Managing the Growth of the Demand for Cooling in Urban Areas and Mitigating the Urban Heat Island Effect

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1. Synopsis

The paper presents strategies to reduce the impact from increasing cooling demand in the European Union and establishes links with the urban heat island effect.

2. Abstract

Cooling is one of the latest fashionable end-uses and seems to become a standard in southern Europe and in service buildings in the whole European Union. Cooling of buildings is becoming particularly important in urban environments where air temperatures in densely built urban areas are higher than the temperatures of the surrounding areas. This phenomenon is known as "heat island" effect and, added to the rising living standards among other factors, contribute to drive up the traditionally low demand for artificial cooling in Europe.

The paper is based on a study called URBACOOL (standing for URBAn efficient strategies for COOLing) financed by the SAVE Programme of the European Commission. An overview is given of the practices, techniques and materials that can help mitigate the urban heat island effect and other impacts resulting from the increasing demand for cooling. Priority is given to practices that avoid cooling needs such as energy and environmental conscious urban planning, usage of vegetation, and "cool" materials in pavements and buildings. Lastly, advanced efficient active systems that provide the remaining cooling needs are treated.

A set of policy measures is proposed, requiring the adoption of techniques, materials and practices described. These measures involve the various actors ranging from city developers, building designers, equipment manufacturers and energy companies, to policy makers. The authors, although conscious that the adoption of these measures encounters numerous barriers, show that numerous solutions exist, to be adopted by actors ranging from local to European Union level.

3. Introduction

Demand for artificial cooling has traditionally been very low in Europe. However, clear signs of a growing air conditioning culture started to appear recently. Reasons for this development include increasing thermal loads in buildings due to more equipment, particularly office equipment, cheaper and more widely available cooling technologies. Cooling is becoming a standard in cars, offices and commercial buildings which contributes to a demand for a "continuous" thermal comfort that is spreading also to households. This effect is much stronger in southern European countries, where the climate and the rising living standards are creating an “air conditioning” culture. The situation becomes more severe in urban environments due to the so-called “urban heat island” effect that increases the air temperature and consequently increases the needs for cooling and the smog formation in summer.

The explosion of room air conditioners (RAC) sales confirms this trend. According to the study EERAC - Energy Efficiency in Room Air Conditioners (Adnot et al. 1999), sales are growing at an average of 12% each year. Since 1990 the RAC stock in the EU has grown by a startling average of 35% per annum, while annual RAC sales have doubled over the same period. The EU stock is forecast to grow to 21 million by 2010. The consumption in room air conditioners was 1,6 GWh in 1990, 11 GWh in 1996 and is estimated to reach 44 GWh in 2010. There is however a very large uncertainty in these projections due to the immaturity of the market. Still according to the EERAC study, without policy intervention, RAC associated CO_2 emissions in the EU is conservatively projected to increase by a factor of 20 from 1990 to 2010, the first commitment period used in the Kyoto protocol.

Strategies to mitigate the urban heat islands can bring large energy savings and delay investments in electricity infrastructures, pavements and roofing. They can also improve local environment conditions, i.e. less smog formation, increased thermal comfort, and, at the same time, contribute to aesthetics and general well being.

4. The URBACOOL study

The URBACOOL (standing for URBAn efficient strategies for COOLing) study aims to investigate and propose strategies, tools and guidelines to promote efficient solutions to satisfy cooling needs in urban environments of European cities. The first objective is to combine and adapt scientific and technological knowledge regarding the improvement of:

- Urban microclimate: promote cool sinks, decrease the impact of anthropogenic heat, and reduce the influence of the urban ambient environment on the cooling demand;
- Buildings: and improve building design in urban areas in order to make the best possible use of passive techniques, as well as of new advanced building materials;
- Active cooling systems from district cooling to individual air conditioning appliances;
- Demand-Side Management actions to manage and control the cooling energy needs in urban areas.

The second objective is to study the existing legislative framework on the application of advanced and energy efficient cooling systems and techniques in urban environments, identify possible barriers and contribute to the development of appropriate national and European codes and standards. The last objective is to integrate the results into a set of guidelines for city planners, building designers, installers of cooling systems, energy companies, etc. A set of integrated strategies that make possible the adoption of these guidelines is also proposed.

The study team is composed of the University of Athens - Greece (Co-ordinator), the University of Seville - Spain and the Ecole des Mines de Paris - France. The work carried out in URBACOOL includes case studies that quantify the heat island effect, characterise the over consumption in urban buildings, and calculate the effect of possible changes at all the levels from city planning to air conditioning appliances. Case studies carried out in a few districts in Seville measured the dispersion of air-conditioning needs and their average value according to the city zone. It also evaluates the gains from planting trees. Another case study carried out in a district of Paris quantifies the interest in promoting centralised solutions for air conditioning and district cooling. Yet other case studies were carried out for Athens. One of these ones evaluated the impact of the heat island in the temperature and the actual energy consumption in cooling. These case studies are described in detail in the Urbacool study report to be published in 2001 (Santamouris et al., 2001).

In this paper, preliminary results from case studies carried out for the Western part of Athens are presented. The impact of measures that influence the urban microclimate is estimated, namely extensive tree planting, the use of cool materials and cool sinks.

5. The urban heat island effect

Air temperatures in densely built urban areas are higher than the temperatures of the surrounding areas. The phenomenon is known as the “heat island” effect and is the most obvious climatic manifestation of urbanisation. It can be defined as a "reverse oasis" - a urban area that is hotter than the surrounding countryside due to a lack of trees and vegetation, and use of dark surfaces like roofs and pavements that absorb and retain the sun's heat. (Gartland, 1999).

The main differences between the urban and rural climatic conditions that affect human comfort result from differences in air temperatures and wind speeds near street level. These differences are caused by changes in the radiant balance of the urban space, the convective heat exchange between the ground and the buildings, the air flowing above the urban area, and the heat generation within the city. Temperature distribution in urban areas is highly affected by the urban radiation balance. Solar radiation incident on the urban surfaces is absorbed and then transformed to sensible heat.

The net balance between the solar gains and the heat loss by emitted long wave radiation determines the thermal balance of urban areas. Because the radiant heat loss is slower in urban areas, the net balance is higher than in the surrounding rural areas, and thus temperatures are higher. Effective design of passively cooled urban buildings requires a good understanding of the urban climate characteristics, in particular of the temperature and wind distribution.

Most European studies concentrate on night heat islands during the winter period[1], but few studies analyse the day-period and summer heat islands. Naturally, in cold climates, the urban heat island effect can be positive in

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[1] Studies have been performed in Essen and Fribourg in Germany, Goteborg and Malmoe in Sweden, Zurich in Switzerland etc. (Santamouris et al. 2001b)

terms of energy consumption as it reduces heating needs. Conversely, the heat island effect in warm to hot climates exacerbates cooling energy use in summer. The effect of urban – rural differences can be seen in figure 1. The temperature profile is also strongly dependent on the time of the day.

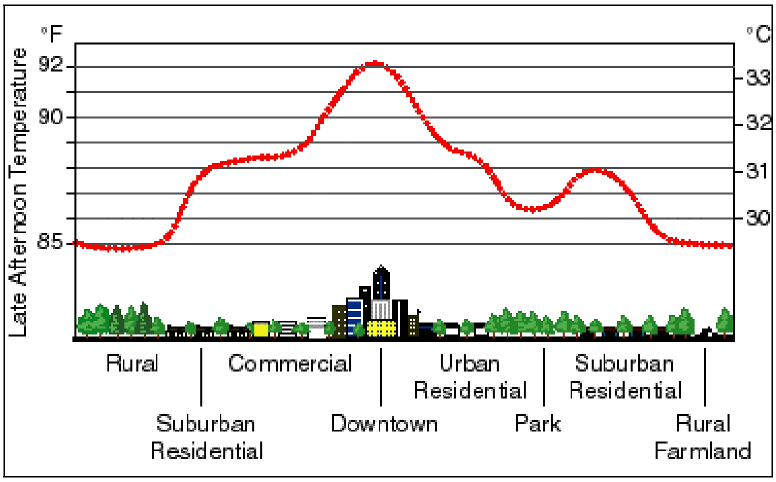

Figure 1. Sketch of a Urban Heat Island Profile (Source: Heat Island Group http://eetd.lbl.gov/HeatIsland)

The Urban heat island phenomenon is characterised by an important spatial and temporal variation related to climate, topography, physical layout and short term weather conditions. The heat island patterns are strongly controlled by the unique characteristics of each city. Factors that influence the heat island effect include:

- Canyon Radiative Geometry that contributes to decrease the long wave radiation loss from the street canyons due to the complex exchange between buildings and the screening of the skyline. Infrared radiation is emitted from the various building and street surfaces within the canyons;
- Thermal properties of materials that increase storage of sensible heat in the fabric of the city during the daytime and release the stored heat into the urban atmosphere after sunset;
- Anthropogenic heat that is released from combustion of fuels either from mobile or stationary sources and the animal metabolism;
- The urban greenhouse effect that contributes to increase the incoming long wave radiation from the polluted urban atmosphere;
- Reduced evaporating surfaces in the city that puts more energy into sensible heat and less into latent heat.

In-depth measurements have been made in Athens (Santamouris et al., 2001b) (Santamouris et al., 1997), where thirty automatic temperature and humidity stations have been installed giving hourly data during more than 3 years since 1996. The main objective of the project was to study various urban micro-climatic conditions. The following conclusions were drawn:

- Cooling degree hours in the central area of the city is about 350% higher than in the suburban areas;
- Maximum heat island intensity[2] in the very central area is close to 16 °C, while a mean value for the major central area of Athens is close to 12 °C;
- The Western Athens area, characterised by scarce vegetation, high building density and a high anthropogenic emission rate, presents twice as many cooling degree-days than the Northern or Southern Athens area. The heat island intensity in the central Park is close to 6.1 °C, compared to 10 °C in stations located nearly. The park further presents almost 40 % less cooling degree-hours than the other urban surrounding stations;
- Heating degree-hours in the very central area of Athens are about 40-60 % lower than in the surrounding suburban areas.

These results indicate clearly the role of urban layout, existence of vegetation and the type of building materials used, on the potential energy demand for cooling urban buildings.

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[2] The Heat island intensity is the difference between the maximum urban temperature and the background rural temperature (Oke, 1987)

6. Strategies at city level

Increased urban temperatures have a direct effect on the energy consumption in buildings, especially during the summer period. Moreover, the production of carbon dioxide and other pollutants also increase. In order to limit the effect of heat islands on energy demand and summer comfort, various measures to be taken at city level are presented in this chapter. They include the use of more appropriate materials, increased plantation and the use of cool sinks.

The role of materials. The use of appropriate materials to reduce the heat island effect and to improve the urban environment has gained increasing interest in the last years. A number of studies try to investigate the impact of the materials' optical and thermal characteristics on the urban temperature as well as on energy consumption for cooling (cf. Special issue of Energy and Buildings, 1997; Rosenfeld et al., 1998). The US Environmental Protection Agency has added roof products to their Energy Star program[3] in 1999 and a cool roofing material database has been produced by the Lawrence Berkeley National Laboratory[4]. Research shows that important energy gains are possible when light coloured surfaces are used in combination with plantation of new trees. Cities, and urban areas in general, are characterised by a relatively reduced effective albedo[5] mainly due to two factors: darker buildings and urban surfaces absorb solar radiation, and urban canyons originate multiple reflections inside them. Typical albedo of European and American cities are close to 0.15 - 0.30, while much higher figures have been measured in some North African cities ranging from 0.45 to 0.60 (Santamouris et al., 2001b). The absence of research of the long-term characteristics of high-albedo materials and the development of alternative building materials with high albedo reflects the lack of awareness and explains the lack of knowledge regarding these materials.

The role of roads and pavements. Paved surfaces like roads, playgrounds and schoolyards can be lightened either by resurfacing or re-paving. Many cities are resurfaced periodically to extend the life of a street or parking area. If the added aggregate is light coloured, a thin layer of asphalt is a good way to increase the albedo of a paved surface. Slurry seal, an aggregate of fine particles mixed with asphalt, is also often used on paved surfaces. Slurry seal typically is cheap but has a low albedo, because of its dark materials. Lighter coloured slurry seals are manufactured around Europe and have been used on tennis courts, plazas, and road shoulders. If a paved surface is structurally damaged and must be replaced, or if a new surface is being constructed, either asphalt or concrete can be used at similar costs. Replacing asphalt with concrete also results in a slight increase in albedo.

The role of trees and vegetation. Vegetation has various effects on urban environment. Beyond the aesthetic role and pleasant nature sensation that trees and vegetation provide, it can increase property value, stabilise soil, provide habitat for wildlife, block noise and improve outdoor air quality. For example, a belt of trees, 30-m wide and 15-m tall, can reduce highway noise by 6 to 10 decibels (Santamouris et al., 2001b). In addition, using the photosynthesis process (vegetation absorbs carbon dioxide and stores some of the carbon) reduces, even if slightly, the greenhouse effect. Leaves can be an efficient filter for air pollutants such as NO, NO_2, NH_3, SO_2 and O_3. In addition, the benefits of trees and vegetation on energy use in buildings are also very important. These effects can be split into direct and indirect effects. The former includes shading and wind shielding while the latter refers to a cooling effect due to evapotranspiration. Air-conditioning energy use can be reduced to 40 or 50 % by shading windows and walls (Santamouris et al., 2001b).

The role of water and cool sinks. A mass of water exhibits a thermal performance different from most land surfaces. The presence of a large mass of water causes an air temperature drop that remains windward depending on wind velocity and the length of the mass of water. Ponds and fountains can be effective air conditioning systems in open spaces because of their ability to keep water temperatures lower than air temperature, and their low reflectivity. As water evaporates from a drop its temperature decreases. Evaporation is proportional to the air-water contact surface area, so incorporating fountains and sprayers (drops with a diameter of several mm) or nozzles (drops of 1 mm or less), effectively decreases the water temperature. The smaller the drops, the greater the air-water contact surface is, and thus evaporation increases. With a constant flow rate, the contact surface produced by a nozzle is 100 times greater than from a sprayer.

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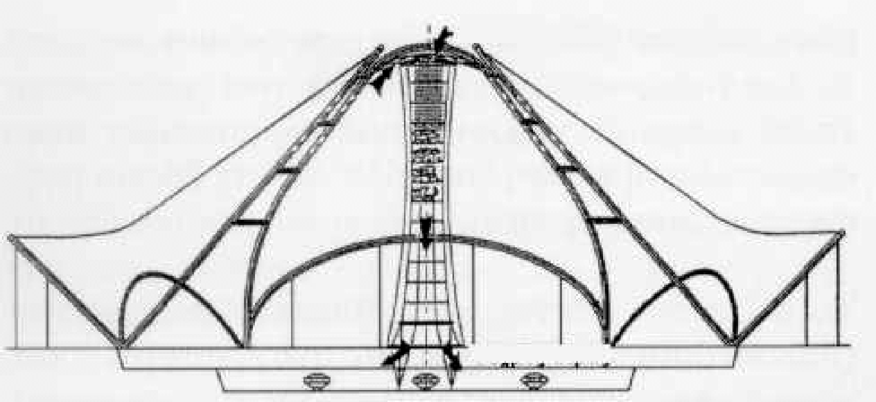
[3] http://www.energystar.gov/products/

[4] http://EETD.LBL.gov/CoolRoof/

[5] The a*lbedo* is the amount of incoming solar energy a material reflects, also called "solar reflectivity" (Gartland, 2000). Use of high albedo materials reduces the amount of solar radiation absorbed (through building envelopes or urban structures) and keep their surfaces cooler.



When fine drops of water are sprayed vertically downward from the top of an open shaft, the falling water entraps a large volume of air. The momentum of the falling water is thus transmitted to an air stream, and an inertial air flow is created. The evaporation of the fine drops cools the air to a level close to the ambient wet bulb temperature.

Figure 2. Inertial/Convective "Shower" Air Cooling Tower - EXPO'92 site in Seville, Spain.

Cooling a neighbourhood or city. Parking lots, plazas, street meridians, sidewalks, private gardens, parks, shopping plazas, and many other niches present potentials for tree plantation. It is important to encourage leaders and developers to keep existing ones from being destroyed, and to include landscaping as part of any development plan. Street design can also allow more green spaces. Modern engineers could use ancient techniques like boulevards to create a green path down the middle of the street and thus double the potential planting space for trees. Each street boulevard km can fit about 250 trees rather than the 125 average of a normal street because the linear curb area is doubled. Unlike the business side of the street, which presents restrictions for trees ranging from sidewalks to power lines, the boulevard can concentrate on landscaping.

7. Natural Cooling Techniques for Buildings in Urban Environments

Even if good practices for environmental and energy-conscious design of buildings are well known, they are not always adopted especially for cooling. One important reason is that only "a few member states have summer requirements in their building regulations" (Maldonado, 2000). Moreover, urban environments usually constrain the adoption of these practices. This chapter focuses on two topics particularly important to buildings in urban environments, which are the building materials that reduce the city's albedo and the use of vegetation in the building envelope. An example of the use of evaporative cooling is also given with the description of a "passive downdraft evaporative cooling towers".

7.1 Building materials and their contribution to the city albedo

Computer simulations shows that white roofs and shade trees in Los Angeles, USA, would lower the need for air conditioning by 18 percent, or around one TWh/year (Rosenfeld et al, 1998). Appropriate materials used in the exterior part of buildings can contribute to decrease its surface temperature and thus reduce the induced air conditioning load. Materials for “cool roofs” or walls present a high albedo to solar radiation, close to 70 %, while conventional roofing or finishing materials have a mean albedo around 20 %. Important energy gains can be expected when solar reflective materials are used in buildings’ exterior surfaces.

Walls and roofs. Some surfaces are easier to modify than others. Building walls are the simplest and cheapest surfaces for albedo modifications. Since many buildings are routinely painted every 10 years or so, changing the albedo of walls is simply a matter of substituting a high-albedo paint for a darker one when repainting. Moreover, some paint companies are now beginning to list reflectivity on their product labels. Changing the albedo of roofs and paved areas can be a more costly measure as it may require the use of more expensive materials. In addition, the energy benefits may not continue over time due to product degradation or dirt accumulation. One simple measure to reduce the albedo in European roofs is the use of lighter-coloured tiles, which has no additional costs.

Results form the case studies in Athens. Three Case studies analysed the impact on the residential buildings of the following measures that influence the microclimate:

- A massive and generic tree planting strategy (distance of 10m between trees with a height equal to 6 m);
- The use of cool materials (road asphalt with an albedo equal to 0.4, and pavement tiles with an albedo equal to 0.6) and cool sinks (water ponds sizing 2x5m each, in the number of 4 per typical canyon);
- The combined use of tree planting, and cool materials and cool sinks.

Several tools were used to perform the simulations including: Geographic Information System tools (ArcView software), tools to simulate the microclimate performance of urban canyons (Green Canyon, developed by the University of Athens), and a building simulation software (TRNSYS). Simulations were performed for each month of the cooling period. The performance of the representative residential building in each zone was evaluated through a series of simulations, according to the main orientations of the selected representative urban canyons. The results were extrapolated in order to take conclusions at a generic city level. The results of the energy performance simulations for the selected representative building are given in table 1. The buildings' cooling requirements were calculated for the two main orientations in the Egaleo area (two other microclimate zones were also simulated to analyse the impact of tree planting).

Table 1. Impact in cooling requirement from the adoption of measures that influence the urban microclimate. Simulations of typical residential buildings in Egaleo - Western Athens area.

Type of intervention	Decrease in temperature	Decrease in energy needs due to intervention	Savings in electricity bill per household (Euro)
Tree planting *	0,5 to 0.7 °C	9%	16
Use of cool materials and cool sinks	0,2 to 0.4 °C	4%	7
Combination of tree planting and use of cool material and cool sinks	0,5 to 0.8 °C	11%	20

* The analysis carried out in 3 microclimates, for two different canyon orientations in each microclimate, gave similar results.

The simulations also showed that the impact in terms of reduction in temperature and cooling requirements does not vary significantly with the microclimate area or with the canyon orientation. It also showed that the heat island effect over the Great Western Athens area (that increases energy requirements of the residential buildings for cooling up to 22%) can be partially reduced.

7.2 Vegetation in the building envelope and planted roofs

Plants transform a very small part of the solar radiation by photosynthesis into chemical energy, and in this way reduce the rate of heating of the urban space slightly. However, the plant's efficiency in transforming energy is negligible (1-2%). On the other hand, evaporation of water from the leaves (evapotranspiration) cools significantly the leaves and the air in contact with them, and at the same time increases the air humidity. Given the limited space available for trees in the cities, the use of vegetation can be planted in the building facade or on roofs.

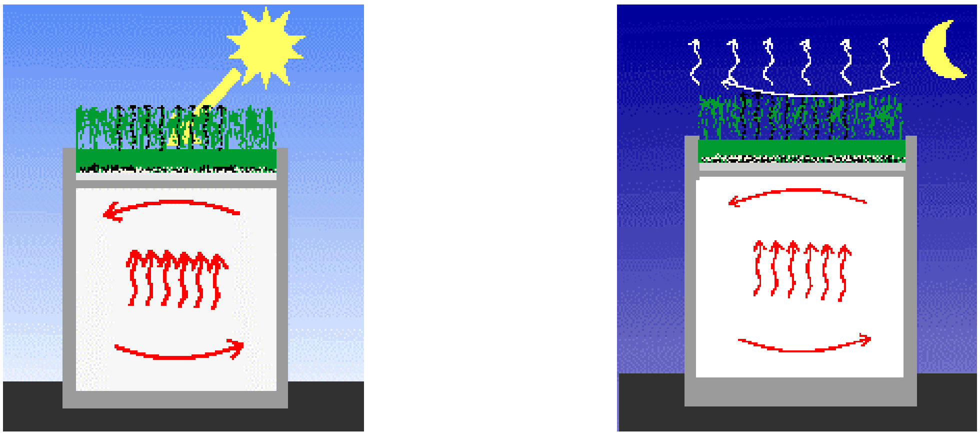


Figure 3. Planted roofs daytime and night (Santamouris et al., 2001)

A roof planted with vegetation may serve a number of different functions. In visual terms, it replaces the area of green removed by the insertion of a building on a site, and, when accessible, it provides a private roof garden. In technical terms, the planting acts as a form of solar control on the roof and provides thermal insulation to the parent building. It can also contribute to stabilise indoor temperatures. Major conclusions of a thorough study and analysis of experimental data, carried out by the University of Athens (Santamouris, 2000), are summarised as follows:

- The type of vegetation used influences the surface temperature of the green roof. Plants should be chosen for the specific conditions of the growing medium laid on the roof, the local climate and the structure of roof. The waterproofing coats (normally three coats of mastic asphalt to total thickness of 30 mm on horizontal surfaces) need protection from roots penetrating the membrane and a drainage layer. Locally found species (adapted to the climate) may require less maintenance and less water, which can be an important limitation and therefore should influence the choice of the plants;
- The green roof contributes to the modulation of the air temperature in the building's interior spaces. During the summer period, the external surfaces with the green roof are heated less than traditional flat roofs. Besides, during winter, planted roofs have lower heat losses;
- The estimated heating and cooling loads are lower in buildings with green roofs, regardless of the kind of roof insulation, the reduction being lower in well insulated buildings.

7.3 Passive Downdraft Evaporative Cooling Towers (PDEC)

The simplest evaporative cooling system consists of an air supply duct incorporating a water spray system or a wetted porous pad. This system is called "direct evaporative system" and its use is recommended only in arid climates. The applicability of evaporative systems in regions other than arid ones is closely linked to the use of these systems in combination with other techniques or strategies. An innovation consists of replacing the wetted pads with rows of atomisers (nozzles, which produce an artificial fog by injecting water at high-pressure trough minute orifices). This possibility produces much better regulation of the system and a significant reduction of the pressure losses. The situation of the micronisers in a tower gives rise to a naturally downdraft effect.

In a urban context, air intakes at roof level minimises the pollution problems and takes advantage of the pressure forces due to the less disturbed wind velocity at such levels. Additionally, the towers can be designed to provide daylight to the interior spaces of the building. The tower is composed of the "body" which crosses all the floors and the "head" that raises over the roof. The head acts as the air inlet for the PDEC and as light catcher and diffuser. It contains the ring of micronisers and the evaporative zone.

The air opening is designed in order to control the wind effect and avoid turbulence inside the tower. The body distributes air and light to the offices using a glazed cylinder of 3-m diameter with circular openings (air inlets) situated close to the ceiling at each floor. The water droplets in the tower evaporate taking energy from the surrounding air, which becomes cooler. The air in the tower is then cooler than the indoor air of the offices creating the downdraft effect. Different inlets and outlets are required in order to equalise the airflow rate in the three floors. The PDEC system only operates when the supply air temperature is at least two degrees below the indoor temperature. In such cases, when the supply air's relative humidity is larger than a prescribed value, the control modulates the number of micronisers. A second modulation of the number of micronisers into operation appears when the outdoor air temperature (and consequently the load) is lower than the design value. Even if the cooling load is zero, the PDEC system operates so as to provide the ventilation needs of the building and an eventual night cooling effect. An example of a PDEC system from building occupied space in an office building and results on its thermal performance can be seen the figure 4a and 4b.

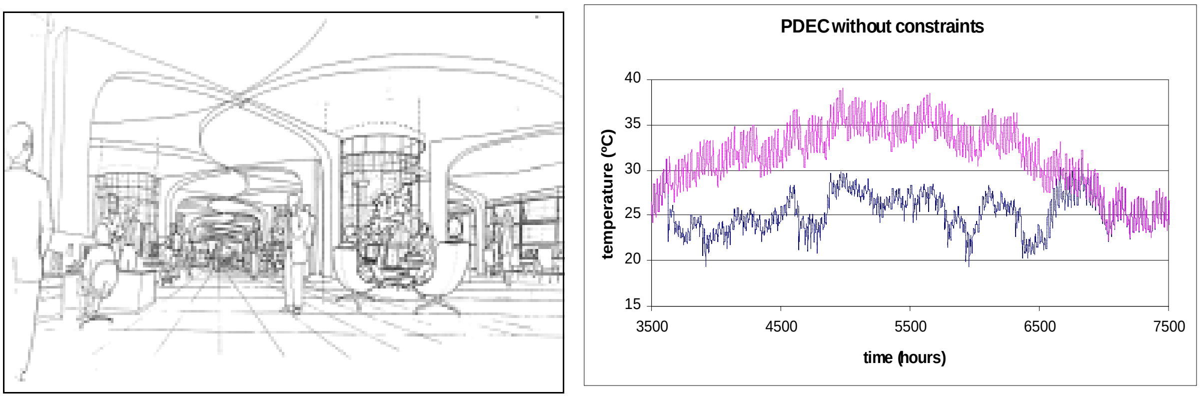


Figure 4a. Passive Downdraft Evaporative Cooling Towers (PDEC) and 4b. Thermal performance of the PDEC (the dark line corresponds to the situation with a PDEC) - (Santamouris et al. 2001)

8. Advanced Cooling Solutions

Energy conscious urban planning and building design are the solutions to be prioritised in providing summer comfort. However, urban environments constrain the use of passive and low energy cooling techniques. Thus, in many situations, it will not be possible to avoid the use of active cooling solutions. Part of the URBACOOL study is to investigate the advanced cooling solutions in urban environments, the barriers preventing their use, and eventually propose regulatory and policy instruments that can contribute to their actual use. Following the descending approach adopted in URBACOOL, the following solutions were investigated: (1) district cooling, namely its economic feasibility, (2) central air conditioning and (3) individual air conditioning.

An air conditioning system is probably the most complicated service utility in the building sector, since it enables to heat, cool, wet and dry the air. The choice of the type of the cooling system is obviously influenced by a myriad of factors. Regarding district cooling, the conditions necessary, or that justify its construction, are even more site dependent. As an illustration, the first district cooling networks appeared in Northern European cities (e.g. Stockholm) where cooling demand is very low but where other networks were being installed, thus permitting the installation of a cooling network at low marginal cost. Others appeared due to a circumstantial overcapacity (Climespace in Paris), or in new urban areas where they were bundled with other developments (e.g. Lisbon World Exposition Expo'98 site).

The need for a better energy efficiency metrics. Policy instruments and information to professionals and consumers are handicapped by the fact that manufacturers provide data on energy efficiency performance that do not correspond to the real life use conditions. The two indicators used - Energy Efficiency Ratio (EER, used for cooling) and the Coefficient of Performance (COP, used for heating) - have two limitations. The first limitation is that EER and COP are obtained at nominal testing conditions. Therefore, a method needs to be developed to better reflect the actual performance under normal functioning conditions. Such a method exists in the USA under the name of Integrated Part Load Value[6] (IPLV) or Seasonal Energy Efficiency Ratio (SEER). This method is an attempt to compute an average EER expressed as the summation of percentages of time working at part load. However, IPLV is available only for the all water system designed in the US way and for US climate and therefore need to be adapted for the EU conditions. The second limitation is that EER, and also IPLV, are usually given by manufacturers for the chiller only and not for the systems, i.e. consumption in auxiliary equipment is not included. This consumption is responsible for 20 to 60% of the systems consumption, being the highest values for "all air systems" and the lowest for "water systems" (EIA, 2000).

Selecting an air conditioning equipment. Even if the EER does not provide the exact measure of a system's actual consumption, it is still a useful indicator of its performance, especially when comparing similar equipment. The EER distribution of the appliances in the market shows the large energy conservation potential of just making an efficient choice. The following figure illustrates this fact for room air conditioners and central air conditioners.

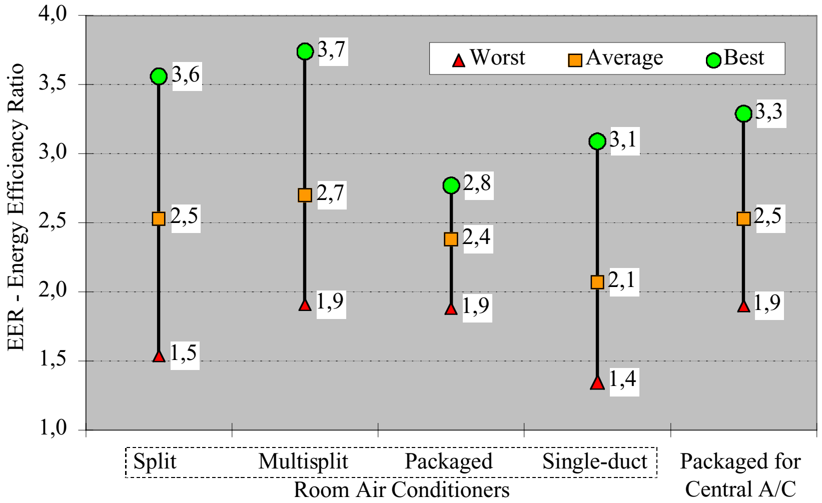


Figure 5. EER distribution on the European Union market of Room Air Conditioners and Chillers - Cooling only, air-air (After Adnot et al. 1999, Eurovent-Certification, 2000)

A life cycle cost analysis constitutes the best approach upon which to base a purchasing decision and it is often used to guide the design of policy instruments, e.g. in studies under the SAVE programme of the European Commission. However, consumption in cooling presents much greater variations than other end-uses since it depends on factors like climate, occupation, internal gains, building thermal performance etc. This makes the

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[6] Defined in the norm American Refrigeration Society ARI 550/590-98

life cycle cost difficult to determine and the design of policy instruments particularly prone to conflicts. Nevertheless, the study EERAC - Energy Efficiency in Room Air Conditioners (Adnot et al., 1999) (Adnot et al., 2000), that provided the bases for the European Labelling of RACs, found out that the lowest life cycle cost corresponds to an increase of 25% in the Energy Efficiency Ratio. Moreover, an increase of 40 to 50% in EER would be possible without increasing the life cycle cost of the appliances presently on the market. These results were obtained for a typical appliance, used in the residential sector, in an "average" climate[7], and can vary significantly depending on the conditions of use.

Individual vs. central air conditioning. Regarding the choice between individual vs. central air conditioners (CAC), a technical and economic analysis is even more difficult to perform as it requires the simulation of numerous situations. Such an exercise has been attempted for different cooling needs and different building areas. The results show that total costs are very similar between RACs and CACs, and that CAC systems are in general more energy efficient than RACs. RACs also provide a more uniform comfort, and, if the costs of discomfort would be taken into account, the result of the life cycle cost analysis would be certainly more favourable to CAC systems. From the local authorities' point of view, CACs are preferable to RACs since they require more local activity with designing, installing and maintaining the central systems, while RACs can be bought in a DIY supermarket. However, the energy efficiency of a CAC system can vary significantly depending on the type of building and its occupancy. The analysis carried out illustrated the sensitivity of energy consumption and total costs to some parameters (losses, auxiliary equipment, occupancy schedules, electricity tariffs, other uses, load curve etc). In some cases, RACs can be the best option (e.g. some hotels with separated buildings and with intermittent occupancy, etc.) and the simple interdiction for energy efficiency reasons might not be the best option. The analysis found out that, in some cases, individual air conditioning can be preferable to central air conditioning.

A subject that is closely related to the increasing penetration of air conditioning equipment is the reversibility, i.e. the heating mode. In fact, the functioning as heat pump presents potential energy efficiency improvements especially when replacing or avoiding the installation of Joule effect heating systems (simple resistive heating element).

9. Cooling: a very expensive end-use and a great potential for DSM

Cooling in cities causes also problems to electricity companies. Dramatic blackouts have occurred in the United States (in 1999 in Chicago - Illinois and Long Island - New York, California in 2000) with an obviously large contribution from air conditioning (ASAP, 2000). In Europe, national electricity system peaks have traditionally occurred in winter, except for Greece. However, a study carried out by INESTENE (Cauret et al., 2000) for France, Greece, Italy, Portugal and Spain indicates that this situation is changing (see table 2 and figure 6). If we except the French case pushed by the electric space heating in winter, the simulations show a possible transfer of the annual extreme peak hours from the winter to the summer in the 3 other countries studied. Furthermore, these peaks were determined in a national perspective and would certainly be worse in some regions, particularly in local urban environments.

Table 2. Annual electricity system peak in 5 EU countries - 1995-2020 (Source: Cauret et al. 2000). Unit: GW

	France	**Greece**	**Italy**	**Portugal**	**Spain**
1995	62.4 January	6.0 July	44.2 December	4.7 January	25.8 December
2020 BAU [1]	90.0 +44% January	9.4 +57% July	64.0 +45% July	8.9 +89% September	42.1 +63% September
2020 DSM [2]	74.0 January	8.1 July	55.0 July	7.4 September	35.0 September
Net gains	16.0	1.2	9.0	1.4	7.0

[1] BAU - Business as usual scenario [2] DSM - Demand-Side Management: scenario considering the adoption of energy efficiency policies and measures.

The growth in cooling demand and the consequent increase in the electricity systems peak induces large investments on the supply side to meet future demand. Therefore, energy efficiency and load management in cooling becomes particularly important since cooling deteriorates the annual load shape due to large monthly

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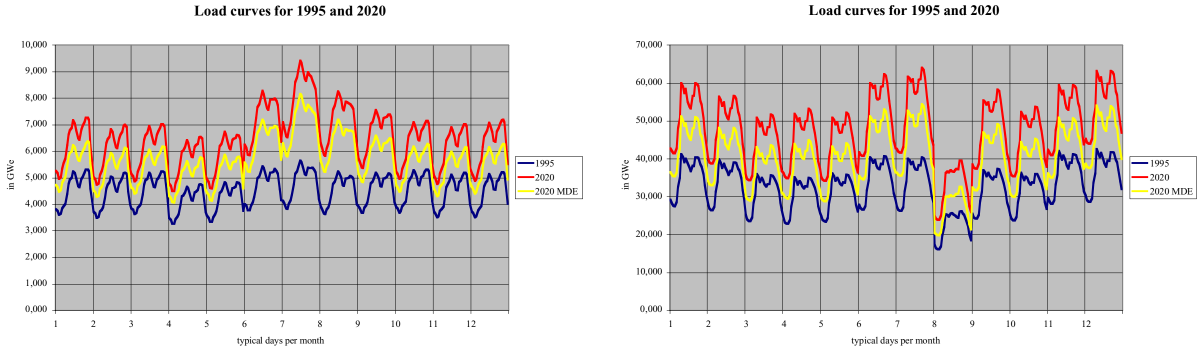
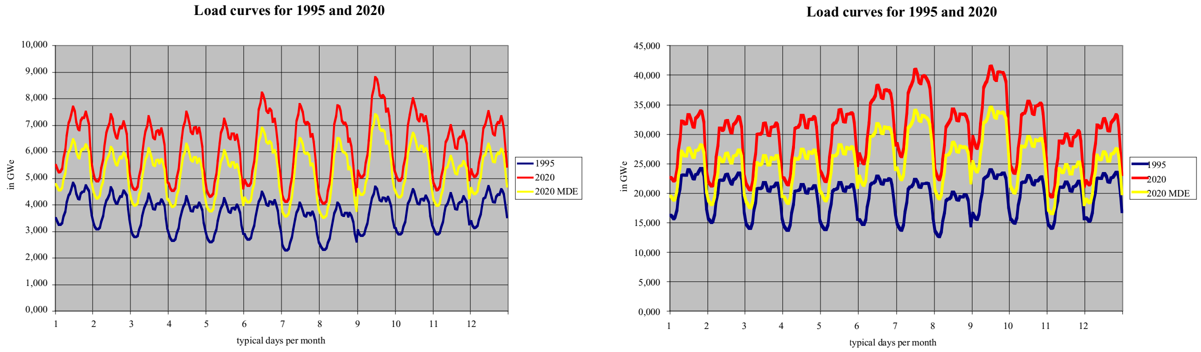
[7] Average of 16 zones in the European Union of equivalent hours at nominal rating conditions, weighted by market shares in the considered zones.

variations, and also the daily load shape due to large time-of day variations (decrease of the load factor). This creates a need for large investments in new generation, transmission and distribution capacities. Moreover, high temperatures originate higher electric losses and increase the likelihood of system failures. In addition, cooling is even more problematic in urban environments where distribution lines are more expensive and cooling needs are higher due to the heat island effect and the high concentration of tertiary buildings. These factors - lower annual and daily load factors, higher electric losses, increased risks of power failures - make too extensive cooling an undesired end-use in Southern European countries. Nevertheless, some Southern European energy companies are still promoting the use of cooling (EDP, 2000). This situation seems to result primarily from short-term objectives and from the difficulty in taking into account that cooling will create reliability problems and reduce subsequent company's profits in the medium term. It is also the result of the difficulty in establishing a tariff system that takes the medium term into account and reflects the real cost of one single end-use as particular as cooling.



Greece : 1995 – 2020 BAU – 2020 DSM

Italy : 1995 – 2020 BAU – 2020 DSM



Portugal : 1995 – 2020 BAU – 2020 DSM

Spain : 1995 – 2020 BAU – 2020 DSM

Figure 6. Evolution of load curves 1995 - 2020. Projections by INESTENE. Source: (Cauret et al. 2000)

When the regulatory framework gives energy companies the possibility to recover through tariffs the additional investments to satisfy all the increasing cooling needs, energy companies do not receive the right incentive to engage in demand-side management activities and might over-invest in infrastructures (Lopes et al. 2000). The regulatory framework could instead give the companies the possibility to recover investments in demand-side management programmes. Therefore, energy companies have to be a crucial party, along with municipalities and regulators, in a process aiming at satisfying the provision of cooling at the least societal cost, e.g. by participating in energy efficiency and DSM measures whenever it is cheaper for society.

10. Integrating the approaches

Energy conservation in heating has been addressed by many instruments, notably building codes at National level. Conversely, little has been done regarding summer comfort and/or reducing consumption for cooling. The fact that the hottest countries were among the poorest in Western Europe, with less tradition of space conditioning (or possibility to afford it), certainly contribute to this fact. However, this situation is changing. Southern European countries have experienced improved life conditions, cooling and heating technologies are more affordable and are present everywhere from cars to commercial and service buildings. This exploding demand for cooling becomes even more problematic in urban environments due to the heat island effect.

Moreover, cooling is particularly expensive to satisfy, since it deteriorates the annual and daily load shape, leading to expensive investments.

Techniques and strategies following an approach that integrate urban planning, building design, active systems and their management have been presented in this paper. However, policy instruments are needed if the mentioned techniques and strategies are to be implemented. Such instruments need to involve several actors: governments, energy companies, manufacturers, designers and installers. Correspondingly, these instruments have to be adopted at various levels: European, National and local. The recommendations presented in table 3 and 4 are classified using the latter structure.

Table 3. Recommendations for policy instruments and measures at European Union, National and local level to reduce cooling consumption in urban environments

Policy measures at all levels

- Provide assistance to municipalities to adopt urban heat island attenuation measures. An interesting initiative is being taken by the International Council for Local Environmental Initiatives (ICLEI, 2000). It consists in the preparation of a model ordinance to assist "cities, counties and other local governments in adopting a local government ordinance to mitigate the effects of urban heat island". It shows the possibilities of synergies between international co-operation and actions at local level.
- Adopt procurement rules for European, National or local public owned facilities based on life cycle cost analysis. This kind of approach exists in the USA[8] and has been proposed in the energy efficiency action plan presented by the European Commission.

Policy measures at European level

- Adopt energy labelling to equipment for both central and room air conditioners.
- Adopt energy efficiency standards eliminating the worse products from the market.
- Implement energy building energy certification and extend it to include air conditioning systems (in 93/76/EEC to limit carbon dioxide emissions by improving energy efficiency -SAVE). Extend inspection of boilers to air conditioning systems.
- Develop standard methods to calculate equivalent annual EER and COP of air conditioning equipment, including a method to take into account climatic regional differences.
- Promote convergence between building regulations within the EU. Obviously, the requirements should not be the same but adapted to the Member States or regional situations, e.g. building codes have to be dependent on the climate and existing building materials available.
- Promote training and certification for installation and maintenance companies.
- Strengthen focus on equipment that are heavy contributors to cooling loads like office equipment (including energy management and stand-by issues) and lighting, thus reaching a "double dividend", to reduce the direct energy consumption and the indirect consumption resulting from air conditioning.

Policy measures at National level

- Adapt building regulation to take into consideration summer comfort and cooling needs, following EU guidelines whenever possible.
- Co-ordinate with forestry institutes to determine the adequate tree management in cities.
- Develop product guides and guidelines for "cool" materials.
- Involve all actors in the air conditioning equipment chain: manufacturers, distributors, designers, installers and consumers.
- Promote energy savings performance contract frameworks specific to air conditioning.

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[8] Federal Energy Management Program of the Department of Energy -USA. Executive order *13123 "Greening the Government Through Efficient Energy Management"* requires federal energy agencies to reduce energy use in Federal building, namely by "using life-cycle cost analysis in making decisions about their investments in products, services, construction, and other projects to lower the Federal Government's costs and to reduce energy and water consumption". http://www.eren.doe.gov.

Table 4. Recommendations for measures at local level to reduce cooling consumption

Measures at local level with municipalities acting as:	
Planning actors	- Require more than the national building codes especially in what respects summer comfort and cooling needs. Additional requirements can include: establish guidelines for using roofs with a higher reflectivity and emissivity than usual; use pavements with higher reflectivity in streets, sidewalks, parking lots etc. - Issue ordinances addressing tree planting requirements as part of a tree management master plan. - Adopt building certification programmes. - Use spatial tools to evaluate energy conservation potentials, plan and verify the implementation of the measures required. - Use their role of licensing entity for electricity distribution and supply. Municipalities can collaborate with license holders or even establish demand-side management obligations. Electricity systems, in most southern European cities, have to cope increasingly with the highest demand when it is more vulnerable and the losses are the highest. Cooling contributes particularly to these periods, resulting in very high costs. Activities to be developed include with energy companies rebates, financial solutions and create energy service provision that promote the adoption of passive and low energy cooling, high energy efficient equipment, advertising campaigns, training courses to installers and users, etc.
Motivators	- Promote, in association with their local energy agencies, energy and environmentally friendly solutions, like planting of trees in ground gardens and roofs, cool materials for private pavements and roofs. This can be achieved by issuing product guides and supplier directories, contacting building owners, etc.
Energy consumers	- Act as leader by example by adopting materials, technologies, and practices that help contribute to attenuate the urban heat island effect and reduce consumption for cooling.

Most of the policy measures presented in table 3 and 4 have been tried for other purposes than cooling, and others need to be reinforced. This non-exhaustive list of recommendations shows that many possibilities exist requiring the involvement of a large number of actors at various levels, which also illustrates the complexity of managing the growth for cooling demand.

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