that the corresponding cost of heating for the richest group.

It is also found that the use of air conditioning increases considerably the annual electricity expenses especially in the low income groups. The use of air conditioning increases in average the annual expenses to about 100 Euros per household, or 0,6 Euros/m², or 12.5 Euros per person. The increase is much higher for the low income groups, where the relative increase of the cost because of the air conditioning use is close to 195 Euros/household, or 1.2 Euros/m², or 87 Euros/person.

Thus, appropriate strategies and energy planning should always consider the specific conditions of the various income groups and should always design appropriate measures for each social and economic group.

8 INDOOR AIR QUALITY

Indoor pollution because of the polluted outdoor air, indoor sources and anthropogenic activities is a serious threat for human health. Although there are a lot of studies on indoor air pollution levels, much more information and knowledge is required on the consequences of poor air quality in dwellings.

Recent research is mainly addresses topics related to the estimation of the indoor concentration of many chemical and biological pollutants, however, carbon monoxide, VOC’s (Volatile Organic Compounds), particulate matter and carbon dioxide are the more common pollutant measured indoors. In parallel, the impact of ventilation rate and the outdoor pollution conditions is a topic of major concern.

In addition, very important research is carried out to identify indoor pollution sources and its impact on indoor pollution. In particular, research on tobacco smoking, has permitted to identify its impact on human health.

Quite recently, measurements of indoor air quality in 50 dwellings have been performed in Athens, Greece. The concentration of CO2, CO, TVOC’s (Total Volatile Organic Compounds) and PM2.5,
PM10 has been measured [18]. It is found that only in 5% of the dwellings indoor TVOC’s concentration is below the threshold of 0.05 ppm. In 90% of the dwellings the concentration is between 0.05 and 0.8 ppm, levels that may cause discomfort, while in 5% of the households concentration is higher than 0.8 ppm where respiratory problems may happen.

Very high concentrations of PM10 and PM2.5 have been measured as well. Only in 16% of the dwellings the concentration is below the threshold value of 65 μg/m³. Finally, it is found that smoking contributes highly to the indoor concentration of PM2.5, PM10 and TVOC’s.

It is clear that indoor pollution is the major problem for dwellings and buildings in general. The combined impact of the indoor pollutants may have an important influence on the health and well being of citizens. Thus, appropriate legislative and technical measures have to be adopted to protect the health of the European citizens.

9 WHICH ENERGY POLICY FOR THE BUILDING SECTOR?

Energy consumption of the building sector is continuously increasing in Europe. In addition, the increase of the peak electricity load in the Southern Europe puts utilities under pressure and obliges them to build additional power plants to satisfy the increasing demand during the peak hours. Finally, energy problems are combined with serious problems of indoor air quality.

Increase of the peak electricity demand, mainly because of the rapid penetration of air conditioning, increases the price of electricity. While the mean cost of a kWh in Europe is close to 3.9 cents, the cost of a kWh under peak conditions is 10.2 cents. In parallel, the average cost to save a kWh is close to 2.8 cents. Thus, it is quite difficult to understand why national energy policies invest on the creation of new conventional power plants and not on energy conservation measures.

It is clear that a new more progressive energy agenda has to be adopted. Main priorities on future initiatives may be:
- To improve the urban microclimate, fight heat island and reduce the energy needs for cooling;
- To use sustainable energy supply systems for buildings based on the use of renewable sources like solar and biomass district heating and cooling;
- To use demand side management techniques to control and regulate the energy consumption of big consumers;
- To integrate passive and active solar systems in the envelope of new and existing buildings, and use of high energy performance supply and management equipment;
- To develop new more efficient legislative frame on the energy performance of buildings.

In the following some of the proposed measures will be discussed.

10. IMPROVING THE URBAN MICROCLIMATE - HEAT ISLAND AND MITIGATION TECHNIQUES

Several techniques have been proposed to mitigate heat islands. Current research on Heat Island Mitigation Techniques concentrates on:
- the increased use of green areas;
- the use of appropriate materials, in particular of white and colored high reflective coatings;
- the decrease of anthropogenic heat;
- the use of cool sinks for heat dissipation;
- appropriate layout of urban canopies involving the use of solar control, techniques to enhance air flow, etc.

Two among them appear to be the more significant: the use of green spaces as well as the use of appropriate materials in buildings and the urban fabric.

Important studies has been carried out to investigate the impact of green areas as well as on the use of cool sinks to mitigate heat island, however, the achieved progress can not be considered as a break
through. Despite this, recent research carried out in the last years on the topic of highly reflecting materials for the building envelope and outdoor spaces has permitted to develop advanced low cost coatings that, when used in the urban environment, contribute highly to decrease the indoor as well as the ambient temperature.

Reflective or cool coatings are characterized by a very high reflectivity to the solar spectrum together with a very high emissivity. White and colored cool coatings have been developed and their optical and thermal characteristics are determined. Comparison between reflective materials and the same color conventional materials present up to 15°C lower surface temperature.

Recent simulations aiming to investigate the possible decrease of the urban temperatures because of the use of cool colored coatings in Athens, Greece, have shown that increasing the albedo of the roofs by 0.45, a feasible target, air temperature in the city may decrease by 1.6°C.

To evaluate the impact of cool coatings on the possible reduction of the cooling load of buildings, simulations have been performed for a typical building and for about 29 places in Middle East, Africa and South America.

It is found that the expected absolute reduction of the cooling load varies between 5 to 70 kWh/m², depending on the local climate characteristics. Lower contributions correspond to small cooling loads but represent a high percentage of the load, up to 70%, while high absolute contributions correspond to high cooling loads and a lower relative reduction of the load (> 20%). The average reduction of the cooling load because of the use of reflective coatings in the roof of buildings in the selected areas is around 30 to 35%. The cumulative frequency distributions of the cooling load as calculated for both cases and for all the places are given in Figure 7. As shown, while for the conventional buildings, the 50% of the distribution corresponds to a value close to 140 kWh/m²/y, for the case of the building with the reflective roof this is reduced to 85 kWh/m²/y.

Simulations carried out for non air conditioned buildings, for the same places, have shown, for all temperature bases, that when reflective coatings are used on the roof of buildings, indoor thermal comfort is improved considerably. The specific reduction of the hours above a threshold temperature depends highly on the distribution of the ambient temperature during the day, and the overall climatic conditions. It is evident that the higher the temperature base the higher the benefits. In particular, for the temperature base of 30°C, 50% of the distribution corresponds to 3400h and 1700h for the conventional and the reflective roof building respectively. The corresponding values for the temperature base of 27.5°C are 6400h and 4400h, while for the base of 26°C the corresponding values are 7400h and 5800h respectively.

The whole analysis has permitted to conclude that reflective coatings when used in the roof of buildings in hot climates, can contribute highly to improve indoor environmental conditions and decrease the needs for cooling.

![Figure 7 - Cumulative Frequency Distribution of the cooling load for the conventional and for the building with the reflecting roof.](image)

### 11 USE OF ENERGY EFFICIENCY AND SOLAR TECHNOLOGIES

During the recent 30 years, important research has been carried out to develop systems, components and techniques aiming to decrease the energy consumption of buildings and improve their environmental quality. A comprehensive catalogue is given in Figure 8.

Very important progress has been achieved on the topic of passive cooling. In particular new solar and heat protection techniques as well as heat dissipation techniques have been developed and applied in buildings. The use of advanced passive cooling techniques in real buildings permits to minimize their cooling needs or to reduce it at least by 80%.

New advanced systems and techniques are commercially available and most of them are much more competitive than conventional systems and techniques. However, their use on the every day life is
Energy in urban buildings

citizenship

quite limited. It is evident that specific market actions have to be planned and carried out in order to facilitate the integration of the advanced and efficient systems and techniques in buildings.

![Energy-Efficient Solar Building Diagram]

**Figure 8** - Catalogue of systems and components to improve the energy efficiency of buildings and decrease the energy consumption.

Source: EUREC, 2002

12 CONCLUSIONS

Buildings in Europe present high energy consumption and important environmental problems. The absolute energy consumption continues to increase although Europe has signed the Kyoto agreement and has put in force policies aiming to decrease the energy consumption.

In parallel, the very rapid penetration of air conditioning, increases tremendously the peak electricity load of the southern European countries and oblige utilities to built additional power plants. Because of the low usability of the power plants operating under peak load conditions the cost of electricity increases and put low income citizens under serious pressure.

Intensive research carried out during the last years has permitted to develop advanced systems, components and techniques that when applied can reduce the energy consumption of buildings and improve the environmental quality of buildings. The application of the new Directive on the energy performance of buildings will contribute highly to decrease the energy consumption of the buildings sector. However, it is well accepted that the contribution of legislative measures when not combined with intensive research, is quite limited and may offer short term results. Unfortunately, research in Europe has been stopped and such a decision does not allow the expression of optimistic opinions on the future of the building sector in Europe.

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