Passive cooling of buildings

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PASSIVE COOLING OF BUILDINGS

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Abstract

The present paper presents the state of the art on passive cooling technologies for buildings. The penetration of air conditioning is increasing rapidly all around the world. This has an important energy and environmental impact. During recent years, passive cooling techniques has received a very important attention and important developments have been achieved. The first part of the paper discusses the actual penetration of air conditioning systems and problems resulting from using mechanical cooling. The second part classifies passive cooling systems while the third and fourth parts deal with the urban microclimate and possible improvements to urban thermal conditions. Finally, the fifth part discusses the recent progress on heat and solar control, thermal comfort and heat inertia techniques as well as heat dissipation methods.

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 (CICA, 2002). 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 (UNCHS, 1993), while is responsible for almost 70% of emitted sulphur oxides and 50% of the CO_2 (Der Petrocian, 2001).

Energy consumption of the building sector is high. Although figures differ from country to country, buildings are responsible for about 30-40% of the total energy demand. Application of intensive energy conservation measures has stabilized energy consumption for heating in developed countries. However, energy needs for cooling increases in a dramatic way. The increase of family income in developed countries has made the use of air conditioning systems highly popular. In Europe the main commercial market for cooling and air conditioning systems totals <u>8 billion Euros</u>. Almost 6% of office, commercial and industry buildings are cooled, making a total volume of about 20 million cubic meters (Adnot, 1999). The volume of air-conditioned buildings in Europe is expected to increase four times by the year 2010.

In the United States, the penetration of air conditioning is extremely high. More than 3.5 billion m^2 of commercial buildings are cooled. The total cooling energy consumption for the commercial sector is close to 250

Twh/y, while the necessary peak power demand for summer cooling of the commercial buildings is close to 109 GW.

The impact of air conditioner usage on electricity demand is an important problem as peak electricity load increases continuously, forcing utilities to build additional plants. In parallel, serious environmental problems are associated with the use of air conditioning.

Passive and hybrid cooling techniques involving microclimate improvements, heat and solar protection, and heat modulation and dissipation methods and systems can greatly contribute to buildings' cooling load reduction and increase thermal comfort during the summer.

Results of the European Research Project PASCOOL , (Santamouris and Argiriou, 1997), showed improved knowledge on this specific topic and develop design tools, advanced techniques to better implement natural cooling techniques and new techniques to characterize the performance of passive cooling components have been developed as an aid to designers (Santamouris and Argiriou, 1997).

This paper aims to present the actual state of the art in the field of passive cooling of buildings. The first part of the paper discusses the actual penetration of air conditioning systems and problems resulting from using mechanical cooling. The second part classifies passive cooling systems while the third and fourth parts deal with the urban microclimate and possible improvements to urban thermal conditions. Following that we will discuss recent progress on heat and solar control, thermal comfort and heat inertia techniques as well as heat dissipation methods.

2. On the Cooling Needs of Buildings

Increased living standards in the developed world using non-climatically responsive architectural standards have made air conditioning quite popular. Importantly, this has increased energy consumption in the building sector. Actually there are more than 240 million air conditioning units and 110 heat pumps installed worldwide according to the International Institute of Refrigeration (IIR) (IIR, 2002). IIR's study shows that the refrigeration and air conditioning sectors consume about 15% of all electricity consumed worldwide (IIR, 2002). In Europe it is estimated that air conditioning increases the total energy consumption of commercial buildings on average to about 40 kWh/m2/year (Burton, 2001).

It is evident that the total energy consumption of buildings for cooling purposes varies as a function of the quality of design and climatic conditions. In hot climates, as in the Mediterranean, commercial buildings with appropriate heat and solar protection and careful management of internal loads may reduce their cooling load down to 5 kWh/m2/year, (Santamouris and Daskalaki, 1998), while buildings of low quality environmental design may present loads up to 450 kWh/m2/y (Santamouris, 1997). Under the same climatic conditions and when internal gains are not important, such as in residential buildings, the use of air conditioning may be completely avoided when efficient solar and heat protection as well as heat modulation techniques are used.

2.1 Recent Penetration of A/C systems

Referring to the IIR data there are almost 79 million room air conditioners, 89 million duct-free and split systems, 55 million ducted split systems, 16 million unitary commercial systems and almost 856,000 water-based air conditioners.

Annual sales of air conditioning equipment approach a level of $60 billion, of which $20.9 billion are spent for room air units, $15.7 billion for packaged systems, $6.5 billion for rooftop units, and $12.3 billion for residential heat pumps (IIR, 2002). This is almost equivalent to 10% of the automobile industry in a worldwide basis

The air conditioning market is expanding continuously. According to the Japan Air Conditioning and Refrigeration News (JARN) and Japan Refrigeration and Air Conditioning Industry Association (JRAIA) in 1998 the total annual number of sales was close to 35,188,000 units; by 2000 it had increased to 41,874,000 units and to 44,614,000 units by 2002, with a predicted level of 52,287,000 units in 2006 (JARN and JRAIA, 2002).

Most of the units are installed in North America, where the sales are not expected to increase further. In Europe, an increase of 22.3% is expected between 2002 and 2006, while the corresponding increases are expected to be 39.2% for the remainder of Asia, 23.2% for Oceania, 13.6% for Africa, 13.3% for South America and 10.5% for Middle East (Table 1).

Table 1. Actual and forecasted air conditioning sales in the world (JARN and JRAIA, 2002).

	1998 Actual	**1999 Actual**	**2000 Actual**	**2001 Actual**	**2002 Projected**	**2003 Forecast**	**2004 Forecast**	**2005 Forecast**	**2006 Forecast**
World total	35,188	38,500	41,874	44,834	44,614	46,243	47,975	50,111	52,287
Japan	7,270	7,121	7,791	8,367	7,546	7,479	7,344	7,459	7,450
Asia (excl. Japan)	11,392	11,873	13,897	16,637	16,313	17,705	19,227	20,890	22,705
Middle East	1,720	1,804	1,870	1,915	1,960	2,010	2,060	2,112	2,166
Europe	1,731	2,472	2,709	2,734	3,002	3,157	3,318	3,489	3,670
North America	10,437	12,408	12,322	11,894	12,521	12,522	12,524	12,525	12,525
Central & South America	1,588	1,665	2,109	1,939	1,866	1,906	1,973	2,043	2,114
Africa	511	670	664	758	781	806	833	861	887

Oceania	539	487	512	593	625	659	693	731	770

(In thousands of units)

The predicted 2002-2006 progression is more marked for room air conditioners, (+20%) as shown in Table 2, than for packaged air conditioners as shown in Table 3, (JARN and JRAIA, 2002).

Table 2. Actual and forecasted room air conditioning sales worldwide (JARN and JRAIA, 2002).

	1998 Actual	1999 Actual	2000 Actual	2001 Actual	2002 Projected	2003 Forecast	2004 Forecast	2005 Forecast	2006 Forecast
World total	26,410	29,208	31,538	34,695	34,238	35,663	37,166	39,049	40,956
Japan	6,599	6,492	7,084	7,638	6,898	6,829	6,692	6,793	6,773
Asia (excl. Japan)	10,101	10,488	12,034	14,593	14,210	15,436	16,776	18,244	19,846
Middle East	1,378	1,454	1,507	1,552	1,591	1,634	1,677	1,722	1,768
Europe	1,442	2,134	2,312	2,319	2,565	2,699	2,837	2,984	3,140
North America	4,501	6,079	5,586	5,581	5,986	5,987	5,988	5,989	5,989
Central & South America	1,449	1,523	1,959	1,793	1,721	1,762	1,826	1,892	1,960
Africa	469	626	623	714	737	761	786	813	838
Oceania	471	412	433	506	530	556	583	612	642

(In thousands of units)

Table 3. Actual and forecasted packaged air conditioning sales worldwide (JARN and JRAIA, 2002).

	1998 Actual	1999 Actual	2000 Actual	2001 Actual	2002 Projected	2003 Forecast	2004 Forecast	2005 Forecast	2006 Forecast
World total	8,778	9,292	10,336	10,139	10,376	10,580	10,809	11,062	11,331
Japan	671	629	707	729	648	650	652	666	677
Asia (excl. Japan)	1,291	1,385	1,863	2,044	2,103	2,269	2,451	2,646	2,859
Middle East	342	350	363	363	369	376	383	390	398
Europe	289	338	397	415	437	458	481	505	530
North America	5,936	6,329	6,736	6,313	6,535	6,535	6,536	6,536	6,536
Central & South America	139	142	150	146	145	144	147	151	154
Africa	42	44	41	44	44	45	47	48	49
Oceania	68	75	79	87	95	103	110	119	128

(In thousands of units)

Air conditioning penetration in Europe is much lower than in Japan and the USA. According to the "Energy Efficiency of Room Air-Conditioners" (EERAC) study, the 1997 penetration rate of room air conditioners was less than 5% in the residential sector and less than 27% in the tertiary sector (Adnot, 1999). The corresponding penetration rate in the tertiary sector is almost 100% in Japan and 80% in the USA, while almost

85% and 65% respectively of the residential buildings in Japan and USA have at least one air conditioner (see Table 4).

Table 4. Penetration of room air conditioners in the tertiary and residential sector in US, Japan and Europe for 1997 (Adnot, 1999).

COUNTRY	TERTIARY	RESIDENTIAL
Japan	100%	85%
USA	80%	65%
Europe	<27%	<5%

As shown in Table 5 almost 74% of the total stock of air conditioners in Europe are installed in Southern countries (Adnot, 1999). 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 (Adnot, 1999).

Table 5. 1996 stock of different systems of room air conditioners in Europe (Adnot 1999).

	Split	Multi-split	Windows	Single-duct	Total
Austria	33 400	21 300	16 600	7 700	79 000
France	752 000	183 850	106 500	216 750	1 259 100
Germany	198 600	59 600	74 500	193 400	526 100
Greece	138 000	51 830	555 000		744 830
Italy	1 504 697	90 177	134 860	382 006	2 111 740
Spain	972 000		245 000	152 000	1 369 000
Portugal	267 157	30 143	17 720	7 800	322 820
UK	516 690		54 867	107 755	674 412
Others	119 160	31 100	44 700	116 040	315 660
Total EU	4 501 534	468 000	1 249 747	1 183 451	7 402 662
%	61%	6%	17%	16%	100%

In the United States, the number of households having a central air conditioning has increased from 17.6 million in 1978 to 47.8 in 1997. In the same period the number of households with room air conditioners increased from 25.1 to 25.8 millions (see Table 6) (EIA, 1997). The electricity consumption for air conditioning during the same period has increased from 0.31 to 0.42 Quadrillion of Btu (kWh or Twh) The main reason that electricity consumption has not followed the rate of penetration of air conditioners is the increased efficiency of air conditioners.

Table 6: Consumption of Electricity for Air-Conditioning and Associated Factors by Survey Year (EIA 1997).

Survey Year	Household Electricity Consumption for Air-Conditioning (TWh)	Number of Households with Central Air-Conditioning (million)	Number of Households with Room Air-Conditioning (million)	Average SEER of Central Air-Conditioning Units Sold During the Year
1978	1.06	17.6	25.1	7.34
1980	1.09	22.2	24.5	7.55
1981	1.12	22.4	26.0	7.78
1982	1.13	23.4	25.3	8.31
1984	1.09	25.7	25.8	8.66
1987	1.50	30.7	26.9	8.97
1990	1.64	36.6	27.1	9.31
1993	1.57	42.1	24.1	10.56
1997	1.43	47.8	25.8	10.66

The US commercial sector’s total energy cooling consumption is close to 250 Twh/y, while the necessary peak power demand for summer cooling is close to 109 GW. As shown in Table 7 in 1997 American households spent almost $140 per year for air conditioning, while almost 40% used their air conditioner all summer (EIA, 1997).

Table 7. Electric Air Conditioning Expenditures and Usage – 1997 (EIA, 1997).

Average Annual Expenditures for Households Having Electric Air Conditioning	Of all Households, Percent Having Electric Air-Conditioners	Of All Households Having Electric Air Conditioners, Percent That Used Them All Summer	Of all Households, Percent That Have Electric Air Conditioners and Used Them All Summer
$140	72	40	30

Most office buildings in the US have at least one air conditioning system (Table 8). Packaged air conditioners, central systems and heat pumps are the more popular systems (EIA, 1995).

Table 8: Number and percent of office buildings in each size category by cooling (EIA, 1995).

	Number of Buildings (thousand)			*Percent of Buildings*		
	Small	**Medium**	**Large**	**Small**	**Medium**	**Large**
All Office Buildings						
Residential-Type Central A/C	122	53	-	30	20	-
Heat Pumps	91	43	5	22	16	12
Individual A/C	-	11	-	-	4	-
District Chilled Water	-	-	3	-	-	7
Central Chillers	-	11	15	-	4	39
Packaged A/C Units	126	124	12	31	48	30

2.2 Main Problems of Air Conditioning

There are different problems associated with the use of air conditioning. Apart from the serious increase of the absolute energy consumption of buildings, other important impacts include:

- The increase of the peak electricity load;
- Environmental problems associated with the ozone depletion and global warming;
- Indoor air quality problems.

High peak electricity loads oblige utilities to build additional plants in order to satisfy the demand, but as these plants are used for short periods, the average cost of electricity increases considerably. Southern European countries face a very steep increase of their peak electricity load mainly because of the very rapid penetration of air conditioning. For example, Italy faced significant electricity problems during the summer of 2003 because of the high electricity demand of air conditioners. Actual load curves for 1995 and the expected future peak electricity load in Spain, are given in Figure 1 (Adnot, 1999). It is expected that the future increase of the peak load may necessitate doubling installed power by 2020.

Air conditioning's significant increase in peak electricity demand is partly blamed for the California energy system collapse. Besant-Jones and Tennebaum noted that in the summer of 2002 the demand for electricity was increased by air conditioning loads because of the highest recorded temperatures for 106 years (Besant-Jones and Tenenbaum, 2001). As a consequence the electricity demand increased and the supply started to fall below demand – thus dramatically increasing California's electricity prices. The market price in the day-ahead Cal PX which was between $25 and $50/MWh in the early months of 2000, had increased to $150/MWh during the summer months of the same year (Besant-Jones and Tenenbaum, 2001).

The main environmental problems of air conditioning are associated with:

- Emissions from refrigerants used in air conditioning which adversely impact ozone levels and global climate. Refrigeration and air conditioning related emissions represent almost 64% of all CFC's and HCFC's produced (AFEAS, 2001)
- Cooling systems' energy consumption contribute to CO_2 emissions.

Refrigerant gases used in air conditioning are either CFC's, HCFC's or HFC's. Chlorofluorocarbons have a very important impact on ozone depletion and they also exert global warming effects. According to the Montreal Protocol, CFC's production and use was banned by 1996 in the developed countries and must be stopped by 2010 in the developing countries. In Europe, "Regulation 2037/2000" totally bans their use for maintenance and servicing of equipment as of January 1, 2001.

Hydrochlorofluorocarbons, HCFC's have less of an impact on ozone depletion and a lower global warming potential than the CFC's. The Montreal Protocol has banned the use of HCFC's in developed countries by 2030 and by 2040 in developing countries. In Europe, HCFC's production will be banned as of 2025, and by 2010 the use of virgin HCFC's will be banned for maintenance and servicing of

Hydrofluorocarbons, HFC's, do not have an ozone depleting effect and their global warming impact is less than CFC's. An important market shift is being made to HFC's (R-407C and increasingly R-410A) in Japan -- where more than 50% of room air conditioners produced are HFC models. Unlike the Japanese and European markets, the US industry keeps R22 (HCFC) equipment longer and aims to shift directly to R410A instead of going through R407C (HFCs).

Air conditioning systems may be an important source of indoor contamination. Cooling coils and condensate trays can become contaminated with organic dust. This may lead to microbial growth. The organic dust may also cause mold and fungal growth in fans and fan housings. Inefficient and dirty filters may also lead to unfiltered air in the building. Contaminated emissions from cooling towers may cause spread of diseases like *Legionelea* from poorly maintained systems. A very comprehensive analysis of all studies related to indoor air quality problems caused by HVAC systems is given by Limb (Limb, 2000) and Lloyd (Lloyd, 1992).

2.3 Recent developments on the field of Air Conditioning, High Efficiency A/C systems

Air conditioning efficiency has increased substantially recently. According to the International Institute of Refrigeration (IIR), the air conditioning industry has improved equipment efficiency in line with recent regulations (IIR, 2003). As mentioned previously, Japan's target COP level for 2004 is almost twice as high as that in 1985. In parallel certain manufacturers in the US have begun marketing air conditioners achieving Seasonal Energy Efficiency Ratios (SEER) of 16 to 19.5.

In fact, a recent study investigating potential improvements of room air conditioners in Europe, shows that an increase of the COP up to 30% is quite feasible (Adnot, 1999). A list of possible improvements and the corresponding increases of the COP are given in Table 9. As a result of this study, the European Commission has published Directive 2002/31/EC dated March 22, 2002, related to "energy labelling of household air conditioners." According to the Directive, household air conditioners will have to be labeled mentioning "the annual energy consumption (kWh) in cooling mode, the cooling output, and the energy efficiency ratio full load'.

Table 9. Possible improvements of room air conditioners and the corresponding COP (Adnot, 1999)

No	Scenario	Efficiency/COP
0	Existing Situation	2.72
1a	Increase of frontal coil area (evaporator+condenser) by 15%	2.81
1b	Increase of frontal coil area (evaporator+condenser) by 30%	2.88
2a	Increase of coil depth (evaporator+condenser) by adding 1 row of tubes	2.97
2b	Increase of coil depth (evaporator+condenser) by adding 2 rows of tubes	3.09
3a	Increase of coil fin density (evaporator+condenser) by 10%	2.76
3b	Increase of coil fin density (evaporator+condenser) by 20%	2.80
4	Addition of subcooler	2.75
5	Improvement of fins	2.85
6	Improvement of tubes	2.87
7a	Improvement of fans using PSC motors	2.74
7b	Improvement of fans using ECM motors	2.75
8a	Improvement of compressor efficiency by 5%	2.79
8b	Improvement of compressor efficiency by 10%	2.87
8c	Improvement of compressor efficiency by 15%	2.94
9	Increase of heat transfer area in coils (combination of scenarios 1b, 2b and 3b)	3.22
10	Improvement of fins and tubes - increase of heat transfer coefficient (combination of scenarios 5 and 6)	3.14
11	Scenario 10 + Improvement of compressor efficiency by 15%	3.39
12	Scenario 9 + Improvement of compressor efficiency by 15%	3.48
13	Scenario 9 + Scenario 10	3.32
14	Scenario 9 + Scenario 10 + Improvement of compressor efficiency by 15%	3.58

In parallel to room air conditioners there is an important improvement of chiller efficiency. According to Bivens, the chilller industry achieved a 33% reduction in energy consumption between 1978 and 1998 (Bivens, 1999). The efficiency of absorption chillers running with natural gas or waste heat has also improved tremendously (Bivens, 1999). While the COP of a typical absorption system is close to 0.7, the use of multi-effect technology may increase it up to 1.5 (IIR, 2002).

2.4 Alternative Techniques to Air Conditioning - Passive Cooling

Addressing successful solutions to reduce energy and environmental effects of air conditioning is a strong requirement for the future. Possible solutions include:

1. Adaptation of buildings to the specific environmental conditions of cities in order to efficiently incorporate energy efficient renewable technologies to address the radical changes and transformations

of the radiative, thermal, moisture and aerodynamic characteristics of the urban environment. This involves the use of passive and hybrid cooling techniques to decrease cooling energy consumption and improve thermal comfort.

2. Improvement of the urban microclimate to fight the effect of heat island and temperature increase and the corresponding increase of the cooling demand in buildings. This may involve the use of more appropriate materials, increased use of green areas, use of cool sinks for heat dissipation, appropriate layout of urban canopies, etc.

Additionally, alternative strategies may be followed to decrease the impact of air conditioning, such as:

- Utilizing centralized or semi-centralized cooling production, and distribution networks based on renewable energies or waste heat (district cooling), together with demand-side management actions like local or remote cycling, (Papadopoulos et al., 2003).
- Using more efficient air conditioning equipment for individual buildings with optimized COP curves, using renewable sources or waste heat.

None of these can be seen as isolated areas of concern. The interrelated nature of the parameters defining performance efficiency of buildings during summer requires that practical actions be undertaken as an integrated approach.

3. Principles of Passive Cooling Techniques

Passive cooling techniques in buildings have proven to be extremely effective and can greatly contribute in decreasing the cooling load of buildings. Efficient passive systems and techniques have been designed and tested. Passive cooling has also proven to provide excellent thermal comfort and indoor air quality, together with a very low energy consumption.

When a building's internal and solar gains are sufficiently reduced, a *lean climatization concept* can be developed (Reinhart et al., 2001). The term *lean* signifies that the system is energy efficient so that only the amount of electricity needed to run fans and circulation pumps is required to maintain comfortable indoor temperatures year-round.

3.1 Classification of Passive Cooling Techniques

Passive cooling techniques can be classified in three main categories, (Santamouris and Assimakopoulos, 1996):

a) Solar and Heat Protection Techniques. Protection from solar and heat gains may involve: Landscaping, and the use of outdoor and semi-outdoor spaces, building form, layout and external finishing, solar control and shading of building surfaces, thermal insulation, control of internal gains, etc.

b) Heat Modulation Techniques. Modulation of heat gain deals with the thermal storage capacity of the building structure. This strategy provides attenuation of peaks in cooling load and modulation of internal temperature with heat discharge at a later time. The larger the swings in outdoor temperature, the more important the effect of such storage capacity. The cycle of heat storage and discharge must be combined with means of heat dissipation, like night ventilation, so that the discharge phase does not add to overheating.

c) Heat dissipation techniques. These techniques deal with the potential for disposal of excess heat of the building to an environmental sink of lower temperature. Dissipation of the excess heat depends on two main conditions: 1) The availability of an appropriate environmental heat sink; and 2) The establishment of an appropriate thermal coupling between the building and the sink as well as sufficient temperature differences for the transfer of heat. The main processes of heat dissipation techniques are: ground cooling based on the use of the soil, and convective and evaporative cooling using the air as the sink, as well as water and radiative cooling using the sky as the heat sink . The potential of heat dissipation techniques strongly depends on climatic conditions. When heat transfer is assisted by mechanical devices, the techniques are known as hybrid cooling.

3.2 Microclimate Issues

Climate is the average of the atmospheric conditions over an extended period of time over a large region. Small-scale patterns of climate, resulting from the influence of topography, soil structure, and ground and urban forms, are known as Microclimates. Temperature, solar radiation, humidity and wind are the principal parameters that define the local climate. The energy balance of the 'earth surface - ambient air', system in an area is governed by the energy losses, gains, and the energy stored in the urban infrastructure and mainly in the opaque elements of buildings, such as Energy Gains = Energy Losses + Energy Storage. Thus:

Energy gains involve the sum of both solar and long wave radiation emitted by opaque elements (building, streets, etc.), as well as the anthropogenic heat, related to transportation systems, power generation and other heat sources.

Energy losses involve sensible or latent heat transfers resulting from evaporation, heat convection between the surfaces and the air, as well as heat transfer between the area and the surrounding environment.

Improvement of the local microclimate during the summer period, mainly decreases of the ambient temperature, necessitates reduction of solar and heat gains and an increase of thermal losses. Appropriate landscaping involving the use of reflective – cool – materials, vegetation and water sources can highly contribute to decrease ambient temperatures.

Given that the world is becoming more and more urbanized, specific attention must be given to the urban climate. The thermal balance in the urban environment differs substantially from that of rural areas. More thermal gains are added such as high anthropogenic heat released by cars and combustion systems, higher amounts of stored solar radiation, and blockage of the emitted infrared radiation by urban canyons. Thus, the global thermal balance becomes more positive and this contributes to the warming of the environment.

As a consequence of heat balance, air temperatures in densely built urban areas are higher than the temperatures of the surrounding rural country. This phenomenon, known as 'heat island', which has an adverse impact on the energy consumption of buildings for cooling. Also, wind speed between buildings, is seriously decreased compared to the undisturbed wind speed. This phenomenon, known as 'canyon effect,' is mainly due to the specific roughness of a city and channelling effects through canyons.

Improvement of the urban microclimate is a priority area of research and has received a great deal of attention during the last few years. Techniques to fight heat island and improve the thermal balance of cities have been proposed, developed and implemented successfully.

3.3 Solar Control and Heat Protection

'Solar control' deals with the permanent or temporal reduction of transmitted solar radiation through a transparent building component. In cooling-dominated climates solar control devices should reduce as much as possible the solar gains and still admit sufficient daylight and visual contact with the outside. This may be achieved either with the combination of a window with an external or internal shading device or by using variable transmittance glazing (switchable glazing). The overall solar control performance of a window is expressed in terms of the so-called g-value which is the sum of the transmitted solar radiation and of the heat gains resulting from the sunlight absorbed in the glazing unit.

Important research has been carried out to improve the global thermal and visual performance of solar control devices, which are commercially available (Wilson, 1999, 2000). Switchable glazing technology has been considerably improved and electrochromic glazing is commercially available. Multifunctional façade components able to provide ventilation, daylight, solar control and other energy benefits have been designed and tested and are expected to enter the market soon (Cromvall, 2001)

Heat protection of the building has to do mainly with the flow of heat between the ambient environment and the building. This is characterised by the U value of both the opaque and the transparent components of the building. During the last years tremendous improvements have been achieved regarding the thermal quality of transparent elements. Low – e coated glazing, noble gas filled windows, triple glazed windows and transparent insulation are already in the market. As shown in Figure 2, low –e windows in Germany now hold a market share of about 90% (Reinhart et al., 2001). According to the European Glass Industry, replacement of single glazed windows in Europe with double low –e glass, will save almost 75 x 10^{15}J, 10.4 million Euros, and 57.7 million tons of CO_2 (GEPVP, 2001). Similarly, replacement of simple double glazed windows with low –e glass will contribute to save almost 340 x 10^{15}J, 3.95 million Euros and 24.6 milliion tons of CO_2.

3.4 Heat Modulation

A very efficient way to reduce indoor air temperatures and cooling load peaks, is to store excess heat in the structural materials of the building, which is referred to as 'thermal mass.' Constructed of material with high heat capacity, such as poured concrete, bricks and tiles, it is typically contained in walls, partitions, ceilings and floors.

The rate of heat transfer through building materials and the effectiveness of thermal mass is determined by a number of parameters and conditions. Optimization of thermal mass levels depends on the properties of the building materials, building orientation, thermal insulation, ventilation, climatic conditions, use of auxiliary cooling systems, and occupancy patterns. For a wall material to store heat effectively, it must have high thermal capacity and a high thermal conductivity value, so that heat may penetrate through the wall during the heat charging and discharging periods.

The distribution of thermal mass is based on the orientation of the given surface and the desirable time lag (Lechner, 1991). During the night when outdoor temperatures are lower than indoor temperatures, it is possible to cool the structural mass of the building by natural ventilation. Such a technique, known as 'night ventilation' may contribute in decreasing the cooling load of air conditioned buildings up to 60%, or decreasing the overheating hours of "free-floating buildings", i.e. of buildings not using a cooling system. (no mechanical air conditioning) up to 75% (Geros et al., 1999).

Phase change materials incorporated in plaster increases the heat storage capacity in the building and thus contribute in decreasing the average indoor temperatures

3.5 Heat Dissipation and Hybrid Cooling

As previously mentioned, heat dissipation techniques are based on the transfer of a buildings' excess heat to a low temperature environmental sink. Main sinks are the ambient air, water, the ground and the sky.

When heat is dissipated to the ambient air, the technique is known as ‘convective cooling;’ when water is used the process is known as ‘evaporative cooling;’ when the ground or the sky are the sinks, the techniques are known as ‘ground and radiative cooling’ respectively.

Convective cooling by (ventilation is a very effective method to improve indoor comfort, indoor air quality and reduce temperature. Higher air speeds inside the building may enhance thermal comfort when they do not exceed certain values. The technique is usually limited to night time ventilation however daytime ventilation may be used when ambient temperature is lower than indoor temperature.

Convective cooling may be natural, mechanical or hybrid. Natural ventilation is due either to wind forces, temperature differences, or both (Allard, 1998). A serious reduction of the cooling potential is observed in dense urban environments as a result of the dramatic decrease of the wind speed in cities (Geros, et al., 2001). Careful positioning of the openings in naturally ventilated buildings is a crucial parameter that determines the effectiveness of the process. A review of the sizing methodologies is given by Anthienitis and Santamouris (Athienitis and Santamouris, 2002).

Evaporative cooling applies to all processes in which the sensible heat in an air stream is exchanged for the latent heat of water droplets or wetted surfaces. Evaporative cooling may be direct or indirect. In direct evaporative coolers, air comes in direct contact with water flowing through fibrous pads. The air temperature is thus reduced by about 70-80% of the difference between the dry bulb temperature (DBT) and the wet bulb temperature (WBT). Therefore, direct evaporative cooling is effective when there is a large difference between DBT and WBT.

When the air is cooled without any addition of moisture by passing through a heat exchanger which uses a secondary stream of air or water, the cooling equipment is characterized as indirect. Thus, the DBT is decreased without any increase of the air’s moisture content. . Indirect evaporative coolers are based on the use of a heat exchanger where the indoor ventilated air passes through the primary circuit where evaporation occurs while the fresh air passes through the secondary circuit. Energy savings of up to 60% compared to mechanical A/C may be achieved in hot dry regions (Santamouris and Assimakopoulos, 1996)

During the summer the soil temperature at certain depth is considerably lower than the ambient temperature (Mihalakakou, et al., 1992). Therefore, the ground offers an important opportunity for dissipation of the buildings’ excess heat . There are two strategies for the use of the ground:

a) Direct Earth contact cooling techniques, and

b) Buried pipes cooling

Earth-contact buildings offer various advantages, i.e., limited infiltration and heat losses, solar and heat protection, reduction of noise and vibration, fire and storm protection and improved security. However they are not free of disadvantages. Inside condensation, slow response to changing conditions, poor daylighting and poor indoor air quality are frequent problems. (Carmody et al., 1985).The concept of buried pipes involves the use of metallic or PVC pipes buried at 1 to 4m in depth (Sinha and Goswami, 1981). Ambient or indoor air is delivered via the tubes where it is precooled and then delivered to the building. When outdoor air is circulated into the pipes the system is characterized as an 'open loop system'; when the indoor air is circulated from the building through the tubes the system is known as a 'closed loop system.'(Goswami and Ileslamlou, 1990) The performance of the buried pipes is a function of the inlet air temperature, the ground temperature, the thermal characteristics of the pipes and soil as well as of the air velocity, the pipe dimension and the pipes' depth (Goswami and Dhaliwal, 1985) Application of buried pipes cooling techniques in buildings has shown that the energy benefits are very important (Tombazis et al., 1990). Advanced modelling techniques have been developed quite recently that permit a very accurate sizing of the system under different boundary conditions (Mihalakakou et al., 1994, 1994b, 1995, 1996). Radiative cooling is based on heat loss by long wave radiation emission from a building to night sky at a much lower temperature.

There are two methods of applying radiative cooling in buildings: direct, or passive radiative cooling, and hybrid radiative cooling. In the first, the building envelope radiates towards the sky and gets cooler, producing a heat loss from the interior of the building. For physical reasons, the part of the building envelope that radiates the most is a flat roof. In the second case, the radiator is not the building envelope but usually a metal plate. The operation of such a radiator is the opposite of an air flat-plate solar collector. Air is cooled by circulating under the metal plate before being injected into the building. Other systems are combinations of these two configurations.

4. Urban Microclimate and Its Impact on the Cooling Needs of Buildings

Cities or urban areas are defined as the physical environment that is composed of

> "a complex mix of natural elements including air, water, land, climate, flora and fauna, and the built environment that is constructed or modified for human habitation and activity, encompassing buildings, infrastructure and urban open spaces" (Hardy et al., 2001).

The last 50 years was a period of the most intensive urbanisation that our planet has ever experienced. Urban population has increased from 160 millions to about 3 billions in just 100 years, and it is expected to increase to about 5 billion by 2025.

An increase of the urban population by 1% increases the energy consumption by 2.2% -- thus the rate of change in energy use is twice the rate of change in urbanization(Jones, 1992).

Increasing urbanization has deteriorated the urban environment. Deficiencies in development control have seriously impacted the urban climate and environmental performance of urban buildings. As reported by Akbari ,New York City has lost 175,000 trees, or 20% of its urban forest in the last ten years (Akbari et al, 1992)..

As a consequence of heat balance, air temperatures in densely built urban areas are higher than the temperatures of the surrounding rural country. This phenomenon known as ‘heat island’, exacerbates electricity demand for air conditioning of buildings and increases smog production, while contributing to increased emission of pollutants from power plants

4.1 Temperature Increase in Cities – Heat Island Phenomenon – Canyon Effect

The heat island phenomenon is mainly due to the following parameters (Oke et al, 1991):

a) Complex radiative exchange between buildings and the screening of the skyline contributes to decreasing the long wave radiation from within street canyons ,

b) Large thermal mass of the buildings that stores sensible heat t,

c) the anthropogenic heat released from transport, air conditioning, industry, other combustion processes and animal metabolism,

d) the urban greenhouse due to the polluted and warmer urban atmosphere,

e) the canyon radiative geometry that decreases the effective albedo of cities because of the multiple reflection of short wave radiation between the canyon surfaces,

f) the reduction of evaporating surfaces in the urban areas.

g) the reduced turbulent transfer of heat from within streets.

Besides the temperature increase, cities affect many other climatological parameters. As mentioned by Landsberg, solar radiation is seriously reduced because of increased scattering and absorption, while the sunshine duration in industrial cities is reduced by 10 to 20% in comparison with the surrounding countryside (Landsberg, (1981)

Wind speed and direction in cities is seriously decreased compared to the undisturbed wind speed. This is mainly due to the specific roughness of a city, channelling effects through canyons and also because of the heat island effect (Santamouris, 2001). Estimation of the wind speed is of vital importance for passive cooling applications and especially in the design of naturally ventilated buildings (Papadopoulos, 2001). Routine wind speed measurements above buildings or at airports differ considerably from the speed at an urban monitoring site. Quite recently, appropriate algorithms to estimate wind characteristics in urban canyons for naturally ventilated buildings have been developed (Georgakis, 2003).

4.2 Documentation of heat island in major cities

Urban heat island studies usually refer to ‘urban heat island intensity’, which is the maximum temperature difference between the city and the surrounding area. Data compiled by various sources shows that heat island intensity can be as high as 15˚C (Santamouris, 2001).

Studies on the intensity of heat island have been performed for many European cities. Watkins et al.’s work (2002) which was based on measurements performed in summer of 1999, reported a heat island intensity for London close to 7˚C. This value is much higher than the values given by Lyall (1977) and Chandler (1965). Lyall (1977) reported that the magnitude of the nocturnal heat island averaged over June-July 1976 was of the order of 2.5˚C . This is not much lower than a daily upper decile limit of 3.1˚C found by Chandler (1965), in a comparison of Kensington and Wisley from 1951-60.

Multiyear measurements performed in the Athens (Greece) area have shown that during summer the maximum heat island intensity in the very central area is close to 16˚C, and the mean value for the major central area of Athens is close to 12˚C. In parallel, cooling degree hours in the central area of the city is about 350% higher than in the suburban areas (Santamouris and Georgakis, 2003).

Data for Goteborg and Malmo in Sweden are reported by Eliasson (1996), and Barring et al., (1985) respectively. In Goteburg, data show an urban heat island ranging from 3.5˚C in winter to 6˚C in summer, while in Malmo, a mean heat island intensity close to 7˚C has been found.

Escourrou (1990/91), reported data on the heat island intensity in Paris, France. As stated, a horizontal thermic close to 14˚C has been recorded gradient between Paris and the suburbs.

Heat island data are available for three German cities. Swaid and Hoffman (1990) have reported limited data on the heat island intensity in Essen, Germany, for September 1986. The observed heat island intensity was between 3-4˚C for both the day and night period. Kuttler et al., (1996) reported a night time difference of 6˚C temperature between the urban and rural areas for Stolberg.

Data on the heat island for various Swiss cities are reported by Wanner (1983). For Bale and Berne the heat island intensity was close to 6˚C, while for Biel and Freiburg it was 5˚C, and for Zurich it was close to 7˚C.

Finally, Abbate (1998), using satellite data for Rome, Italy, reports important temperature differences between high density urban areas and low density urban and agricultural areas.

In the United States, Akbari et al. (1992) presented trends in absolute urban temperatures in several cities. The overall analysis is based on the use of average annual and maximum annual temperatures. The observed increase of temperatures in North American cities becomes clear when the cooling degree days corresponding to urban and rural stations are compared. Taha (1997) reported the increase of the cooling degree days due to urbanization and heat island effects for selected North American locations (see Table 10). As shown, the difference of the cooling degree days can be as high as 92%, while the minimum difference is more than 10% .

Table 10: Increase of the cooling degree days due to urbanization and heat island effects. Averages for selected locations for the period 1941-1970 (Taha ,1997).

Location	Urban	Airport	Difference (%)
Los Angeles	368	191	92
Washington DC	440	361	21
St. Louis	510	459	11
New York	333	268	24
Baltimore	464	344	35
Seattle	111	72	54
Detroit	416	366	14
Chicago	463	372	24
Denver	416	350	19

Heat island studies are available for three Canadian cities, Montreal, Edmonton and Calgary. Oke and East's 1971 study of heat island characteristics in Montreal showed a maximum intensity during winter nights close to 10.5˚C. Hage (1972) studied heat island conditions at Edmonton, Alberta and found a heat island intensity of about 6.5˚C.

Numerous studies on heat island intensity of tropical cities have been presented by the World Meteorological Organization (WMO) (WMO 1986, 1994), and Givoni (1989). Cities presenting a very high intensity of the phenomenon include Bombay, 9.5˚C, Delhi, 10˚C, Kuala Lumpur, 7˚C, and Buenos Aires, 7.5˚C, etc.

4.3 Impact of heat island on the cooling demand of buildings (Recent data)

Increased urban temperatures increase electricity demand for cooling in the summer they may reduce the heating load of buildings during winter.

Cooling load variation calculations of a reference building in the major Athens area, based on experimental data from 20 stations was reported by Hassid et al. (2000). They reported that the cooling load of the reference buildings was about double at the centre of the city than in the surrounding Athens area. Hassid et al.

also reported that almost a double peak-cooling load was calculated for the central Athens area than the surrounding area. It is known that higher ambient temperatures result in lower efficiency air conditioners. Hassid et al. reported that the minimum COP values were lower by about 25% in the central Athens. The lower COP necessitates an increase in the size of the A/C systems resulting in increased peak electricity demand and energy consumption for cooling.

Studies on the Tokyo area reported by Ojima (1991) conclude that during the period between 1965 to 2000 the cooling load of existing buildings increased up to 50% on average because of the heat island phenomenon.

In the USA, comparisons of high ambient temperatures to utility loads for the Los Angeles area have shown that an important correlation exists. It is found that the electricity demand increases by almost 540 MW per ˚C increase in ambient temperature (Akbari et al., 1992). There has been a 5˚F (2.8˚C) peak temperature increase in Los Angeles since 1940, resulting in an additional 1.5 GW electricity demand due to the heat island effect. Similarly, it has been calculated that summer electricity costs for the USA due to the heat island alone could be as much as $1 million per hour, or over $1 billion per year. It is estimated that 3% to 8% of the current urban electricity demand is used to compensate for the heat island effect alone.

4.4 Impact of canyon effect on the cooling demand of buildings. Recent experimental data

As already mentioned wind speed in the canopy layer is much lower that the undisturbed wind speed above buildings. The specific wind and temperature regime in canyons dramatically affect the potential for natural ventilation of urban buildings and thus the possibility to use passive cooling techniques instead of air conditioning.

Specific studies investigating the reduction of flow rate in naturally ventilated buildings because of the canyon effect are reported in Santamouris et al. (1998). They noted that the natural ventilation potential in single and cross ventilation configurations is seriously decreased inside the canyon. For single side ventilation configurations the air flow is reduced up to five times, while in cross ventilation configurations the flow is sometimes reduced up to 10 times.

Based on the previously defined potential for natural ventilation in urban canyons ,Geros (1998), calculated the reduction of the performance of night ventilation techniques when applied to naturally ventilated buildings located in urban canyons. The study was performed for 10 different urban canyons where detailed meteorological and energy data were measured.

It was found that in single side configurations the cooling load of buildings located in canyons is 6 to 89% higher than the load of unobstructed buildings, while in cross ventilation configurations the cooling load increases by 18 to 72%. Thus, canyon effect has a very considerable impact on the performance of passive cooling techniques located in dense detrimental canyons.

4.5 Increase of the ecological footprint of cities because of the heat island phenomenon

A population group's ecological footprint is defined by Rees as:

> 'the area of land and water required to produce the resources consumed, and to assimilate the wastes generated by the population on a continuous basis, wherever on Earth that land is located' (Rees, 2001).

Calculations have shown that the average ecological footprint of every person on Earth corresponds to 1.5 hectacres (ha) of ecologically productive land and about 0.5 ha of productive ocean (Rees, 2001b).

Studies have shown that the eco-footprint of residents of high income countries ranges from 5 to 10 ha per capita (Rees and Wackernagel 1996; Wackernagel and Rees. 1996). People in the less developed countries have footprints of less than one hectare, (Wackernagel et al., 1997; Wackernagel et al., 1999).

Buildings' energy consumption for cooling purposes increases the eco-footprint of cities. The higher the consumption the higher the eco-footprint. Degradation of the urban environment and in particular an increase of urban ambient temperatures has a great impact on building's energy consumption, thus increasing the ecological footprint of a city.

Based on heat island data from many urban stations in Athens, Greece, the energy demand increase and the increased ecological footprint have been calculated. The results show that if all buildings of the Athens Municipality were fully air conditioned, then almost one million ha should be reserved annually just to compensate for the extra CO_2 emissions caused by the heat island effect, (Paraponiaris et al, 2004). The energy penalty because of the heat island effect varies between 1,340 and 1,770 GWh per year (see Table 11).

Table 11. The energy cost, CO_2 emissions and ecological footprint of the Athens' heat island

Year	1997	1998
Athens' heat island energy cost (kWh/m^2)	38.2	29.0
Total Athens' heat island energy cost (GWh)	1772.5	1345.6
CO_2 emissions tons	5317440	4036800
Ecological footprint of the Athens' heat island (ha)	1036901	787176

Data from Paraponiaris et al, (2004).

5. Technologies to Improve the Urban Microclimate

Techniques to improve the urban microclimate are receiving increasing attention. Recent research has shown that the use of more appropriate materials, increased use of green areas, use of cool sinks for heat dissipation, appropriate layout of urban canopies, etc., may be effectively used to counterbalance the effects of temperature increase.

The first priority for utilities seems to be adoption of measures to decrease the electricity demand of air conditioners, thus avoiding unnecessary costs of new power plants operating for limited periods. Such a strategy, adopted by the Sacramento Municipal Utility District (SMUD), has proven very effective and economically profitable (Flavin and Lenssen, (1995). It was calculated that a megawatt of capacity is actually eight times more expensive to produce than to save it. This is because energy saving measures have low capital and no running costs, while construction of new power plants involves high capital and running costs.

5.1 The role of materials. Impact on the temperature regime of cities

The thermal and optical characteristics of the materials used in the urban environment define at large its thermal balance. Reflectivity of the materials to solar radiation as well as their emissivity is the more important of the optical parameters.

Important research has been performed to better understand the thermal and optical performance of materials as well as their impact on the city climate. The US EPA published a detailed guide on light colored surfaces (Akbari et al., 1992), while Yap (1975) reported that systematic differences between urban and rural surface emissivities are responsible for a portion of the heat island effect. However, Oke et al. (1991) found the role of emissivity to be minor. On the contrary, the effect of thermal properties of the materials is more important. For a flat land, it is reported that if the urban admittance is 2,200 $J/m^2/K$ and the rural one is 800 units lower, a heat island of about 2˚C develops during the night, yet when the urban admittance is decreased to 600 $J/m^2/K$, a cool island of over 4˚C may be formed during night. Finally, Berg and Quinn (1978), reported that during mid-summer white painted roads with an albedo close to 0.55 have almost the same temperature as the ambient environment, while unpainted roads with albedo close to 0.15 were approximately 11˚C warmer than the air. Admitance is defined as the reciprocal of the thermal resistance or impedence of an element to cyclic heat flow from the environmental temperature point and has the same units as the U value.

Research investigations have been carried out recently regarding the thermal performance of various materials used in the urban fabric and mainly in pavements and streets. Asaeda et al. (1996) conducted an experimental study of summertime performance of various pavement materials used commonly in urban environments. As expected, they found that the surface temperature, heat storage and its subsequent emission to the atmosphere were significantly greater for asphalt than for concrete and bare soil. Taha et al. (1992), measured the albedo and surface temperatures of a variety of materials used in urban fabric. They reported that white elastomeric coatings having an albedo of 0.72 were 45˚C lower than black coatings with an albedo of 0.08. They also reported that a white surface with an albedo of 0.61 was only 5˚C warmer than ambient air whereas conventional gravel with an albedo of 0.09 was 30˚C warmer than the air. Doulos et al. (2003), performed comparative measurements of 93 different materials commonly used for pavements in the urban environment. Surface temperature differences of more than 25˚C were measured. Analysis of the building materials according to them showed that tiles made of marble, mosaic and stone were cooler than other construction material. Finally, analysis based on the material's textures showed that tiles with smooth and flat surface were cooler than tiles with rough surfaces.

The so-called "cool-materials" are characterized by a high reflectivity factor to the short wave radiation and a high emissivity. They reduce the amount of the absorbed solar radiation by the building envelopes and urban structures and keep their surfaces cooler. Respectively, they are good emitters of long wave radiation and release the energy that has been absorbed as short wave radiation. Using "cool materials" in urban environment planning contributes to lower surface temperatures which affect thermal exchanges with the air, improve comfort in outdoor areas, and decrease the ambient temperature (Akbari et al., 1997; Bretz and Akbari, 1997). Research shows that important energy gains are possible when light color surfaces are used in combination with the plantation of new trees. For example computer simulations by Rosenfeld et al. (1998), showed that white roofs and shade trees in Los Angeles, USA, would lower the need for air conditioning by 18% or 1.04 billion killowatt-hours, equivalent to a financial gain of close to $100 million per year.

Industrial research has succeeded in developing paints with excellent optical characteristics for the urban environment. Comparative measurements of white marble tiles covered with these new highly reflective paints, shows an almost 6˚C lower surface temperature during summertime noon (Santamouris, 2003).

Large scale changes in urban albedo may have important indirect effects on the city scale. Using meteorological simulations Taha et al. (1988) showed that afternoon air temperatures on summer days can be lowered by as much as 4˚C by changing the surface albedo from 0.25 to 0.40 in a typical mid-latitude warm climate. Taha (1994) also used more advanced simulations while investigating the effects of large scale albedo increases in Los Angeles. Taha reported an average decrease of 2˚C and up to 4˚C may be possible by increasing the albedo by 0.13 in urbanized areas. Further studies by Akbari et al. (1989), showed that a temperature decrease of this magnitude could reduce electricity load from air conditioning by 10%.

5.2 The role of green spaces. Impact on the temperature regime of cities

Trees and green areas greatly contribute in reducing temperatures in our cities and save energy. Trees can provide solar protection to buildings during the summer period while evapotranspiration can cool our cities. In addition, trees absorb sound and block erosion-caused by rainfall, filter dangerous pollutants, reduce wind speed and stabilize soil. As evapotranspiration is defined the combined loss of water to the atmosphere by evaporation and transpiration. Evaporation is the process by which a liquid is transformed into gas, and in the atmosphere usually water changes to water vapor. Transpiration is the process by which water in plants is transferred as water vapor in the atmosphere. The American Forestry Association (1989), estimated that the financial value of an urban tree is around \$57,000 for a 50 year-old mature specimen. As mentioned by Akbari (1992), this estimate includes a mean annual value of \$73 for air conditioning, \$75 for soil benefits and erosion control, \$50 for air pollution control and \$ 75 for wildlife habitats.

Duckworth and Sandberg (1954), reported that temperatures in San Fransisco's heavily vegetated Golden Gate Park average about 8˚C cooler than nearby areas that are less vegetated. Bowen (1980) reported 2-3˚C temperature reduction due to evapotranspiration by plants. Oke (1977) reported that in Montreal, urban parks can be 2.5˚C cooler than surrounding built areas. In Tokyo, vegetated zones in summer have been found to be 1.6˚C cooler than non-vegetated spots (Tatsu, 1980; Gao et al. 1994). Saito et al. (1990/1991) studied the effect of green areas in the city of Kumamoto in Japan. They found that the maximum temperature difference between inside and outside the green area was 3˚C. Jauregui (1990/1991), reported that the park in Mexico city was 2-3˚C cooler with respect to its boundaries. Taha et al. (1989; 1991) , reported that evapotranspiration can create oases that are 2-8˚C cooler than their surroundings Measurements have shown that evapotranspiration from plants at the National Park of Athens create “oases” of 1-5˚C during the night (Santamouris, 2001).

Givoni (1989) advised spacing trees and public parks throughout the urban area rather than concentrating them in a few spots. This is supported by the measurements of Lindqvist (1992), in Goteborg, Sweden, where the air temperature increased 6˚C from 100 m inside the park to a point within the built-up areas 150 m outside the park. More frequently, the air temperature gradient in the transition zone was 0.3 - 0.4˚C per 100 m outside the park.

Numerical simulations have been used to evaluate the effect of additional vegetation to the urban temperature. Huang et al.’s (1987), computer simulations predicted that increasing the tree cover by 25% in Sacramento and Phoenix, USA, would decrease air temperatures by 10˚F (5.6˚C) 2:00 p.m. in July. Taha (1988), reported simulation results of the effect of canopy on daytime and night time temperature for Davis, California.

Taha showed that a vegetative cover of 30% could produce a noontime oasis of up to 6˚C, in favourable conditions and a night time heat island of 2˚C. Gao (1993) reported that green areas decrease the maximum and average temperatures by 2˚C, while vegetation can decrease the maximum air temperatures in streets by 2˚C.

Simulations by Sailor (1995, 1998), revealed a potential for reducing peak summertime temperatures in Los Angeles by more than 1.3˚C, through the implementation of a 14% increase of fractional vegetative cover. He also evaluated the impact of added vegetation on the heating degree days, and cooling degree days, of cities located in the US. He reported that increasing the vegetative cover by 15% over only the residential neighborhoods, reduces the number of cooling degree days by 2-5% and increases the number of heating degree days by 0.5 - 3.5%. According to the author, one would expect a city-wide savings of up to 5% of summertime air conditioning energy use.

The National Academy of Sciences of United States (NAS, 1991), reported that the planting of 100 million trees combined with the implementation of light surfacing programs could reduce electricity use by 50 billion kWh per year. This is equivalent to 2% of the annual electricity use in the US. Computer simulations by Akbari et al. (1992), highlight the combined effect of shading and evapotranspiration of vegetation on the energy use of typical one-story buildings in various US cities. It is found that by adding one tree per house, the cooling energy savings range from 12- 24%, while adding three trees per house can reduce the cooling load between 17-57%, with shading accounting for only 10-35% of the total cooling energy savings. Simpson and McPherson (1998), calculated the magnitude of tree shade in 254 residential properties in Sacramento, California. They used 3.1 trees per property which reduced annual and peak cooling energy use by 153 kWh, (7.1%), and 0.08 kW, (2.3%), per tree respectively.

5.3 The role of heat sinks. Impact on the temperature regime of cities

Decrease of the ambient temperature can be achieved by dissipation of the ambient heat to a lower environmental sink, like the ground, water and air.

Buried pipes have been used in different projects to supply cool air in an open environment. Monitoring has shown that in 30m long pipes buried at about 3m depth the achieved temperature decrease is close to 12˚C, (Santamouris et al, 1982). The possible temperature decrease of the ambient air depends on the global thermal balance of the air and the supply of the cool air through the pipes. Alvarez et al. (1992), proposed to irrigate the soil around the pipes in order to counterbalance the low conductivity of the soil and the continuous heating of the ground around the pipes.

Pools, ponds, sprays and fountains are the main components based on evaporative processes. Calculations based on mean summer climatological conditions give an evaporation rate between 150-200W per square meter, which defines the cooling potential of these techniques. Since water surfaces increase air humidity they are very beneficial in dry climates, but they may create some problems in very humid climates. In hot climates, their cooling effect should be maximised through design strategies which prevent diffusion of the cooled air and direct it to inhabited spaces.

A cooling tower system was proposed and applied by Givoni (1994). The system consisted of an open shaft where fine drops of water were sprayed vertically downward. A wind catcher could be placed above the shaft to increase the air flow. Alvarez (1990) showed that when the inlet temperature was close to 36˚C, the corresponding exit temperature was around 23˚C.

5.4 Recent case studies demonstrating the reduction of cooling needs of buildings through microclimatic improvements

As previously mentioned techniques aiming to improve microclimate around buildings have gained an increasing acceptance recently. Several big projects have been successfully designed and realised using such techniques .

The first important example of the designs deals with Expo 92 in Seville, Spain, (d'Asiain, 1997; Alvarez et., 1992). A number of known techniques were used to improve microclimate in environs of Expo 92. To decrease surface temperature of the outdoor spaces extensive shading was applied in almost all zones where visitors were circulating. This was achieved by using plants, pergolas, etc. Lower surface temperatures decrease the emitted infrared radiation by the materials, while shading protect the visitors from solar radiation and thus improve thermal comfort. Fountains, pools, ponds and springlers were used to evaporate water in the ambient air and thus decrease its temperature. Earth-to-air heat exchangers were also used to circulate the ambient air through the ground and thus decrease its temperature. Finally, cooling towers, as described previously, were installed in various parts of the area. Extensive monitoring showed that the application of these passive cooling techniques contributed in decreasing ambient air by to 5˚C..

Another example of microclimatic improvement techniques was Expo 98 in Lisbon, Portugal. Specific air flow studies were performed in order to optimize the air flow through the area. To decrease surface temperature of the materials, decrease ambient temperature and improve outdoor thermal comfort, extensive use of plants, pergolas, pools, ponds and fountains were employed. Monitoring of the area showed that because of the application of passive cooling techniques the ambient temperature was reduced by 3-4˚C.

A third important application is the Olympic Village 2004, in Athens, Greece (Fintikakis and Santamouris, 2002). In order to improve microclimate, cool materials, pergolas and plants, external shading, pools, ponds and fountains as well as air flow enhancement techniques have been used. It is calculated that the ambient temperature is reduced by 4˚C, the maximum wind speed has been reduced by 3m/sec, while the period inside the comfort zone has been increased by 65%.

6. Recent Progress on Solar Control and Heat Protection of Buildings

Important industrial and scientific research has been carried out recently, resulting in new, highly efficient components. Thus, new advanced shading devices that allow a better integration of daylight quality, glare control and efficient solar control are available. In parallel, new advanced types of glazing have been developed that present a much lower U value while able to provide efficient solar control. In real terms the progress achieved by the glazing industry is really impressive. Intelligent windows have been designed and applied in many buildings. Intelligent windows provide solar and heat protection, optimisation of daylight and natural or hybrid ventilation in an integrated way. Finally, heat protection techniques, like planted roofs, have gained an increased research interest for optimum use.

In the next sections, the recent progress achieved on the previously mentioned systems and techniques will be presented.

6.1 Recent industrial developments on advanced solar control devices and systems

Transparent components appropriate for warm climates are characterised by a low transmittance to the solar radiation and a high transmittance to the visible spectrum, thus providing solar control and adequate daylight. The very rapid development of the solar control coatings technology has permitted to use single- or double-layer silver coatings that present very good g and U values. The g-value is the sum of the solar transmittance and a factor for heat gains resulting from sunlight absorbed in the glazing unit. More advanced solar control systems and techniques deal with thermotropic and thermochromic coatings, gasochromic and photochromic glazings and angle selective coatings,. All these techniques are on the verge of entering the market (Hutchins, 2003).

Thermotropic and thermochromic coatings are characterised by a variable transparency as a function of their temperature. Thermotropic layers are composed of a mixture of a polymer and water or two polymers. As both components have different refractive indices, when the temperature is above a threshold value they segregate and the material becomes opaque. According to Wilson (1999) a polymer blend in combination with a low-e coating can have a visible transmittance range of 73% at 30˚C to 31% at 50˚C.

A gasochromic glazing is composed of two glazed panes with a coating on one of the two inner surfaces. The coating consists of a WO3 film whose color changes to blue when exposed to a low concentration of hydrogen. When the coating is exposed to oxygen it resumes its initial color. Experiments have shown that the transmittance varies from 11-74%. Additional research aimed at changing the color of the coating from blue to gray.

Photochromism is based on the effect of ultraviolet radiation on a photochromic material. A major problem is that solar radiation is absorbed by the glazing surface and not reflected.

The basic idea behind angle-selective coatings is to develop a window structure that presents a high reflectance to incident light at high solar altitudes and a high transmittance at low angles. Thus, the visual contact with the external environment is achieved while solar gains and glare are reduced.

Finally, the development of nanoparticle-doped polymeric solar control glazing seems a promising solution (Hutchins, 2003). Experiments show that the visible transmittance of such a glazing can be close to 0.87, while the solar transmittance close to 0.62.

6.2 Advanced glazings for heat control

Thermal losses or gains from glazing elements represent a significant part of the thermal balance of buildings. Recently the glazing industry has been developing glazing units with a high transmittance to the visible spectrum and a low heat loss coefficient, U. Low e-glass, triple glazing and use of noble gases in a sealed glass unit can contribute in dramatically decreasing heat losses or gains through the glazings.

Actual developments as well as the trend concerning glazing characteristics are shown in Figure 3, (Adapted from Reinhart et al., 2001). Table 12, gives the main optical and thermal characteristics of some reference and advanced glazings (Hutchins, 2003). As shown in Figure 3, the U value of commercially available windows may be as low as 0.6 W/m2/K

Table 12: Visible and solar energy transmittance, U-value of insulating double-glazed units using low emittance, and solar control coatings for heating- and cooling-dominated applications (Hutchins, 2003).

Glazing	Gas Fill	τ_v	G	U ($Wm^{-2}K^{-1}$)
Clear float single glazing	-	0.90	0.86	6.4
Clear float double glazed unit.	Air	0.81	0.76	2.9
Double Glazed Unit low-e pyrolytic heat mirror for use in heating-dominated applications	Argon	0.75	0.72	1.9
Double Glazed Unit low-e sputtered solar control for use in cooling-dominated applications	Argon	0.66	0.34	1.2

The impact of high insulating glazing on economy and energy consumption is important. According to EUROACE (1998), a Europe-wide domestic window upgrading program could save 94 million ton of carbon dioxide emissions. More than 110,000 jobs could be created in the process, while additional savings of 25 million tons may be achieved through similar measures in the commercial, public and industrial building sectors.

To support the use and application of advanced windows, specific tools able to calculate their visual and thermal characteristics, have been recently prepared (Dijk and Hutchins 2002; Mitchell R., Christian Kohler, and Dariush Arasteh, 2001, Dijk and Baker, 1995; These tools calculate the thermal and solar properties of commercial and innovative window systems, on the basis of known component properties (glazings, shading devices, frames and edges, gases, etc.), and are also suitable in calculating the performance of complex facades.

6.3 Other developments

The use of planted roofs undoubtedly present, numerous energy, environmental and social benefits especially in non-insulated buildings. They act positively on the climate of a city counteracting heat island, and contribute in improving the thermal performance of buildings and indoor environmental conditions. In fact, planted roofs offer increased solar protection, reduction of thermal losses through the fabric, while increasing the thermal capacity of buildings.

Recent research has developed advanced design tools and solutions permitting a better understanding of the performance of planted roofs (Haifeli et al., 1998; Eumorfopoulou et al., 1994, 1995; Cappeli et al., 1998; Palomo, 1999; Domingez and Lozano, 1998; Good 1990; Niachou et al. 2001).

Niachou et al. (2001) showed that the planted roof systems greatly contribute in decreasing the cooling load of non-insulated buildings close to 50%. This benefit reduces to just 2-5% for buildings with moderate or good insulation levels.

7. Heat Amortization Techniques – Night Ventilation

Night ventilation techniques are based on using cool ambient air, decreasing the indoor air temperature as well as the temperature of the building's structure. The cooling efficiency of night ventilation is mainly based on the relative difference between indoor and outdoor temperatures during the night, the air flow rate, the thermal capacity of the building, and the efficient coupling of air flow and thermal mass.

Important theoretical and experimental research has been carried out to better understand the phenomena and also to develop design tools and computational codes. The specific impact of the urban environment on the efficiency of night cooling techniques is also the subject of recent research.

Extended experimental work on night ventilation techniques is reported by Santamouris and Assimakopoulos, (1996), Givoni, (1994), Blondeau et al., (1995), Van der Maas and Roulet, (1991), Kolokotroni et al.,(1997), Zimmerman and Anderson, (1998), Geros et al., (1998), and Dascalaki and Santamouris, (1998). As Geros et al. (1998) performed measurements on non air conditioned buildings and night ventilated A/C, and showed that the use of this technique decreases peak indoor temperature, up to 3^0C. Sensitivity analysis showed that the expected reduction of overheating hours varies between 39% and 96% for air flow rates between 10 - 30 ACH respectively. For air conditioned buildings, early morning indoor air temperature can be reduced by 0.8 - 2.5^0C depending on the set point temperature. Sensitivity analysis for air conditioned buildings shows that the expected energy conservation varies between 48% - 94% for air flow rates 10 - 30 ACH respectively.

Givoni (1994) reported the development of an empirical formula to predict the indoor maximum temperature as well as the cold storage and the diurnal cooling capacity of the building. Blondeau et al. (1995) developed indices characterizing the energy gain and comfort improvements due to night ventilation.

A detailed methodology to calculate the performance of air conditioned as well as of non air conditioned night ventilated buildings was presented by Santamouris et al. (1995). The method is based on the principle of Modified Cooling Degree Days and is extensively evaluated against experimental data. Other methods which calculate the cooling potential of night ventilation are proposed by Roulet et al. (1997) and Kolokotroni et al. (1997).

As previously mentioned Geros (1998), performed measurements in 10 urban canyons and calculated the reduction of the performance of night ventilation techniques applied to non air conditioned buildings in urban canyons. Geros found the reduction in performance to be 2.6^0C for single sided naturally ventilated buildings, and 0.2^0C to 3.5^0C. for buildings with cross ventilation.

8. Advances in Thermal Comfort Studies

Thermal comfort of buildings has received a lot of attention during the last few years. Existing knowledge covers methods predicting thermal comfort under steady-state conditions. The most well-known and widely accepted methods are the "Comfort Equation" proposed by Fanger (Fanger, 1972), and the J.B. Pierce two-node model of human thermoregulation (Gagge, 1973; Gagge et al. 1986). Several steady state thermal comfort standards have been established based on these models (ISO, 1984; ASHRAE, 1981; Jokl, 1987).

As a result of the thermal interaction between the building shell, occupants, and the cooling system, steady-state conditions are rarely encountered in practice in many types of buildings. Indoor temperatures in “free-floating buildings” vary widely while fluctuations of 0.5^{0}C and 3.9^{0}C are found in passive solar buildings with constant set-point control system (Madsen, 1987). Thus, knowledge of thermal comfort under transient conditions is necessary.

Basic thermal comfort research concludes that there is an important discrepancy between steady-state models and those where no mechanical conditioning is applied (Humphreys, 1976). This is mainly due to the temporal and spatial variation of the physical parameters in the building (Baker, 1993).

Experimental comfort surveys have shown significant discrepancies between thermal comfort in real buildings conditions versus laboratory conditions. Nicol and Humphreys (1973) concluded that this discrepancy could be the result

> “… of a feedback between the thermal sensation of subjects and their behaviour and that they consequently ‘adapted’ to the climatic conditions in which the field study was conducted.” Nicol and Humphreys (1973

Based on data collected in many field studies, Humphreys and Nicol proposed an adaptive comfort model (Humphreys, 1992). They demonstrated that for a group of people the comfort temperature is close to the average temperature they experience. The fundamental assumption of the adaptive approach is expressed by the adaptive principle:

> “If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort” (Nicols, 2003).

To allow for the discrepancies in relating PMV, (Predicted Mean Vote), that is the comfort index of the Fanger’s theory, to field measurements, Fanger and Toftum (2002) presented a correction for free-floating buildings in warm climates. Based on the Humphreys work, the Comfort Group of the European PASCOOL research project, carried out field studies to understand the mechanisms by which people make themselves comfortable at higher temperatures (Baker, 1995). They concluded that people are comfortable at much higher temperatures than expected, while finding that people make a number of adaptive actions to make themselves comfortable including moving to cooler parts of the room. Specifically this research found that in 864 monitored hours of more than 500 persons, there were 273 adjustments to building controls and 62 alterations to clothing

Based on surveys carried out in the frame of the European research project SCATS [identify this acronym], scientists tried to determine the rate of change of comfort temperature using surveys conducted over a period of time (Nicol and Raja, 1996; McCartney and Nicol, 2002). Evidence was found that the comfort temperature in free-running buildings [are free-running buildings different from free-floating buildings?] depends on the outdoor temperature. The proposed equation for comfort temperature T_c is given by :

$$T_c = 13.5 + 0.54\, T_o \qquad \text{(Eq. 1)}$$

Where, T_o is the monthly mean of the outdoor air temperature.

As Humphreys' and Nicol's 2000 research shows, there is a remarkable agreement between their work on ""free-floating buildings"" and the 1998 ASHRAE database (Humphreys, 1978; deDear, 1998) (Figure 4). It is also found that the relationship between the two databases for air conditioned buildings is more complex, showing a 2^{o}C difference in indoor comfort temperatures (Humphreys, 1978; deDear, 1998).

Variable indoor temperature comfort standards for air conditioned buildings may result in remarkable energy savings (Auliciems, 1990; Milne, 1995; Wilkins, 1995; Hensen and Centrenova, 2001). Energy savings of about 18% are estimated over that from using a constant indoor temperature in Southern Europe, (Stoops et al., 2000), while the corresponding energy savings for UK conditions have been estimated close to 10%.

9 Heat Dissipation Techniques

Heat dissipation techniques, involving ground, evaporative, radiative and convective cooling present a very high cooling potential. The overall efficiency of such systems depends on the specific climatic conditions in the area, the cooling needs and patterns in the building, as well as on the efficiency of the technology used. The specific performance of heat dissipation techniques has been extensively studied during the last decade. In the frame of the PASCOOL research program, an atlas on the potential of heat sinks was developed (Alvarez et al. 1997), while the Sink research project of the European Commission, (Alvarez and Tellez, 1996), studied and documented the performance of almost all known heat dissipation technologies for the different climatic zones of Southern Europe.

9.1 Natural ventilation, Technological and Social Developments and Needs

Natural ventilation is an important and simple technique that when appropriately used may improve thermal comfort conditions in indoor spaces, decrease the energy consumption of air conditioned buildings, and contribute to fight problems of indoor air quality by decreasing the concentration of indoor pollutants.

It must be recognized that natural ventilation is not just an alternative to air conditioning. Instead it is a more effective instrument to improve indoor air quality, protect health, provide comfort, and decrease unnecessary energy consumption.

Given the great inequalities in terms of income and energy use in the world, what natural ventilation may offer is a function of the actual needs, the characteristics of the building as well as the type of energy used, and the services and systems employed. Thus, three main clusters of possible uses/contributions may be defined as a function of income and the corresponding energy use (Figure 5).

- In very poor households natural ventilation can greatly contribute in avoiding indoor air pollution problems caused by combustion processes. Almost 2 billion people are living under these specific conditions, without access to electricity and modern fuels. High concentrations of indoor pollutants pose a tremendous health threat to the population of the less developed countries. Worldwide, close to 2 million deaths per year are attributable to indoor air pollution from cooking fires (Birol, 2002). Recent studies of the World Health Organization (WHO) have shown that 30-40% of 760 million cases of respiratory diseases world-wide are caused by particulate air pollution alone. “Mostly, these health effects are caused by indoor air pollution due to open stove cooking, and heating in developing countries" (World Bank, 2000). Efficient components designed to enhance ventilation in these settlements is a simple task for a low or negligible cost. This must be considered in association with other policies, such as the design of more efficient stoves and the use of cleaner fuels.
- Natural ventilation may greatly contribute in improving indoor air quality and indoor thermal conditions for about 3 billion people of low and medium income. Most of these people live in poorly designed buildings suffering from high indoor temperatures during summer. This population doesn’t have the means to use any cooling equipment and relies fully on natural systems and techniques. Design and integration of efficient natural ventilation systems and components like wind and solar towers, can greatly assist in improving indoor thermal comfort. As it concerns indoor air quality, high levels of outdoor air pollution and its impact on the indoor environment, is a major problem for this part of urban population. According to the United Nations Global Environmental monitoring system an annual average of 1.25 billion

urban inhabitants are exposed to very high concentrations of suspended particles and smoke,, while another 625 million urban citizens are exposed to non-acceptable SO_2 levels(UNCHS, 1993).

- Natural ventilation can greatly contribute in improving thermal comfort, decrease the needs for air conditioning, and improve indoor air quality in the developed world. As previously explained, a serious limitation of natural and night ventilation application in dense urban environments has to do with the severe reduction of wind speed in urban canyons. Outdoor pollution is also a grave limitation for natural ventilation in urban areas. As reported by Stanners and Bourdeau (1996), it is estimated that in 70-80% of European cities with more than 500,000 inhabitants, the levels of air pollution exceeds the WHO standards at least once in a typical year. Filtration and air cleaning is possible only when flow-controlled natural ventilation components are used. Noise is also a limitation for natural ventilation in the cities of the developed world. Stanners and Bourdeau (1996) reported unacceptable noise levels of more than 65 dB(A), affecting between 10-20% of urban inhabitants in most European cities. OECD [define this acronym] , has calculated that 130 million people in OECD countries are exposed to noise levels that are unacceptable(OECD, 1991).

Extensive experimental and theoretical studies investigating techniques and methods to improve natural ventilation efficiencies as applied in dense urban areas, were conducted by the European research project URBVENT, (URBan VENTilation), (Ghiaus et al, 2003). Algorithms to calculate the wind speed in urban canyons as a function of the undisturbed wind speed above the buildings, as well as methodologies to assess the potential of natural ventilation in some hundreds of thousands configurations of urban buildings have been developed and experimentally validated (Santamouris, 2003b). Intelligent software tools based on neural networks that permit estimates of required opening areas required in order to achieve a defined air flow, have been developed and are currently available.

Finally, in the PASCOOL research project, a new method ($CPCALC^+$) to calculate the pressure difference around certain building configurations has been developed, (Grosso, 2002). The method is based on experimental data collected through wind tunnel experiments as well as on the existing knowledge. These results were used to obtain regression curves for determining the pressure coefficient distribution over flat and tilted roofs.

9.2 Recent developments on the field of hybrid ventilation

Hybrid ventilation use both natural ventilation and mechanical systems with different features of these systems at different times of the day or season of the year and within individual days to provide a comfortable internal environment (Heiselberg, 2002). Hybrid ventilation systems are based on an intelligent control system than allows switching between natural or mechanical modes in order to minimize energy consumption.

The main advantages of the hybrid ventilation systems are summarized by Heiselberg (2002):

- Hybrid ventilation results in higher user satisfaction as it permits a greater degree of individual control of the indoor climate.
- It optimizes the balance between indoor air quality, thermal comfort, energy use and environmental impact and fulfilling the needs for a better indoor environment and reduced energy consumption
- It accesses natural and mechanical ventilation modes and exploits the benefits of each mode the best way.
- It is a very appropriate solution for complex buildings as it is associated with more intelligent systems and control.

Different hybrid ventilation systems have been proposed and applied in various types of buildings. An extended review of these systems and their existing applications is provided by (Delsante and Vik, 2001).

Results from first generation hybridly ventilated buildings, show that such techniques have great potential. Hybrid systems were found to be quite effective in providing good IAQ and thermal comfort, while the energy performance was good but not excellent. Hybrid ventilation is proved to be suitable for schools and cellular offices while in open- plan offices there were some complaints.

Hybrid ventilation is a very new and promising technology but several problems still remain. Design tools and methodologies as well as more robust control strategies and sensors for demand control ventilation must be developed in the future.

9.3 Recent developments in evaporative cooling

The efficiency of mechanical evaporative systems has significantly improved recently. Improvements mainly deal with the type of system cooling media and their performance. Efficiencies close to 90% have been achieved in industrial products. Developments in passive evaporative cooling systems are important as well. Improvements of the Passive Downdraft Evaporative Cooling systems (PDEC), and extended testing of this system are among the more important developments.

Cooling towers are traditionally used in Middle East and Persian architecture (Bahadori, 1978). New developments and in particular coolers where the air was forced by a blower through wetted pads have been used in the past in desert areas of the USA . In natural downdraft evaporative coolers, the air is not forced through the pads but provided just by gravity flow (Cunningham and Tompson, 1986). The performance of natural downdraft evaporative coolers have been studied in details by various authors and design tools have been proposed (Thompson et al., 1994;, Givoni, 1991; Sodha et al., 1991; Chalfoun, 1992).

An innovative development of the system is achieved through the PDEC research program of the European Commission (PDEC, 1995). Their improvement consists of replacing the wetted pads with rows of atomizer nozzles that produce an artificial fog by injecting water at high pressure through minute orifices. This feature produces much better regulation of the system, as there is a significant reduction of pressure losses and smaller equipment can be used.

10. Conclusions

The building sector energy consumption is quite high and is expected to further increase because of improving standards of life and swelling world population Air conditioning use has increasingly penetrated the market during the last few years and greatly contributes in the upsurge of absolute energy consumption. In parallel, urbanization increases city-wide temperatures and thus increases the cooling load as well as the required peak electricity load. Several passive techniques have been proposed to decrease buildings' energy consumption and improve environmental quality, involving techniques aiming at bettering the urban environment and corresponding thermal conditions, and improving buildings' thermal characteristics by using passive and hybrid cooling systems and techniques. Theoretical studies have shown that the application of all the above techniques in buildings may decrease their cooling load up to 70%.

During the last few years important basic and industrial research has been carried out that has resulted in the development of new high-efficiency materials, systems, tools and techniques. However, the continuing increase of energy consumption of air conditioning suggests a more profound examination of the urban environment and the impact on buildings as well as to an extended application of passive cooling techniques. Appropriate research should aim at better understanding micro-climates around buildings, and to understand and describe comfort requirements under transient conditions during the summer period. Also of importance are improving quality aspects, developing advanced passive and hybrid cooling systems, and finally, developing advanced materials for the building envelope.

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Figures

Figure 1. Load curves for 1995 and 2020 in Spain, (Adnot 1999)

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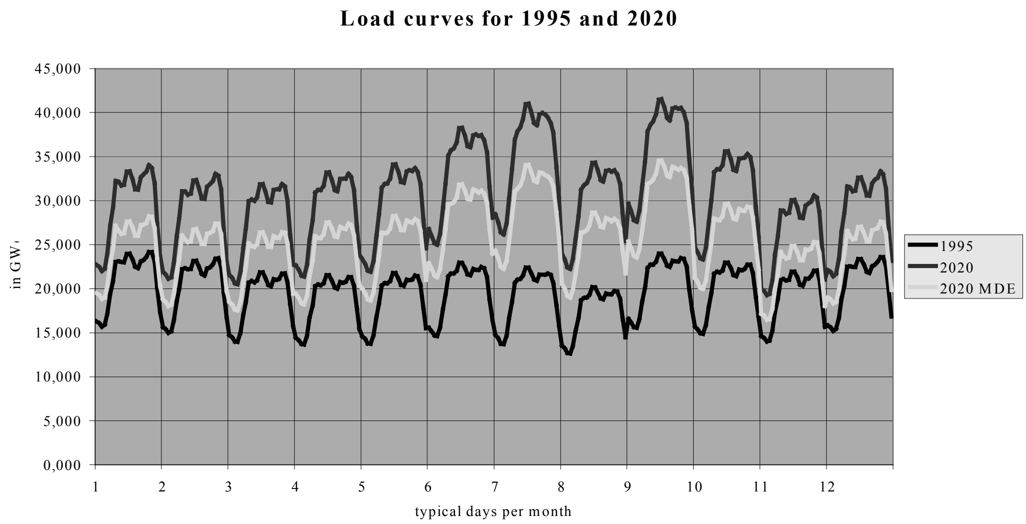

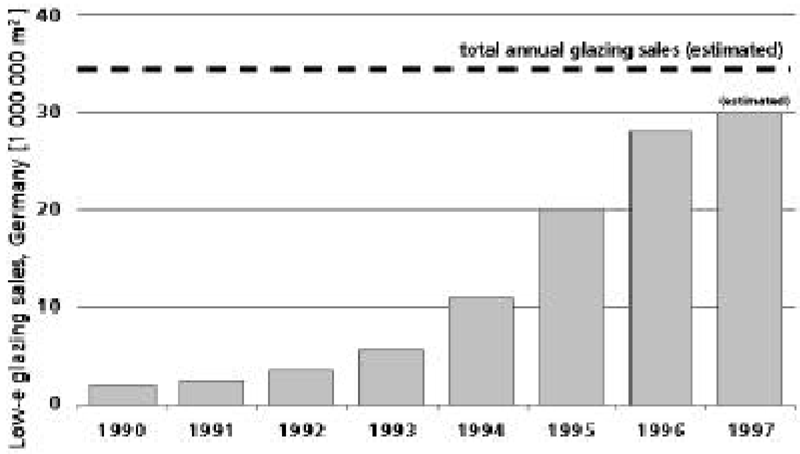

Figure 2. Development of low-e glazing sales in Germany. (Reinhart C.F et al, 2001).

Figure 3. Total Solar Transmittance against U value for modern glazing, The g-value is the sum of the solar transmittance and a factor for heat gains resulting from sunlight absorbed in the glazing unit.
(Adapted from Reinhart et al, 2001)

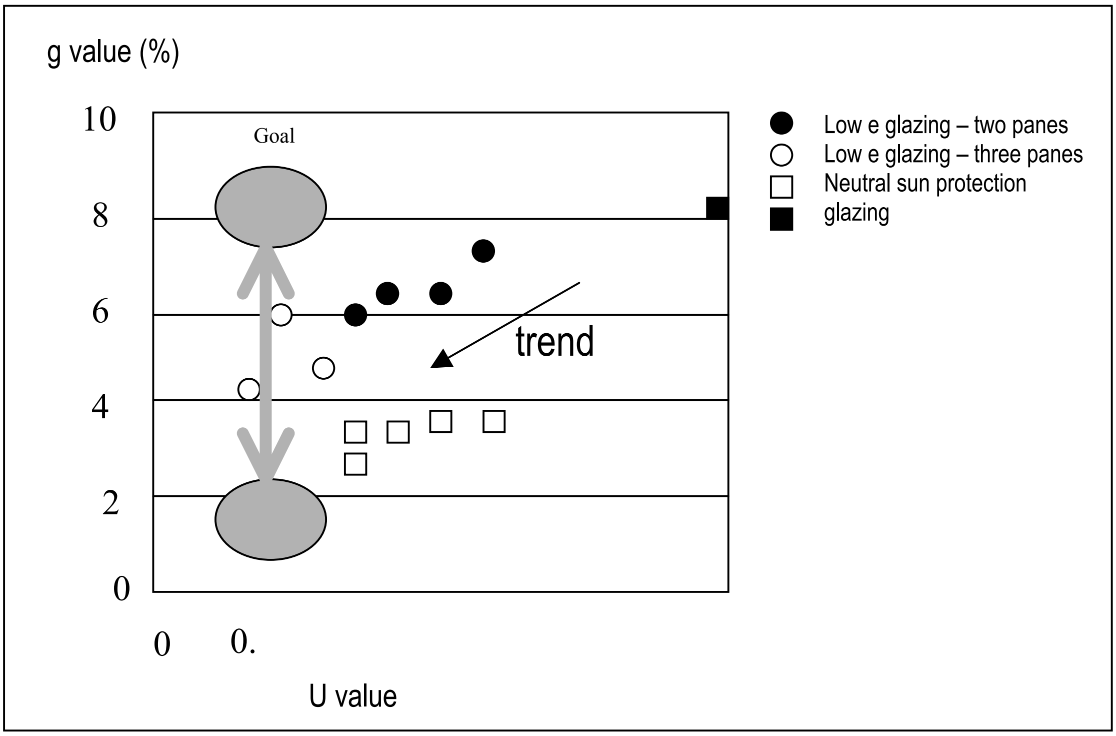

Figure 4. The change in comfort temperature with monthly mean outdoor temperature for free floating and air conditioning buildings, (From Nicols, 2003)

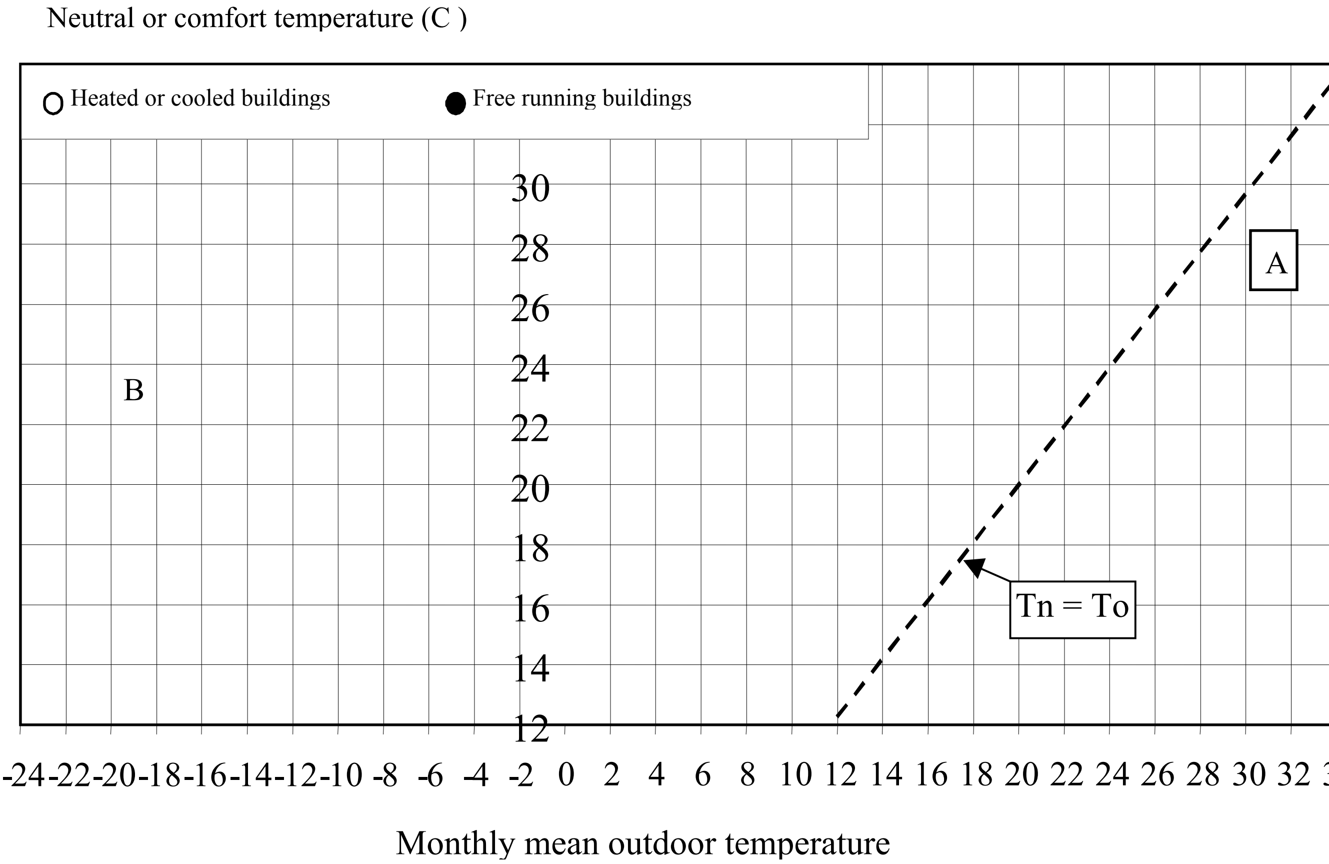

Figure 5. Household fuel transition and possible contribution of natural ventilation. (From United Nations Council for Human Settlements (UNCHS): The State of the World Cities, 2001)