Chapter 1: Collection and Documentation of the Input Data and Evaluation Tools Required to Carry out the Study

1. Introduction

Urbanization and Industrialization are directly affecting the urban environment. Building and population density are continusly increasing. Vegetation and plantation have greatly diminished in the urban environment, giving way to large building settlements.

From the climatic point of view, human history is the history of urbanization. Cities are steadily expanding their boundaries and populations. Recent industrialization and urbanization have affected dramatically the number of the urban buildings with major effects on their energy consumption. The number of urban dwellers has risen from 600 in 1920 to 2 billion in 1986 and almost one - half of the world's population is living in cities, where 100 years ago, only 14 % lived in cities and in 1950, less than 30 % of the world population was urban. Today, 170 cities support more than 1 million inhabitants each. Estimations show that urban populations will occupy 80 % of the total world population in 2100.

The situation will be even more dramatic in developing countries. Already, twenty three of the thirty four cities with more than 5 million inhabitants are in developing countries.

The urban environment modifies microclimate in numerous ways, the net result being termed as the "urban heat island effect". In general urban climates are warmer and less windy than rural areas. However, the modification to urban climates is highly variable and depends on the local climate, particular topography, regional wind speeds, urban morphology, human activity and many other factors

The form and fabric of an urban area differ substantially from rural zones and this alters the way in which heat flows into and out of the area. Solar gain is more efficiently captured in a city and, together with heat from anthropogenic sources, is better stored. Likewise the way in which heat may be dispersed through re-radiation and air cooling is less effective in cities than in the countryside.

The alteration to temperature i particularly important to building users, as it directly affects energy consumption of buildings for heating/cooling purposes. The energy used for cooling in summer will rise (including night cooling) while energy used for heating in the winter will decrease but generally to a less extent. The degree to which increased cooling demand is offset by lower heating needs varies considerably. Thus, in hot and warm climates the increase of cooling requirements is considerably higher than the corresponding decrease of the heating needs. In more temperate and cooler climates, the conclusions are not clear yet as heating and cooling are affected more or less in the same degree and thus there is need for further investigation in order to identify better the phenomenon.

What is important is to describe the mean features by which the urban climate differs from the climatic conditions of the surrounding rural areas. The main differences between the urban and "rural" climatic conditions that affect human comfort, are focused in the values of air temperatures and wind speeds near street level. These differences are caused by changes in the radiant balance of the urban space, the convective heat exchange between the ground and the buildings, the air flowing above the urban area and the heat generation within the city.

It is clear that urban areas without a high climatic quality use more energy for air conditioning in summer and even more electricity for lighting. Moreover, discomfort and inconvenience to the urban population due to high temperatures, wind tunnel effects in streets and unusual wind turbulence due to the wrongly designed high rise buildings is very common. Thus, it becomes increasingly important to study urban climatic environments and to apply this knowledge to improve people's environment in cities.

The air space above a city can be divided in the so-called urban air 'canopy', and the boundary layer over the city space called 'the urban air dome'. The urban air canopy is the space bounded by the urban buildings up to their roofs. The air dome layer is defined as 'that portion of the planetary boundary layer whose characteristics are affected by the presence of an urban area at its lower boundary', and is more homogeneous in its properties over the urban area at large.

Temperature distribution in urban areas is highly affected by the urban radiation balance. Solar radiation incident on the urban surfaces is absorbed and then transformed to sensible heat. Most of the solar radiation impinges on roofs, and the vertical walls of the buildings, and only a relatively small part reaches the ground level.

Walls, roofs and the ground emit long wave radiation to the sky. The intensity of the emitted radiation depends to the view factor of the surface regarding the sky. Under typical urban conditions, most of the sky dome viewed by walls and surfaces is blocked by other buildings and thus the long wave radiant exchange does not really result in significant losses.

Passive cooling in urban areas is highly affected by the wind and temperature distribution in the city. Effective design of passively cooled urban buildings requires a good understanding of the urban climate characteristics and in particular of the temperature and wind distribution.

The net balance between the solar gains and the heat loss by emitted long wave radiation determines the thermal balance of urban areas. Because the radiant heat loss is slower in urban areas, the net balance is more positive than in the surrounding rural areas and thus higher temperatures are presented.

2. Urban Climate Characteristics

2.1 Heat Island

Definitions and Physical Principles

The temperature of air in urban areas are usually higher than in the rural sides of the city. The phenomenon known as 'heat island',and is very well documented as far as of climatic modification is concerned and was first noticed by meteorologists more than a century ago. Heat island is a direct result of urbanization and is present in every town and city.

Higher urban temperatures have a serious impact on the power demand for air conditioning of buildings, increase smog production, while contribute to increase emission of pollutants from power plants, including sulfur dioxide, carbon monoxide, nitrous oxides and suspended particulates.

The phenomenon is characterized by an important spatial and temporal variation related to climate, topography, physical layout and short-term weather conditions. A detailed description of the more important factors influencing heat island are summarized below:

- *Canyon Radiative Geometry* contributes to decrease the long wave radiation loss from the street canyons due to the complex exchange between buildings and the screening of the skyline. Geometry also decreases the effective albedo of the system because of the multiple reflection of short wave radiation between the canyon surfaces.

- *Reduction of evaporating surfaces* in the city putting more energy into sensible and less into latent heat.

- *Urban greenhouse*, that contributes to increase the incoming long wave radiation from the polluted urban atmosphere.

- *Thermal properties of materials* that may increase storage of sensible heat in the fabric of the city during the day time and release their stored heat into the urban atmosphere after sunset.

- *Anthropogenic heat* released from combustion of fuels either from mobile or stationary sources and animal metabolism.

- *Reduced turbulent transfer* of heat from within streets due to reduced wind velocities within urban canyons

Heat island phenomenon may occur during the day or the night period. It is well known that for a large city with cloudless sky and light winds and just after sunset, the boundary between the rural and the urban areas exhibits a steep temperature gradient, to the urban heat island, then the rest of the urban area appears as a 'plateau' characterized by a weak gradient of increasing temperatures, and finally a peak at the city center where the urban maximum temperature is found. Heat island patterns are strongly controlled by the unique characteristics of each city. The difference between the maximum urban temperature and the background rural temperature is defined as the urban heat island intensity. The intensity of the heat island is mainly determined by the thermal balance of the urban region and can result up to 10 degrees of temperature difference.

Parametric Models to study Heat Island

Heat island studies aim mainly to understand the role of the main parameters influencing temperature increase in cities. Studies have concentrated on the role of city size and population, weather conditions like cloud cover wind speed, humidity, urban canyon characteristics, etc.

Various studies on the intensity of heat island have been performed for many European cities. Data on the heat island intensity in Malmo, Sweden provide a mean heat island intensity close to 7 C. Measurements of the heat island in Fribourg, Germany, show that the intensity of the phenomenon is close to 10 C.Data on the heat island for various Swiss cities are reported. For Bale and Berne the heat island intensity was close to 6 C, while for Biel and Fribourg was 5 C, and for Zurich was close to 7 C.Information on the heat island intensity in Essen, Germany give a heat island intensity between 3-4 C for both the day and night period. Data on the heat island intensity in Goteborg, Sweden, show a well developed urban heat island of magnitude 5 C, ranging from 3.5 C in winter and 6 C in summer. It is found that during the summer season on nearly all of the night hours the heat island intensity was greater than 0.5 C and on the 40 % of the night hours it was greater than 1 C. Finally, the use of satellite data for Rome, provides important temperature differences between high-density urban areas and low-density urban and agricultural areas

According to theoretical assessments the Paris mean albedo is equal to 0.159 for a surface temperature of 23°C (whereas *a* is equal to 0.235 for ground overrun with weeds [22,5°C], 0.191 for great peripheral estates -great blocks - [21,5°C] and 0.185 for suburban houses [20,5°C]). The small difference between urban and open country albedos (0,076) and between infra-red balances are nevertheless not enough to explain the island heat. The anthropogenic heat is the dominant factor in that case. There is a relationship between the urban population and the observable temperature deviation. According to that relationship the mean temperature increase in Paris due to the heat island effect is 4.3 C.

Detailed investigations of the urban climate were carried out in London in the 1960s. It was found that London was usually warmer than its rural surroundings on summer days up to 4°C, but for one third of the time was cooler. A current study of the summer urban heat island of London has been performed by researchers in BRE and Brunel University. Approximately 70 measurement stations were installed through the city with temperatures recorded every hour. Data have been gathered during summer 1999. The main conclusions derived from the analysis of that measurements, are:
•The intensity of London's heat island effect varies considerably in time and space
• In average London was warmer than the reference rural site by 1.8°C
• In general it was derived that London is much warmer than rural areas at night but less so during day

Many consequences are ascociated with the increase of the mean temperature. One of them is the decrease of freezing days : from 56 days in 1901-1910 to 22 days in 1971-1980. An other consequence is the creation of a country-breeze which is resulting from the temperature difference between the centre of Paris and the suburb (thermal winds). The country-breeze is however very low (from 2, up to 3 m/s). The relative humidity (ratio between effective humidity and saturated humidity) is more important in the suburb because of a more important evapo-transpiration and because of a lower temperature. The temperature increase reduces relative humidity to 75 % (against 79 % in Orly).

High temperature differences have been recorded during summer 1996, between the urban and reference stations. During the summer and winter period much higher temperatures have been recorded in the central Athens area especially during the day time. Temperature differences up to 18 C have been recorded during the daytime and in particular between a station suffering from high traffic load and a reference station. In general temperature difference is increasing with high temperature in the urban station. This is mainly due to the thermal balance of the urban region where heat inputs are added mainly from the traffic increasing thus local temperatures, something that does not happen to the surrounding suburban reference regions.

Analysis of the ambient distribution during the summer period in Athens results to the following conclusions:

- Cooling degree hours in the central area of the city is about 350 per cent higher than in the suburban areas.
- Maximum heat island intensity in the very central area is close to 16 C, while a mean value for the major central area of Athens is close to 12 C.
- Absolute maximum temperatures in the central area is close to 15 C higher than in the suburban areas, while absolute minimum temperatures are up to 3 C higher in the center.

- West Athens area, characterized by low vegetation, high building density and high anthropogenic emission rate presents almost double cooling degree days than the northern or southern Athens area.

2.2 Urban Environment and Thermal Balance

In the urban environment thermal balance differs substantially than that of rural areas. This is because of the following reasons:

- Anthropogenic heat released by cars and combustion systems,
- higher amounts of solar radiation stored,
- blockage of the emitted infrared radiation by urban canyons

The factors mentioned above make the global thermal balance more positive and contributes to the warming of the environment.

The energy balance of the 'earth surface - ambient air', system in the urban environment can be analysed using the first thermodynamic law. In a general way:

Energy Gains = Energy Losses + Energy Storage.

Energy gains involve the sum of the net radiative flux, Q_r, both under the form of solar and long wave radiation emitted by the opaque elements, (building, streets, etc), as well as the anthropogenic heat, Q_T, originating from vehicles, power generation and other heat sources.

Energy Losses are under the form of sensible, Q_E, or latent heat, Q_L, originating from heat convection between the building surfaces and the air as well evapotranspiration. Energy is also lost due to advection to the surronding environment.

Taking into account the energy balance in a suburban and rural environment as derived from experiments, it is obvious that the radiative flux is the most important term and is slightly higher in the rural than in the urban environment. During the day period, the net radiative input is higher in the suburban than in the rural environment, however night losses are much higher and compensate daytime gains. Radiative surplus in the suburban environment in the daytime is mainly lost through sensible heat flux. Sensible heat remained positive during the late afternoon hours contributing significantly to the heating of the urban atmosphere. Higher stored energy in the suburban environment is mainly due to the higher surface for absorption than in the rural environment, where rural vegetation cover provides a type of insulation. The latent heat in urban areas is seriously reduced. The energy content of evapotranspiration is close to 597 Kcal per gram of evaporated water at 0 C, and 575 at 40 C. In the urban area the total latent heat is reduced according to the morphology and the characteristics of the city and in particular is a function of the existing green areas.

The Role of Anthropogenic Heat

Anthropogenic heat affects significantly the ambient temperature and increase the heat island intensity. Anthropogenic heat is related to transportation, power generation and other heat sources. Estimations for US city centres range between 20-40 W/m2 in summer and 70-210 W/m2 in winter. Others suggested a range between 84-167 W/m2 for mid latitude cities in winter, or constant fluxes of 92 and 17 W/m2 for the winter and summer period respectively. Measurements in Bonn show that in winter, a diurnal pattern comprising two maximum inputs of 45 W/m2 at 08:00 hours and 1700 hours, and a minimum of 30 W/m2 from midnight till 0600 hours. A mean daily heat flux of 54 W/m2 from transportation and domestic electrical use in summer is reported

Solar Radiation in Urban Areas

Solar radiation and sunshine duration in the urban environment is seriously reduced because of the increased scattering and absorption by particulates in the urban atmosphere. As mentioned the sunshine duration in industrial cities is reduced by 10 to 20 %, in comparison with the surrounding countryside and similar losses are observed in received energy. Urban pollution affects drastically as well the spectral composition and the direction of the incoming solar radiation, while because of the increased scattering and of the characteristics of the scattering agents, diffuse radiation increases while visibility is reduced and the color of sky changes.

Absorbed solar radiation is a direct function of the mean albedo of a city. Use of high albedo materials reduces the amount of solar radiation absorbed through building envelopes and urban structures and thus keeps their surfaces cooler.

2.3 Wind Distribution in the Urban Environment

The urban wind field is complicated. Small differences in topography may cause irregular airflows. As the air flows from the rural to the urban environment, it must adjust to the new boundary conditions defined by the cities. This results to the development of a two layers vertical structure. The so called 'obstructed sub-layer', or urban canopy sub-layer which is extended from the ground surface up to the buildings height, while the so called 'free surface layer' or urban boundary layer, is extended above the roof tops.

The obstructed or canopy sub-layer has its own flow field driven and determined by the interaction of the flow field above and the uniqueness of local effects as topography, building geometry and dimensions, streets, traffic and other local features, like the presence of trees. In a general way, wind speed in the canopy layer is seriously decreased compared to the undisturbed wind speed.

Estimation of the wind speed in a city in of vital importance for passive cooling applications and especially in the design of naturally ventilated buildings. It has been proved that wind speeds measured above the buildings or at airports differ considerably from the speed at an urban monitoring site. As roughness length is greater in an urban area than in the surrounding countryside, the wind speed at any height is lower in the urban area, and much lower within the obstructed area.

Air Flow in Urban Canyons

Knowledge of the airflow characteristics in urban canyons is necessary for all studies related to natural ventilation of buildings, pollution studies, thermal comfort, etc. The air flow patterns in urban canyons has received important attention during the last years. Urban canyons are characterized by three main parameters, H, the mean height of the buildings in the canyon, W, the canyon width, and L the canyon length. Given these parameters, the geometrical descriptors are limited to three simple measures. These are the ratio H/W, the aspect ratio, L/H and the building density.

Knowledge of the air flow patterns in urban canyons is resulting either from numerical studies or from field experiments within real urban canyons or within scaled physical models in wind tunnels. Most of the existing studies deal with the determination of the pollution characteristics within the canyon and put emphasis on situations where the ambient flow is perpendicular to the canyon long axis, when the highest pollutant concentration occur in the canyon

Perpendicular wind speed

For perpendicular flow and when the buildings are well apart, their flow fields do not interact. At closer spaces, the wakes are disturbed and the flow regime is an Isolated Roughness Flow. When height and spacing combine to disturb the bolster and cavity eddies, the regime changes to one referred to as wake interference flow. This is characterized by secondary flows in the canyon space where the downward flow of the cavity eddy is reinforced by deflection down the windward face of the next building downstream. At even greater H/W and density, a stable circulatory vortex is established in the canyon and transition to a "skimming" flow regime occurs where the bulk of the flow does not enter the canyon.

In deep canyons, wind tunnel research, has found that two vortices are developed, an upper one driven by ambient airflow and a lower one driven in the opposite direction by the circulation above

Flow along the canyon

For parallel ambient air flow, a mean wind is generated along the canyon axis with possible uplift along the canyon walls as airflow is retarded by friction. If the wind speed out of the canyon is below some threshold value the coupling between the upper and secondary flow is lost and the relation between wind speeds above the roof and within the roof is characterized by a considerable scatter.

Flow at an angle to the canyon axis

At intermediate angles of incidence to the canyon long axis, canyon air flow is a product of both the transverse and parallel components of the ambient wind, where the former drives the canyon vortex and the latter determines the along canyon streching of this vortex.

2.4 Canyon Effect

The urban air canopy is the space bounded by the urban buildings up to their roofs. It involves an unlimited number of microclimates generated by the various urban configurations. The specific climatic conditions at any given point within the canopy are determined by the nature of the immediate surroundings and in particular of the geometry, the materials and their properties.

The upper boundary of the urban canopy varies from one spot to an other because of the variable heights of the buildings and the wind speed. Air circulation and temperature distribution within urban canyons is of significant importance for energy consumption of buildings, pollutant dispersion studies, heat and mass exchange between the buildings and the canyon air including studies on the energy potential of natural ventilation techniques for buildings, pedestrian comfort, etc.

Temperature Distribution in Urban Canyons

Temperature distribution in urban canopy layer is highly affected by the urban radiation balance. Solar radiation incident on the urban surfaces is absorbed and then transformed to sensible heat. Most of the solar radiation impinges on roofs, and the vertical walls of the buildings, and only a relatively small part reaches the ground level.

Walls, roofs and the ground emit long wave radiation to the sky. The intensity of the emitted radiation depends to the view factor of the surface regarding the sky. Under urban conditions most of the sky dome viewed by walls and surfaces is blocked by other buildings, and thus the long wave radiant exchange does not really result in significant losses.

The net balance between the solar gains and the heat loss by emitted long wave radiation determines the thermal balance of urban areas. Because the radiant heat loss is slower in urban areas the net balance is more positive than in the surrounding rural areas and thus higher temperatures are presented.

Surface Temperature in Canyons

The temperature of the external materials in a canyon is governed by its thermal balance. Surfaces receive short wave radiation as a function of their absorptivity and exposure to solar radiation, receive and emit long wave radiation as a function of their temperature, emissivity and view factor, transfer heat to or from the surrounding air and exchange heat via conduction procedures with the lower material layers.

The optical and thermal characteristics of materials used in urban environments and especially the albedo to solar radiation and emissivity to long wave radiation have a very important impact to the urban energy balance.

The vertical distribution of the external temperature of buildings in a canyon is of important interest as define the convective transfer from and to the ambient air.

Air Temperature in Canyons

Temperature in a canyon is influenced by the temperature of the canyon surfaces, as energy is transferred through convective process, however, in spite of the fact that the street surface is influenced by the canyon geometry, there is a weak connection between geometry and air temperature and this because the air temperature is dependent upon the flux divergence in air volume including that of the horizontal transport.

Stratification during day

Air temperature stratification is not significant. Maximum DT rarely exceeds 2-3 C. Air temperature in the streets is governed by more complex and regional factors than their surface temperature, even if the canyon geometry is of importance. Lower temperatures are measured at the ground and temperature increased with height

Stratification during night

The vertical stratification of the air temperature in the canyon is low. The maximum temperature difference between the different canyon levels never exceed 1.5 C. Higher temperatures are measured at the ground level, and temperature is found to decrease with height.

3. Use of high albedo materials

3.1 General and Physical Principles

The albedo of a surface is defined as its hemispherically and wavelength - integrated reflectivity. Materials use in the external facade of buildings as well as in streets and pavements either absorb or reflect the incident solar radiation. Use of high albedo materials reduces the amount of solar radiation absorbed through building envelopes and urban structures and thus keeps their surfaces cooler. In parallel materials emit long wave radiation. The emitted radiation is a function of the material's temperature and emissivity. Materials with high emmisivities are good emitters of long wave energy and readily release the energy that has been absorbed as short wave radiation.

Although the impact of solar reflectivity and material's emissivity are important, it has to be clearly pointed out that the temperature of the materials is determined by its thermal balance, where conductive and convective phenomena have to be taken into account. In particular, the role of convective flows is very important. It is shown that the surface temperature of a black roofing membrane reached 82 C at no wind, but only 46 C with a wind of 15 m/sec.

The use of appropriate materials to reduce heat island and improve urban environment has gained increasing interest during the last years. Many research works have been carried to identify the possible energy and environmental gains when light colored surfaces are used. Studies try to investigate the impact of the materials optical and thermal characteristics on the urban temperature as well as the possible energy conservation during the summer period. A detailed guide on light colored surfaces has been recently published by US EPA. 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, shows that white roofs and shade trees in Los Angeles, USA, would lower the need for air conditioning by 18 percent or 1.04 billion kilowatt-hours, equivalent to a financial gain close $100 million per year.

3.2 Optical and Thermal Behavior of Materials

The optical characteristics of materials used in urban environments and especially the albedo to solar radiation and emissivity to long wave radiation have a very important impact to the urban energy balance. Materials with high emmisivities are good emitters of long wave energy and readily release the energy that has been absorbed as short wave radiation. Lower surface temperatures contribute to decrease the temperature of the ambient air as heat convection intensity from a cooler surface is lower. Such temperature reductions can have significant impacts on cooling energy consumption in urban areas, a fact of particular importance in hot climate cities.

The solar absorptivity of specific materials has been correlated with their surface temperature when materials are in horizontal position. The temperature difference between white and black coatings are close to 45 C, and 20 C between concrete and asphalt. The figure shows the average surface temperature of a hypothetical green city with surface temperatures 17 C cooler than an average city because of the combination of white roofs, light streets, parking lots and urban vegetation. In the hypothetical 'white city', there is less urban vegetation and thus the surface temperature is further reduced

Materials for Pavements and Streets

The impact of various pavement materials during summer used commonly in urban environments has been experimentally tested. The surface temperature, heat storage and its subsequent emission were significantly greater for asphalt than for concrete and bare soil. At the maximum, asphalt pavement emitted an additional 150 W/m2 in infrared radiation and 200 W/m2 in sensible transport compared to a bare soil surface. It was also found that the rate of infrared absorption by the lower atmosphere over asphalt pavement was greater by 60 W/m2 than that over the soil surface or concrete pavement.

Materials for Buildings Exterior

Appropriate materials used in the exterior part of buildings can contribute to decrease its surface temperature and thus reduce the induced air conditioning load. Materials for 'cool roofs' or walls should present a high albedo to solar radiation, close to 70 %, while conventional roofing or finishing materials have a mean albedo around 20 per cent. Important energy gains can be expected when solar reflective materials are used in buildings' exterior surfaces.

- Roof coatings can be white, tinted or aluminum. White roof coatings include transparent polymeric materials, such as acrylic, and a white pigment, such as titanium dioxide or zinc oxide in order to be opaque and reflective. Typical reflectivity of these materials are around 70-80 per cent.
- Colored coatings and in particular light colors are produced by adding tints to white coatings reducing thus its solar reflectance. Aluminum roof coatings generally are using an asphalt type resin containing 'leafing' aluminum flakes.
- Roofing membranes usually contain a fabric made from felt, fiberglass or polyester which is laminated to or impregnated with a flexible polymeric material which may range from bituminous hydrocarbon materials like asphalt, to PVC or EPDM, (synthetic rubber). In general roofing membranes are fabricated from waterproof materials that are flexible and strong. The color and the reflectance of the membrane is determined by its upper surface that generally is coated with a pigmented material or is simply ballasted with roofing gravel.
- Metal roofs are almost steel or aluminum constructions. Mean solar reflectivity is close to 60 percent while their emmissivity is low. Cool white coatings can be used to increase the reflectivity of the roof.

Cities and in general urban areas are characterized by a relatively reduced effective albedo because of two mechanisms :

- Darker buildings and urban surfaces absorb solar radiation
- Multiple reflections inside urban canyons reduce significantly the effective albedo

Typical albedo of European and American cities are close to 0.15 - 0.30. Much higher albedo have been measured in some North African cities, (0.45-0.6).

3.3 The Role of Materials on the Energy Consumption of Buildings and Cities

Simple materials used in cities are characterized by various albedo values, that determine the albedo of a city. Increase of the albedo has a direct impact on the energy balance of a building. Large scale changes on urban albedo may have important indirect effects on the city scale. Studies have been performed to evaluate direct effects from albedo change.

Measurements of the indirect energy savings from large scale changes in urban albedo are impossible. However, using simulations the change of the urban climate can be evaluated. It is shown that afternoon air summer temperatures can be lowered by us much as 4 C by changing the surface albedo from 0.25 to 0.40 in a mid - latitude warm climate. Studies on the effects of large scale albedo increases in Los Angeles have shown than an average decrease of 2 C and up to 4 C may be possible by increasing the albedo by 0.13 in urbanized areas. It is shown that a temperature decrease of this magnitude could reduce A/C electricity load by 10 %.

Measurements in New Mexico have indicated a similar relationship between naturally occurring albedo variations and measured ambient air temperatures. The atmospheric impacts of regional scale changes in building properties, paved surface characteristics and their microclimates are analyzed and it is found that implementing high albedo materials has a net effect of reducing ozone concentrations and wide population weighted exceedance exposure to ozone above the standards is decreased by up to 12 % during peak afternoon hours.

3.4 Choosing Places For Light-Colored Surfacing

At present, there is little public awareness of the benefits of albedo modification. Although, most people are aware that dark colors absorb more solar heat, there is little understanding about what constitutes high-albedo surfaces, and virtually no awareness that massive albedo changes can affect the temperatures of entire cities or neighborhoods. Similarly, few people realize that simple changes in albedo levels can reduce home energy use by 10 to 50 percent. The lack of public awareness of the benefits of increased urban albedo is reflected in the absence of research into the long-term characteristics of high-albedo materials, or the development of alternative building materials with high albedo. Nevertheless, we can begin to identify surfaces, methods, and potential problems with some degree of accuracy.

4. Use of trees and green spaces

4.1 General - Physical Principles

Vegetation has various effects on urban environment. Beyond the aesthetic role of trees and vegetation, it can increase property value, stabilize soil, provide habitat for wildlife, block noise and improve outdoor air quality. In this, a belt of trees 30 m wide and 15 m tall can reduce highway noise by 6 to 10 decibels. In addition, using the photosynthesis process, vegetation absorbs carbon dioxide and stores some of the carbon, reducing greenhouse effect. Lastly, leaves can be an efficient filter for dangerous pollutants from the air such as NO, NO_2, NH_3, SO_2 and O_3. Also, the benefits of trees and vegetation on energy use in buildings are also very important. These effects can be split into direct and indirect effects. The former ones are shading and wind shielding when the latter is a cooling effect due to evapotranspiration.

Trees, shrubs and vines can have a direct effect on urban climate by blocking the rays of the sun. For instance, trees in full leaf can block up to 95 percent of the incoming radiations. For deciduous trees, the values of the absorbed and the transmitted solar radiation vary from the summer to winter. Air-conditioning energy use can be reduced to 40 or 50 percent by shading windows and walls. Tree shading is a benefit in summer but not during winter when heating is needed.

Tree shade reduces cooling energy use inside buildings in three ways:
- preventing direct solar radiation through windows,
- reducing the amount of heat reaching the interior through the envelope,
- keeping the soil around the buildings cool ("heat sink" effect).

Vegetation creates a barrier to the wind and therefore reduces air pressure differences on the building surfaces. By lowering wind speeds around buildings, vegetation modifies the convective interaction between the building envelope and the outside air. This effect is dependent on wind speed and direction, and landscape configuration. Considering energy use, blocking the wind is beneficial during winter (heat losses reduction) but not in summer (cooling effect reduction). Nevertheless, the heating energy saving is higher than the excess of cooling demand.

Large trees should be planted on the west and on south sides to cast the maximum shadows and on the east side to shade the air- conditioner. Shrubs planted on all sides of the house help to reduce wall and soil temperatures. Trees in temperate climates must be chosen and planted to shield a house from both the hot summer sun and the cold winter winds.

When the wind shielding and shading effects are considered together, the net energy impact of these two effects on the building's heating and cooling energy use can be evaluated and numerical simulations have shown that vegetation reduces both the heating and cooling energy use in both hot and cold locations.

In order to dissipate the sensible heat from solar radiation and warm air, the vegetation transpire moisture. This phenomenon is called *evapotranspiration* and represents the main part of the thermal balance of vegetation. During the day, two-thirds of the net all wave radiation flux is used to evaporate water, the last third is dissipated in sensible heat flux since the net energy storage is very small.

The heat transferred by evapotranspiration process is close to 2320 kJ per kg of evaporated water. So, this phenomena is important since, for instance, a normal size deciduous tree can transpire up to 375 kg of water a day. The corresponding energy consumption is 870 MJ, which is the cooling effect of five air-conditioners. Furthermore, theoretical analysis has shown that the evapotranspiration from one tree can save 250 to 650 kWh of electricity used for air conditioning per year. The evapotranspiration has an indirect effect on outside air temperature because the solar energy is expended for evapotranspiration instead of directly heating the air. So, the increase on temperatures during the day will be reduced. Reported observations indicate a temperature reduction of 2-3°C due to vegetation evapotranspiration.

Comparing the direct and indirect effects of vegetation on energy use shows that the evapotranspiration of vegetation i.e. the indirect effect produces greater cooling energy saving than direct effects that is to say shading and wind shielding. In this, direct effects provide a relatively small percentage (only 10 to 35 percent) of the total energy savings.

4.2 The Impact of Trees and Urban Parks on Ambient Temperature

Evapotranspiration from soil - vegetation systems can contribute significantly to reduce urban temperatures. Sailor considers that the low evaporative heat flux in cities is the more significant of the factors in the development of urban heat island. As reported below, evapotranspiration from plants at the National park of Athens create 'oases' of 1-5 C during the night period. Duckworth and Sandberg found that temperatures in San Francisco’s heavily vegetated Golden Gate Park average about 8 C cooler than nearby areas that are less vegetated. In Tokyo, vegetated zones in summer are 1.6 C cooler than non-vegetated spots, while in Montreal, urban parks can be 2.5 C cooler than surrounding built areas. Jauregui, reports that the park in Mexico City was 2-3 C cooler with respect to its boundaries. Lindqvist, has performed studies in Gotemborg, Sweden, and he reports that in some occasions 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. Taha et al report that evapotranspiration can create oases that are 2-8 C cooler than their surroundings, while Bowen reports 2-3 C temperature reduction due to evapotranspiration by plants. Finally, Saito et al, has studied the effect of green areas on the thermal environment of Kumamoto city in Japan. He reports that even small green areas of 60 m x 40 m indicated the cooling effect. The maximum temperature difference between inside and outside the green area was 3 C.

4.3 Impact of Trees on the Energy Consumption of Buildings

The impact of trees on the energy consumption of buildings is very important. As reported by the National Academy of Sciences of United States, the plantation of 100 million trees combined with the implementation of light surfacing programs could reduce electricity use by 50 billion kWh per year, which is equivalent to the 2 per cent of the annual electricity use in the US and reduce the amount of CO_2 dumped in the atmosphere by as much as 35 millions of tons per year.

Shading from trees contributes to decrease significantly energy for cooling. Shaded surfaces present a much lower temperature and thus decrease heat convection rate to the building interior. However, the presence of vegetation may decrease the radiation exchange of the wall with the sky and thus contribute, especially during night, to a higher temperature of the wall. Simulation studies using limited numbers of buildings and tree configurations for cities across the US indicate that shade from a single well placed, mature tree of about 8 m crown diameter, can reduce annual air conditioning use 2 to 8 % and peak cooling demand 2 to 10 %.

4.4 Cooling A Neighborhood Or City

To help lower an entire city’s temperatures through evapotranspiration, it is required to plant as many street trees as possible in public as well as private spaces. Parking lots, plazas, street meridians, sidewalks, residential yards, corporate lawns, parks, shopping plazas, and many other niches are currently full of empty tree spaces. New developments - which spring up constantly in many communities – are an excellent place to begin planting for heat-island reduction. Too often, however, these developments are just bulldozed in as quickly as possible, rather than being environmentally landscaped. Existing trees often are plowed under in this process, leaving a landscape bereft of their cooling and aesthetic benefits.

The difference between the two approaches reflects the attitude of city leaders, planners, and citizens toward the relationship between cities and nature. It’s important to encourage leaders and developers to keep existing ones are destroyed, and to include landscaping as part of any development plan. Unfortunately, many of our older cities were built with the latter attitude. But if new communities and developments learn from the mistakes of older cities, we can utilize the opportunities of the natural environment right from the outset. The result will be a better urban environment, at a lower-term cost to the citizenry.

The best time to make a city fit into the natural environment, of course, is during the planning and development phase. For instance, new subdivisions in treeless areas can be required to plant large-growing trees as part of their development plan. Even very large trees can be transplanted into new urban development sites through skillful planning and execution. Proper placement of trees in new constriction is a logical a part of development as locating trees and sewers and isn't overly expensive. Obviously, that time is long past in many urban places. The best strategy, then, is to improve planting and management programs so as to mimic the natural world as closely as possible.

Parking lots can be shaded with little or no reduction in parking capacity. Extra planning to coordinate tree locations with lighting facilities, however, is needed. Tree planting space at least 1.5 meters wide can be borrowed from paved areas between rows of cars by allowing car bumpers to overhang planter space. Designs of streets should change to allow more greening. Modern engineers could use techniques like boulevards that create a green path down the middle of the street and double the potential planting space for trees. Each street boulevard mile can handle about 400 trees rather than the 200 average of a normal street because the linear curb area is doubled. Unlike the business side of the street, which presents restrictions for trees ranging from sidewalks to power lines, the boulevard can concentrate on landscaping.

Cities, have options which are not without costs, but sound investments that result in long-lived, healthy forests are nearly always more cost-effective than their alternatives.

5. Solar Control of Open Spaces

5.1 Sun penetration into urban streets

In hot climates in summer, thermal comfort in outdoor areas is improved if shade is provided. To avoid sunlight penetrating to the ground, one approach is to have very tall, narrow streets. Street orientation is also important.

East-west streets are to be avoided in hot climates. They have significantly higher annual sunshine penetration than the other street orientations, and all of this occurs in the six summer months. In mid summer the sun can reach the north side of the street for nearly all the hottest part of the day. The only exception to this is if the street is very narrow indeed compared to its height. For Athens H/W would need to be at least 4, for Rome an H/W of 3.5 would be best to avoid sun penetration.

North-south streets have the least sun penetration, and around a third of it occurs in the six winter months when it will be more welcome. The sunlight is concentrated around the middle of the day, and at other times of day the whole of the street will be in shade. Over the six summer months, sunlight penetration is less than half that for an east-west street.

This lower sun penetration arises at the cost of sunlight on the building faces. The same amount of sun enters the top of each canyon. With the E-W street more reaches the ground, with the N-S street more reaches the building faces. However the sun for the N-S street is more likely to strike the east and west facing buildings at an oblique angle, resulting in less solar gain. Different solar shading strategies will need to be adopted, overhangs will work less well and vertical fins and deep reveals will be better. Shading the upper storeys of the buildings could be a problem.

People have to move about the city somehow, and if all the streets run north-south then they have little opportunity to get from east to west or vice versa. If we consider the typical grid pattern of streets running at right angles to each other, a NE-SW/SE-NW grid has significantly less sun penetration than an E-W/N-S grid. Adding the summer sun penetrations together gives as a sunlight score of 46 for Rome and 47 for Athens, compared with 59 for Rome and 66 for Athens with the E-W/N-S grid.

5.2 Shade as Prerequisite for Cooling Outdoor Spaces

Before considering any means for lowering the air temperature in an outdoor space shade from the sun should be provided. There are two reasons for the primacy of shading:
a) Protection from solar radiation has a larger physiological effect in reducing heat stress than the effects that can be expected form lowering the air temperature without providing shade in outdoor spaces.
b) Shading does not involve any expenditure of energy or water for irrigation, as do almost all the systems that can lower the temperatures in an outside area.

Materials that commonly are used the shade outdoor spaces are not solid and, in effect, transmit some fraction of the solar radiation. The transmitted radiation raises the ground surface temperatures in the shaded place. In practice, even with "tight" shade materials about 20% of the radiation falling on the shade can be assumed to be transmitted. The geometry and dimensions of the area affect the effectiveness of the shading.

Even in cases shading elements covers where the whole treated outdoor area. Solar radiation can enter from the sides. The narrower the shaded area the greater is the fraction that is affected by this lateral penetration, especially if the area extends in the north-south direction.

The Temperature of the Shade's Underside during the same time, except when the shade is provided by plants, is usually above the ambient air level, as a result of the solar radiation that is absorbed by the shade. The temperature of the underside of the shade effects the longwave radiant field to which people staying in the area are exposed, and consequently it affects their thermal comfort. The shade's underside temperature depends on the external color of the material and its thermal conductance. The lighter the color the lower the conductance the closer will the shade's underside temperature be to the ambient air level.

An exception is when shade is provided by a thick layer of leaves, such as that given by trees or vines with dense foliage. The lower leaves are protected form the sun by the upper part of canopy and cooled by evapotransiration, so their temperature is very close to the ambient air level-in fact, it might even be lower.

5.3 Use of Water to Cool Outdoor Spaces

A mass of water exhibits a thermal performance different from most land surfaces. This is a consequence of:
(i) solar radiation that can be transmitted or absorbed
(ii) convection and mixing that allow the water to store heat, passing it deep within the water.
(iii) heat loses due to evaporation.

The presence of a large mass of water causes an air temperature drop that it remains windward depending on wind velocity and the length of mass of water. Ponds and fountains can be effective air conditioning systems in open spaces because of their ability to keep water temperatures lower than air temperature, and their low reflectivity.

Ponds and fountains can be effective air conditioning systems in open spaces because of their ability to keep water temperatures lower than air temperatures, and their low reflectivity. Ponds have a reflectivity of approximately 3 % at times of maximum solar radiation, and therefore reflect little solar radiation towards occupied zones. They absorb a lot of solar radiation, up to 80% depending on the depth of pond. All solar radiation does not however produce a significant increase of water temperature because of the pond's thermal inertia and evaporation at its surface. The water pond inertia is directly proportional to water mass and therefore to its depth. With increasing water pond inertia, the water temperature decreases. The daily range of water temperature (difference between maximum and minimum) is reduced and there is a phase between air and water temperatures.

When the pond is in shadow, the incoming solar radiation is reduced, with a reduction in water temperature. This temperature reduction increases with increased shading of the pond.

As water evaporates from a drop its temperature decreases. Evaporation is proportional to the air-water contact surface area, so incorporating fountains and sprayers (drops with a diameter of the order of several mm) or nozzles (drops of the order of 1 mm or less), produces a large decrease in water temperature. The smaller drops are, the greater the air-water contact surface is, increasing evaporation. With a constant flow rate, the contact surface produced by a nozzle is 100 times greater than from a sprayer.

Energy Flows of Water Droplets

A single ware drop moving through still air experiences the following process:

- Heat flows from the air to the drop (if the air is hotter than the drop)
- Water evaporates from the drop to the surrounding air. The hotter the drop is, the more water will be evaporated
- The drop slows down as it moves through the air

The first two processes affect the temperature of the drop in different ways. Inward heat transfer will warm it up but evaporation will cool it down. As a result of these two opposite tendencies, an equilibrium drop temperature is reached (the wet bulb temperature of the air). Once the drop has reached the wet bulb temperature, the extra energy needed to evaporate more water has to come from the surrounding air. This means the surrounding air is cooled, unless the air becomes saturated after which no more evaporation takes place.

So there are two different periods in the evaporation of a single water drop in the air:

1. The drop temperature is changing from initial temperature to its equilibrium temperature (the air wet bulb temperature)
2. The drop reaches equilibrium temperature and its radius decreases with evaporation

The relative length of each period within the airborne life of the drop depends mainly on the initial drop size and so this will be the most important design variable for cooling by fountains and sprays.

Cooling by water drops can be achieved by two different ways:

- Water drops directly cool the air of the space being conditioned. Total evaporation of the water droplets is preferred, so that their air cooling capacity is maximized while preventing people from getting wet.
- Indirect cooling of the air by using cool water as an intermediate medium. In this case, water drops cool the water in a pond and the aim is to obtain the maximum reduction of the temperature of the drops with the minimum water loss.

In short, water pond temperature depends on the existence of sprays, their number and kind, when they operate, if the pond is shaded, and pond depth.

5.4 Lowering The Air Temperature In Outdoor Spaces

Once an area is effectively shaded and partially separated from the surrounding air by being sunken and/or surrounded by walls, trees, or shrubs the air and radiant temperatures in it can be lowered below the level of the outdoor air. The air within a semi confined space can be cooled either by the introduction of precooled air or by direct evaporative cooling of the air inside it. Air can be precooled by a passive evaporative cooling tower or by convective "shower" cooling tower, systems that are discussed below.

To maximize the physiological benefits from the cooled air it is advisable to introduce it near ground level. In this way temperature stratification over the area would be enhanced, with the cooler air at the level where people are standing or sitting.

Untreated river water, brackish water, or even sea water can be utilized for same of the cooling systems possible in indoor spaces, as will be noted in the discussion of the specific systems. Such water sources are available in many arid and desert regions.

The depression of the wet bulb temperature (WBT) below the air temperature (DBT) in summer during the hot hours of the day is the most direct quantitative criterion for assessing the potential of evaporative cooling in a given location. The expected temperature drop, below the ambient air level, of air exiting from an evaporative cooling system would be about 60 to 80% of the WBT depression (DBT-WBT).

<u>Artificial Fog</u>

Injecting water at high pressure through very minute orifices can generate artificial fog. If the water droplets are small enough, and the WTB depression below the air temperature is large enough, the droplets evaporate almost instantly. The evaporation of the droplets cools the air without forming liquid water over people staying nearby, although the fog is visible.

<u>The Tucson Passive Evaporative Cooling Towers</u>

A passive evaporative air-cooling tower attached to a building has been developed by Cunningham and Thomson at the Environmental Research Laboratory of the University of Arizona in Tucson. It consists of a downdraft tower topped by vertical wetted cellulose pads. Water is distributed at the top of the pads, collected at the bottom by a sump, and recalculated by a pump. Such a passive evaporative cooling tower can be used to provide cool air for semi confined outdoor areas.

6. Comfort In Outdoor Spaces

It is evident that in order to cool the urban environment effectively, a combination of actions should be applied to the treated spaces. These actions should include all or some of the techniques described in the previous sections (landscaping, use of plants and trees, use of cool materials, use of cools sinks, etc.), according to the specific characteristics of the area and the availability and applicability of the potential interventions. The effect that the application of global strategies for the cooling of urban spaces has on the human thermal comfort will be presented below.

The duration and intensity of the use of outdoor spaces is closely linked to how comfortable they are. It is possible to control the climate of outdoor spaces, but compared with the conditioning of buildings there are big differences:

- The number of variables to be manipulated. Outside, wind and rain can be important.
- The relative influence of each variable. For example, direct sun on people is generally much more important out of doors since it may not penetrate far inside a building. Indoors, air temperature has more influence.
- How far each variable can be manipulated. For example, it is more difficult to achieve still conditions out of doors on a windy day. Indoors, the temperatures of surrounding surfaces are likely to be relatively stable, whereas outdoors they can vary a lot if the surfaces are sunlit.
- The comfort level required. Outdoors, people can be comfortable in a wider range of conditions because they can usually move about more easily and carry out a different range of activities.

Thus to improve the level of comfort on a hot day means reducing the unfavorable heat gains, eliminating them whenever possible, for convection and long wave exchange, changing then into favorable heat losses. Conversely, on a cold day it is best to increase heat gains and reduce heat losses. The criteria for designing a thermally comfortable urban site are therefore complex and sometimes contradictory. They include solar control in summer, but also solar gains in winter, wind protection in winter but generally wind access in summer.

Strategies to provide thermal comfort in an outdoor urban environment on a hot summer day can be divided into three groups:

- Control of direct and diffuse solar radiation
- Reduction of the radiant temperature
- Reduction of the air temperature

Narrow streets and courtyards provide extra shade as they stop the access of direct solar radiation at ground level for most of the day, especially in orientations NE-SW or NW-SE. This blocking of solar radiation also produces low temperatures on the surfaces surrounding the pedestrian, reducing the infrared radiation. However, narrow streets can lead to high pollution levels due to the poor ventilation at the bottom of the street canyon, high noise levels where there is traffic and a very hot environment when air conditioning systems release waste heat onto the street.

Wider streets can become efficient in terms of summertime thermal comfort if they include awnings or other shading devices that protect the occupied spaces from solar radiation. An advantage of wide streets from the thermal point of view is that they can include streetscape elements (such as street furniture, seating, vegetation, trees, shelters, canopies, structures and water features) to promote shading and good comfort conditions. Avenues of trees are appreciated by pedestrians and allow the use of wide and sunny streets in urban planning with good summer comfort for pedestrians. In cities where rain protection is important, trees can be replaced by colonnades.

In cold climates, thermal comfort is highly influenced by wind flows. The form and layout of buildings, particularly tall buildings, can have a big impact on air flow and therefore the comfort of pedestrians. Vegetation and windbreaks can also help. Sunlight in the spaces between buildings will air thermal comfort here.

7. Microclimate Aspects Related to the Energy Efficient Refurbishment of Settlements

7.1 The Urban Climate

The urban climate differs substantially than that of rural areas. Anthropogenic heat released by industry, air conditioners, cars and combustion systems, higher amounts of solar radiation stored mainly in buildings and other surfaces, and blockage of the emitted infrared radiation by urban canyons and greenhouse effect, makes the global thermal balance more positive and contributes to the warming of the environment. As a consequence of the positive heat balance, air temperatures in densely built urban are higher than the temperatures of the surrounding rural country. This phenomenon is known as 'heat island', is due to many factors the more important of which are summarized by Oke, Johnson, Steyn and Watson , (1991), and deal with : a) the canyon radiative geometry that contributes to decrease the long wave radiation loss from within street canyon due to the complex exchange between buildings and the screening of the skyline, b) the thermal properties of materials that increase storage of sensible heat in the fabric of the city, c) the anthropogenic heat released from combustion of fuels and animal metabolism, d) the urban greenhouse, that contributes to increase the incoming long wave radiation from the polluted and warmer urban atmosphere, e) the canyon radiative geometry decreasing the effective albedo of the system because of the multiple reflection of short wave radiation between the canyon surfaces, f) the reduction of evaporating surfaces in the city putting more energy into sensible and less into latent heat, and g) the reduced turbulent transfer of heat from within streets.

Except of the temperature increase, the urban environment affects almost all other climatological parameters. Solar radiation is seriously reduced because of increased scattering and absorption by urban aerosol. As reported by Landsberg, (1981), the sunshine duration in industrial cities is reduced by 10 to 20 per cent, in comparison with the surrounding countryside and similar losses are observed in received energy.

In parallel wind speed and direction, around buildings and in canyons, is seriously decreased compared to the undisturbed wind speed. This is mainly due to the specific roughness of a city, channeling effects through canyons and also because of the heat island effect.

As a sequence of the specific climatic conditions in cities, the energy consumption of cities is seriously increased during the summer period and may decrease during winter

7.2 Energy Impact of the Urban Climate

Recent European statistical data, (Stanners and Bourdeau, 1995), show that the amount of energy consumed in cities for heating and cooling of offices and residential buildings has increased significantly in the last two decades. An analysis on the energy impact of urbanisation, (Jones, 1992), showed that a 1 percent increase in the per capita GNP leads to an almost equal (1.03), increase in energy consumption. However, an increase of the urban population by 1 % , increases the energy consumption by 2.2 %, i.e., the rate of change in energy use is twice the rate of change in urbanization. These data show clearly the impact that urbanization may have on energy use.

Increased urban temperatures have an important impact on the energy consumption of buildings during the summer and the winter period. Recent studies and research have found that during summer, higher urban temperatures increase the peak electricity load, the electricity demand for cooling, decrease the efficiency of air conditioners and increase the production of carbon dioxide and other pollutants, while higher temperatures may reduce the heating load of buildings during the winter period.

Heat island effect in warm to hot climates exacerbates cooling energy use in summer and increase peak electricity demand. It is reported, (Akbari H. et al, 1992), that in US cities with population larger than 100000 the peak electricity load will increase 1.5 to 2 percent for every 1 F increase in temperature. It is calculated that 3 to 8 percent of the current urban electricity demand in US, is used to compensate for the heat island effect alone.

Studies on the Tokyo area reported by Ojima (1990/91), conclude that during the period between 1965 to 1975, the cooling load of existing buildings has increased by 10 - 20 % on average because of the heat island phenomenon, while it was expected that if the phenomenon continues to increase at the same rate, it had to make more than a 50 % increment in 2000.

Extensive experiments have been performed in Athens, Greece to estimate the impact of heat island on the energy consumption of buildings. Calculations of the spatial cooling load distribution in the major Athens area, reported by Santamouris, 2001, found that the cooling load of a reference building is about the double at the center of the city than in the surrounding Athens area. It is also reported that peak electricity loads for cooling increases up to 150 % and put a serious strength on the local utilities. Finally, a very important decrease of the efficiency of conventional air conditioners, because of the temperature increase, is reported. It is found that the minimum COP values are lower to about 25 % in the central Athens obliging designers to increase the size of the installed A/C systems and thus intensify peak electricity problems and energy consumption for cooling.

7.3 Solutions to Improve the Urban Thermal Environment

Studying successful and appropriate solutions to counterbalance the effects of heat island on the energy performance of urban buildings is a first priority for the future. The improvement of the ambient microclimate in the urban environment involving the use of more appropriate materials, increased use of green areas, use of cool sinks for heat dissipation, appropriate layout of urban canopies, etc., seems to be the more appropriate techniques.

The appropriate characteristics of materials used in streets and pavements and in the outdoor facade of buildings and in particular the albedo to solar radiation and emissivity to long wave radiation have a very important effect to the urban energy balance and the performance of buildings. Higher surface temperatures, (Figure 1), contribute through convection to increase ambient temperatures, while because of the high radiated infrared radiation, comfort in outdoor areas is seriously affected.

Increase of the surface albedo has a direct impact on the energy balance of a building. Large scale changes on urban albedo may have important indirect effects on the scale of an urban settlement. Numerous studies have been performed to evaluate direct effects from albedo change. All researches prove benefits when reflective surfaces are used especially in warm climates. In all cases the temperature of the urban surfaces are seriously decreased, but the degree to which cooling load is reduced deals with the structure of the settlements, and the overall thermal balance of the buildings.

Taha, (1994b), using detailled simulations techniques of the effects of large scale albedo increases in Los Angeles has shown than 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), have shown that a temperature decrease of this magnitude could reduce electricity load from air conditioning by 10 %.

Trees and green spaces contribute significantly to cool urban settlements and save energy for cooling. Trees can provide solar protection to individual houses during the summer period while evapotranspiration from trees can reduce urban temperatures. In parallel, trees absorb sound and block erosion causing rainfall, filter dangerous pollutants, reduce wind speed and stabilize soil and prevent erosion.

Shading from trees contribute to decrease significantly energy for cooling. Parker, 1983, report that trees and shrubs planted next to a South Florida residential building can reduce summer air conditioning costs by 40 %.

Numerical simulations reported by Gao, (1993), trying to simulate the effect of additional vegetation to the urban temperatures, show that green areas decrease maximum and average temperature by 2 C, while the vegetation can decrease maximum air temperatures in streets by 2 C. In parallel, as it concerns the placing of green spaces, Honjo and Takakura, (1990/91), based on numerical simulations of the cooling effects of green areas on their surrounding areas, have suggested that smaller green areas with sufficient intervals are preferable for effective cooling of surrounding areas.

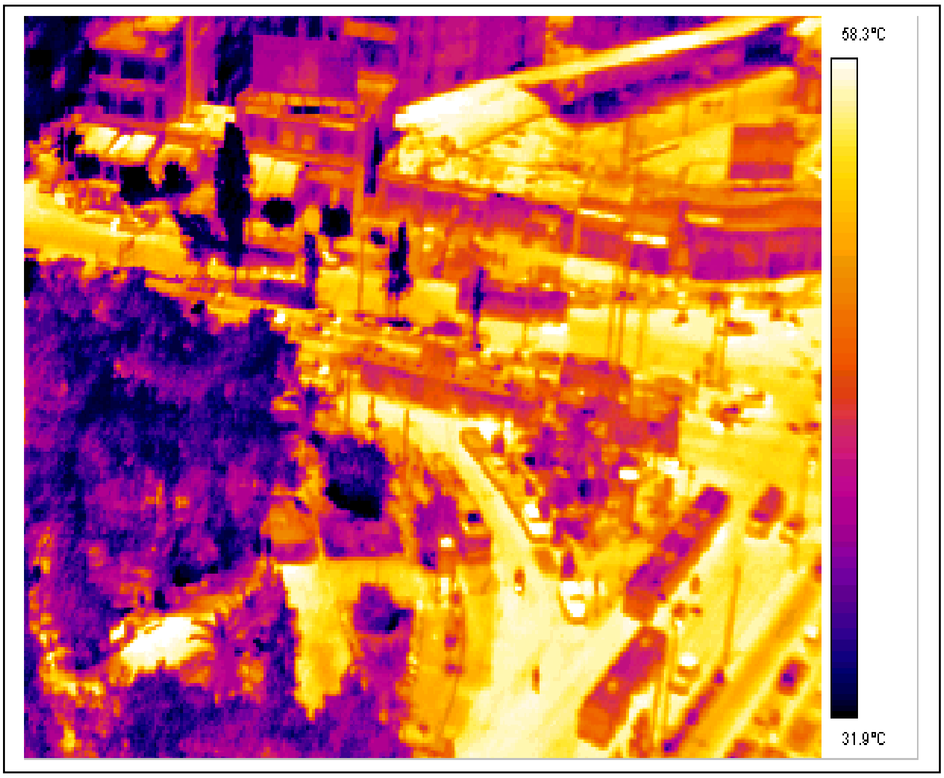
The air flow patterns in urban areas and in particular in urban canyons is of high importance as it defines the real potential for natural ventilation of urban buildings. Although, the layout of buildings, may not change easily in settlements, major rehabilitations should take into account the air flow patterns. Extensive information on the air flow processes in canyons is given by Santamouris, (2001).

The wind speed in the canyon is a small fraction of the undisturbed wind velocity flowing over the buildings. Measurements of wind speed in more than ten canyons in Athens during the summer period have shown that the wind speed inside the canyon and close to the buildings was between 10-25 % of the undisturbed wind speed. Studies aiming to investigate the potential of natural ventilation in buildings located in dense building environments have shown that, (Geros et al, 1997), air flow in naturally ventilated buildings located in urban canyons is reduced up to ten times compared to the air flow in non wind obstructed areas.

Appropriate positioning and dimensioning of the openings located in canyons in order to optimize the air flow through it is a serious exercise for designers. Recent design of naturally ventilated buildings, characterized by this type of constraints, have shown that the appropriate design of combined stack and cross ventilation techniques can provide the necessary air flow and reduce significantly the cooling load of the buildings.

Figures

Figure 1. Surface Temperatures Down Town Athens.



8. Aspects Related to Advanced Air Conditioning, Demand Side Management and District Cooling for the Energy Efficient Refurbishment of Settlements

8.1 Introduction

Addressing the cooling demands of settlements need a clear strategy on the techniques and systems to be used. Planning of the cooling strategy has to consider, except of the optimum design of buildings, centralized systems mainly operating with the use of renewable energies, individual systems operating at the highest possible efficiency as well as optimum management tools for the electricity or thermal cooling load.

Design of existing settlements rarely considered such an integrated strategy. Very few communities have planned the energy and in particular the cooling strategies form the very beginning. Most of the consumers in the communities are driven by the market forces and cover cooling forces by using individual, mainly split, cooling units. Such a situation creates important peak electricity loads while the total energy consumption is very high. This situation has become a serious problem for many European countries, (Santamouris, 1991), as well as for USA, where the total electric peak load induced by air conditioning is estimated equal to 38 percent of the non coincident peak load, (Adrews, 1987).

Retrofitting of settlements and Communities provide an excellent opportunity to proper address their cooling supply. Recent progress on district cooling techniques, mainly based on the use of renewables, the development of air conditioning with a high efficiency as well as the very important progress on demand side management techniques, offers new possibilities to better plan the cooling strategies and provide comfort to citizens with much low energy consumption.

8.2 District Cooling Systems and Demand Side Management

District energy systems are based on the production of steam, hot or chilled water at a central station. In particular for district cooling systems, the chilled water is distributed through pipes to individual buildings and avoids a number of distributed air conditioners with poor performance and high cost. All district energy systems have four basic components : the resource, the thermal production unit, the distribution system and the end user. Although district energy systems are well known for more than 100 years, during the recent years district heating and cooling systems have received a high acceptance and millions of buildings are served by district energy systems.

District cooling systems has mainly developed in the United Sates and present a number of very important advantages. The more important advantage has to do with the dramatic decrease of peak electricity load. A good example is given in Figure 1, where the reduction of the peak electricity load in Cleveland is shown prior and after the integration of a district cooling system in the city.

In parallel, the systems are very efficient as operate at high efficiencies, can increase effective building space, decrease operational , maintenance and capital cost of the user, and can improve indoor air quality as do not generate any chemical or biological pollution in the building. District cooling can be produced with the use of renewable energies or by hybrid systems involving the use of renewables and high efficient gas techniques. District systems can rely as well on cogeneration, simultaneous production of heat and electricity. In parallel, district cooling techniques when operated by Municipalities and Community authorities may be the source of important of revenues for the local society.

District cooling systems present some disadvantages as well. They are characterized by high capital cost. Fixed cost represents almost 80 % of the cost of delivered energy form district cooling systems and thus high interest rates may prevent the systems to provide low price energy services. Also, they need several years of construction before their operation and require major works on the city level.

Regarding Demand Side Management six types of actions can be identified :

DSM1. Use of more energy efficient air conditioners, that implies better performance and better design and integration to the building. Because of the temperature increase air conditioners have a longer duty cycle, which means that the payback time can be shorter than in other cases.

DSM2. Application of advanced control systems like inverters, fuzzy logic in order to take into account the operational profiles of urban buildings, like the highly intermittent occupation of residential and commercial buildings in urban areas.

DSM3. Direct load control like remote cycling, by the utilities on the cooling usage as on other usage. This techniques is widely applied during peak periods on a few millions of appliances room air conditioners in the US. By limiting the available duty cycle during peak periods, utilities can reduce significantly the peak demand. Attention has to be given on consumers comfort.

DSM4. Improvements on the building design to decrease their cooling load. This may involve actions on heat and solar protection, heat modulation and dissipation of excess heat in a lower temperature environmental sink.

DSM5. Use of cogeneration techniques. This type of distributed generation of electricity + possibly cold/hot water or steam can reduce peak transportation costs and use of fuel.

DSM6. Use of district heating and cooling techniques as explained above

8.3 Advanced Air Conditioning

Technology of cooling systems has been tremendously improved during the last years. Research and new developments have been permitted to create high efficiency A/C systems better adapted to the urban environment. Improvements have been recorded in many components of the systems as well as on their operational characteristics. In principle, improvements can be classified in the five following major categories :

- Those that aim to increase the heat transfer surface. These techniques involve the increase of the frontal coil area, the increase of the depth of the coil, the increase of the fin density, the addition of a subcooler to the condenser coil, etc.
- Those that aim to increase the heat transfer coefficients. These techniques involve the improvement of the fin design, the improvement of the tube design, the spray condensate onto the condenser coil, the improvement of the fan and of the fan motor efficiency, the improvement of the compressor efficiency, the use of variable speed compressors, the use of alternative refrigerants, the use of electronic expansion valves, etc.
- Those that aim to improve the control of the devices. These techniques involve between others the use of thermostatic static control, as well as of the fuzzy logic control.
- Techniques aiming to adapt the load curve of the air conditioning devices in the specific climatic conditions of the urban environments. These techniques permit to the systems to operate under the optimum conditions although the temperature increase in the cities.

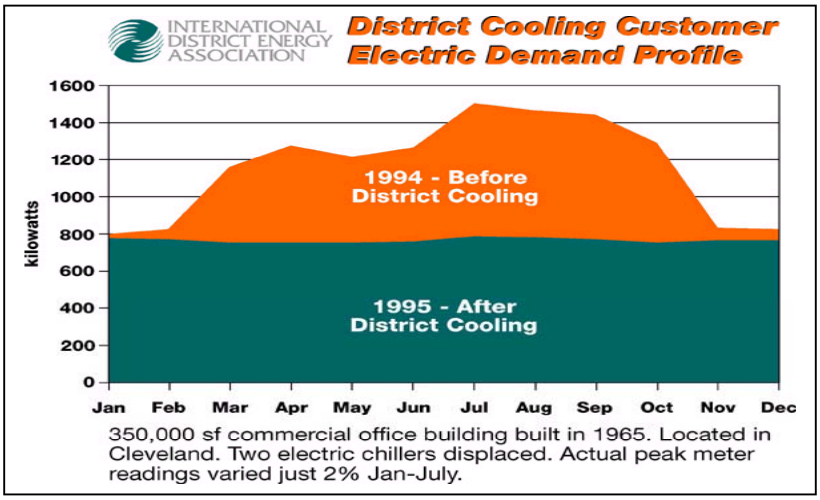
- Alternative cooling systems making use of new advanced techniques like indirect evaporative coolers, etc. These techniques permit to operate under high COP values.

In the frame of the EERAC project coordinated by Ecole des Mines of Paris, (2000) for the European Commission, an attempt has been made to calculate the potential improvement of the room air conditioning. The considered scenarios as well the calculated scenarios are given in the following Table. As shown there is a very important potential to improve COP that may be high up to 30 per cent.

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

Figures

Figure 1. Decrease of the peak electricity demand for cooling in Cleveland, USA, because of the use of district cooling systems.



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CHAPTER 2: ON THE USE OF TECHNIQUES TO IMPROVE MICROCLIMATE, FOR THE ENERGY EFFICIENT REFURBISHMENT OF SETTLEMENTS

1. Introduction

1.1. The role of microclimate on the energy consumption and thermal comfort in settlements

Increasing urbanization and industrialization have deteriorated the urban environment. Deficiencies in development control have important consequences on the urban climate and the environmental efficiency of buildings. The size of housing plots have been reduced increasing thus densities and the potential for traffic congestion. Increasing number of buildings has crowded out vegetation and trees. As reported, New York has lost 175000 trees, or 20 % of its urban forest in the last ten years, (1).

As a consequence of heat balance, air temperatures in densely built urban are higher than the temperatures of the surrounding rural country. The phenomenon known as 'heat island', is due to many factors the more important of which are summarized by Oke, Johnson, Steyn and Watson , (2), Except of the temperature increase, the urban environment affects many other climatological parameters. Global solar radiation is seriously reduced because of increased scattering and absorption. As mentioned by Landsberg, (3), the sunshine duration in industrial cities is reduced by 10 to 20 per cent, in comparison with the surrounding countryside and similar losses are observed in received energy.

In a general way, wind speed and direction, in the canopy layer, is seriously decreased compared to the undisturbed wind speed. This is mainly due to the specific roughness of a city, channeling effects through canyons and also because of the heat island effect.

In parallel, the urban environment affect precipitation and cloud cover. The exact effect of urbanization depends on the relative place of a specific city regarding the general atmospheric circulation. It is mentioned that in Budapest, because mainly of the industrialization the cloud cover has been increased by 3 % during the winter period. As mentioned by Escourrou, (4), urbanization causes a proportional increase of the precipitation in cities like London, that because of its geographic location is more often in the zone of perturbations, than in cities like Paris. Studies in Bombay, India, have shown that the development of an industrial zone close to the city has increased precipitation by 15 per cent, (5).

Higher urban temperatures have a serious impact on the electricity demand for air conditioning of buildings, increase smog production, while contributing to increased emission of pollutants from power plants, including sulfur dioxide, carbon monoxide, nitrous oxides and suspended particulates. Heat island effect in warm to hot climates exacerbates cooling energy use in summer. As reported, (1), for US cities with population larger than 100000 the peak electricity load will increase 1.5 to 2 percent for every 1 F increase in temperature. Taking into account that urban temperatures during summer afternoons in US have increased by 2 to 4 F during the last forty years, it can be assumed that 3 to 8 percent of the current urban electricity demand is used to compensate for the heat island effect alone. 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 net rate of increase of the electricity demand is almost 300 MW per F. Taking into account that there is a 5 F increase of the peak temperature in Los Angeles since 1940, this is translated into an added electricity demand of 1.5 GW due to the heat island effect. Similar correlation between temperatures and electricity demand have been established for selected utility districts in USA. Based on the above rates of increase, it has been calculated that for USA the electricity costs for summer heat island alone could be as much as $ 1 million per hour, or over $ 1 billion per year, (1). Computer studies have shown for the whole country the possible increase of the peak cooling electricity load due to the heat island effect could range from 0.5 to 3 percent for each 1 F rise in temperature.

Heat island studies in Singapore reported by Tso, (6), show a possible increase of the urban temperature close to 1 C. According to the reports if there were to be similar changes in temperatures 50 years from now, the anticipated increase in building energy consumption, mainly in air conditioning, is of the order of 33 GWh per annum for the whole island. Studies reported by Watanabe et al, (7), analyzing the land temperature distribution and the thermal environment of the Tokyo metropolitan area have shown that a much higher energy consumption corresponds to the central Tokyo area. Other studies on the Tokyo area reported by Ojima (8), conclude that during the period between 1965 to 1975, the cooling load of existing buildings has increased by 10 - 20 % on average because of the heat island phenomenon. If it continues to increase at the same rate, it will make more than a 50 % increment in 2000.

Calculations of the spatial cooling load distribution in the major Athens area, based on experimental data from thirty stations have been reported by Santamouris et al, (9), It is found that the cooling load of reference buildings is about the double at the center of the city than in the surrounding Athens area. It is also reported that high ambient temperatures increase peak electricity loads and put a serious strength on the local utilities. Almost a double peak cooling load has been calculated for the central Athens area than in the surroundings of the city. Finally, a very important decrease of the efficiency of conventional air conditioners, because of the temperature increase, is reported. It is found that the minimum COP values are lower to about 25 % in the central Athens obliging designers to increase the size of the installed A/C systems and thus intensify peak electricity problems and energy consumption for cooling.

Increase of the energy consumption in the urban areas put a high stress to utilities that have to supply the necessary additional load. Construction of new generating plants may solve the problem but it is an unsustainable solution while it is expensive and takes a long time to construct. Adoption of measures to decrease the energy demand in the urban areas, like the use of more appropriate materials, increased plantation, use of sinks, etc, in association with a more efficient use of energy, involving demand side management techniques, district cooling and heating, etc. seems to be a much more reasonable option. Such a strategy, adopted by the Sacramento Municipal Utility District, (SMUD), has proved to be very effective and economically profitable, (10). It has been calculated that a megawatt of capacity is actually eight times more expensive to produce than to save it. This because energy saving measures have low capital and no running cost, while construction of new power plants involves high capital and running costs.

1.2 Techniques to improve microclimate in existing settlements

Addressing successful solutions to counterbalance the effects of temperature increase on the energy performance of urban buildings is a necessary condition for the future. Addressing successful solutions to counterbalance the effects of increased energy consumption for cooling of urban buildings due to the temperature increase and increased living standards is a necessary condition for the future. One of the more important solutions is associated with the improvement of the ambient microclimate in the urban environment involving the use of more appropriate materials, increased use of green areas, use of cool sinks for heat dissipation, appropriate layout of urban canopies, etc., to counterbalance the effects of temperature increase.

In the following chapters the main techniques to improve urban microclimate are presented and their main characteristics and benefits are discussed.

2. Existing Microclimate Problems in Communities and Settlements

2.1 The thermal balance in settlements and communities

The thermal balance in the urban environment differs substantially than that of rural areas. Anthropogenic heat released by cars and combustion systems, higher amounts of solar radiation stored, and blockage of the emitted infrared radiation by urban canyons makes the global thermal balance more positive and contributes to the warming of the environment.

The energy balance of the 'earth surface - ambient air', system in the urban environment is governed by the energy gains, losses as well as the energy stored by the opaque elements and mainly buildings, streets and other opaque components. In a general way :

Energy Gains = Energy Losses + Energy Storage

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

Energy Losses are under the form of sensible, Q_E, or latent heat, Q_L, resulting from heat convection between the opaque surfaces and the air as well evapotranspiration. Losses can also occur because of the advective heat flux between the urban and the surrounding environment. Thus the energy balance of the surface - air system can be written as. :

$Q_r + Q_T = Q_E + Q_L + Q_s + Q_A$

where :

Q_s is the stored energy while Q_A is the net energy transferred to or from the system through advection under the form of sensible or latent heat. The advective term can be ignored in central urban areas surrounded by an almost uniform building density, but may be imported in the boundaries between the urban and the rural environment.

The radiative flux is the most important term and is slightly higher in the rural than in the urban environment. During the day period, the net radiative input is higher in the suburban than in the rural environment, however nigh losses are much higher and compensate daytime gains. As shown in the previous equation . absorbed solar radiation is a direct function of the mean albedo of a city. Use of high albedo materials reduces the amount of solar radiation absorbed through building envelopes and urban structures and thus keeps their surfaces cooler

Sensible heat flux, was the main mechanism to dissipate the daytime radiative surplus in the suburban environment. Sensible heat remained positive during the late afternoon hours contributing significantly to the heating of the urban atmosphere. Higher stored energy in the suburban environment is mainly due to the higher surface for absorption than in the rural environment, where rural vegetation cover provides a type of insulation, (11).

The latent heat in urban areas is seriously reduced. The energy content of evapotranspiration is close to 597 Kcal per gram of evaporated water at 0 C, and 575 at 40 C. In the urban area the total latent heat is reduced according to the morphology and the characteristics of the city and in particular is a function of the existing green areas. Escourrou, (4), reports that the reduction of evaporation is a function of the waterproofness of the urban soil. Thus, evaporation is reduced by 19 % when 25 % of the urban soil is waterproof, 50 % for the 38 % of the surface, while it is reduced close to 75 % for 59 % of waterproof soil.

Anthropogenic heat is mainly related to transportation systems, power generation and other heat sources. Anthropogenic heat in urban areas may affect significantly the ambient temperature and increase the heat island intensity. It is characteristic that in New York, anthropogenic heat is almost the double of the solar radiation input, (4), while in Barcelona human induced energy acounts for about one fifth of the total solar radiation, (12).

2.2 Air flow processes

The urban wind field is complicated. Small differences in topography may cause irregular air flows. As the air flows from the rural to the urban environment, it must adjust to the new boundary conditions defined by the cities. This results to the development of a two layers vertical structure. Oke, (13), has characterized the wind variation with height, over cities by defining two specific sub-layers. The so called 'obstructed sub-layer', or urban canopy sub-layer which is extended from the ground surface up to the buildings height, while the so called 'free surface layer' or urban boundary layer, is extended above the roof tops.

The obstructed or canopy sub-layer has its own flow field driven and determined by the interaction of the flow field above and the uniqueness of local effects as topography, building geometry and dimensions, streets, traffic and other local features, like the presence of trees. In a general way, wind speed in the canopy layer is seriously decreased compared to the undisturbed wind speed.

Estimation of the wind speed in a city in of vital importance for passive cooling applications and especially in the design of naturally ventilated buildings. Wind speeds measured above the buildings or at airports differ considerably from the speed at an urban monitoring site. As roughness length is greater in an urban area than in the surrounding countryside, the wind speed u at any height z is lower in the urban area, and much lower within the obstructed area. Knowledge of the air flow characteristics in urban canyons is necessary for all studies related to natural ventilation of buildings, pollution studies, thermal comfort, etc.

Urban canyons are characterized by three main parameters, H, the mean height of the buildings in the canyon, W, the canyon width, and L the canyon length. Given these parameters, the geometrical descriptors are limited to three simple measures. These are the ratio H/W, the aspect ratio, L/H and the building density j=Ar/A1 where Ar is the plan of roof area of the average building and A1 is the 'lot' area or unit ground area occupied by each building.

When the predominant direction of the airflow is approximately normal (say ± 30 degrees), to the long axis of the street canyon, three type of air flow regimes are observed as a function of the building (L/H), and canyon (H/W), geometry, (Figure 1)When the buildings are well apart, (H/W>0.05), their flow fields do not interact. At closer spacing, the wakes are disturbed and the flow regime is known as “Isolated Roughness Flow”. When the height and spacing of the array combine to disturb the bolster and cavity eddies, the regime changes to one referred to as wake inteference flow. This is characterized by secondary flows in the canyon space where the downward flow of the cavity eddy is reinforced by deflection down the windward face of the next building downstream. At even greater H/W and density, a stable circulatory vortex is established in the canyon because of the transfer of momentum across a shear layer of roof height, and transition to a “skimming” flow regime occurs where the bulk of the flow does not enter the canyon

There have been proposed threshold lines dividing flow into three regimes as functions of the building (L/H) and canyon (H/W) geometry. The proposed threshold lines are given in the figure 2.

For parallel ambient air flow, a mean wind is generated along the canyon axis with possible uplift along the canyon walls as airflow is retarded by friction. For flows at an angle to the canyon axis, a spiral vortex is induced along the length of the canyon, a cork - screw type of action.

2.3 Heat Island

Air temperatures in densely built urban areas are higher than the temperatures of the surrounding rural country. The phenomenon known as 'heat island', was first noticed by meteorologists more than a century ago, (14), and is the most well documented phenomenon of climatic modification.

Heat island deals with : a) the canyon radiative geometry that contributes to decrease the long wave radiation loss from within street canyon due to the complex exchange between buildings and the screening of the skyline, b) the thermal properties of materials that increase storage of sensible heat in the fabric of the city, c) the anthropogenic heat released from combustion of fuels and animal metabolism, d) the urban greenhouse, that contributes to increase the incoming long wave radiation from the polluted and warmer urban atmosphere, e) the canyon radiative geometry decreasing the effective albedo of the system because of the multiple reflection of short wave radiation between the canyon surfaces, f) the reduction of evaporating surfaces in the city putting more energy into sensible and less into latent heat, and g) the reduced turbulent transfer of heat from within streets.

Urban heat island studies refer usually to the ‘urban heat island intensity’ which is the maximum temperature difference between the city and the surrounding area. Data compiled by various sources, (15), shows that heat island intensity can be as high as 15 C. Extensive studies on the heat island intensity in Athens involving more than 30 urban stations show that urban stations present higher temperatures compared to reference suburban stations between 5 to 15 C..

Heat Island data in some North American cities are reported in (1). The importance of temperature increase becomes more apparent when the cooling degree-days corresponding to urban and rural stations are compared.. In, (16), the increase of the cooling and heating degree-days due to urbanization and heat island effects for selected North American locations, is given Tables 1-2. As shown, the difference of the cooling degree-days can be as high as 92 percent, while the minimum difference is close to 10 per cent. Regarding the heating degree-days the maximum difference is close to 32 percent while the minimum one is close to 6 percent. Increase of the cooling degree-days has a tremendous impact on the energy consumption of buildings for cooling.

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

Table 1 : Increase of the cooling degree days due to urbanization and heat island effects. Averages for selected locations for the period 1941-1970. Source :(16).

Location	**Urban**	**Airport**	**Difference (%)**
Los Angeles	384	562	-32
Washington DC	1300	1370	-6
St. Louis	1384	1466	-6
New York	1496	1600	-7
Baltimore	1266	1459	-14
Seattle	2493	2881	-13
Detroit	3460	3556	-3
Chicago	3371	3609	-7
Denver	3058	3342	-8

Table 2 : Increase of the heating degree-days due to urbanization and heat island effects. Averages for selected locations for the period 1941-1970. Source (16).

Higher urban temperatures have a serious impact on the electricity demand for air conditioning of buildings; increase smog production, while contributing to increased emission of pollutants from power plants, including sulphur dioxide, carbon monoxide, nitrous oxides and suspended particulates. Heat island effect in warm to hot climates exacerbates cooling energy use in summer. As reported, (1), for US cities with population larger than 100000 the peak electricity load will increase 1.5 to 2 percent for every 1 F increase in temperature. Taking into account that urban temperatures during summer afternoons in US have increased by 2 to 4 F during the last forty years, it can be assumed that 3 to 8 percent of the current urban electricity demand is used to compensate for the heat island effect alone.

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 net rate of increase of the electricity demand is almost 300 MW per F. Taking into account that there is a 5 F increase of the peak temperature in Los Angeles since 1940, this is translated into an added electricity demand of 1.5 GW due to the heat island effect. Similar correlation between temperatures and electricity demand has been established for selected utility districts in USA. Based on the above rates of increase, it has been calculated that for USA the electricity costs for summer heat island alone could be as much as $ 1 million per hour, or over $ 1 billion per year, (1). Computer studies have shown for the whole country the possible increase of the peak cooling electricity load due to the heat island effect could range from 0.5 to 3 percent for each 1 F rise in temperature.

Studies on the Tokyo area reported in (8), conclude that during the period between 1965 to 1975, the cooling load of existing buildings has increased by 10 - 20 % on average because of the heat island phenomenon. It is concluded, that if it continued to increase at the same rate, it had to make more than a 50 % increment in 2000.

Calculations of the spatial cooling load distribution in the major Athens area, based on experimental data from twenty stations has been reported in (15). It is found that the cooling load of reference buildings is about the double at the centre of the city than in the surrounding Athens area. It is also reported that high ambient temperatures increase peak electricity loads and put a serious strength on the local utilities. Almost a double peak-cooling load has been calculated for the central Athens area than in the surroundings of the city. Finally, a very important decrease of the efficiency of conventional air conditioners, because of the temperature increase, is reported. It is found that the minimum COP values are lower to about 25 % in the central Athens obliging designers to increase the size of the installed A/C systems and thus intensify peak electricity problems and energy consumption for cooling, (34,35).

2.4 Canyon effect

Air circulation and temperature distribution within urban canyons is of significant importance for energy consumption of buildings, pollutant dispersion studies, heat and mass exchange between the buildings and the canyon air including studies on the energy potential of natural ventilation techniques for buildings, pedestrian comfort, etc.

The distribution of the ambient air temperature in a canyon influences highly the energy consumption of the buildings. Higher temperatures in a canyon increase the heat convection to the building and increases the cooling load due to ventilation. Therefore, it is very important to understand the mechanism determining the distribution of the ambient temperature in a canyon.

Temperature in a canyon is influenced by the temperature of the canyon surfaces, as energy is transferred through convective process, however, as already reported, in spite of the fact that the street surface is influenced by the canyon geometry, there is a weak connection between geometry and air temperature and this because the air temperature is dependent upon the flux divergence in air volume including that of the horizontal transport.

Experiments, focusing on the distribution of the air temperature in canyons, have mainly concluded that the air temperature stratification in the canyons during the daytime period is not significant. Maximum daily temperature differences rarely exceeds 2-3 C. No specific temperature distribution pattern with the canyon height has been observed. In most of the cases lower temperatures are measured at the ground levels and temperature increased as a function of the canyon height. This agrees with the distribution of the building surface temperatures in the canyon.

Air temperature distribution across a canyon presents an important interest. It is observed that close to the facade of the buildings an air film governed by the temperature of the building surface and the vertical air transport, is developed. At the middle of the canyon, and at ground level, air temperature is more dependent upon the flux divergence in air volume including that of the horizontal transport, (17-18). Thus, the middle canyon temperature is far from the mid temperature of the two air films developed close to the facade of the buildings.

As it has to be expected, the air temperature close to the south, south west or south east facades in a canyon presents higher air temperatures. Measured air temperature differences between the two facades vary as a function of the canyon layout and surface characteristics. The mean maximum reported temperature difference during the peak temperatures period is close to 3 C. The absolute maximum measured temperature difference may be close to 5 C.

Measurements have shown that in most of the cases, temperature at the middle of the canyon is lower than the corresponding film air temperature. In all these cases the film air temperature is higher than the undisturbed air temperature measured above the buildings.

The temperature distribution in a canyon during the night period is low. During the summer period, the maximum temperature difference between the different canyon levels never exceed 1.5 C, (15).

In all cases, higher temperatures are measured at the ground level, and temperature is found to decrease as a function of the height. This is in agreement with the distribution of the surface temperature in the canyon during the night period and is related to the radiative balance of the canyon surfaces. No significant air temperature differences have been measured between the air temperature close to the S-SW-SE and the N-NW-NE facades. In a general way the S-SW-SE facades presented a higher air temperature, but rarely temperature difference exceeds 0.5 C, (15). The temperature of the air in the middle of the canyon is found to be higher than that of the air film close to the facades of the canyon. In particular, the difference regarding the S-SW-SE facades is close to 0.3 C, while the corresponding difference with the N-NW-NE facade is close to 0.7 C.

3. Techniques to Improve Microclimate

3.1 General Description of the techniques to improve microclimate

Improvement of the ambient microclimate in the urban environment involving the use of more appropriate materials, increased use of green areas, use of cool sinks for heat dissipation, appropriate layout of urban canopies, etc., to counterbalance the effects of temperature increase, is among the more efficient measures.

Increase of the energy consumption in the urban areas, because of the heat island effect, put a high stress to utilities that have to supply the necessary additional load. Construction of new generating plants may solve the problem but it is an unsustainable solution while it is expensive and takes a long time to construct. Adoption of measures to decrease the energy demand in the urban areas, like the use of more appropriate materials, increased plantation, use of sinks, etc, seems to be a much more reasonable option. Such a strategy, adopted by the Sacramento Municipal Utility District, (SMUD), has proved to be very effective and economically profitable, (10). It has been calculated that a megawatt of capacity is actually eight times more expensive to produce than to save it. This because energy saving measures has low capital and no running cost, while construction of new power plants involves high capital and running costs.

3.2 The role of Materials

Use of high albedo materials reduces the amount of solar radiation absorbed through building envelopes and urban structures and keeps their surfaces cooler. Materials with high emmisivities are good emitters of long wave energy and readily release the energy that has been absorbed as short wave radiation. Lower surface temperatures contribute to decrease the temperature of the ambient air as heat convection intensity from a cooler surface is lower. Such temperature reductions can have significant impacts on cooling energy consumption in urban areas, a fact of particular importance in hot climate cities.

The use of appropriate materials to reduce heat island and improve urban environment has gained increasing interest during the last years. Many research works have been carried to identify the possible energy and environmental gains when light colored surfaces are used. Studies have investigated the impact of the materials optical and thermal characteristics on the urban temperature as well as the possible energy reduction during the summer period. A detailed guide on light colored surfaces has been published by US EPA, (1). It has been shown that important energy gains are possible when light color surfaces are used in combination with the plantation of new trees. For example computer simulations reported in (19), show that white roofs and shade trees in Los Angeles, USA, would lower the need for air conditioning by 18 percent or 1.04 billion killowatt-hours, equivalent to a financial gain close $100 million per year.

Santamouris et al, ,(15) using infrared thermography has assessed the temperature of used materials in pavements and streets in the major Athens area during the summer period. A typical picture is shown in Figure 3. As shown, the temperature of non shaded asphalt was close to 59 C In parallel, the temperature of green areas was close to 31 C.

Extensive measurements of surface temperatures for more than 70 materials used for streets and pavements have been performed during a whole summer, (20). Instant temperature differences of more than 45 C, have been measured between asphalt and white cover materials.

Large scale changes on urban albedo may have important direct and indirect effects on the urban scale. Measurements of the of the indirect energy savings from large scale changes in urban albedo are almost impossible. However, using computer simulations the possible change of the urban climatic conditions can be evaluated. Taha et al (21), using one dimensional meteorological simulations have shown that localized afternoon air temperatures on summer days can be lowered by us much as 4 C by changing the surface albedo from 0.25 to 0.40 in a typical mid - latitude warm climate. The same author, (22), using three - dimensional mesoscale simulations has calculated the effects of large scale albedo increases in Los Angeles. It has been shown than 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, (23), have shown that a temperature decrease of this magnitude could reduce electricity load from air conditioning by 10 %. Recent measurements in white Sands New Mexico have indicated a similar relationship between naturally occuring albedo variations and measured ambient air temperatures.. Taha et al, (24), have analyzed the atmospheric impacts of regional scale changes in building properties, paved surface characteristics and their microclimates and they discus the possible meteorological and ozone air quality impacts of increases in surface albedo and urban trees in California's South Cost Air Basin. By using photochemical simulations it is found that implementing high albedo materials would have a net effect of reducing ozone concentrations and domain wide population weighted exceedance exposure to ozone above the local standards would be decreased by up to 12 % during peak afternoon hours.

3.3 Vegetation and Green spaces

Trees and green spaces contribute significantly to cool our cities and save energy. Trees can provide solar protection to individual houses during the summer period while evapotranspiration from trees can reduce urban temperatures. Trees also help mitigate the greenhouse effect, filter pollutants, mask noise, prevent erosion and calm their human observers. As pointed out in (1), 'the effectiveness of vegetation depends on its intensity, shape, dimensions and placement. But in general, any tree, even one bereft of leaves, can have a noticeable impact on energy use'.

The American Forestry Association, 1989, estimated that the value of an urban tree is close to $ 57000 for a 50 years old mature specimen. As mentioned (1), the above 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.

Numerical studies trying to simulate the effect of additional vegetation to the urban temperatures have been performed by various researchers and provide very useful information. In (80), it is predicted that increasing the tree cover by 25 % in Sacramento and Phoenix, USA, would decrease air temperatures at 2:00 p.m. in July by 6 to 10.0 F.. Simulation results for Davis California using the URBMET PBL model reported in (25) show that the vegetation canopy produced daytime temperature depressions and night time excesses compared to the bare surrounds. The factors behind temperature reduction are evaporative cooling and shading of the ground, whereas temperature increase during night is the result of the reduced sky factor within the canopy. Results of the simulations show 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.

The impact of trees on the energy consumption of buildings is very important. As reported by the National Academy of Sciences of United States, (26), the plantation of 100 million trees combined with the implementation of light surfacing programs could reduce electricity use by 50 billion kWh per year, which is equivalent to the 2 per cent of the annual electricity use in the US and reduce the amount of CO_2 dumped in the atmosphere by as much as 35 millions of tons per year.

Urban agriculture, growing vegetables and fruits, in and around cities, can help to improve urban microclimate and provide essential food to people. In fact, one seventh of the planet's food supply is grown in cities, and there are 800 million urban farmers in the world, (27).

In Europe, almost 72 per cent of all urban households in Russia food, and Berlin has more than 80 000 urban farmers, (28). In St Petersburg, the Urban Gardening Club has very efficiently promoted the roof top gardening. Estimations show that in just one district, it is possible to grow 2 000 tonnes of vegetables per season from 500 roof tops.

In Chicago, the local environment department promotes the construction of gardens a top several city buildings as part of a U.S. Environmental Protection Agency program studying ways to help cool cities and reduce smog. In parallel, the city of Vancouver in collaboration with City Farmer, a non-profit association promotes urban food production and environmental conservation. This has resulted to a new public garden which demonstrates conservation methods ‘such as contouring of the ground, soil conditioning using compost, collection of rain water, and the use of native plants’, (29).

3.4 Techniques to enhance air flow in settlements

Natural ventilation is one of the most effective passive cooling techniques. Passive cooling in urban areas is highly affected by the wind distribution in the city. Wind speed in urban canyons is seriously reduced compared to the undisturbed wind velocity. Besides, wind direction inside canyons is almost completely different than the one measured by routine meteorological stations.

The serious reduction of the wind speed, reduces considerably the potential for natural ventilation in urban canyons. Recent experimental studies in Europe, have proposed empirical guidelines to consider natural ventilation in urban canyonsa) During the day time, when the ambient wind speed is considerably higher than wind speed inside the canyon and inertia phenomena dominate the

gravitational forces, the natural ventilation potential in single and cross ventilation configurations is seriously decreased inside the canyon. In practice this happens when the ambient wind speed is higher than 4 m/sec. 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 ten timesb) During the day time and when the ambient wind speed is lower than 3-4 m/sec, gravitational forces dominate the air flow processes. In this case the difference in wind speed inside and outside the canyon, do not play any important role and especially in single side configurations.
c) During the night time the ambient wind speed is seriously decreased and is comparable to the wind speed inside the canyon. In this case the air flow calculated for inside and outside the canyon is almost the same.
d) The calculated reduction of the air flow inside the canyon is mainly a function of the wind direction inside the canyon. When the ambient flow is almost vertical to the canyon axis, the flow inside the canyon is almost vertical and parallel to the window. In this case a much higher pressure coefficient correspond to the conditions outside the canyon, and thus a much higher flow is calculated when the ambient conditions are considered and inertia forces are dominating. When the ambient flow is parallel to the canyon axis, a similar flow is observed inside the canyon, thus the pressure coefficients are almost similar, (30).
Passive cooling techniques present a very serious alternative to conventional air conditioning of buildings. Night ventilation techniques, when applied to massive buildings, can reduce significantly the cooling load of air conditioning buildings and to increase the thermal comfort levels of non air conditioning building.
Night ventilation techniques are based on the use the cool ambient air as a heat sink, to decrease the indoor air temperature as well as the temperature of the building's structure. The cooling efficiency of these techniques is mainly based on the air flow rate as well as on the thermal capacity of the building and the efficient coupling of air flow and thermal mass.
Use of night ventilation techniques in buildings, (for example the Tombazis Office in Athens, picture), has contributed to extremelly important energy gains, and have decreased the cooling load down to 5 kWh/m2/y, (30)*Because of the serious reduction of the wind speed in the urban environment and the corresponding reduction of the air flow rate, for both single and cross configurations, the cooling load on the buildings inside the canyons is much higher than the one of buildings where wind is not obstructed. In particular, recent studies have shown, (30), that in single side configurations the cooling load is higher between 6 to 89 %, while in cross ventilation configurations the cooling load increases by 18 to 72 %. Thus, canyon effect has a very considerable effect on the performance of night ventilation techniques of air conditioned buildings.*

Thus, it is very important to consider, other techniques than windows to enhance air flow in urban buildings. Traditional techniques like solar chimenys or wind towers can be easily integrated in urban buildings and may contribute significantly to increase natural air flow through the building
Other advanced techniques like the PDEC evaporative cooling component or the advanced/intelligent AIRLIT – PV window have been developed recently.
Solar Chimneys are ideal alternative ventilation techniques for the urban environment. May be used in deep urban canyons to promote air flow through vertical shafts.
In solar chimneys air exits through a vertical shaft because of the temperature difference between the upper and the lower part of the shaft. To enhance the air flow, the upper external surfaces of the shaft are heated by solar radiation. Air may eneter the building through side windows.
Recently, many buildings have been designed to use solar chimneys for ventilation. A very interesting and succesful building is the Environmental Building of BRE in Garston, UK.
Solar Chimney techniques have been commercialised and aesthetically accepted chimneys are now available for direct and immediate integration to buildings.Wind Towers are traditionally used in urban areas as may catch the undisturbed wind flow. Inlets have to be positioned at the windward façade while outlets at the leeward one.

Passive Downdraught Evaporative Cooling is a technique that has been used for several centuries in parts of the Middle East. In this tradition, wind catchers guide outside air over water filled porous pots, inducing evaporation and bringing about a significant drop in temperature before air enters the interior, (31).. The technique is very well suited to be applied in an urban context, as the air intakes are in an above-roof position, where the pollutant concentration is lower. A the same time, it is very independent of the air velocity and direction, so that there is no negative influence of eventually existing nearby taller buildings, that could disturb the wind patterns.

The Airlit - PV intelligent façade unit is designed recently to face the problem of controlled natural ventilation in urban buildings, (31). It incorporates the latest thinking in solar control, natural ventilation, daylighting and photovoltaic power. The unit has three main sections:

•lower section is a vent for providing fresh air for comfort cooling in peak daytime conditions and night cooling

•central section a conventional view window openable by the occupants in extreme conditions

•upper section of the unit is a high level window which also acts as a ventilation pathway.The design integrates all of these by the means of a local intelligent controller which operates either in a stand-alone mode or by communication with the building BEMS as part of the building environmental control system

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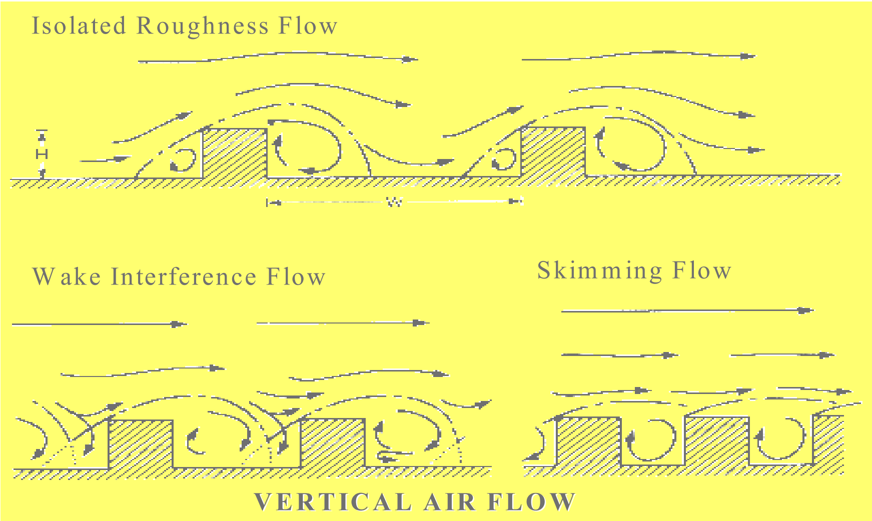
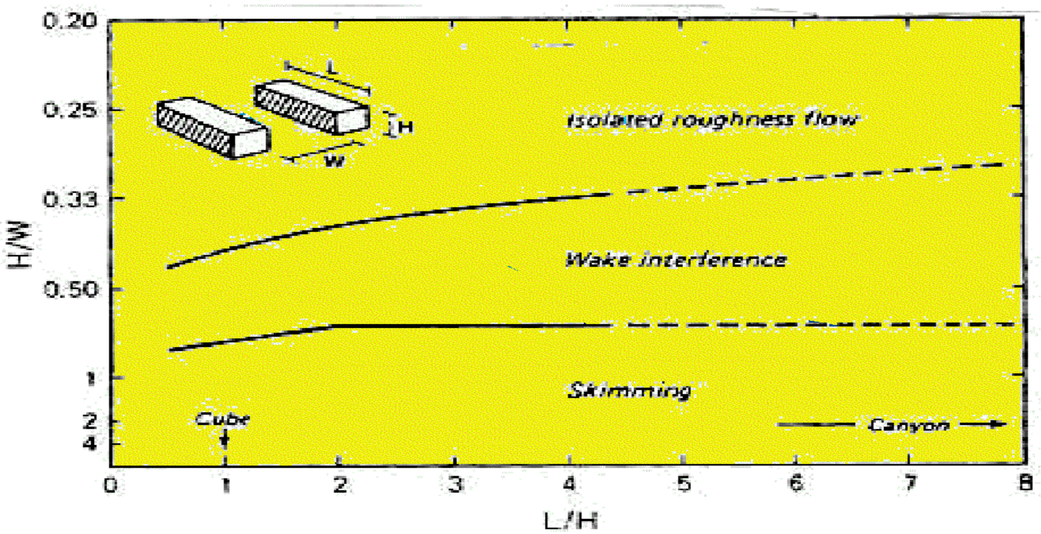
Figures

Figure 1.

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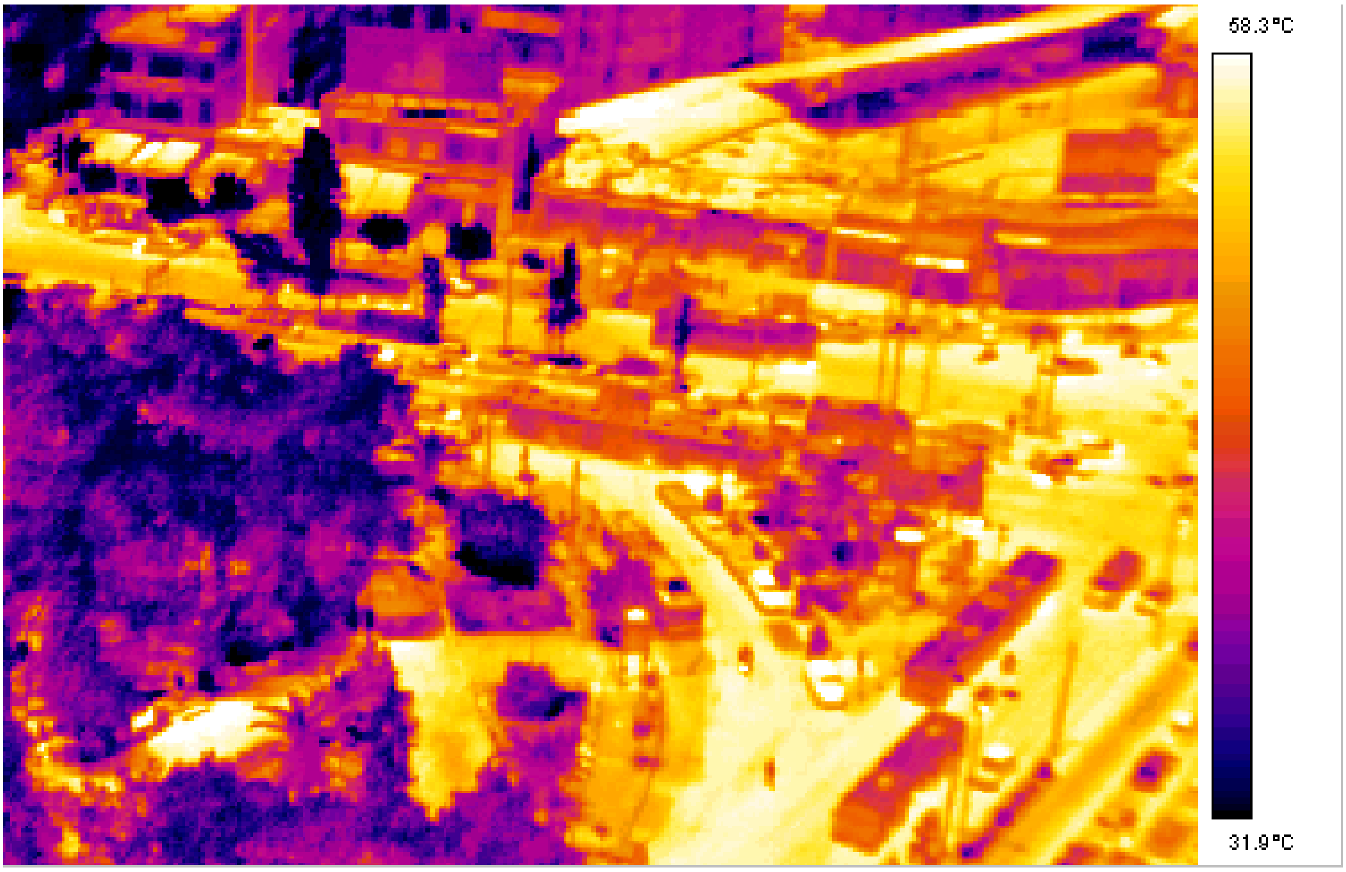
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31.9°C

CHAPTER 3 : DEVELOPMENT AND ASSESSMENT OF THE POTENTIAL OF PASSIVE AND ACTIVE SYSTEMS TO IMPROVE THE DESIGN AND PERFORMANCE OF BUILDINGS

1. INTRODUCTION

Energy retrofit measures on the building envelope influence the heat exchange between the air and the ambient air and regulate the penetration of solar energy to the building. A clear distinction has to be made between actions aiming to improve the performance of the opaque external elements with actions aiming to improve external openings. It is well know that existing technical solutions to improve external walls and roofs are limited, although the potential for energy saving is tremendous.

A previous step is to evaluate the contribution of the envelope to the heating and cooling loads and, at the same time, to assess, the relative weight of heating and cooling as compared to the other sources of energy consumption (lighting, appliances, hot water production etc). Obviously, those aspects are closely connected to climate and the building use.

Next, it is important to assess or to estimate the relative contribution of the different elements of the envelope to the heating and cooling loads of the buildings.
As an example, next figure shows the contribution of every element to the total losses through the building envelope in apartments and single-family dwellings for a sample of two hundred buildings in Belgium.

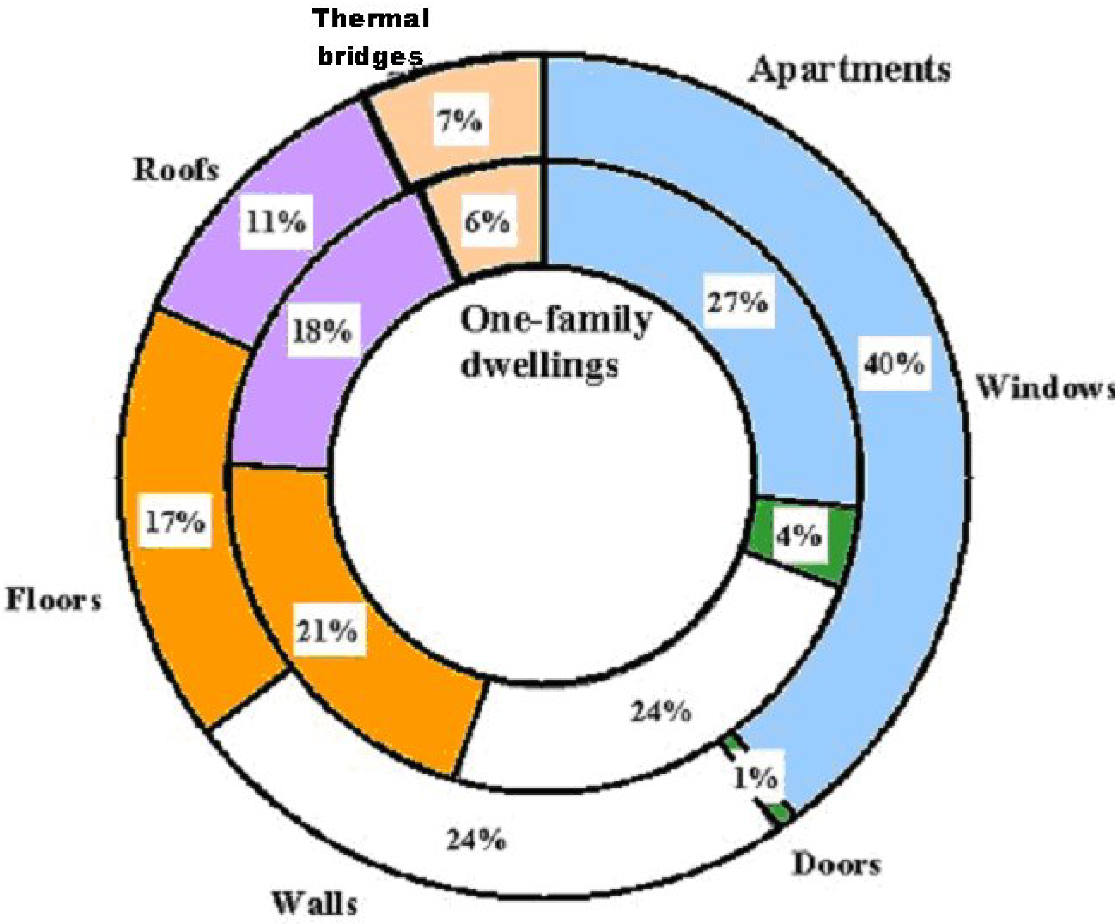


Figure 1. Contribution of different constructive elements to global losses in one-family dwellings and apartments in Belgium. Source: VLIET-SENVIVV project 1994.

A similar scheme could be prepared for the different countries, via measurements or simulations, for the heating and cooling periods. From this data, it is possible to identify the relevant actions to be undertaken.

2. EXTERNAL WALLS

Insulation of the external opaque elements or use of additional insulation to the façades and the roof is one of the simplest, but more efficient measures to be considered. Retrofit measures carried out on the building façade in order to save energy almost always occur in conjunction with façade renovations for other reasons. It is theoretically possible to insulate a wall so well that the heat loss will be practically negligible.
Technological improvements, mainly in the field of transparent insulation, offer another alternative, especially useful for Northern climates.

2.1 Adding insulation

Reducing the U value is the key issue. This action is relevant for heating, but secondary, uncertain or neutral for cooling, relevant for housing more than for non-residential buildings.

A reference about the insulation level to achieve can be taken from the requirements in the thermal regulations of the different countries. These requirements are usually dependent on the climate.

Figure 2 shows the U values required for external walls in locations of different countries (every location appears in terms of its Climate Severity Index CSI)

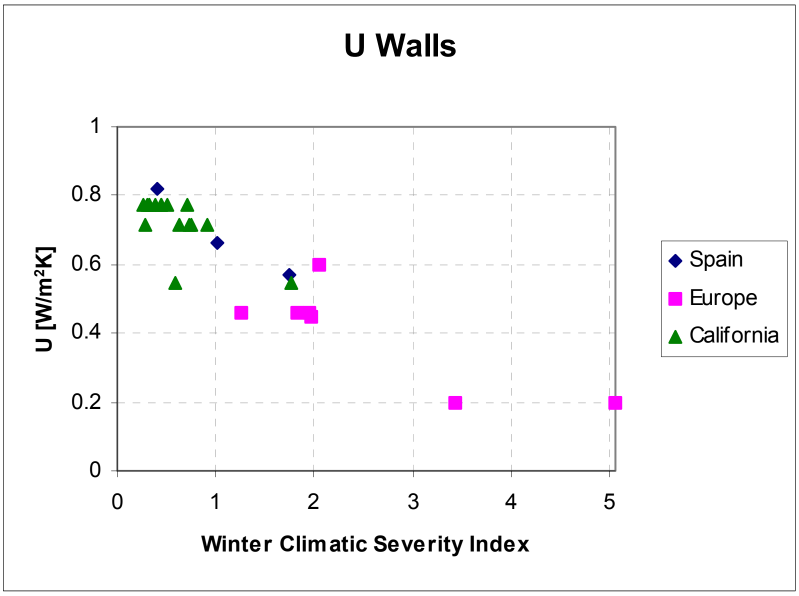


Figure 2 .- Required U values for walls as in the thermal regulations.

As additional effects, adding insulation improves the air tightness of the structure, reduces or eliminates condensation risks on surfaces and increases indoor thermal comfort.
Three are the possible ways: External insulation, internal insulation and insulation of the cavity wall. For external insulation, insulating sheet materials made of rigid plastic foam or mineral fibers are adhesively bonded onto the existing external masonry. To add internal insulation, thermal boards or timber battens can be used. Most of the thermal boards have a backing of expanded polystyrene insulation but other insulation materials are also available. Internal insulation must be protected from moisture by a vapour barrier and from degradation by wear and tear. To insulate the cavity wall "Uf "foam, mineral wool or polystyrene beads or granules can be used.

Table 1 summarizes the relative advantages and drawbacks (Santamouris M. and Asimakopoulos D. 1995):

	Cost	Practical implementation issues.	Influence on the thermal inertia
External	Only recommendable if renovation of the external walls is already necessary or desirable. More expensive as the height of the building increases. The cost is much higher for buildings with 2 or more stories.	Not applicable in general to a fraction of the external wall. Not applicable in case of historic buildings.	Positive. Increases the effective storage mass and consequently the usability of the solar radiation
Internal	Cost effective, although it is necessary to take into account that it takes place.	May cause some problems like removal of doors and windows moldings, skirting boards and electrical fittings. Can interrupt the normal operation of the building	Negative. Reduces the effective storage mass and consequently the usability of the solar radiation
Cavity	Cost effective Pay-back period of less than 4 years in U.K. Not expensive if cavity exists.	Attention should be paid to ensure that wall materials are compatible with the type of insulation and that there will not be damages either of the wall structure or the insulation	Neutral. The existing thermal capacity of the external walls is not modified.

Table 1.- comparison between insulation alternatives.

Concerning the external insulation option, it is worthwhile to mention the elimination of some of the thermal bridges in the intersections between walls and floors.

In the Spanish case study carried out in the framework of this project demand energy savings of 29 KWh/m^2 were obtained using external insulation; in the French case study regarding the settlement called “La grande motte” 48 KWh/m^2 demand energy savings were obtained also using external insulation. For more details please refer to the case study chapter.

2.2 Glazed and ventilated walls

A solar alternative to the addition of insulation is the glazed wall (Elmroth and Kjellsson, 1997). These glazed walls s can be vented or unventilated depending on how and when the heat is to be used. The alternatives considered are Trombe walls and ventilated envelope elements.
A Trombe wall is a glazed wall with vents at the top and bottom. Some of the absorbed heat is conducted through the wall as with the mass wall. In addition, heated air between the wall and the exterior element is delivered to the house by natural convection. At night the vents are closed to prevent reverse circulation, which would cause cooling of the building. The vents should have good seals. The exterior element can be opaque or transparent.

Ventilated envelope elements are Trombe walls but working in open loop, as in the case of Trombe walls the exterior element can be opaque or transparent.

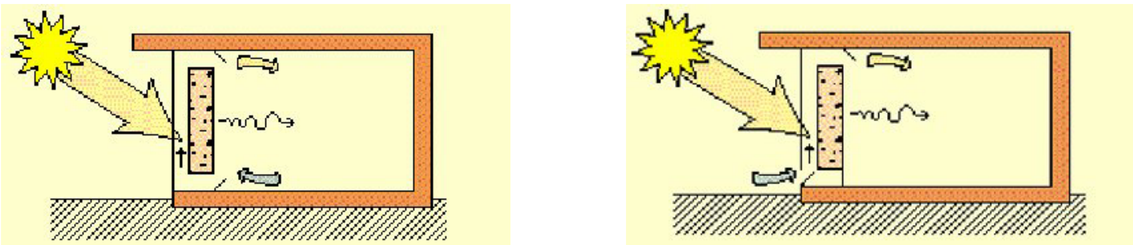


Figure 3 .- Left: Close loop Trombe wall . Right: Open loop ventilated envelope element.

The next design guidelines have been obtained by assessing the behaviour of these elements following the prEN iso 13790 on Thermal Performance of Buildings:

- For Trombe walls, when air is moved by fan, the air velocity should be in the range of 0.2 m/s, lower values make decrease the efficiency.
- Ventilated envelope element, must work to supply exactly the air requirements of the zone, but if the flow rate is superior to this requirement, the efficiency decreases faster than if, the flow rate is under this point.
- Trombe walls and Ventilated envelope elements with internal absorber, works well if the external element is double-glazing. The U-value of the internal wall can be maintained without changes.
- For Trombe walls and Ventilated envelope element with external absorber, the U value of the internal wall should be increased in order to increase the efficiency.
- Typically, the efficiency obtained by elements with internal absorbers is approximately twice than elements with external absorbers.

2.3 Transparent insulation materials

More recently, transparent insulation materials (TI) have been introduced which enhance the performance of such systems by further reducing heat losses through the walls, while still allowing significant capture of solar heat. Like traditional external insulating facade systems, such “solar walls“ are used to improve the building envelope - to protect or replace an old facade, to reduce the need for space heating and/or to preheat ventilation air. The glazing or TI not only reduce the

coefficient of thermal transmittance (U-value) of the facade, but also increase heat gain from solar radiation.
Transparent insulation is most effective on un-insulated concrete, lime stone or clay constructions, which have the highest storage capacity. When transparent insulation materials are used in solar walls, they must be protected by glass from the elements. Consequently, issues that must be addressed early in the design phase are condensation and glare. In addition, some sort of shading device (e.g. movable or fixed Venetian blinds), must typically be employed to prevent unwanted solar heat gains during the warm season.
In Germany, a compound TI material has been developed, which enables the TI to be installed directly to an existing wall. The TI is in a matrix that is similar in appearance to traditional exterior insulating facade systems and can be readily adapted to match existing stucco-like/masonry facades. This permits the renovation of historic buildings with TI without compromising their unique characteristics. An added benefit is, that by virtue of its construction and heat/light transmission properties, this TI does probably not require shading. It is also less expensive than glazed TI solar walls, and may open the way for new and interesting architectural designs.
The next design guidelines have been obtained by assessing the behaviour of these elements following the prEN iso 13790 on Thermal Performance of Buildings:

- Transparent insulation shows high efficiency values and it works better with no insulated walls.
- The solar angle incident affects strongly the behaviour of the transparent insulation, thus it must be oriented to the south. The efficiency decreases quickly for other orientations than south.

2.4 Photovoltaic ventilation in retrofit housing

This technique consists on using PV panels supported by metallic profiles fixed to an external wall of a building (Pedersen, 1999), it is envisaged to install these elements separated from the wall in order to keep an air gap between the wall and the solar panel. When solar radiation reaches the panels, they get warm and consequently the air in the gap arise its temperature too, now the air could be introduced inside the building for pre-heating ventilation air. This system can be considered as a ventilated envelope element with exterior opaque element, thus all the conclusions explained in the point 2.2 are applicable now.
It is going to be described some changes in the basic configuration.
These techniques began to be developed in the frame of PV-VENT project, where a crystalline building-integrated PV module was installed on a south-facing gable, and it was also used for preheating ventilation air.
In 1996, it was developed a type of amorphous PV module that was very well designed for building integration.
The use of fans with reliable DC motors for heat recovery systems makes it possible to use PV modules to cover part of the electricity demand directly, which means that a further reduction of electricity use can be obtained to achieve the targeted low electricity use of only 25-40 W per dwelling for ventilation systems with heat recovery.
In the frame of PV-VENT project it was proposed to develop and test the following prototypes of innovative, economically optimised, PV-powered ventilation systems with a considerably reduced electricity use compared to normal:

- An energy-efficient shared ventilation system with heat recovery and direct PV electricity supply to fans with DC motors.
- Multifunctional solar energy ventilation elements for façade integration with a building integrated heat recovery ventilation system in combination with building integrated PV modules and preheating of ventilation air.

- An integrated, energy-efficient, shared ventilation system with heat recovery and direct PV electricity supply to fans with DC motors, including grid connection, and a larger building integrated PV area per apartment.
- A PV-powered, low-cost exhaust ventilation system with preheating of ventilation air in the PV modules.
- An energy-efficient, shared ventilation system with heat recovery, with the PV modules integrated in an air solar collector surface which can also be used for preheating domestic hot water in summer through a water-to-air heat exchanger.

3. ROOFS

Heat transmission through roofs is relevant for heating and for cooling. Its relative effect increases on low rise buildings. Consequently, special attention should be paid on roofs when we are dealing with single family residential buildings.

3.1 Insulation

Addition of insulation to the building's roof decreases heat transmission through the roof and reduces probable high temperature problems on the top floor of the building during the summer period. It also, reduces condensation risks when outdoor temperatures are low. Various insulation materials can be used such as polyurethane foam or minerals fibres.
As in walls, a good reference about the insulation level can be obtained from the thermal regulations.
Figure 3 shows the U values required for roofs in locations of different countries (every location appears in terms of its Climate Severity Index CSI). In general, the U values required are lower than those for external walls.

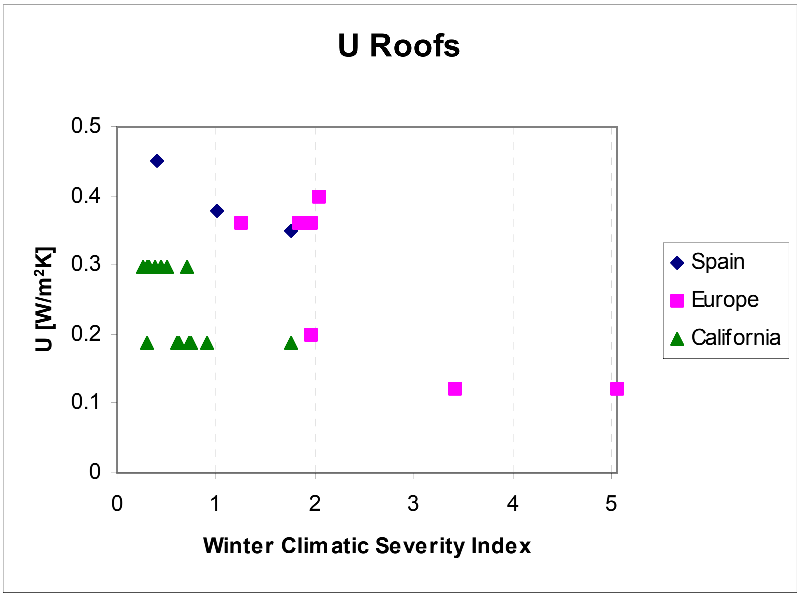


Figure 4.- U values for roofs.

3.2 Modification of the roof's colour

The objective of this technique is to reduce the energy demand by means of a reduction in solar radiation absorbed in roofs. It is then applicable for cooling dominated climates.

It could be interesting over dark coloured roofs of 1 or 2 floor buildings. In any case the measure has to be implemented if the heat gain by the roofs represents a significant percentage of total demand.
The decrease of the solar heat gains using light colours is more significant as the lower is the inertia of the roof and the higher its U value.

The technical implementation is carried out using low solar absorption materials such as:

- Reflective finish materials.
- Adding white gravel or pebbles, that, in addition has an insulating effect.
- Light coloured tiles.

When gravel is used, it is necessary to take into account the overweight in the structure and to check that the system of pluvial collection is not disabled.

Due to the solar position and the reduced length of the sunny periods during winter, this action has not a significant negative effect regarding the heating loads.

The evaluation of improvements derived of the use of light colours must be done taking into account the degeneration of the materials by means of dust.

3.3Roof solutions for passive cooling

Extensive theoretical and experimental research on the use of Natural Cooling by techniques based on the building roofs has been carried out in the JOULE II Project ROOFSOL and in the works in the project DG TREN ALTENER ROOFSOL.

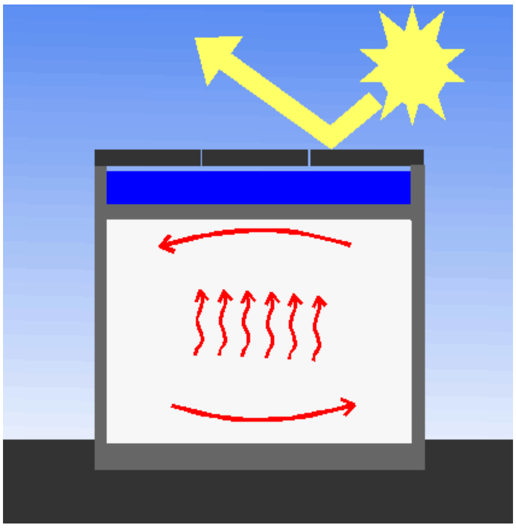
From the systems examined in the above projects we will next briefly describe those specially appropriated in refurbishing of existing buildings. More information can be found in a handbook published as a final deliverable of the Cluster 9 project titled: “Roof Cooling Techniques, A Design Handbook” (Yannas et al,2003).

3.3.1 Roof pond

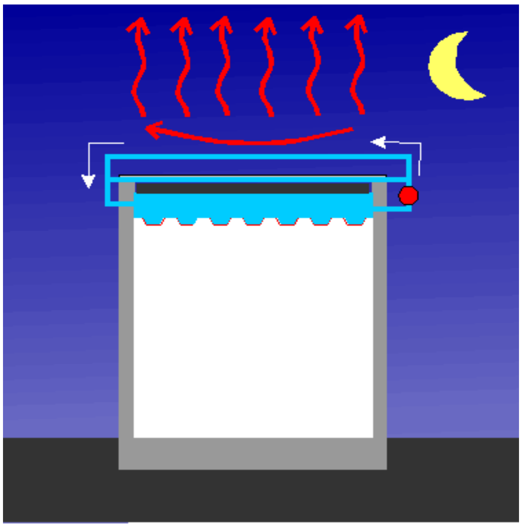
The roof pond concept combines the traditional functions of a roof with a means of natural heating and cooling. The key elements of the concept are:

- use of water for heat storage and as interim heat sink
- thermal coupling of the water with the occupied spaces
- exposure of the water pond to sunshine for heating
- exposure of the water pond to the night sky for cooling.

The principal constituents of a roof pond system are the container for the water, the supporting structure, and the thermal insulation with which the thermal coupling and decoupling of the water are achieved. With these elements a roof pond can contribute to thermal comfort in all seasons. The water is commonly contained in watertight plastic bags laid on an uninsulated metallic ceiling deck.



Roof pond during day operation



Roof pond during night operation

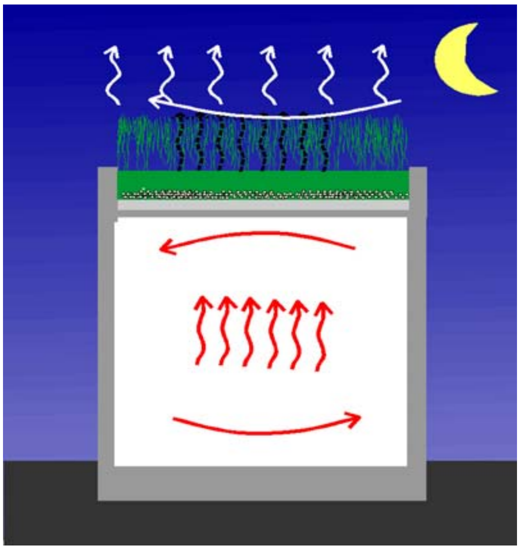
When applied in refurbishing the designer must be sure that the building structure supports the overloads due to the mass of water, and the water tightness of the roof. The cold water can be used in the cooling coil of a conventional air handling system or just be maintained there to cool the top ceiling and also reduce the heat gains during the day.
When the water of the roof pond is opened to the ambient, it is possible to combine the previous effects with the evaporative cooling obtained when the water is circulated through a set of sprayers. The number of circulations per hour, the height of the jets and the water drop size are key design variables for the spray systems. Additional problems can arise from the losses of water due to evaporation, so a system for refilling the pond must be installed.

3.3.2 Planted roofs

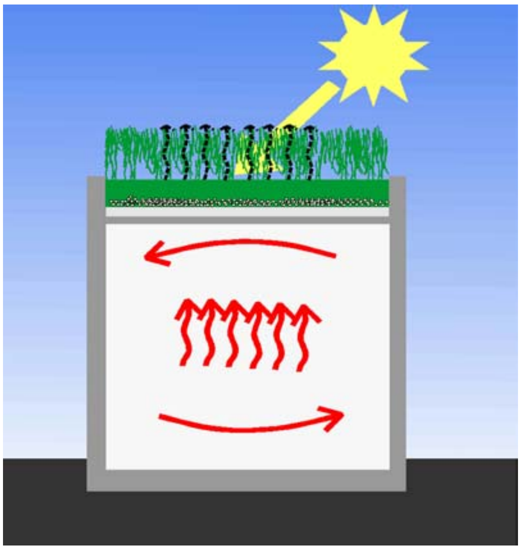
Planted roofs have a layer of vegetation growing on a specially designed substrate over a usually flat roof structure. A planted roof may serve a number of different functions:

- replace the area of green removed by the insertion of a building on a site; on an urban site this can be particularly welcome as a form of microclimatic improvement
- provide a private roof garden (when accessible)
- act as a form of solar control on the roof
- act as thermal and acoustic insulation for the building below
- contribute to stable indoor temperatures.

Two distinct applications have evolved: intensive planted roofs (also known as 'roof gardens'), and extensive planted roofs (also known as 'ecological green roofs').



Planted roof during night operation



Planted roof during day operation

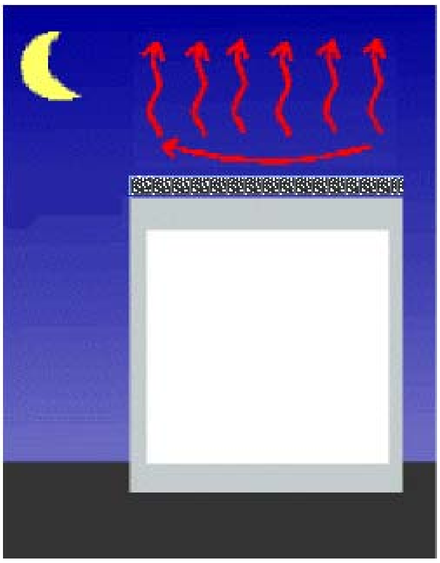
As the roof ponds, when applied in refurbishing the designer must check the overloads due to the layer of soil (and water) and also the availability of water for irrigation.

3.3.3 Wet sand or pebbles roof

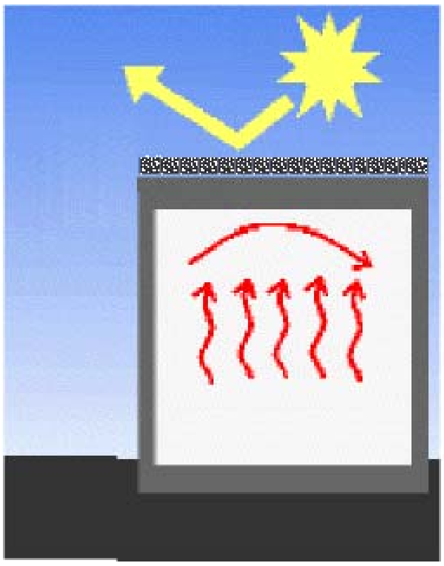
It consists of a flat roof in which a layer of sand or pebbles is laid. The layer is irrigated with water in order to maintain it moist. The main features of the system are:

- moist sand or pebbles are a way of maintaining water on top of the roof with the same advantages that the roof pond
- the water absorbs solar radiation using the heat gained in evaporating itself, thus reducing the heat gains of the building below the roof.

In refurbishing applications, as in previous systems, the overload due to the additional material must be checked, and also the water losses due to evaporation. The system has the same applications as the roof pond without water circulation.



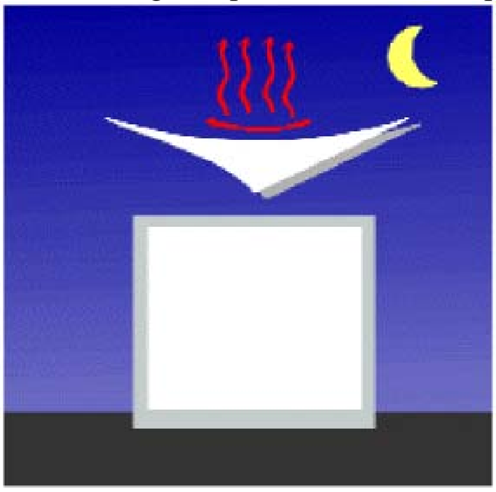
Sand roof during night operation

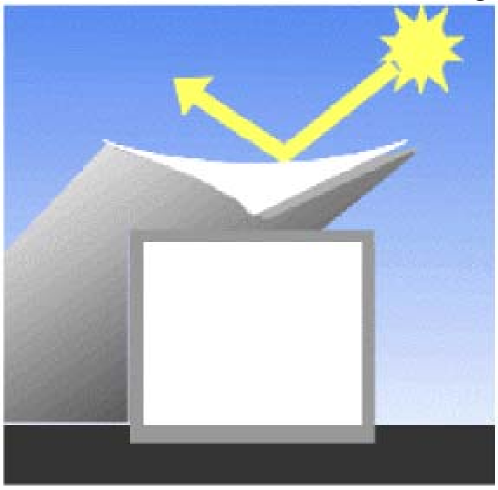


Sand roof during day operation

3.3.4 Shading roof covers

The shading of the roof is an efficient way of reducing the solar heat gain in the roof of the buildings during the day. As the shading blocks the solar radiation, part of it is absorbed increasing the shading temperature to increase. The overheating can increase the longwave exchange with the roof of the building, so special care must be paid to the air movement around the shading system





Shading roof during day operation Shading roof during day operation

In refurbishing the shading is one of the best and cheapest ways for controlling the solar heat gains of the buildings. Automatic operation of the system could remove it during night, when the direct longwave exchange with the sky is a benefit.

3.4 Solar renovation concepts for roofs

Roof-integrated solar collectors can be applied to existing roof structures when roof renovation is required. They can be used for preheating domestic hot water and/or providing space heating. In northern European countries, it can be cost-effective to provide as much as 40 percent of the domestic hot water heating requirement with a solar water heating system. The collectors are typically placed on the roof or integrated in a south facing roof or wall. When integrated, they can also serve to improve the building envelope.

Roof-integrated solar collectors can easily be incorporated in a roofs architectural design.

An ideal opportunity to add solar collectors is when rebuilding a flat roof to an inclined one. Many buildings with flat roofs have problems with water leakage and need frequent re-roofing (10 - 15 years). In Sweden, such roofs are frequently being rebuilt with an incline to correct this problem. A method has been developed that uses roof-integrated solar collectors that not only provide hot water, but actually act as a waterproofing element (e.g., serve as the roof membrane). The specially designed prefabricated roof modules are mounted directly on the roof trusses. The modules arrive on the building site completely pre-assembled and need only to be connected to the pipes. Once the solar collector is installed, it acts as a waterproofing layer on the roof. This means that the cost for repairing a leaky roof can be shared with the cost of the solar collector. The net cost of this roof-integrated collector (collector costs minus the cost of the traditional roofing membrane materials) makes this system much more competitive with conventionally fuelled water or combined water and space heating systems. In volume production, it is anticipated that even the current costs could drop significantly.

4. FLOORS

Non-insulated slab-on-grade floors should be insulated around the perimeter as heat transfer occurs mainly around the perimeter. Heat losses through the centre of the floor are not significant due to the insulating effect of the earth. It is preferable that insulation materials be placed vertically along the outside perimeter of the floor, as the depth depends on local climate the typical values for it vary from 50cm to 120cm. below the floor surface. Rigid boards can be used as insulating materials. Suspended floors above unheated spaces may be insulated on the underside.

A reference about the insulation level to achieve can be taken from the requirements in the thermal regulations of the different countries. These requirements are usually dependent on the climate. Figure 4 shows the U values required for slab-on-grade floors in locations of different countries (every location appears in terms of its Climate Severity Index CSI).

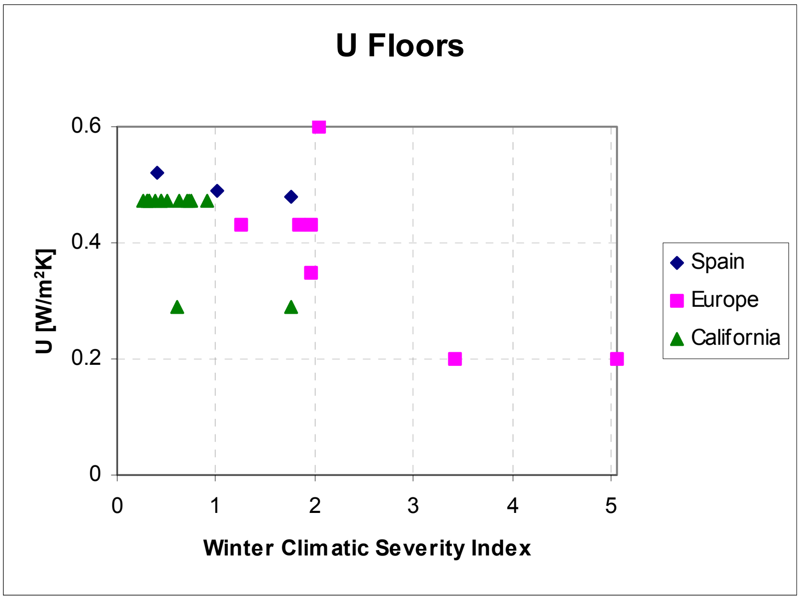


Figure 5 .- Required U values for floors in the thermal regulations

5. INFILTRATION

Infiltration of external cold air into the building can be responsible for a high part of the heating load. Air infiltrates or exfiltrates the building through cracks, openings, gaps around windows and doors, etc. Infiltration or exfiltration can be responsible for as much as 25 percent of the building annual energy consumption.

To decrease infiltration rates to the buildings various actions should focus on:

- The balance of the mechanical ventilation system.
- The weather-stripping of windows and doors.
- The replacement of window frames in bad conditions.
- The reduction of flow to vertical shaft and stairs.

Mechanical ventilation systems should be balanced, i.e. the rate of air entering a building must equal the air of air leaving the building. If the rate of exhaust air is higher than the rate of air introduced into the building then infiltration occurs. In this case the rate of exhaust should be reduced. The quantity of outdoor air for ventilation should exceed the total exhaust from the building by 10 per cent to promote exfiltration rather than infiltration.

To reduce infiltration through cracks and openings gaps around windows and doors, caulking cracks around window and doorframes and weather-stripping windows and doors are particularly effective measures. Also, replacement of old frames in bad condition may drastically reduce infiltration rates. In buildings with important traffic through external doors, the use of vestibules may reduce airflow through exterior doors. The same effect is achieved using revolving doors. Shading devices like overhangs, celosias or shutters act like wind deflectors contributing to decrease infiltrations.

Stack effect experienced in vertical shafts and stairs may be reduced if self closing doors are used to connect these spacing with living spaces in the floors and isolate them from the rest of the building.

6 GLAZINGS

Windows and skylights regulate the transmission of solar radiation to the building as well as the heat loss or gains through convective and conductive heat transfer. The choice of the window glazing as well as the thermal barriers determines the energy consumption, thermal comfort, lighting and acoustics of the interior zones.

Existing buildings already have openings in place. The improvement of the performance of windows has to be done without changing two of their basic design variables: window areas and orientations.

> Refurbishment actions to improve or replace openings components should focus on the global performance of the openings and should combine criteria in order to enhance penetration of solar radiation during the heating period and minimize it during the cooling period, decrease heat flow through the opening, improve daylighting, and permit a more efficient air flow during the summer season.

The window industry has witnessed revolutionary changes during the past two decades. Advances in physics and engineering sciences have resulted in many improvements in window design, performance, and construction. Emerging window and glazing technology and research offers exciting potential for development of new and innovative windows and glazing products

6.1 Insulation

> Improve the insulation of the window areas has a tremendous effect for heating but null in general for cooling.

The improvement on the thermal insulation performance of windows is achieved through a combination of:

- Increasing number of panes.- up to triple glazing or quadrupled-glazed windows.

- Different types of low emisivity coatings.- can be soft coatings that are used in sealed glazing units or hard coatings that can also be used in single panes.
- Vacuum windows.- Heat transfer is reduced through evacuation of the inter-pane space to a pressure of about 0.01 Pa.
- Aerogel.- Aerogel is an interesting material, having a silicate cell structure, with cell sizes less than the mean free path length. This result in a extremely low value of the material's thermal conductivity (lower than that of the air). However, it is expensive and not completely transparent.
- Gases with low thermal conductivity (e.g. argon).-Can be used in sealed glazing units.

Examples of the U-values for the center of windows illustrate the improvements that can be made (The Energy Book, 1996).

- Single glazing.- 5.7 W/m^2K.
- Double glazing.- 2.8 W/m^2K.
- Triple glazing.- 1.9 W/m^2K.
- Sealed triple glazing unit with low-emission coating.- 1.4 W/m^2K.
- Sealed triple glazing unit with low-emission coating and argon filling.- 1.2 W/m^2K .
- Sealed triple glazing unit with two low-emission coatings and argon filling.- 0.8 W/m^2K.
- Vacuum window (high vacuum).- 0.5 W/m^2K.
- 20 mm Aerogel window (low vacuum).- 0.3 W/m^2K.

Window replacement with others of lower U value presents important advantages except for the reduction of the solar heat transmission.

Change simple glazing for double or low emissive glazing, shows an important improvement that is especially important in cold climates, and in north directions.

Additional advantages are associated with the reduced condensation and window back – draught risk, increased radiant temperature during the winter period and reduced infiltration rates.

In the next graphic the threshold values for the U of the glazing are shown as a function of the window to wall percentage and the orientation. The data has been taken from the Spanish Building Technical Code for the climatic zone in which Madrid is contained.

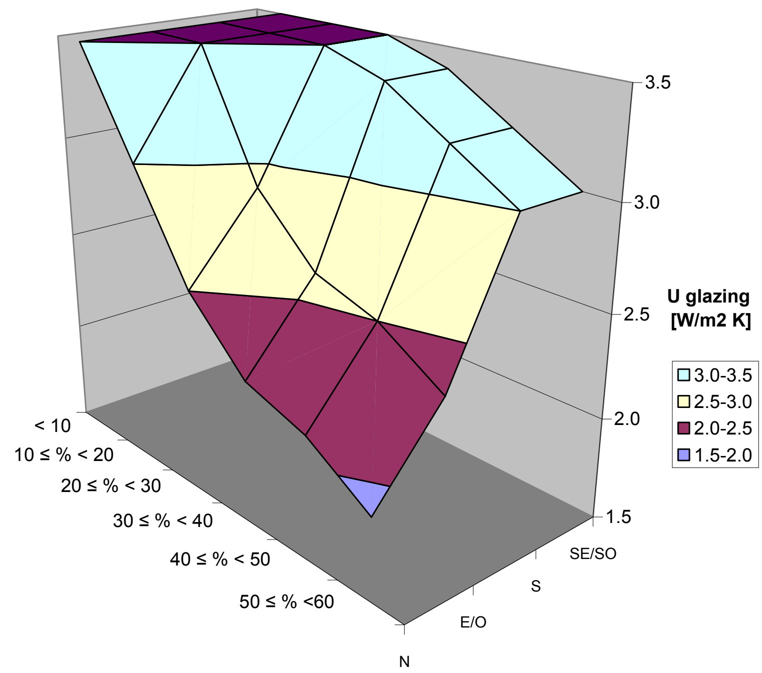


Figure 6.-Required glazing U values depending on window to wall percentage and orientation.

In the Spanish case study the demand energy savings obtained by means of improving the glazing from single to double were 30.5 kWh/m^2; in "La grande motte" this figure was slightly lower 27 kWh/m^2. For more details please refer to the case study chapter.

6.2 Solar control and daylighting

Generally, direct sunlight on the workplane should be avoided and indirect light optimized. In summer, shading may be necessary to prevent overheating while in winter optimal advantage of solar radiation for heating may need to be taken. It is often necessary to make a compromise between daylighting and sunshading.

Typical conventional solar protection systems include:

- Façade obstructions (canvas, awnings).
- Reflective glass.
- Exterior venetian blinds.

Advanced systems that combine properties for simultaneous solar control and daylighting are:

6.2.1 Spectrally selective window films

A relatively new product that admits a high proportion of visible daylight while excluding most of the heat gain arising from the solar infrared. Unlike tinted glasses with similar solar-control properties, these new products are almost clear, resulting in energy savings from lighting compared to solar-control products with lower visible transmittance. In addition, cool glazings reflect rather than absorb the solar infrared and outperform other options in retrofit applications. While these films perform very reliably in sealed, insulated units, however, their durability for retrofit applications where they would be laminated to single-pane glass has not been proven.

6.2.2 Prismatic solar protection

Physical properties of light make it possible to separate sunlight from daylight. The sun radiates "parallel beams" of direct sunlight to the earth. Light from the sky, whether clear or cloudy, comes to the earth diffused. Thus, if one uses a back-reflecting prism it is possible to reflect back sunlight. The diffused skylight passes unhindered with the exception of the area of angle of the reflected sunlight, resulting in a negligible loss of light into the room.(Bartenbach and Klinger, 1994).

6.2.3 Switchable Glazing

The ability to alter *in situ* the transmittance of a glazing in response to the needs of the internal environment has long appeared an attractive option for optimising the thermal performance of a building.(Elmahdy and Cornick, 1990).

Switchable glazing will enable the user to change the optical or thermal properties of sealed glazing units. The most useful and potentially applicable switchable property is the chromogenic phenomenon in which materials change their reflectivity and absorptivity. Examples of chromogenic processes are: thermochromic and electrochromic glazings, and photochromic materials.

- Thermochromic glazing changes optical properties in response to temperature changes. It mainly consists of liquids or gels sandwiched between layers of glazing. Thermochromic windows are designed to block solar gain. A drawback is that they reduce visible light transmission.
- Electrochromic glazing changes optical properties when an electric current goes through the unit. A thin metallic film is deposited on the glass similar to low emissivity coatings. Another technique involves sandwiching a liquid quartz film between two layers of glazing.
- Photochromic materials change their properties in response to light. Photo gray sunglasses are the best known example. When photochromic materials change their transmittance, the absorptivity is increased, thus causing the glass to absorb more heat. On sunny cold days, they absorb solar heat and room source heat and then radiate some heat back to the surroundings. On sunny hot days, they do not reject as much solar heat as reflective windows.

6.2.4 Automatic solar control devices

Solar shading devices management allows to benefit from the free solar gains in winter or even spring and autumn, and to reject them during summer.
It must be pointed out that dynamic solar protections act simultaneously: on visual comfort by smoothing glare effects, and on thermal load reduction.

- External products.- Roller shutters (which openwork curtains are very interesting in solar protection), external screens, external Venetian blinds, are commonly motorized as a standard. If so, they include AC integrated tubular actuators or AC square actuators which are not seen by the user since located in the rolling tube or in the headrail. External solar devices are sometimes made of individual or collective shades. In that case, the previous tubular actuators can sometimes apply, but it also happens that external actuators are necessary to drive individual or groups of shades (according to their weight and sizes). One product just coming from EC research is SOS window. SOS is the acronym of self opening and shading. This PV window regulates shading and air quality by self opening using solar energy (ref. S.O.S. Self Openings and Shadings – LEARN University of North London). Through the simulations required to analyze the French case study known as "La grande motte" we have checked that the building average temperature can be decreased 1ºC and in hot zones this diminish can reach up to 5ºC.

- Internal products. Internal Venetian blinds, roller blinds, roman-, pleated- or cellular blinds, soft shades usually require much less power than external products. The size of tubes and/or headrails is much smaller: typically 25 to 35 mm. In these widths or diameters, only low voltage DC motors can be used at reasonable prices. This gives the advantage of a more simple wiring: low voltage separated from mains does not require ducts or double insulation and security regulations. Conversely, since the energy comes from mains, it is necessary to implement an AC/DC converter. According to the number of products to be supplied, this electrical conversion is done individually or for a whole group of products. All these actuators usually include (as AC integrated actuators) limit switches (or equivalent functions) which allow automatic cut off when reaching top and down positions.
- Double skin & Interpane products. In double-skin architecture, the solar protection devices are located between the internal façade and the glass curtain wall and are protected against rain, wind and dust (if proper filtering). For mechanical reasons, nearly only motorised products are used in these circumstances. Usually the sizes lead the architect to choose 'external' products with AC actuators. Interpane and interglazing elements are equipped with much smaller internal type products, which are low power DC motorised.

6.3 Air flow windows

6.3.1 General

An air flow window generally consists of a double glazed sealed unit with a single pane on the exterior side. Air is allowed to flow between the single pane and the double glazing. Interest in air flow windows has stemmed from the possibility of improved thermal performance and the trend towards providing controlled air changes within a building.
There are two types of air flow windows, the exhaust air window, and the supply air window.
In an exhaust air window, indoor air is forced through the window space and then exhausted outdoors. During the heating season, warm inside air would transfer some of its heat to the window, reducing the temperature differential across the inside panes, and therefore reducing the heat loss. When cooling is required, an exhaust air window would expel some of the solar heat gained by the window and lower the cooling loads. Solar blinds can be introduced in the window space to reflect additional solar heat.
Supply air windows draw air from the outside, through the windows, into the building. During the heating season, cold outdoor air flows over the inside panes absorbing heat from the window and solar energy before being introduced into the building. The preheating of outside air tends to lower the heating requirements for the building. Test models indicate that the average air temperature rise inside the window is approximately 50% of the difference between interior and exterior temperatures.

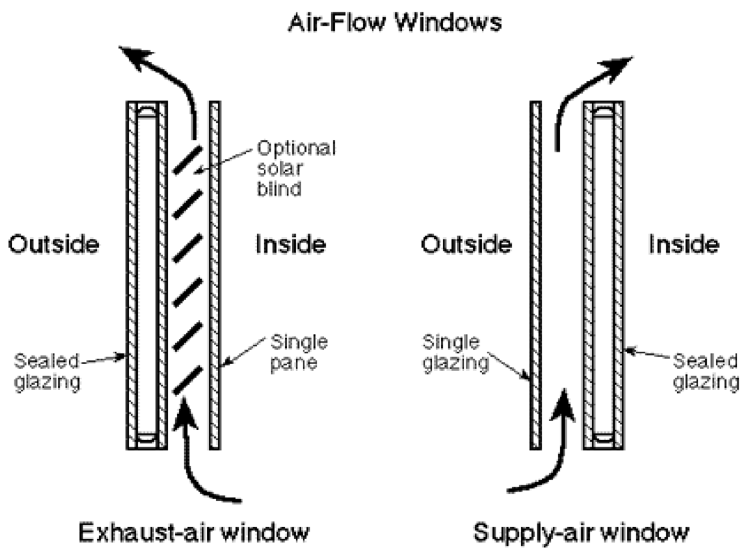


Figure 7-.Air flow windows. (Elmahdy and Cornick, 1990).

Two versions of air-flow windows developed or tested in the frame of EU projects are described below:

6.3.2 SAV Window system

SAV stands for Solar-Acoustic-Ventilated. SAV windows include two glass panes separated by 80mm and with a venetian blind in between; openings on both window faces allow for air flowing within the space in one or another direction, exhausting air to the outside or accepting fresh air to the interior. The combined effect of double glazing and internal blind produces an accumulation of heat in the space between panes, and the heat is conveniently forced inside or outside the building dependent on the season. To this end, the ventilation system includes double speed fans.

6.3.3 SOLVENT system

The system consists of a reversible window frame holding two glazing components: transparent glazing providing a weatherproof seal and a glazing with a high coefficient of absorption in the solar spectrum (SOLVENT project). The absorptive glass is fixed at a small distance from the clear glazing, forming an airspace which is sealed at the sides but open at the bottom and top. The airspace may be ventilated either by thermodynamic forces or by means of a small electric fan. The frame holding the two glazing components may be rotated so that the absorptive glazing is either on the interior (for winter use) or on the exterior (during summer).
The clear glazing may consist of a single glass, double glazing for greater thermal conductive resistance, or double glazing with low-emissivity coating to reduce long-wave radiative heat transfer. An optional manifold incorporating small fan(s) can be installed either at the top opening or the bottom opening between the glazing components, to increase air movement between them. The fans can be powered either by a small photovoltaic device incorporated in the window, or by electric power from the grid.

Winter mode
The window frame is rotated so that the dark glazing faces the interior. Solar radiation is transmitted through the clear glazing (which faces the exterior), and is absorbed by the absorptive glass. This glass is heated, generating thermodynamic air flow in the space between the two panes:

room air enters through the bottom opening of the system, is heated by contact with the absorptive glass and is exhausted through the upper opening. Additional space heating is provided by long wave radiation from the warm absorptive glass into the space. Space heating is achieved but visual discomfort and damage to furnishings by short-wave solar radiation is reduced significantly.

Summer mode

The window frame is rotated so that the absorptive glazing faces the exterior. Most of the short wave solar radiation is absorbed by this glass, and is prevented from being transmitted through the clear glazing to the building interior. The energy absorbed by the absorptive glazing causes it to rise in temperature. However, the long wave radiation it emits is not transmitted to the building interior by the clear glazing, which is nearly opaque at wavelengths above 4μm. Further reduction of transmission of long wave radiation can be achieved if a low-E coating is used on the clear glazing. The energy released by the warm glass sets up a thermodynamic air flow in the space between the two glazing components, preventing overheating of the air and removing unwanted energy. Space overheating is prevented and visual comfort is improved.

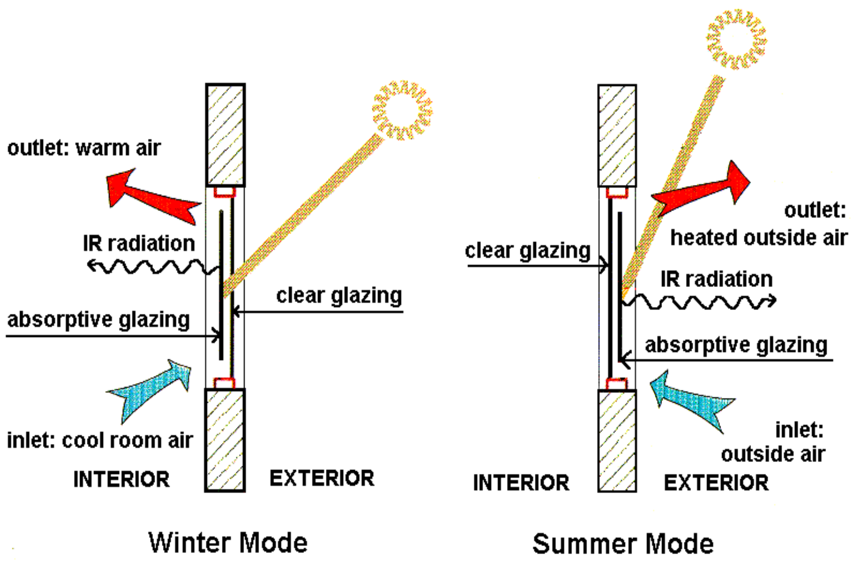


Figure 8.-Operation of the SOLVENT system.

7. SOLAR RENOVATION IN BALCONIES AND GALLERIES

Glazed balconies and galleries can be used to improve the building envelope. They can be used to protect the old facade, reduce the need for space heating, add living space, and in some cases, preheat ventilation air (Elmroth and Kjellsson, 1997). In older buildings, balconies often have to be repaired due to corrosion. Instead of replacing the balcony, it can be repaired and enclosed with glazing, which will protect the balcony from the weather, and associated moisture-related corrosion problems. Buildings most suitable for glazed balconies are old apartment buildings. Balconies that are fully recessed (e.g. “aligned“or in the same plane as the building surface) or partially aligned offer the greatest opportunity for energy savings following enclosure. Apartments with glazed balconies are often more attractive and increases the value of the house.
If a glazed balcony is to be used to reduce the need for space heating while maintaining/enhancing daylighting opportunities, it must be designed with careful consideration of the amount of glazed area relative to the unglazed area, the type of glazing used (e.g. single-pane, double-pane, low-e,

etc.), and the manner in which the space is to be used. If the balcony is to be used as additional living space the year around, this may well result in increased energy requirements.

8. NIGHT VENTILATION

The use of night ventilation is proposed in order to take advantage of the outdoor temperatures. This system works on summer at night when the outdoor temperature is lower than the indoor temperature, refreshing not only the air, but also walls, roofs and furniture -elements with thermal inertia-, in this way the structure of the building is used as energy storage.
Two kinds of night ventilation can be described as a function of the place of inlet and outlet openings:

- Single side ventilation, when both openings are in the same place or the same opening is the inlet and the outlet.
- Cross ventilation, when one opening is in front of the other one.

Two kinds of night ventilation can be described as a function of the origin of the force that origin the movement of the air:

- Natural ventilation.
- Mechanical ventilation.

Natural ventilation is very attractive for designers or architects because it offers robust solutions capable of providing an acceptable indoor air quality and meeting comfort needs throughout the full range of climate conditions. In most cases, the minimum ventilations rates needed for indoor air quality are easily reached and the maximum ventilation rates needed for summer thermal control of the building are well identified.
The open-widow environment associated with natural ventilation is often popular and offers a wide range of creative design to architects, especially in pleasant environments. Natural ventilation also appears very cost effective compared with the capital, maintenance and operational cost of mechanical systems and it does not need any plant room space.
However, the effectiveness of natural ventilation depends greatly of the design process.
Design guidelines and criteria for natural ventilation include recommendations and rules on (Allard et al., 1998):

- *site design* aspects regarding the location, orientation and layout of buildings as well as landscaping;
- *design programme* aspects related to indoor air quality and ventilative cooling requirements;
- *building design* aspects related to the building form, the vertical and plan distribution of spaces, and the location and sizing of openings;
- *opening design* aspects concerning the selection of the types of opening and screen, as well as their operational features.

Mechanical ventilation. The only requirement is an exhaust fan situated in the correct place in order to get a good air movement, avoid the stagnation in certain zones, and favour the contact with the building structure.

Computational fluids dynamics are very useful tools in order to predict the air movement. Next graphs show the paths of four particles in the air obtained by means of a commercial CFD program.

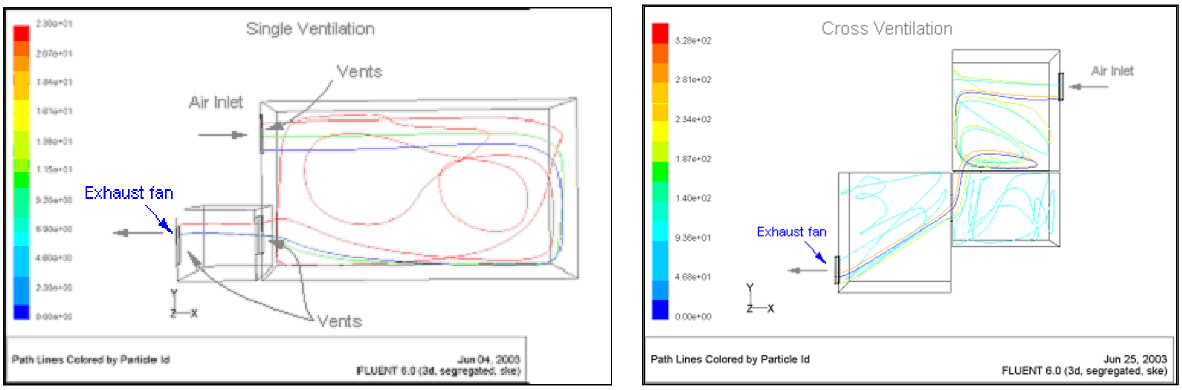


Figure 9. Plan views of two flats in La Grande Motte building when single side and cross ventilation have been implemented. The colored lines represent the air path.

Ventilation rates have to be calculated in order to obtain comfort condition, an interesting design criteria consist on simulate the temperatures inside the building increasing the ventilation rate successively, when this increase in ventilation air flow has no effect over the indoor temperatures the optimum point has been reached. Trough the simulations that have been carried out for the analysis of the case studies we have checked that using this technique the indoor temperature in very hot zones of the building can be reduced in 5ºC and the building average temperature can be decreased up to 2.5ºC.

9. PASSIVE EVAPORATIVE COOLING TROUGH EXTERNAL WALLS

Two EU projects named PDEC and PDEC II (1995 and 2000 respectively) have addressed the problem of the passive downdraught evaporative cooling using towers.
The tower contains in its upper part rows of atomizers (nozzles which produce an artificial fog by injecting water at high pressure trough minute orifices). Compared to the “traditional” wetted pads, this possibility produces a better regulation of the system, a significant reduction of the pressure losses and a lower size of equipment. The situation of the micronizers in a tower gives rise to a naturally downdraft effect that eliminates in some cases the use of fans.
The water droplets in the tower evaporate taking energy from the surrounding air, which in its turn become cooler. The air is in the tower is then, heavier than the indoor air of the building. This creates the downdraft effect. Different inlets and outlets areas are required in order to equalize the air flow rate in the different floors.

In PDECII an analysis of the practical implementation of the system in existing building was performed.
Two levels were identified:

- Minor intervention.

This level is where light wells or other internal shafts or wells could be used as PDEC towers. It is suggested that the dimensions of such shafts should not exceed 3.0m x 3.0m (in plan). Furthermore, the dimension of the light well to an external wall should not exceed 12.0m.

- Intermediate intervention.

This category could be defined where a PDEC tower can be fixed to the fabric of a building. It is envisaged that PDEC towers would be fixed in internal courtyards or another appropriated locations like external façades.

The key criterion for intermediate intervention is building depth. Where building depth exceed 12.0m, PDEC applications will be inappropriate (at least without major intervention). In this level of intervention it is recommended to use extract fans in order to assist the PDEC process.
The building depth is defined as the mean dimension from a light well or patio to an external façade. The procedure to assess it is illustrated in figures 8 and 9. Figure 9 provides the percentage of the building in which the PDEC system is potentially applicable.

Next plan shows 5 different blocks in Catania, now we are going to focus in block III_02

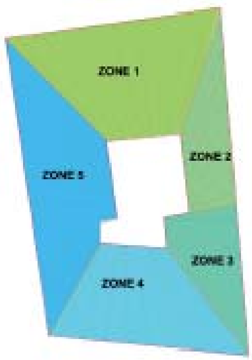


Figure 10.- Partial Catania map and block III_02
The analysis of the “air beams” from the patio to the external perimeter brought as a result the next distribution of lengths:

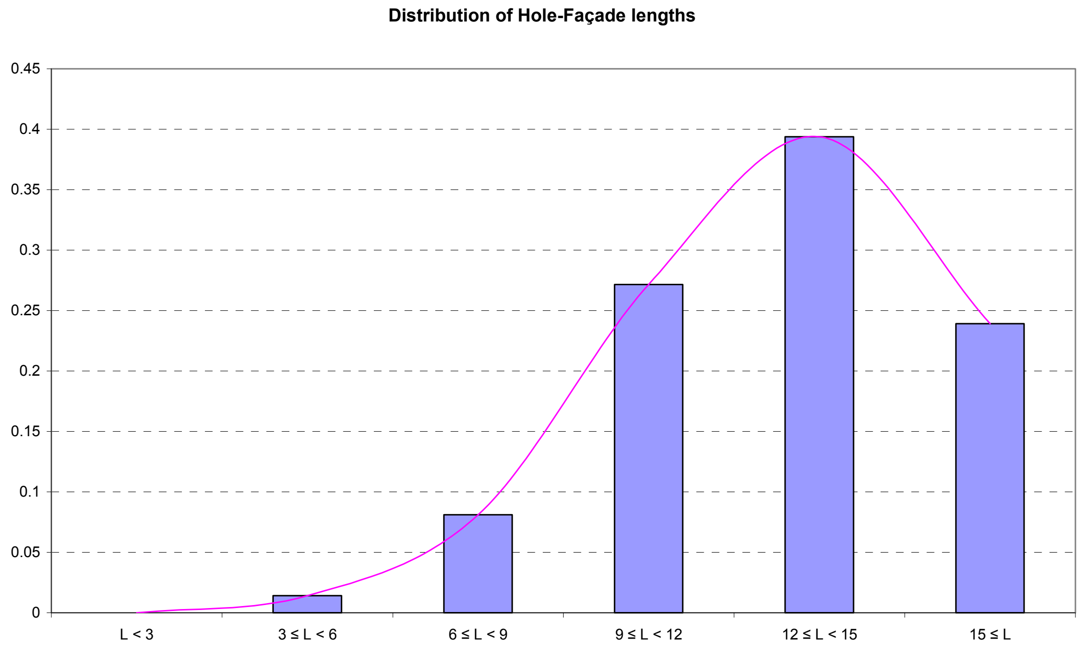


Figure 11 .- Distribution of the Hole-Façade lengths.

APPENDIX I.- CLIMATIC SEVERITY INDEX AND U VALUES REFERRED IN FIGS. 2, 3 AND 4.

Country	*Localion or Climatic Zone*	*CSI*	*Walls*	*Roofs*	*Floors*
			U [W/m²K]		
	BURGOS	1.75	0.57	0.35	0.48
	MADRID	1.01	0.66	0.38	0.49
	SEVILLA	0.40	0.82	0.45	0.52
SWEDEN (2)	HAPARANDA	5.06	0.20	0.12	0.20
SWEDEN (2)	STOCKHOLM	3.43	0.20	0.12	0.20
BELGIUM (3)	BRUXELLES (UCCLE)	2.05	0.60	0.40	0.60
	PARIS	1.84	0.46	0.36	0.43
	LYON	1.96	0.46	0.36	0.43
	MARSEILLE	1.25	0.46	0.36	0.43
U.K. (5)	LONDON	1.96	0.45	0.20	0.35
	cz01	0.60	0.55	0.19	0.29
	cz02	0.71	0.77	0.30	0.47
	cz03	0.45	0.77	0.30	0.47
	cz04	0.51	0.77	0.30	0.47
	cz05	0.38	0.77	0.30	0.47
	cz06	0.30	0.77	0.30	0.47
	cz07	0.27	0.77	0.30	0.47
	cz08	0.32	0.77	0.30	0.47
	cz09	0.33	0.77	0.30	0.47
	cz10	0.45	0.77	0.30	0.47
	cz11	0.76	0.71	0.19	0.47
	cz12	0.73	0.71	0.19	0.47
	cz13	0.64	0.71	0.19	0.47
	cz14	0.91	0.71	0.19	0.47
	cz15	0.29	0.71	0.19	0.47
	cz16	1.76	0.55	0.19	0.29

Source: (1) New Spanish regulations (Building Technical Code)
(2) Personal communication
(3) CSTC Centre Scientifique et Technique de la Construction – Division Physique du Bâtiment et Climat Intérieur
(4) Décret 2000 /0143/F. Ministere de l'equipement, des transports et du logement
(5) British Standard Assessment Procedure
(6) Energy Efficiency Standards for Residential and Non-residential Buildings. California Energy Commission. (The climate zones of California are not formally linked to specific locations, although climate files are available for any of them)

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Chapter 4: Applicability and assessment of the energy potential of using advanced cooling systems in settlement buildings

Introduction

With the development of inexpensive and reliable Carnot refrigerator systems fifty years ago the basis for the wide spread use of air conditioning systems was laid. In the last decade the purchase of air conditioning devices boosted significantly. The desire for moderate tempered, quiet and well moisturised living space was enforced by a drastic change of the living conditions in Europe. Air pollution and noise became common phenomena in larger settlements which means that windows are kept closed all day. In consequence, rooms become hot and stuffy. At the same time climate change leads to rising overall temperatures which enhances so called heat islands in densely populated areas. Air conditioning allows to keep out the heat, noise, and smell. Inside, we have a quiet, cool and well-ventilated room independent from the specific climate conditions. This means that air conditioning has to regulate the humidity of the air as well as its temperature.

Definition of air conditioning

Air conditioning is defined as the process of maintaining a constant climate in a room. Thus, air conditioning devices keep the temperature and humidity in a facility constant all year round.
Air conditioning does not just mean cooling, as is commonly understood. An air conditioner must be able to do four things:

- cooling
- heating
- moisturising
- de-moisturising

Cooling

Cooling in all air conditioning systems is performed by evaporation of a cooling fluid that extracts the heat from its surrounding. The substance condenses in a separate section, releasing the thermal temperature which is then discharged by a heat transmitter or a cooling tower.

Moisturising

There are different techniques to moisturise room air. Steam can be blown into the room directly or into the transport channels. This is only possible if an external steam source is available. Otherwise, a vapour can be generated with an evaporator or diffuser/sprayer.

De-moisturising

There are two ways of de-moisturising air: cooling and adsorption.
In the first case, a cooler, for example a gilled pipe cooler, is used to cool down the air. When the surface temperature of the cooler is below the dew point of the inserted air, water will start to condense on its surface. Thus, the air leaving the cooler has less moisture in it than the air flowing into it.
If larger amounts of water need to be extracted from the air, cooling is not a good option. The dew point temperature depends on the amount of moisture in the air. The wetter the air, the higher the dew point. But with large amounts of moisture, the surface temperature of the cooler would have to be below the freezing point of water in oprder to remove enough moisture. To avoid this problem, adsorption techniques are chosen to de-moisturise very humid air.

By letting the air flow through highly hygroscopic materials, like silica gel, the steam is bound to the substance by adsorption. Condensation then takes place. The Condensate is then taken away. (Reeker/Kranenburg 1979).

Heating

The same equipment, ran in the opposite direction, can be used for heating as for cooling the air. There are air conditioners designed to run in both directions. However, in middle and northern Europe, the climate is not suitable for this kind of heating. Since the winter months are fairly cold in most parts of Europe, big heating loads are required for several months. It is very inefficient to use electricity to cover these demands. It is much more economic to use gas or oil heaters instead.

Air Conditioning Sales in Europe

The demand for air conditioning in Europe is growing rapidly. In 1996 around 7.7 million RAC devices were installed in Europe especially in the southern EU countries Italy and Spain. The following table shows RAC sales between 1990 and 1996 in different countries in Europe.

0	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**Total sold**
Austria	7.600	16.000	11.500	20.000	25.000	24.600	23.800	128.500
France	110.000	132.800	143.000	115.900	147.200	174.000	177.000	999.900
Germany	58.750	74.875	118.500	96.375	130.250	179.750	194.500	853.000
Greece	76.000	72.010	75.440	89.570	126.730	154.200	150.880	744.830
Italy	223.668	214.400	262.667	235.614	345.207	457.639	439.491	2.178.686
Spain	279.000	315.000	342.000	199.000	228.000	274.000	318.000	1.955.000
Portugal	20.850	27.100	41.300	33.000	36.200	40.650	45.800	244.900
UK	74.600	69.500	67.600	64.100	77.300	109.000	133.800	595.900
All Countries	850.468	921.685	1.062.007	853.559	1.115.887	1.413.839	1.483.271	7.700.716

Table 1: Total Room Air Conditioners Sold (Santamouris, 1999)

Conservative assumptions based on manufacturers indications predict a growth of 1.5 - 2 million each year, leading to a stock of about 32 million RACs in 2020 (Adnot, 1999).

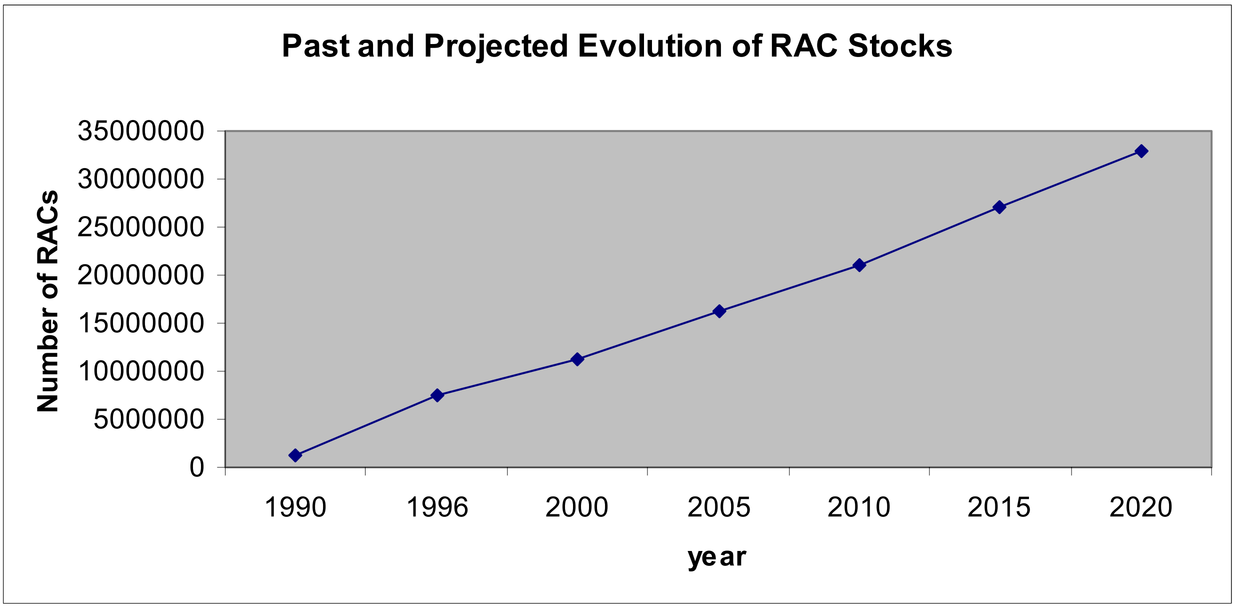


Figure 1: Evolution of RAC Stocks

In 1996, split packages were most frequently bought in all countries. But the newer single-duct units, are becoming more popular. They were already the second most frequently bought system in the European countries, with the exception of Austria, Greece, and Portugal. They are easy to install and are available in department stores and Do-It-Yourself retailers. Another aspect that may lead to an increase in single-duct unit sales is the nature of the market. If there is a long period of hot weather, a lot of people decide to buy an air conditioner on the spot. There is no planning ahead of time, and a solution is wanted as soon as possible. Window units and multi-splits require a fitter, while splits and single-ducts can be installed easily without professional help. Therefore, the latter are preferred in this "impulse" market (Santamouris, Adnot et al. 2001).
Special developments in certain country's markets can be observed. While the Italian market is slowly getting saturated, Portugal and Spain are estimated to have substantial growth in cooling demands. Sales in Portugal are said to increase by a factor of 5 within 24 years, in Spain, they will at least double, according to estimates from CCE and IDEA (Santamouris, Adnot et al. 2001).

With CAC systems, smaller appliances are increasingly penetrating the market. Table 2 shows CAC sales in European countries in 1997.

Country	**Outdoor or packed units (number)**	**Chillers with water systems (number)**
Spain	267.972	2.634
Greece	2.468	1.218
Great Britain	4.280	2.766
Germany	4.663	3.273
Portugal	866	556

Table 2: CAC Sales in 1997 in Some EU Countries (Mad, 1999)

CACs have little market share compared to RACs. For example, in Italy, there were about 400000 RAC systems installed in 1996, compared to 40000 CAC systems (1997). When evaluating this figure, however, one has to consider that CAC systems cool significantly more space (m^2) than RACs. One CAC system can cool an entire building, while one RAC system only cools one room. CACs require careful planning in advance, and have much higher fixed costs. Even though they may be more efficient and energy saving (see next section) they are not suitable for all situations. RAC penetration also varies significantly between different sectors. The following tables compare RAC and CAC stocks in different types of buildings in some European countries.

Country	**Total room surface area (m^2)**	**% equipped with CAC**	**% equipped with autonomous RAC**
Austria*	10.500.000	10%	10%
France	140.000.000	11%	14%
Germany	n a	N a	n a
Italy***		70%	30%
Portugal	25.259.440	46%	22%
UK**	70.188.000	23,8%	6,3%

Table 3: Air Conditioning in Offices

Country	**Total room surface area (m^2)**	**% equipped with CAC**	**% equipped with autonomous RAC**
Austria	41.000	n a	< 5%(estimated)
France	550.000	0 %	25%
Germany	n.a	n.a	n.a
Italy***		2%	98%
Portugal	14.619.480	17%	12%
UK**	93.938.000	11,5%	4,2%

Table 4: Air Conditioning in Small Business (Trade)

Country	Total room surface area (m^2)	% equipped with CAC	% equipped with autonomous RAC
Austria*	6.500.000 m^2	10%	3%
France			
Germany*	13.000.000 m^2	10%	3%
Portugal	4.803.613 m^2	36%	10%

Table 5: Air Conditioning in Hotels

Country	Total room surface area (m^2) or nr. of households (hls)	% equipped with CAC	% equipped with autonomous RAC
Austria	3.110.000 hls	0%	< 1%(estimated)
France	25.000.000 hls	0 %	1,4 %
Germany	37.281.000 hls	0%	0,1%
Greece	2.850.519 hls	0,2%	11%
Italy	57 million m^2	2% (1.142.000m^2)	33,8%
Spain	1009 million m^2	0,1%	4,8%
Portugal	3.120.000 hls	0,06%	0,96%
UK**	23.960.871 hls		

Table 6: Air Conditioning in Households

* estimations
** These data (for all sectors and subsectors) only covers England and Wales – Scotland and Northern Ireland are excluded.
***The percentage indicated for Italian offices and small businesses actually corresponds to the share of the surface air conditioned by a centralised system or by an autonomous Room Air Conditioner, **out of all** the offices or small businesses which are air-conditioned.

Energy Demand and Environmental Concerns

The documented boost of air conditioning in Europe and world wide raises two major environmental concerns:

a) High demand for electrical energy
b) Employment of refrigerants with negative environmental impacts

High Demand for Electrical Energy

The 7,4 million devices of RAC in Europe in the year 1996 consumed 11 TWh of electricity. In respect of the predicted growth to 33 million units in 2020 this sum will mount up to 43,9 TWh (Adnot et al. 1999). Moreover, The demand peak of air conditioning is during the hot hours around noon, when the electric energy peak load can be found in almost all European regions. Thus, the growing demand will bring the need of additional power plants which will primarily base on fossil or nuclear fuels – causing environmental problems like global warming or nuclear waste.
Here is an estimate (Adnot et al. 1999) of CO_2 emission due to RAC between 1990 and 2020.

Unit: tons CO_2	1990	1996	2010	2020

Austria	157	1 603	15 748	31 467
France	26 860	87 377	285 231	468 957
Germany	7 845	25 615	139 241	265 983
Greece	99 235	959 939	2 387 187	3 737 087
Italy	182 591	2 247 038	2 923 568	3 623 486
Portugal	147 358	358 099	1 038 841	1 519 546
Spain	n.a. (around 90 000)	1 124 255	4 381 826	7 130 489
UK	47 710	219 640	704 204	1 165 583
Other E.U.	4 694	15 369	83 545	159 590
Total E.U.	516 451 (606 4519)	5 038 935	11 959 391	18 102 187

Table 7: CO_2 Emissions by Country (Adnot et al. 1999)

Air pollution is also a health problem, causing respiratory illnesses etc. It has been shown to damage agricultural crops, building surfaces, forests and ecosystems.

Environmentally Dangerous Refrigerants

Besides of the large electricity demand, air conditioners have other negative effects on the environment. Refrigerants like HFCs or PFCs are released into the atmosphere causing ozone depletion and stimulating climate change. The cooling fluid R-134a is free from ozone depleting substances, however its climate effects have been confirmed by the Kyoto Protocol which enclosed them into the so-called Kyoto Gases (Integral, 2002).

Strategies to Reduce Environmental Damage

There are two major strategies for diminishing the environmental damage caused by the rapid market penetration of air conditioning in Europe:

1) Drastic raise of the energy efficiency of today's standard technique of electricity driven compression cooling. The European Commission concludes that the energy efficiency of RAC could technically be raised by 50 %. On economically viable terms, 25 % would be possible (Adnot et al. 1999).
2) Further development of alternative cooling systems. Several alternative techniques have been developed recently, which have proved their technical maturity in various pilot projects. The most important approach uses heat for a "chemical compression", other systems use solar energy or evaporative cooling. Market penetration has to be supported by enhanced research efforts, financial incentives, a favourable legislative framework, PR, and awareness raising activities.

For both strategies a labelling on air conditioning would be very helpful, which already exists for example in New Zeeland and Japan. However, despite already having been suggested to the European Commission in 1999 (Orpheus et al. 1999), it has not been introduced so far into the European Union.

Air Conditioning using Conventional, Mechanical Compression

Basic Principles

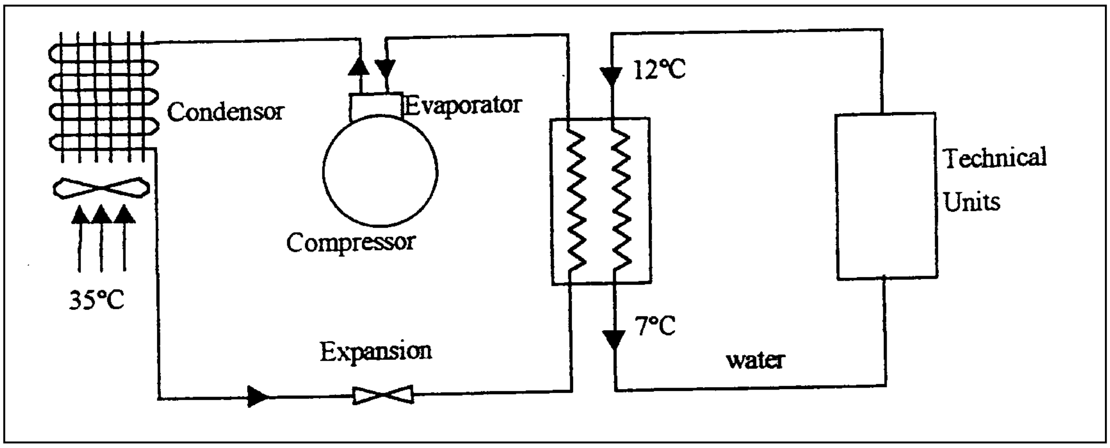
The standard air condition system is based on an electric energy driven mechanic compression.

Components

A standard air conditioning device consists of three components: a chiller, a moisturiser/de-moisturiser, and one or more fans. Often, cooling towers are combined with the chillers to complete the system.

Chiller

A chiller of an air conditioner works like a standard refrigerator. Its four main components are evaporator, compressor, condenser and expansion valve. They are connected with pipes through which a cooling fluid is pumped.



air washer, or

A *spray apparatus* creates water vapour by breaking a water film into very small particles and mixing them into the dry air.
An *air washer* sprays water into the air through atomiser nozzles inside of a mixing chamber. Excess water can condense, while the moistened air leaves flows out of the chamber.
Steam humidifiers use steam from an external source and pump it into the air. They have to control the steam so that only dry steam is ejected. The steam can either be added to the air inside the air ducts or be released directly into each room.
De-moisturisers can be combined with a chiller, using cooling to cause condensation. Adsorptive dehumidifiers can be installed as separate units.

Fans:

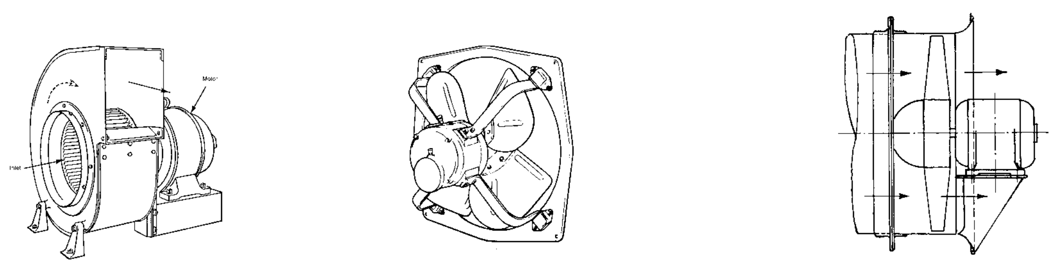


Figure 3: Centrifugal fan, Helical Gearwheel fan, Axial fan

There are three main categories of fans:
Centrifugal fans have a helical casing. The air is sucked in from the front and blown out at a ninety-degree angle. The purpose of the helical casing is to convert the high dynamic pressure at the tip of the blades into a static pressure. There are various ways to shape the blades of centrifugal fans

(radial, bent forward/backward) to influence air pressure and speed. The efficiency of these kinds of fans is lower compared to other fans because the air has to be turned ninety degrees. This uses up additional energy through vorticities and collision losses. The fans are often used in larger chillers, because of their robustness and capacity. They are also practical for achieving higher pressure and lower velocity flow. This reduces pressure losses in the flow beyond the fan.

Helical gearwheel fans are widely used for simple fans and ventilators. This is because they can be used with a very high efficiency in areas where the airflow encounters very little resistance. Helical gearwheel fans suck in air from all directions and blows it out mostly axial, but also partly radial. If there is too much resistance for the airflow, the air is pushed back through the fan in the centre and near the tips of the blades.

Axial fans are being used increasingly, as they have a high efficiency, are easy to install and don't need much space. Air flows through the fan in a straight line, making it highly compatible with straight air ducts. As with centrifugal fans, there are various ways of designing the blades. The length, the aerodynamic curve and the angle at which the blade stands toward the direction of rotation determine the efficiency of the fan.

Cooling Towers

There are two ways to extract the heat from the refrigerant: cooling in open circuit and cooling in closed loop. In large, liquid coolant-based applications, open circuit means that the secondary fluid will be discarded into a sewer after picking up heat from the cooling fluid. When this method is not possible, closed loop cooling, with cooling towers in large applications, is used. There are three types of cooling towers: indirect contact or direct contact towers and wet-dry towers.

Room Air Conditioning (RAC)

RAC means that each room has its own independent system, including, chiller, fans, moisturiser/de-moisturiser etc. RACs make use of a cooling fluid. The cooling fluid releases the collected heat to the outside air. Several models of RACs are possible:

- **Split Systems:** A split system consists of two units, one indoors, the other outdoors, connected by a pipe that transfers the refrigerant. The outdoor part includes compressor and condenser. Evaporator and fan are part of the indoor unit.
- **Packaged Systems:** Packaged systems are always single unit systems, which means that all components of the system are installed on one frame. They are commonly sold as window or wall RACs.
- **Single Duct Systems:** A single duct unit ejects hot air from its condenser through a duct. The air can be ejected from the room through an opening designed for the system, or through a door or window. The latter option, however, is somewhat inefficient.

Central Air Conditioning (CAC)

CAC systems always have one central unit that serves several rooms of one or more buildings with water and/or air. The cooled medium is delivered to each room via transport channels. Whereas RAC systems are always all air systems, CAC systems can also be all water systems or water-air systems. There are also CAC systems where only part of the cooling system is centralised. Each room has its own evaporator and fan, and the central unit distributes the cooling fluid instead of the cooled medium. The major technologies are:

- **Multi Split Systems:** Multi split systems can be compared to the split RAC systems. Each room has its own evaporator and fan, but all room units use a central compressor and condenser unit. The central unit can only serve a limited number of rooms, making this system usable for small buildings or a small group of rooms only.
- **Air Systems:** An air system cools the entire building with air. The central unit mixes fresh air and exhaust air. It cools, de-moisturises/moisturises the air and ejects it into the main air channel. The air is then transported to all of the rooms.
- **Water Systems and Fan Coil Unit:** Water systems transport cold water to each room instead of cold air. The central unit is a water chiller. The air in the rooms is cooled by

conduction, convection or radiation. Since the central unit only transports water to the rooms, the exhaust air needs to be replaced with fresh air through a separate system. Often fan-coiled units are used because they can treat air and serve as the room's cooling unit.

Direct Refrigerant Systems: These systems work similar to the multi-split systems but can be used for a nearly unlimited number of rooms. A Variable Refrigerant Volume (VRV) system adjusts the amount of refrigerant flowing through the system according to the demand. This is accomplished with an electronic expansion valve. As a result, the system can maintain virtually constant temperatures independent of the current load.

Technical Improvements for Air Conditioning using Mechanical Compression

Rating Energy Efficiency of Air Conditioners

The energy demand of air conditioning depends on the outside climate conditions (air temperature, humidity, radiation) as well as the inside cooling demand. Standard conditions for the design of air conditioning devices are an outside temperature of 32 ° C and a relative humidity of 40 % (Henning, 1996).

Before monitoring the potential for technical improvements it is necessary to define transparent criteria for the energy performance of a specific device. Suitable are the use of the following different ratios or values: EER (Energy Efficiency Ratio) and SEER (Seasonal/Average EER).

$$EER = \frac{Pc}{Pe}$$

where *Pc* is the heat extracted from inside the room and *Pe* is the electric energy used to extract this heat. Therefore, the higher the EER, the more efficient is the system. For a country with modest climate like Germany it is assessed that the energy demand of room air conditioning is around 15 kWh/m^2 a. For Cagliary, Italy, 50 kWh/m^2 a are reported (Henning, 1996).

The EER can be computed in testing conditions, thus applying to specific conditions only. To take into account that climatic conditions vary, causing different loads for the same system, one can calculate the SEER. The SEER is the average EER over one year.

Air conditioners that are driven by thermal energy can be compared using their COP (Coefficient of Performance) rather than the EER. The COP is also used for cooling machines that can run as heaters. The COP is computed as follows:

$$COP = \frac{Q_V}{Q_G}$$

Where Q_V is the cooling capacity and Q_G the thermal motive power. As with the EER, it is possible to calculate a SCOP (Seasonal Coefficient of Performance) in addition to the COP.

New ARI rating systems

However, both of the COP and EER rating methods neglect the effect that part-load operation has on performance. An air conditioning unit only actually spends a small fraction of its time working at full-load. An Integrated Part Load Value (IPLV) takes account of this by rating an average efficiency over a pre-defined spread of operating points (the SEER also does something similar). This value, developed by the ARI (Air Conditioning and Refrigeration Institute, USA) in 1998, produces a single, but more representative value.

The following table shows the cycle used for the calculation of the IPLV, and so the seasonal average efficiency of the air conditioning unit.

Load (%)	**Operating hours**
100	1
75	42
50	45
25	12

Table 8 : Weighting of part load points by ARI (1998)

These standards have been defined for American requirements and building sizes, and only scaled (not fully redefined) for European conditions. (Santamouris et al., 2002; ARI, 2002; EUROVENT-CECOMAF, 2002)

Selection of Efficient Systems

In a settlement refurbishment the most efficient system type should be chosen. Some general guidelines for this choice are valid all over Europe. The efficiency of an air conditioner has to be evaluated in the context of the overall insulation of a building. Poor insulation reduces the EER of every air conditioning device. Moreover, controlled ventilation in the building diminishes the cooling load. In office spaces it is important to extract internal heating sources for example by using energy saving devices for computer and lightening (Henning, 1996).

In general the efficiency of CAC systems is higher than of RAC systems. The latter, however, can be installed with lower costs in the existing building structure. Within CAC the water-cooled systems in most cases have higher EERs than the air-cooled ones.

Air conditioning should find an optimal combination of the functions cooling and de-moisturising. It is possible to perform the cooling and the de-moisturising in one process step by cooling the surface under the dew point of the steam. Since in this technique temperatures of less than 6 ° C are necessary, the efficiency performance is rather low (Henning, 1996). Therefore, it is preferable to split up the cooling and the de-moisturising in separate working steps. The de-moisturising is performed with sorption materials.

Finally, the individual set-up of the chosen device should secure a high energy efficiency. In the following section the status quo of energy efficiency and suitable measures for technical improvement are scrutinised.

Energy Efficiency – The Existing Situation

In a first step the average energy efficiency of different RAC devices is shown:

Type	Average Size (kWc)	Average Value of EER
Split	5	2.48
Packaged	4.5	2.38
Single Duct	1.7	2.07

Table 9 : Average Size and EERs of RACs (Santamouris, Adnot et al. 2001)

Positioning of Air Conditioning Unit

The positioning of the air conditioning unit (and eventually the thermostat) in the room, can have a significant impact on the cooling efficiency, through changes in the air circulation. If for example, the unit is placed where there is poor circulation with the entire room, it may end up drawing in mostly cold air, and so minimising the cooling effect.

Generally, units are placed high up to exploit the negative buoyancy of the cold air. The danger remains however that there is insufficient horizontal circulation across the room, especially since units are often placed in a corner (for aesthetic reasons) and blow air out parallel to one of the walls.

Technical Improvements for RAC

Three fields for technical improvement are mainly considered by the manufacturers:

- Improvement of heat exchangers
- Improvement of compressors
- Improvement of control.

Improving Heat Exchangers and Compressors

Increasing coil area, adding tubes, or improving fins, can increase the heat exchange area. The compressor efficiency can be raised to improve the entire system. Another option is the use of a variable speed compressor.

Improving Control

The differences in load for a system due to different climatic conditions throughout the year need to be taken into account. An efficient system should be able to adjust to different cooling loads smoothly, so that energy is not wasted and room temperature remains constant.

One very promising solution is to use variable speed (inverter-type) compressors instead of single frequency ones. In some cases, this may lead to savings of up to 10% - 40% (Santamouris, Adnot et al. 2001).

A study has been done by the Ecole des Mines (Orphelin et al. 1999) simulating the effect of changing several aspects, including those explained above, of conventional RAC systems. Three split systems and one single duct system were used for testing. In the table below are the results of this study, as summarised in the final report.

Option	Technical improvement	Average increase in EER (%)
1(a)	Increase frontal coil area (15%)	4%
1(b)	Increase frontal coil area (30%)	8%
1I	Increase frontal coil area (45%)	11%
2(a)	Add one refrigerant tube	10%
2(b)	Add two refrigerant tubes	16%

3(a)	Increase fin density (10%)	10%
3(b)	Increase fin density (20%)	16%
4	Add subcooler to condenser coil	1%
5	Improve fin design (modify fin pattern)	11%
6	Improve tube design	8%
7(a)	Use of a high efficiency fan motor	1%
7(b)	Use of an electronically commutated motor	2%
8(a)	Improve compressor efficiency (5%)	3%
8(b)	Improve compressor efficiency (10%)	5%
8I	Improve compressor efficiency (15%)	8%
9	Use of R410a with □ystem□ie system	5%?
10	Use of variable speed compressors	12%
11	Use of electronic expansion values	5%?
12	Use of (fuzzy) controls	4%?

Table 10: Average Gain Per Option (Orphelin et al. 1999)

Technical Improvements for CAC

There are a large number of possibilities to improve CAC systems. For multi-split or VRV systems, the options which have been explained for RAC systems above apply as well. For air and water systems, some of these options may also help, but there are several other, more effective methods. The following items can be found in the EU funded research "URBACOOL" (Santamouris, Adnot et al. 2001).

Reducing Load by Variable Air Flow

A system with variable airflow keeps the temperature of the supply air constant. The temperature in the rooms is controlled by varying the amount of supply air that enters the space. A Variable Air Volume (VAV) terminal device delivers the appropriate amount of air.

Multiple-Compressor Use

By distributing the cooling load on several compressors one can improve the part load efficiency. All of the compressors work in parallel, powering a common heat exchanger. Depending on the climatic condition, some machines can be turned off. Another advantage is that a machine can easily be replaced by another one in the system. This is convenient if a machine needs to be repaired or replaced.

Variable Speed

This technique is similar to the one discussed in the section about improving RAC systems. It can be applied to motor driving compressors, pumps and fans in cooling towers and air handling units. Since the system will mostly run on part load with variable speed control, a significant amount of energy can be saved. It should also be noted that the variable speed causes the power input and the cooling capacity to be proportional.

Advantages of variable speed (Santamouris, Adnot et al. 2001):

- Optimisation of the voltage supply, improvement of the cosine phi. As a result, the apparent power input and losses are reduced.
- On start up, the current is only 100 to 160% of the rated current, instead of 5 to 7 times the rated current.
- The speed varies linearly which reduces mechanical constraints and maintenance costs. This has a direct and positive effect on the lifetime and reliability of the motor. Variable speed motors also incorporate a PI regulator for better control.

There are limits to the use of variable speed. There has to be enough speed to ensure proper lubrication of mechanical parts and to get a good seal for spirals and screws in scroll and screw generators. There can only be as much speed as the bearings can support. Otherwise the machine could be damaged.

A system needs to be designed for variable speed in order to work properly. If this is the case, variable speed can be very effective.

Free Cooling

Free cooling uses cold outside air for cooling. It is a good option for European countries with moderate climate conditions. There are two possibilities: total system cooling and cooling at the cooling-tower.

Total system cooling means using the outside air directly (without additional cooling) to cool a room/building. It is only a good option if there is a sufficient number of hours during which the system can operate, because special equipment (fans, air mixing equipment, dampers, filters, etc.) is needed.

Cooling at the cooling tower is easier to realise. There are three methods that can be considered:

- Direct free cooling – there is a direct contact between the condenser water and the chilled water.
- Indirect free cooling – the heat transfer between the chilled water circuit and the condenser water circuit is accomplished via a separate heat exchanger.

- Vapour migration system – the compressor is bypassed, allowing the refrigerant vapour to enter the condenser directly. The liquid refrigerant flows back to the evaporator using gravity. Thus, the compressor does not have to be operated.

Use of Auxiliary Heat Exchangers

Supplementary heat exchangers can be used to improve the performance of the cooling cycle. There are two types of auxiliary heat exchangers:

- Subcooler – This is a heat exchanger located between the condenser and the expansion valve. It sub cools the refrigerant which can reach evaporation temperatures after compression.
- Recuperator – The recuperator recovers the heat that is given off at the discharge. This avoids excess heat being dissipated into the atmosphere by the condenser.

Heat Recovery System within the System

The overall energy balance of the RAC system can be improved significantly by recycling the heat in the waste air before discharge. This recycling step can be performed by water and air heat exchangers.

Use of Favourable Part Load Characteristics

Oversized chillers display a higher auxiliary consumption at part load but ensure less friction and heat losses. Some chillers even have well chosen intermediate power levels so that their part load behaviour stabilises on optimal operating points.
In order to use these favourable part-load characteristics, it is possible to oversize equipment of all water systems. But, this may also have negative consequences, namely:

- Losses increase with size of equipment (distribution losses)
- Some free cooling may take place in some terminal units.

Innovation for Mechanic Compression-Based Air Conditioning

It is possible to reduce some of the environmental damage caused by the air conditioning boom by technical innovation namely the use of PV systems and of environmentally sound refrigerants.

Electric Energy from Photovoltaic Systems

Solar energy has the advantage that the time of the day – noon – with the highest cooling demand is the period with the strongest sunlight radiation. Therefore, solar based air conditioning is widely independent from energy storage facilities. It depends on the individual design of the air conditioning device and the specific climate conditions, if auxiliary electric energy generation is necessary. Some R&D actions brought significant results.

R&D action 1: Photovoltaic Air Conditioning

Aim of Project: Design and test of a solar photovoltaic air conditioning device powered by a PV generator.
Project Reference: JOU20199
Prime Contractor: Jourde, Patrick – Commissariat à l'Energie Atomique (CEA)
Others: Baltas, Platon – Centre for Renewable Energy Sources; Siri, Yves – Alpes-Froid SA; Paes, Pedros – National Laboratory for Engineering and Industrial Technology;
Source: http://www.cordis.lu

Replacement of FCs

Important research progress has been performed in the field of replacing environmentally hazardous (high greenhouse potential) cooling fluids like HFCs and PFCs (e.g. R134a, R404A, R407C). Promising alternatives are ammonia (NH_3), water (H_2O) and carbon dioxide (CO_2).

R&D action 2: NH_3 as Refrigerant

A project on the use of NH_3 was done by the Institut für Kältetechnik at the University of Hannover. NH_3 is an environmentally optimal refrigerant that neither adds to the ozone depletion nor contributes to the green house effect. The use of NH_3 was explored for small and medium sized chillers. For this purpose, a test system with a cooling capacity of 10 kW was built. A semi-hermetic ammonia compressor was built especially for the use in this project. In addition, an ammonia calorimeter according to the DIN 8977 guidelines was developed to measure the compression capacity of the refrigerant.

The results acquired with the NH_3 system were comparable to those of a system using the refrigerant R22. The researchers also showed that the use of aluminium pipes is a good (and necessary) alternative because aluminium is neutral towards ammonia and mixtures with up to 10% water. Overall, it was conceived that a system with NH_3 as a refrigerant is possible when using a soluble lubricant. Since 1997, a pilot system using the developed system is in use.

Source: http://www.dbu.de

R&D action 3: H_2O as Refrigerant

INTEGRAL Energietechnik GmbH has specialised in research about using water as a refrigerant. Water carries the advantages of being environmentally benign, having a low boiling point and often being readily available. Because of these useful properties, Integral has developed and tested new water-based concepts for cooling and refrigeration hardware. The most important result is a mechanical steam compressor. Different heat exchangers have also been developed.

Source: http://www.energ-ice.com

R&D action 4: CO_2 as Refrigerant

A study has been done by the ZAE Bayern to show how a cooling system that uses CO_2 as its refrigerant can be improved. The influence of the heat exchanger surface area and of the gas cooler pressure on the power coefficient was determined to try to find the optimal working conditions. The results show that with increasing total heat exchanger surface area, the power coefficient increases. Decreasing the pressure with increasing surface area yields even higher values. With a heat exchanger surface just over 0.25 m^2 / kWc the maximal power □ystem□ient, approx. 3.75, corresponds to the lowest pressure, 85 bar. The highest pressure, 120 bar, reduced the power coefficient to about 2.75 with the same heat exchanger surface.

Contact: www.zae-bayern.de

Engine Driven Cooling

Engine Driven cooling is realised with an internal or external combustion engine that drives the compressor of a standard vapour-compression cycle. These engines are designed for use with natural gas and propane fuel. Engine driven cooling is used for RAC systems.

Air Conditioning using Thermally Aided Compression

In cases where a heat source is readily available, thermally-aided compression may be desirable, as it avoids first converting this thermal energy into electricity. The necessary heat may be supplied by combustion, industrial waste heat or solar collectors.

There are two principal processes by which this can be realised: absorption and adsorption aided compression. These use a liquid and solid solvent respectively to absorb coolant and thereby help in the compression stage of the air conditioner. The thermal energy is used in the separation of the coolant and solvent.

Absorption Cooling

In an absorption cooling machine the help offered by the absorption fluid comes from changing the vapour from the evaporator into a liquid state (a "shifting of the condensation curve") by absorbing it. This hugely facilitates the compression which is now carried out by a mechanical pump. After this compression an external heat source is used to evaporate the cooling liquid at a higher pressure (see below). The refrigerant separates from the solvent again and circulates on towards the condenser.

Most suitable for room air condition devices proved water (H2O) as cooling fluid and Lithiumbromid (LiBr) or Ammonia (NH_3) as absorbing substance. It is also possible to use absorption solids like Calciumchlorid (Henning, 1997). The four main components for a liquid absorbing material of this closed system are: Evaporator, absorber, the desorber and a condenser.

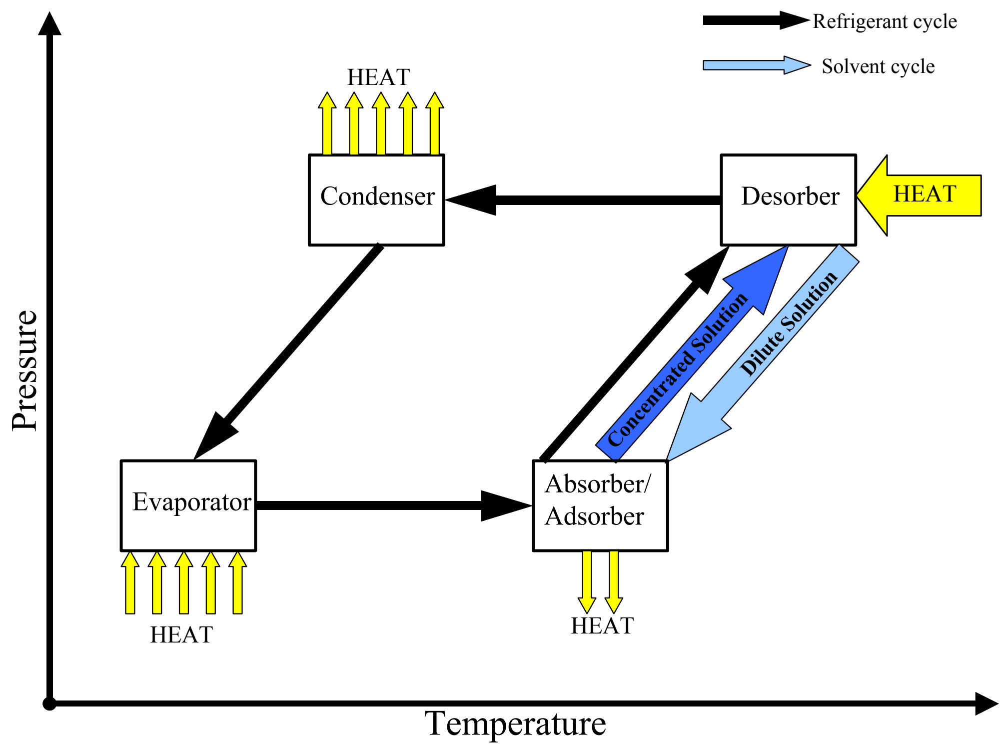


Figure 4: Schema of an absorption cooling machine

Absorption machines require thermal energy of high temperatures: Single effect systems need up to 150 ° C (Henning, 1996). Most innovative single effect absorption techniques can operate on temperature level of 80 – 90° C (Todt, 2002). Still the efficiency performance declines significantly at lower temperatures. Double effect devices – however more expensive – require less temperature. Still the higher the temperature(up to 150 ° C), the better the efficiency. The decrease from 115 ° C to 100 ° C brings with it a decline of efficiency of approximately 25 %. (Wolkenhauer, 2001)

Due to the small co-efficiency large amounts of heat are required. Therefore, complex units are necessary for the discharge of the heat current (University of Hannover, 2002).

Adsorption Cooling

In the adsorption cooling machine the cooling fluid vapour is bound on the surface of adsorption substances which are solid in most cases. The cooling machine runs periodically because the solid cannot be regenerated in one step. To assure constant cooling, there are at least two sorption containers necessary. Adsorption cooling machines can operate on temperature levels of 90 ° C (Wolkenhauser, 2001). Adsorption is best suitable for cooling sizes of more than 10.000 m^3/h. A prominent combination is to use as cooling fluid water and for the adsorption material Silica Gel. The heating increases the pressure of the system facilitating the condensation of the cooling liquid. In the configuration shown in figure 5 it is even possible to make a mechanical feed water pump completely redundant.

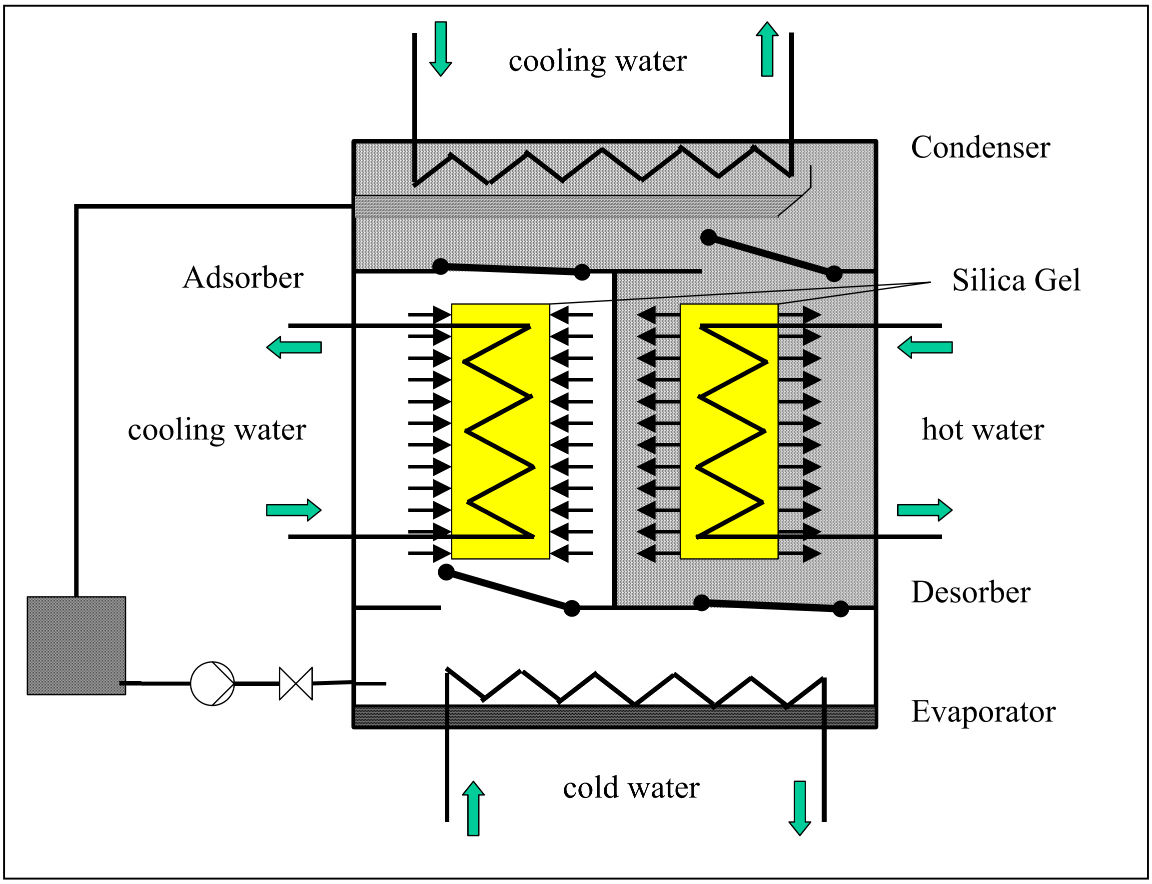


Figure 5: Schema of an Adsorption Cooling Machine

R&D Actions for Thermally Aided Cooling Machines

Various research and demonstration actions have been performed in Europe in the last years. They can be defined by the kind of heat they make use of. Major heat sources are:

- Heat from fossil fuels
- Heat from biomass fuels
- Heat from solar energy
- Heat from geothermal

Heat from Fossil Fuels

In industrial countries large amounts of waste heat is produced in industrial processes and particularly within electric energy generation. This waste heat is usually discharged, unused, into the environment. Therefore, it is an obvious choice to use this waste heat to run air-conditioning.

Moreover, the infrastructure for residential heating is not used in many European regions during the summer months. Also here, it is a very effective approach to install heating – cooling networks in which the cooling is generated from the same heat source.
In both cases the consumed heat is available at very small prices. Moreover, the supply of heat for thermal driven air conditioning improves the economic performance of the heat producer himself.
Various research and demonstration work has tackled the option of cooling machines run on fossil fuel based heating.

R&D action 5: LiBr – Absorption Chiller for Building Air Conditioning

The project explored the use of a directly fired generator to drive an absorption process. The research included two major aspects, the development of a direct fired, high performance generator and a new Lithiumbromide absorption unit. The resulting system also includes an improved cooling tower that uses a combination of wet and dry parts.
The Absorption chiller cycle was modified to increase the COP from 1,1 to almost 1,3. Complete calculations for the design of an absorption chiller with 1 MW cooling capacity were made. It has been shown that the cooling tower system can save up to 50 % of the cooling water used in a conventional cooling tower. The generator can be adapted to heat sources such as direct firing, flue gas from gas engines and gas turbines. It was not tested on fuel oil, mixed fuel, or biomass in this study.
Source: (Scharfe, 2000)

R&D action 6: Wegracal-Absorber

The German Company EAW GmbH started a project in conjunction with the Institut für Luft- und Kältetechnik Dresden in 1997. The goal was to develop an absorber for an absorption maschine that can make use of the cooling water temperatures and the high exhaust gas temperatures (multi-effect system). The result was a Wegracal-Absorber with water as refrigerant and a Lithiumbromide solution as a solvent. The heat transfer is very efficient, because the pipes are coiled up in spirals, thus offering maximal surface area in very little space.

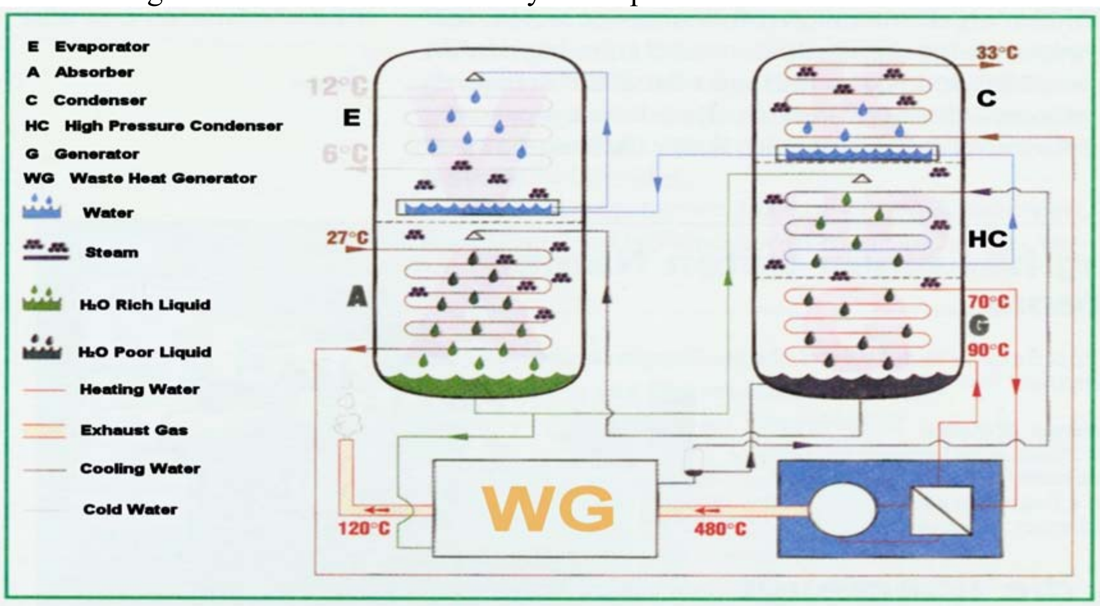


Figure 6: Wegracal Absorber

Source: (Todt, 2002)

R&D action 7: Integration of Microcomputerised EM Systems with CHP and Absorption Chiller

Aim of Project: Demonstrate the unique combination of a micro computerised energy management system to control and monitor small-scale CHP, absorption chiller with CHP heat input around 120 °C

Project Reference: BU./00444/92

Prime Contractor: Ryan, W. – Temp Technology LTD, Ireland

Others: –

Source: http://www.cordis.lu

Heat from Biomass

Biomass is considered as a major column for renewable energy supply in Europe. Due to the high transport expenses biomass resources have to be exploited locally e.g. by a decentralised co-generation. Very suitable is to make use of the biomass directly on the farming site. It is therefore a very promising approach to use the waste heat of these decentralised co-generation for cooling options. Despites still being very cost intensive, the technical maturity of biomass-based cooling devices was proved in different commercial size demonstration sites.

R&D action 8: Rape-oil based multi-effect absorption cooling

In the hospital of Wolgast in Northern Germany a highly innovative multi-effect cooling system has been installed. The heat is produced from biomass based co-generation with 240 kW_e. Rape-oil is used as biomass feed-stock. The cooling water of the engine of 90 ° C and the exhaust gas of 480 ° C is used to run the absorption site. The plant is successfully under operation since September 2001. Source: www.euu-gmbh.de

R&D action 9: Biological Gas Plant

A prominent biological gas plant in Germany that uses waste heat for cooling is the farm Loick-Hof. The plant consumes per year 11.000 tons of biomass mainly the manure and harvest residues of the farm. This allows to reduce the temperatures inside the pigsty from 35 °C to about 26°C.

The lower temperature reduces the stress of the animals and so prevents sicknesses. The biological gas plant has an annual power of 249 kW, producing approximately 2 million kWh electricity. Three quarters of the waste heat that would otherwise be released into the environment can be used up by the air conditioning system.

Contact: ENR GmbH, http://www.enr.de

R&D action 10: Bio-diesel based cooling

In the frame of the refurbishment of the Reichstag building in Berlin to be usable for the German Parliament a bio-diesel based co-generation plant has been installed with a capacity of 1600 kW_e. The generated heat is used for the air-conditioning of the building based on an absorption machine. Heat and cold storage as well as the connection to the general electricity grid enable the system to cope with demand peaks and gaps. The plant has been operating since 1998 without larger problems.

Contact: University of Stuttgart, IER, www.ier-uni-stuttgart.de

Heat from Thermal Solar Energy

Using thermal solar energy as heat source for air conditioning is a very promising approach. It is more efficient to produce thermal energy than electricity from solar radiation (Wolkenhauer, 2001). Next to the thermal cooling machine, the two main components are the solar collectors and the heat/cold store. The thermal cooling machine can be absorption or adsorption based, as seen above. All common collector types are suitable: flat collector, CPC-flat collector, vacuum tube collector and parabolic channel collector. Stores can be thermal stores, thermo-chemical stores or photochemical stores. The size depends on the specific cooling requirements. (Wolkenhauer et al. 2001). Auxiliary systems can be heat pumps or fossil combustion (e.g. natural gas or waste heat.) A very cost efficient heat supply is possible in district heating networks. At least 40 % solar coverage of the solar system is necessary to have a better primary energy performance than conventional cooling machines (Wolkenhauer et al. 2002).

Careful planning and design is necessary for each solar assisted air conditioning unit. In each individual site the plant modules have to be optimised in their interdependences. An adsorption cooling machine with its lower temperature requirements is well suited to a standard flat collector, while absorption techniques in most cases require a vacuum tube collector. If a fluid absorption material is chosen, the separation can be done directly in the solar panel.

Intense research and development actions have been performed recently:

R&D action 11: Air Conditioning Absorption Heat Pump

Aim of Project: Verify the technical and economical value of a single stage absorption heat pump using improved and advanced components such as plate heat exchangers, rectifier column and solution pump.
Project Reference: BU./00040/91
Prime Contractor: Annibali, M. – Ente per le Nuove Tecnologie, l'Ambiente (ENEA), Italy
Others: –
SOURCE: HTTP://WWW.CORDIS.LU

R&D action 12: An Integrated Hybrid Solar / Gas System for Buildings

Aim of Project: Investigate a novel hybrid solar/gas system that also uses an environmentally friendly refrigerant, such as water, intended for use in buildings to provide heating, cooling and electricity generation.
Project Reference: JOR3970183
Prime Contractor: Oliveira, Armando C. – Universidade do Porto, Portugal
Others: Riffat, Saffa B. – University of Nottingham; marmont, Tony – Beacon Energy Limited, United Kingdom; Mahdjuri, Faramarz – Thermomax LTD, United Kingdom; Emmett, Peter – All Venturi Equipment Limited, United Kingdom
Source: http://www.cordis.lu

R&D action 13: Solar Space Conditioning with a Chemical Heat Pump

Aim of Project: Research and development of a new integrated, solar assisted air conditioning system, the operation of which will be based on the use of a chemical heat pump. The goal is to use/improve existing technologies (high efficiency solar collectors, chemical heat pump, device for automatic control and optimal energy management) and integrate them into a complete system.
Project Reference: ENK5-2000-35007
Prime Contractor: Kestekides, Andreas – Foco LTD, Greece
Others: Berkman, Rainer – Ikarus Solar, Germany
Source: http://www.cordis.lu

R&D action 14: Solar Assisted, Gas-driven Absorption Cooling Machine

A solar assisted, gas-driven absorption cooling machine has been designed and build in a common effort by Atecnic, Ineti, Inta, the University of Valencia, and ZAE. Based on simulations that compared real cooling needs of ordinary houses and hotels in several Iberian cities several solar-assisted cooling systems were considered.
After simulations of all three systems, the mixed-mode single/double-effect machine was chosen for the prototype because it could achieve the maximal energy savings. The unit for the solar operation was thermohydraulically optimised. The main heat exchangers were built with a rectangular shape, to achieve a compact, commercial-friendly design. Included in the prototype is a control strategy that makes optimal use of the available solar heat. If enough solar energy is available, the machine runs in single mode with the gas burner switched off. If the solar energy is not enough to cover the cooling demand, the gas burner is used as a secondary heat source. The gas burner can also operate the system alone, in the double effect mode, if solar energy is not enough to reach the necessary operation temperature.
Due to the optimised parts and the control system, this new cooling system is very efficient and environmentally friendly. The performance of the chiller was not measured in detail before the end of the project due to some delays with the manufacturing.

Source: http://www.cordis.lu

R&D action 15: Demonstration of a solar assisted absorption cooling

The complex of buildings of the press-centre of the German government has been equipped with a solar assisted absorption cooling in 2000. A collector space of 348 m^2 supplies two single-step absorption cooling machines which generate a cooling performance of 46 kW. If more cold is produced than it is required (e.g. during the week-end), the surplus can be fed in a district cooling network. The percentage of heat demand that cannot be covered by solar sources, is supplied by the district heating network.
Source: (Wolkenhauer, Albers, 2001)

R&D action 16: Demonstration of a solar assisted adsorption cooling

The hospital of Freiburg in May 1999 has been equipped with a solar assisted adsorption cooling system. The temperature of the solar heated water ranges between 72 and 85 ° C. High efficient vacuum solar heating of 90 m^2 produces 60 % of the unit's cooling demand in the summer months. While in spring and autumn still 40 % of the demand can be covered, the solar heating in winter is used to pre-heat the outside air which is used in the hospital heating system.
Contact: (Glaser, 2001)

R&D action 17: Diffusion-Absorption Chiller (DAKM)

A new kind of absorbtion □ystem, a Diffusion-Absorption Chiller (DAKM) is being run and tested in the laboratory of the HfT Stuttgart. The diffusion-absorption technique is based on the equalisation between the high-pressure and the low-pressure side with the help of a gas and the use of a thermally powered gas bubble pump. This technique eliminates all mechanically movable parts inside of the machine.
Like a conventional absorption chiller, the diffusion-absorption chiller's main components are condenser, absorber, evaporator and extractor. In addition, the system has a solvent heat exchanger, a gas heat exchanger and a dephlegmator. Helium is used for the gas cycle, the solvent is a NH_3-H_2O solution. An additional feature of this system is to use solar energy. Thorough study of real possible power coefficients yielded a COP of about 0.53 for the diffusion-absorption machine. If the rectification heat losses are recycled, the COP could go up to 0.72.
Source: (Jakob, Eicker, 2001)

R&D action 18: Integrated solar air-conditioning system

Aim of Project: Research and development of an integrated solar air conditioning system which is based on the use of thermal solar energy. Basic energy technologies are adapted, optimised and integrated into a complete system.
Project Reference: JOR3971022
Prime Contractor: Lamaris, Panos – Sole S.A., Greece
Others: Lutz, Johannes – GBU Gesellschaft für Bodenanalytik und Umwelttechnik mbH, Germany.
Source: http://www.cordis.lu

Heat from Geothermal Energy

Another renewable heating source is geothermal energy. In sight of the high development costs geothermal energy can only be used for air conditioning when combined with other purposes e.g. with industrial processes or large scale district heating.

R&D action 19: Cascade use of Geothermal Energy for District Air Conditioning

Aim of Project: Innovative demonstration of cascade use of the geothermal field of Xanthi. Aspects are the reduction of CO_2 emissions and other pollutants caused by fossil fuels, multiple use of thermal water and ensuring a safe thermal energy supply for the population.
Project Reference: GE./00334/98
Prime Contractor: Tifin SA, Greece
Others: –
Source: http://www.cordis.lu

Air Conditioning using Evaporative Cooling

Air conditioning systems which work without compression have strong advantages: They do not have high electricity consumption of the mechanic compression nor the high heat demands of the absorption techniques. Moreover, no environmental hazardous cooling fluids are required.

All compression free cooling techniques are based on evaporative cooling. Water is evaporated by the air stream. The evaporation process extracts the heat from the air. Direct and indirect evaporative cooling is possible. Direct evaporative cooling means that the water is evaporated from the primary air stream, which is used to cool the rooms. Indirect evaporative cooling uses a secondary air stream from which water is evaporated. The primary air stream is then cooled with the chilled secondary air. Evaporative cooling systems are always open cycle: The humid air is – after the cold has been extracted by a heat exchanger – blown outside. This of course creates the requirement to constantly replenish the water supply. This limits the scale of such applications, because the water consumption generally becomes prohibitive beyond a certain size.

Very innovative evaporative cooling devices include a desiccant unit which dries up the air in a pre-step and so raises the evaporation efficiency. Research actions have also been performed on systems without desiccant material, for example on Passive Downdraft Evaporative Cooling (PDEC).

Combined Desiccant and Evaporative Cooling (DEC)

DEC uses desiccant material, either solid or liquid, to de-moisturise the air. The cooling medium in this technique is the air itself. The solid substances extract the water through adsorption (water is attracted to the surface of the material). Liquid desiccants absorb the water. Suitable adsorption materials are Silkagel, suitable absorption fluids are Lithiumchlorid or Calciumchlorid. The solvent fluid or substance needs to be regenerated before being cycled through the system again. For this step external heat is required (of appr. 50 – 90 ° C). The amount of energy demand is significantly lower than in the absorption and adsorption machines. The dried air is then cooled by evaporation.

The desiccant technique can also be used to only regulate the humidity of the air. In this case the cooling performance can be accomplished by mechanic or thermal compression (Santamouris, Adnot et al 2000). The advantage of such a separate de-moisturising step is that it makes unnecessary to lower the temperature below the dew point. Another advantage of a desiccant cooling system is that the latent and the sensible heat are being handled separately and thus more efficiently. This allows better control of the indoor temperature and humidity.

If a liquid desiccant is used, it can be regenerated by distributing the diluted solvent on the desorber. As seen before the mixed fluid can also be sent through a solar collector. Solid desiccants can be dried by blowing dry regenerated air trough them. The waste air picks up the moisture and is released into the environment. A common method is the use of a rotating drying wheel (see figure 8).

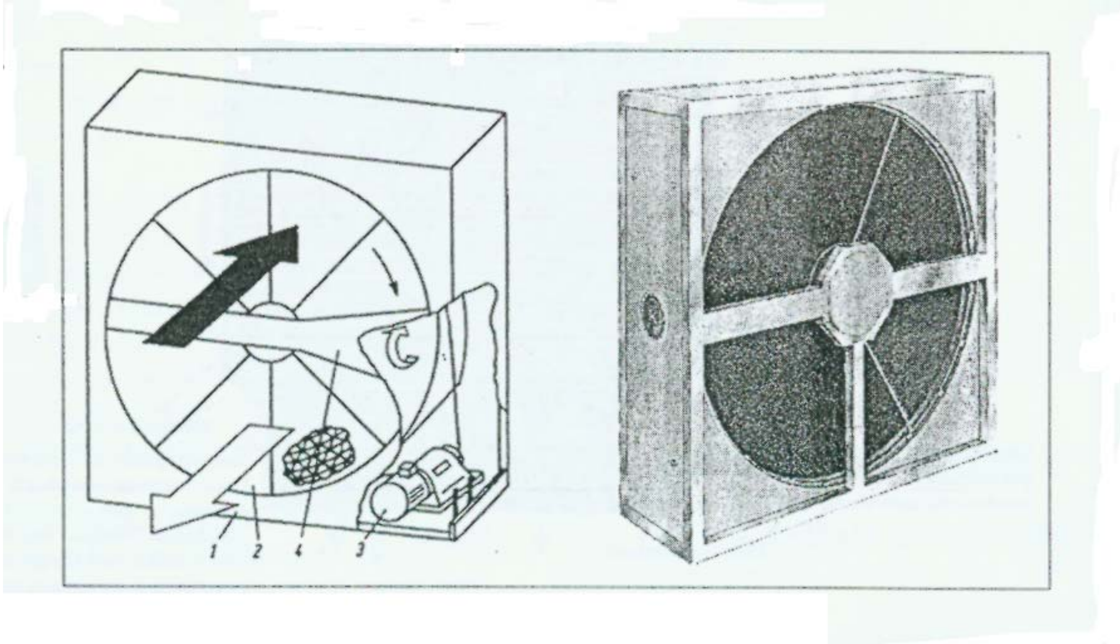


Figure 7: Scheme of a Rotating Drying Wheel

1 – Wheel casing

2 – Rotating wheel chamber containing desiccant

3 – Drive motor

4 – Dry/ humid air divider

– Warm, dry air

– Cold, wet air

Combined desiccant and evaporative cooling are very efficient and environmentally sound air conditioning systems. They bring together the advantages of evaporative cooling with those of de-moisturising with a desiccant material. Therefore, intense research actions are undertaken in Europe.
Desiccant cooling is an open cycle system. Most of the DEC plants include a device to recycle the heat in the waste air (Wolkenhauer, 2001). The recycled heat is used for the restoration of the desiccant materials. The recycling step improves the overall system efficiency.
The suitability of combining DEC with solar energy has been proven in several demonstration plants in Europe. It is possible to operate the sites with a heat supply of 50 ° C. In this case solar collectors with an absorber field of 6 – 10 m^2 are required for the cooling of 1000 m^3 per hour (Hindenburg, Henning, 2002).

R&D action 20: Demonstration of a solar based DEC site

In June 2001 a solar based DEC plant has been installed in the IHK, an administrative building in Freiburg, southern Germany. A 100 m^2 solar air heating plant supplies the complete energy for the residential cooling in the summer months. Small variety in the cooling performance allow to save the expenses for auxiliary heating and for heat storage facilities.
Contact: (Hindenburg, Henning, 2002).

R&D action 21: A novel high efficient solar collector for desiccative and evaporative cooling

Aim of Project: Development of a low-cost solar collector with new materials and a novel absorption method, suitable for heating and cooling (CFC-free) by desiccative and evaporative

cooling, heat production for modular desalination and water purification plants, commercial use in domestic water heating by low-cost collectors.
Project Reference: JOR3950003
Prime Contractor: Washull, Joerg – Institut für Luft und Kältetechnik gGmbH, Germany
Others: Palou Ortiz, José – Instituto Nacional de Técnica Aerospacial 'Esteban Terradas', Spain ; Kornacher, Klaus – Brand-Erbisdorfer Lichtquellenproduktions- und Vertriebsgesellschaft, Germany; Correia de Oliveira, Joao – Setsol, Portugal; Collares Pereira, Manuel – Instituto Nacional de Engenharia e Tecnologia Industrial, Portugal.
Source: http://www.cordis.lu

R&D action 22: Solar driven Air Conditioner using a LiCl Solution

ZAE Bayern has developed a new combined desiccant and evaporative cooling system that uses a LiCl-solution for de-moisturising and a solar collector as the heat source to recover the desiccant. The LiCl-solution is recovered continuously, thus assuring permanent cooling performance. The de-moisturising process releases the air at the same temperature it arrived with, thus taking care of the latent heat. Part of the dry air is used for cooling the room air. It gets moisturised completely and cools down. A air to air heat exchanger uses this cooled secondary air to cool the primary air. A prototype is available for further testing and researching at ZAE.
Source: (Kuhlen, 2001)

Other Evaporative Cooling Techniques

Other evaporative cooling techniques are not as mature as DEC. Still first research actions have brought interesting results.

R&D action 23: Passive downdraft evaporative cooling (PDEC)

This research at the De Montfort University took place between 1996 and 1998. There were several positive results but also a number of aspects that still need improvement before a PDEC system can be used efficiently.
PDEC systems are best suited for ventilation and cooling in hot, dry climates. There are four main components: a supply tower, a capture zone, the internal occupied spaces and the exhaust route.
The researchers examined and tested three different sites: The Pavillion of the Americas at the Seville Expo, a new office building in Seville, Spain and a new office building in Catania, Italy. In all of these buildings, PDEC was partly successful. One of the major problems was the inability to create uniform living conditions. Upper floors tended to be much hotter than lower ones. Wind had some disrupting effects as well. The Seville office building worked well in the night venting mode. Overall, it was concluded that PDEC systems are a good alternative option if auxiliary cooling is available. The technique is not developed enough to work efficiently and satisfactory as a stand-alone system.
Source: (Bowman, 1999)

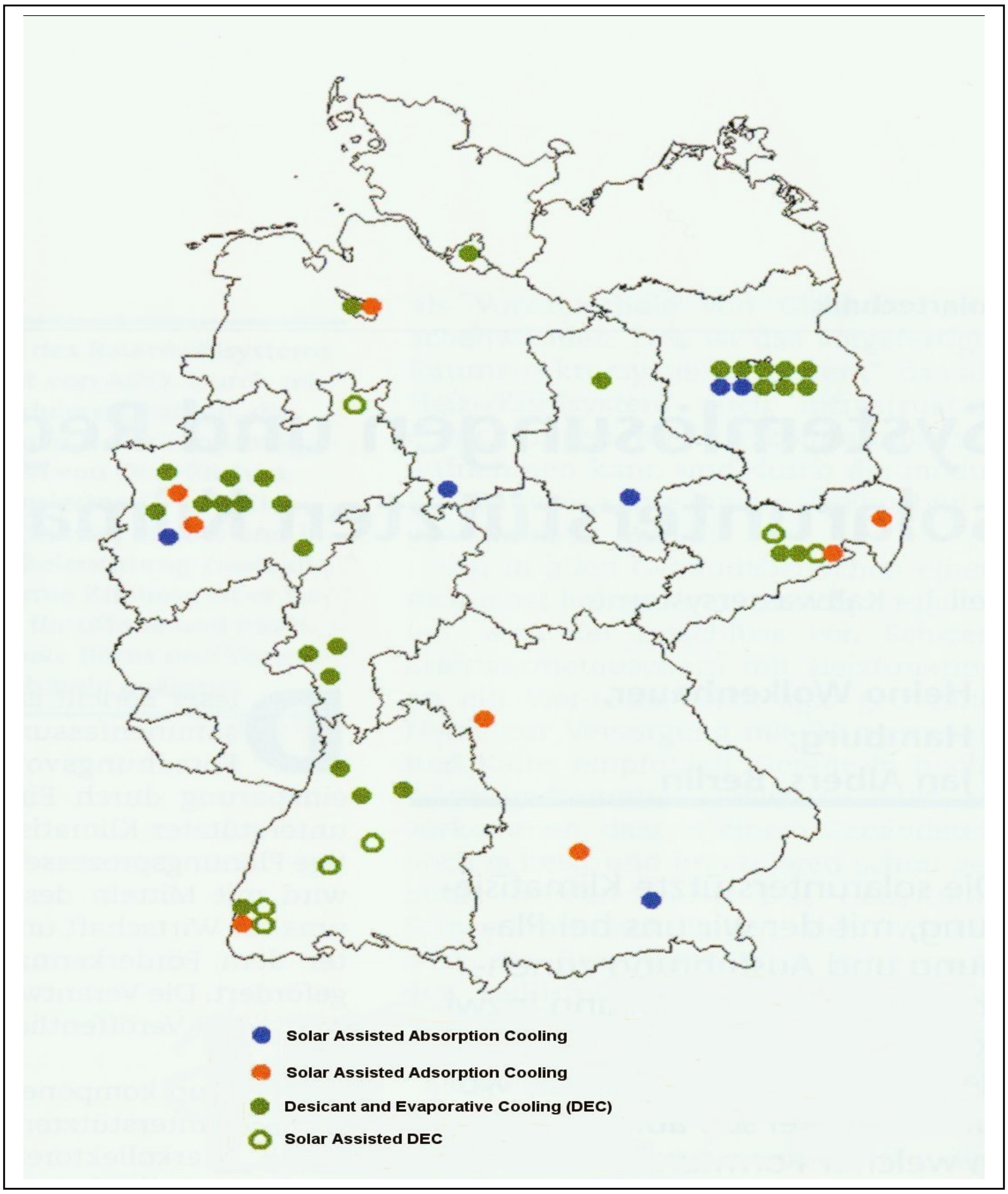
R&D action 24: Ecological cooling for buildings by combining a closed wet cooling tower with chilled ceilings

Aim of Project: Create a free, cheap, smart and energy efficient cooling system by combining the two well known parts indirect contact evaporative cooling tower and chilled ceiling.
Project Reference: JOR3970195
Prime Contractor: Oliveira, Armando C. – Universidade do Porto, Portugal
Others: Siren, Kai – Helsinki University of Technology, Finnland; Kofoed, Peter – Sulzer Infra AG, Schweiz; Riffat, Saffa B. – University of Nottingham, United Kingdom; Niessen, Roland – Sulzer-Escher Wyss GmbH, Germany.
Source: http://www.cordis.lu

Market Penetration of Innovative Air Conditioning

Most of the described air conditioning devices are known since at least a decade, still the market penetration of all of them is marginal. The reason for this lies with the strong technical advances of electricity based compression machines. The environmental problems posed by conventional air-conditioning have recently stimulated a renaissance of thermally driven devices. In countries with decisive public support, commercially sized versions of such plants are increasingly implemented. Most of them make use of the overproduction of heat in co-generation and industrial processes. In addition, the implementation of combined heating and cooling networks is growing quickly. The graph on the following page shows the distribution of absorption and adsorption plants in Germany.

Figure 8: Distribution of Absorption and Adsorption Plants in Germany



(Wolkenhauer, Albers, 2001).

Innovative air conditioning systems can very well operate on renewable energy sources, particularly solar radiation and biomass. The technology for such applications is already mature and proven in different commercial size demonstration plants. Particularly DEC is a suitable technology to be supplied by solar energy. Research and demonstration plants of significant size can be found in various European countries, what can be seen in following table.

Plant	**Application**	**Installed air capacity (m^3/h)**	**Collector Type**	**Collector Surface, m^2**	**Present State**
Germany					
ILK Dresden,	Meeting room	3000	Flat collector with volumetric absorber	20	In operation since 1997
Technology Center, Riesa	Meeting room	3000	Flat collector	20	In operation since 1997
Municipal utility of Bückeburg	Conference hall, lobby	5000	Solar air collector	100	In operation since 1998
Technical college (Fachhochschule) Stuttgart	Exhibition hall	3000	Solar air collector	20	In operation
Establishment Meyer, Alt-Hengstett	Production hall	18000	Solar air collector	100	In operation since 2000
International Chamber of Industry and Commerce Freiburg	Meeting room	10200	Solar air collector	100	In operation since 2001
Fraunhofer ISE Freiburg	Test plant	4000	Solar air collector, flat collector	40	In operation since 2000
The Netherlands					
Energy provider EZK Heemstede	Conference hall	7700	Flat collector	77	In operation since 1999
Verhuelst,	Office rooms	3250	Flat collector	33	Operation start 20002
Portugal					
ATECNIC, Sintra	Office	9600	CPC-Flat	72	In

	rooms		collector		operation since 2000
INETI, Lisbon	Office rooms	5000	CPC-Flat collector	40	In operation since 1999
Austria					
Ecological center Hartberg	Seminar room and office rooms	6000	Vacuum tube collector	20	In operation since 2000
Armenia					
American Univ. of Armenia, Yerevan	Auditorium	8500	Flat collectors	64	Operation start 2002

Table 11: Solar-Based Air Conditioning in Europe

Economic Considerations

Europe

The economic feasibility of innovative air conditioning in respect to conventional units has to be analysed in respect to the individual climate conditions of the plant location. The temperatures in the summer months influence the operation hours and the cooling load of the plant. The following figure gives a survey on the operation time of air conditioning devices in the different European countries (Adnot et al):

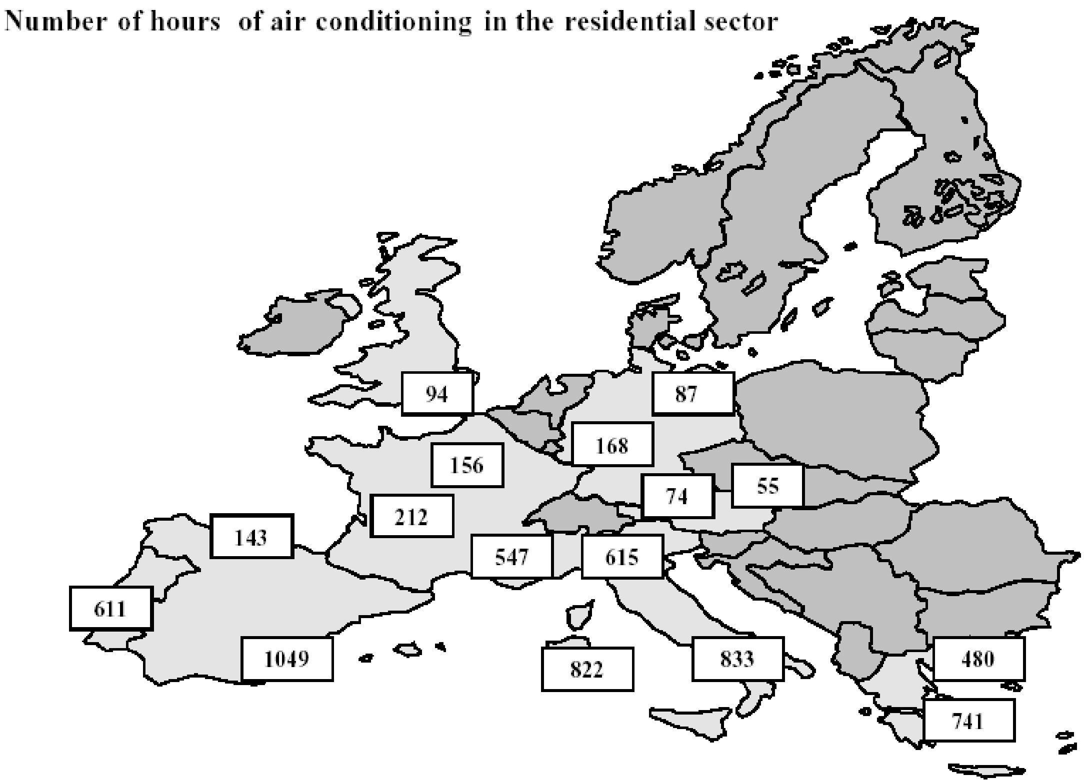


Figure 9: Operation Time of Air Conditioning in European Countries (Adnot et al. 1999)

Those figures have to be seen in reference to the average operation hours which can be seen in following table:

Weighted number of Hours			
Commercial	Office	Household	Hotel
1019	803	519	768
All Sectors			
773			

Table 12: Average Operation Hours of Air Conditioning in Europe (Adnot et al. 1999)

Also the cooling load of the individual site depends on the climate conditions: While Cagliari in Italy has a yearly cooling demand of 52 kWh/m^2 and a heating requirement of 20 kWh/m^2, Freiburg i.Br. in southern Germany requires cooling of 15 kWh/m^2 per year and heating of 65 kWh / m^2.

The economic feasibility of innovative air conditioning can be significantly improved by an optimum plant design, namely:

- exact dimensioning of the plant in respect of the on-site cooling demand (a certain flexibility concerning the cooling performance in unusual conditions reduces costs for auxiliary systems and storage)
- set-up of a module based system which can react flexibly on varying supply and demand situations
- Integration in the overall energy planning of the buildings (insulation, controlled ventilation, heating etc.) and the neighbourhood (micro-climate, district cooling network)

The technical engineering must be performed on suitable computer based modelling and planning tools which pay attention to the overall set-up of the refurbishment site.

Also in the plant operation various options for cost reduction can be exploited by

- installing well working monitoring and control devices
- teaching the residents and users in the plants specialities.

Finally the economic competitiveness of advanced air conditioning strongly depends on the energy prices, particularly on the prices for electric energy. The heterogenous electricity market can be seen on the following survey from 1999 which shows the monthly electricity expenses of an average household in one year (estimated consume of 3.500 kWh):

Country	Euro
Italy	77,95
Portugal	66,15
Irland	55,90
Belgium	54,36
Denmark	48,72
Germany	48,21
Austria	45,64
France	44,10
The Netherlands	42,56

Luxemburg	42,05
United Kingdom	38,46
Greece	34,87
Spain	31,79
Sweden	27,69
Finland	26,15
Average	**45,64**

Table 13 Survey on electric energy prices in Europe from VDEW

Case Study: Germany

Under the German climate conditions and economic framework a comparison between a conventional cooling machine and a thermal driven DEC shows that the slightly higher investment cost are compensated by the 40 % lower operation expenses (Wolkenhauer, et al. 2002).
Solar heat as energy source however is not competitive with large scale heat production from fossil fuels. While the latter has expenses of 0,02 and 0,05 €/kWh the solar heat still costs between 0,1 and 0,15 €/kWh (Wolkenhauer, 2001). These different climate conditions bring with them that the specific energy costs of a solar assisted DEC device almost twice as high in the climate conditions of Germany than in Italy (Henning, 1996). Solar systems therefore can therefore only be the most cost effective solution when financial incentives are given and no fossil waste heat source is available.

Executive Summary

Conservative assessments predict that the air conditioning boost in Europe will lead to a market of more than 34 million units in the near future. This dramatic increase will result in environmental problems and a significant rise in electric energy demand. Therefore, it is important to support the market penetration of energy efficient and renewable energy based air conditioning techniques. The predominant air conditioning techniques of **electricity based compression cooling** has an efficiency potential of almost 50 % of which 25 % could be exploited on economically feasible terms. Relevant actions aim to increase the heat exchange and to improve the compressors and the device control. Still the technique of mechanic compression cooling machines remains doubtful due to the high demand for electricity and the environmentally harmful refrigerants.

Thermal driven cooling machines are a promising alternative. Even when their energy efficiency is in the same rate of large scale electric compression chillers, they can often make use of waste heat from industrial processes and co-generation that otherwise would be discharged. For using external heat those systems require district heating and cooling networks which are not always easy to install in refurbishment sites. The thermal energy can be generated from renewable sources as well, mainly biomass and solar. The maturity of these techniques has been proven in various commercial size demonstration plants. Large scale market penetration of RES based solutions still need financial incentives to compete with conventional set-ups. Still niche markets exist already today. Cooling devices are suitable within decentralised biomass based co-generation sites or in regions with long and hot summers and high daily average radiation.

The most environmentally promising solution is **evaporative cooling**. Since it requires neither mechanic nor chemical compression, it is able to operate with lower temperatures and without cooling fluids. The innovative technique of DEC (Desiccant and Evaporative Cooling) operates on temperatures down to 50 ° C and thus can operate very well with thermal energy from solar collectors.

Refurbishment projects are very suitable occasions to install those advanced air conditioning techniques. **Careful and comprehensive planning of the individual plant** is necessary to ensure technical maturity and to raise all cost saving potentials. Air conditioning in a first step has to be designed under recognition of its four possible functions heating, cooling, moisturising and de-moisturising of the inside space. Furthermore, the air conditioning has to be integrated in the broader energy design of the refurbished building. Building insulation and controlled ventilation, the neighbourhood microclimate and shading devices have a strong impact on the cooling and heating demand. Thus, the design of air conditioning devices should be optimised in reference to these items. Additional planning support like computer based modelling tools and energy labels for specific air conditioning types are under preparation.

The **efficiency and economic feasibility** of advanced air conditioning units strongly depends on the predominant climate conditions and electric energy prices. In regions with above average operation hours and high cooling loads, the energy efficiency actions make short pay-back times possible. Furthermore, the heat driven applications will be more cost effective than conventional sites in all places where cheap waste heat is available and district heating and cooling networks can be installed in the refurbishment sites. Solar based DEC applications will soon be economically viable in the southern part of the EU.

R&D Actions

Tables

Figures

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CHAPTER 5: SUSTAINABLE SUPPLY SYSTEMS – DISTRICT HEATING AND COOLING

1. Introduction

Sustainable energy supply systems and mainly the use of district heating and cooling systems based on the use of renewable energies like solar and biomass or the use of waste heat, is the major tool to introduce clean and sustainable energy in cities. Produced energy may supply the residential sector, industry, urban agriculture, and any other sector requiring hot or cold water.

District heating and cooling consist of a heat production unit using one or more energy sources, a heat transmission pipeline, a heat distribution network and finally the network of the consumers. May be very large systems supplying a whole city or small and medium systems able to supply some building blocks or districts. During recent years, important developments have been achieved concerning the used heat production technologies and the management of the networks, increasing considerably the overall efficiency of the systems.

District cooling brings cool into the buildings (by way of chilled water), and avoids a number of distributed air conditioners with poor performance and high cost. It pays itself on economies of scale but brings large energy and environmental advantages. Both district heating and cooling provide opportunities to significantly reduce electrical consumption, peak electricity load, and thus pollutant emissions. District systems have gained an increasing acceptance. In some countries, particularly Denmark, Finland and Sweden, market penetration in relation to total space heating needs is very high, (up to 50 %). District cooling systems have also penetrated very rapidly in the market, mainly in US and in Scandinavian countries.

The present chapter aims to present the basic technological aspects of district heating and cooling systems. In parallel, aims to present the existing market penetration of these systems and discuss their main advantages and disadvantages. Finally, aims to assess the possible energy benefits and gains from the possible use of district systems.

2. Market Penetration of District Heating and Cooling Systems

It was in 1877, at Lockport in New York, US, where the first district heating system was installed by Birdsill Holly. The total length of the network was 2 km and has supplied 14 musltistorey buildings. The first district heating system downtown New York was installed during 1882 – 1883. By 1932, more than 300 American and Canadian cities have district heating systems to supply hot water for heating. Actually, the more important system is the one of New York with 4 central production units, 61 km of supply network and 2000 clients.

In Europe, the first district heating system was installed in Dresden, Germany at the beginning of the last century, 1900. Other German cities followed, like Hamburg in 1921, Kiel and Bremen in 1922, etc.

In the 80's the total installed heat production capacity for district heating in the IEA region was close 122,000 MWth, mostly concentrated in Denmark, Finland, Germany, Sweden and the United States. Installed capacity in Europe was 82,000 MWth, together with 40,000 MWth in the United States. Combined production linked to district heating systems was very prevalent in Europe and accounted for 36% of installed heat capacity. During the 90s, installed heat production capacity in Europe has been increased and was close to 110,000 MWth.. For the United States, installed capacity has almost doubled to 80,000 MWth. Thus, the total installed capacity is close to 250,000 MWth in the IEA region.. This was the result of a total additional investment in district heating and combined heat and power of about US$38bn, assuming a global cost of US$300 per kWth.

In our days, district heating is supplied to over 22 million people in Europe, and 100 million people in the Greater Europe. The maximum heat output capacity in European Union countries, is close to 141000 MWth, (1), 45000 of which is installed in Germany, and 29000 in Sweden. The use of district heating systems result in significant energy savings, of closes 10 Mtoe of primary energy per year. This represents 0.5% of total primary energy supply, or import savings of about US$2bn annually.

The development of district heat capacity and production in EU countries was important during the very last years. As shown in Table 1, (1), in the period 1994-199, the maximum heat capacity has been increased by 1.6 %, while the heat delivered to the pipeline system has been increased by 2.4 %. The fact that the production has increased more than the capacity built up indicate a more efficient use of the equipment.

	Maximum Heat Output Capacity	Change 1994-1999	Heat Delivered to the pipeline system	Change 1995-1999
	1999		1999	
	MWth	%	GWh	%
Austria	6000	17.6	11893	34.6
Denmark	17500	15.9	31200	10.1
Finland	17810	9.4	28790	7.2
France	18298	-14.6	27446	-17.1
Germany	44889	-3.7	92047	-2.8
Italy	2911	40.4	4371	89.6
Netherlands	4310	10.4	6400	39.3
Sweden	29000	3.4	46535	5.1
Total	140718		248688	
Change	2190	1.6	5723	2.4

Table 1. Development of District heat capacity and production in the EU countries, (1994-1999), (1).

In Central and Eastern European Countries, district heating has a very important market share, Figure 1, (1). In Russia, district heating systems covers almost 70 % of the heating market while the produced heat is close to 465 TWh.

District heating systems generate an important revenue in Europe. It is estimated that the sales of heat alone amounts to over 10.5 billion Euros, (1). The cost of the delivered energy, varies substantially in the various European countries as a function of the local energy policy. The average prices as well as the generated revenue in selected European countries is given in Table 2., (1)

	Average Price ex VAT	Total ex VAT
	Euros/ MWh	Min Euros
Austria	44,7	465,4
Denmark	51,0	1352,5
Finland	31,0	834,5
France	35,8	834,8
Germany	48,7	3919,3
Greece	25,3	6,8
Italy	71,.3	264,8
Netherlands	40,4	242,2
Sweden	41,0	1774,4
United Kingdom	35,8	834,8
Total		10529,4
Estimated Total Revenue		10529,4

Table 2. Average prices and revenue from district heating in EU, 1999, (1).

District cooling systems, (DCS), has mainly developed in the United States and present a number of very important advantages. During the recent years, important district cooling networks have been installed in Europe, Figure 2, (2). The maximum district cooling capacity installed in European Union countries is close to 762 MWc, mainly installed in Northern European countries, like Sweden, Germany, France and UK, (3). The main characteristics of some European (DCS) are given in Table 3, (2)

Site	L (km)	P (MW)	P/L (KW/m)	Energy (MWh)	Energy /Power (h)

Central Paris	40	125	3	154000	1200
Gothenburg	----	12	---	n.a.	n.a.
Stockholm	10	60	6	40000	670
La Defence	10	123	12.3	145000	1200
Lyon	10	36	3.6	n.a.	n.a.
Lisbon	20	60	3	n.a.	n.a.
Small Swedish Projects	1-5	3-16	3	n.a.	n.a.
Small French Projects	2-12	12-36	3-6	n.a.	n.a.

Table 3. Main Characteristics of some district cooling systems in Europe.

District cooling has gained increasing acceptance in Sweden, where the first Swedish district cooling network started in 1992. By the end of 2000, 25 district cooling networks were in operation. During 2000 the networks supplied around 340 GWh of district cooling, (Figure 3), (4). In parallel, district cooling systems are installed in the other Northern countries like Norway with 9 MWe, Finland with 1.5 MWe and Denmark with almost 0.9 MWe.

In France, there are twelve main district cooling networks, totalling more than 450 MW. Most of the systems are in the major Paris area, while important networks exist in Lyon, Montpellier , Monaco and Bordeaux. The more important network is the one installed in La Defence , Paris, where electricity is used for the production of chilled water. The installed power of that system is close to 243 MWc.

In Germany, there are 7 district cooling networks operating with absorption chillers connected to an existing DHS. Systems are installed in Berlin, Bremen, Chemnitz, Dresden, Hamburg, Hanover and Kassel . The one with the maximum capacity is that installed in Chemnitz with 6 MWc of power.

In United Kingdom there are two main district cooling networks, one in the Channel of 28.2 Mwe and a second one in Heathrow airport with 35 Mwe. Both systems use electricity as primary energy.

In Southern Europe, district cooling systems have been installed in Portugal, Spain and Italy. In Portugal, the network is recently installed in the area of Lisbon Expo 98, with a total capacity of 22 Mwe, while it uses electricity and steam as primary energy. In Spain there are two systems. One in Barcelone of 5.8 MWe using steam as a primary energy and a second one in Valladolid, of 2 MWe using hot water and electricity. Finally, there are 4 district cooling systems in Italy. One installed in the Bologna University of 2 MWe, a second in Genova of the same installed power, a third in Regio Emilla of 2.8 MWe and a last one in Vincenza, (3).

In the United States, there are more than 1000 district cooling systems installed. There are 56 major DCS, most of them , thirty three, are installed in commercial buildings, ten in Universities, two in hospitals, four in airports, and six in other institutions. The maximum cooling capacity is installed in the International Business Center in New York, (almost 170 MWc), while important systems are those installed in the Pentagon, Washington, at the Capitole, at Hardford in Connecticut and at the University of North Carolina in Chappel Hill.

In Japan, district cooling present a major source for supply of cooling in buildings. The installed capacity exceeds, 723 MWc, while in the States the installed capacity exceeds 1900 MWc. (3).

3. Technological Aspects

The energy production system, the heat distribution pipeline, the distribution network and the network of the clients compose district energy systems, (Figure 4). Many sources of energy and different types of fuels may be used, while the distribution media may be hot or cold water or steam. District energy systems may involve combined heat and power techniques for the simultaneous production of heat and electricity.

In the following the main technological aspects that characterize a district energy system are presented.

3.1 Heat Production Techniques

3.1.1 District Heating Systems

In district heating systems, the hot water or the steam may be produced in heating-only boilers and turbines, in combined heat and power production plants, by using refuse incineration plants, by using renewable energy sources like solar heat or geothermal energy, by waste heat recovery from various types of plants or the industry, or by using any other heat source combined with heat pumps, like low-temperature water streams. In parallel, combination of the above systems may be used.

Small scale district heating systems are mainly based on the use of hot water boilers combined with the necessary auxiliary equipment like the burners and the controls. The size of boilers may range from 1 MWth to 15 MWth, and usually are fired by oil, gas and coal and present a mean efficiency close to 90 %. The use of biomass, (wood or peat), is also possible. In many cases, boilers can be coupled with waste heat recovery or refuse incineration systems with heat recovery. These systems may be used in many urban areas where waste disposal is high. Actually, there are more than 350 municipal waste incinerators and most of them are installed in Central Europe.

In plants using combined heat and power units, usually electricity is produced and the waste heat is recovered. In some cases heat is first produced and used to cover a given thermal load, while the exhaust heat is used to produce electricity. In such systems, heat is mainly generated in extraction and back pressure steam turbines by using coal or gas fired turbines ranging from 30 Mwe to 350 Mwe. Other types of machines like diesel systems and combined cycle turbines may be used as well.

Primary energy used in district heating systems in Europe is mainly coal, oil, natural gas, refuse and waste, renewables and other sources. The primary energy used for district heating and CHP production in EU countries during the period 1994-1999 is given in Figure 5, (1). As reported, the use of coal and oil has been reduced while natural gas has become the choice for district heating systems.

3.1.1 District Cooling Systems

In district cooling systems, chilled water is produced by using either compression water chillers or absorption technologies. Alternative technologies to produce chilled water are : the so called deep water source cooling, free cooling techniques, adsorption chillers, gas expansion technologies, etc, (3)

3.1.1.1 Compression Systems

Compression technologies are based on the well known compression cooling cycle machines composed mainly by a compressor, a condenser, an expansion valve and an evaporator. Three are the main types of compressors used : The reciprocating compressors, the screw type compressors and the centrifugal compressors. Reciprocating compressors are used in small capacities under 1.5 MW, while screw type compressors are appropriate larger district cooling applications , up to 7 MW. Finally, centrifugal compressors are the most suitable for district cooling systems. Their capacity goes up to 25 MW. An important advantage of the centrifugal compressors is that can adapt to fluctuating loads until a minimum of 40 % of their nominal power.

Compression chillers are usually electrically driven. However, steam turbine drives are in use in US, where heat from industrial processes or incineration plants is used. Refrigerants used in compression cycle applications are selected according to the new international conventions as well as the European Directives on the selection of refrigerants. In general, refrigerants should present a very low or zero Ozone Depletion Potential, while their Global Warming Potential should be as low as possible. The Ozone depletion potential of some conventional and alternative refrigerants is given in Table 4, (Adapted from 3, original reference 5). Research on alternative refrigerants is important, and new fluids have been proposed recently. Ammonia, is a very interesting solution, as it does not affect the stratospheric ozone, but it has toxic effects in case of leakages.

Refrigerant Fluid	ODP referred to R11	Refrigerant Fluid	ODP referred to R11
R 11	1	C02	0
R 12	0.9-1	R 123	0.013-0.022
R 22	0.04-0.06	R 124	0.016-0.024
R 23	0	R 125	0
R 32	0	R 134a	0
R 113	0.8-0.9	R 141b	0.07-0.11
R 114	0.6-0.8	R 142b	0.05-0.06
R 115	0.3-0.5	R 143b	0
R 13B1	7.8 –13.2	R 152 a	0
NH3	0	R 500	0.66-0.74
H20	0	R 502	0.17-0.28
		Propane	0

Table 4. Ozone depletion potential of different refrigerant fluids, (Adapted from 3, original reference 5).

3.1.1.2 Absorption Systems

Absorption technologies is based on the use of heat as a primary energy to produce chilled water instead of mechanical rotation used in compression chillers. The basic configuration of a one stage absorption cycle is given in Figure 5. The cycle is based by an absorber where fluid under low evaporation pressure is absorbed, a generator where the solution of refrigerant/absorbent is boiled, the condenser, the evaporator , heat exchangers and pumps. Steam or hot water may be used as the heat source. Two stage absorption chillers are also available. District heating systems may be coupled with district cooling systems to supply the necessary heat. Figure 6 shows the diagram of the coupled district heating and cooling network in Helsinki, Finland, (6).

The efficiency of the absorption systems varies highly as a function of the temperature of the heat medium in use. The lower the temperature of the driving energy, the lower the efficiency of the system. Absorption systems are available for a range of cooling power close to 6 MWe. An important advantage of these systems is their ability to operate between 10 to 100 % of their nominal power, thus, to be easily adapted to the fluctuating demand of the district cooling networks. A major disadvantage, is the long time required to start up and shut down the chiller.

A very interesting comparison between the commercially available compression and absorption chillers is given in (3). Table 5, summarises these technical characteristics, (3). As shown, absorption chillers are available in lower capacities and present a much lower COP than the compression chillers. On the contrary, the later consumes large amounts of primary energy mainly because of the compressor.

	Chiller Technology				
	Compression Chillers			Absorption Chillers	
Parameter	Reciprocating	Screw	Centrifugal	One – Stage	Two - Stage
Primary Energy	Rotation work	Rotation work	Rotation work	Hot water 65C<T<80 C	Steam or fire, T > 170 C
Fluids	R134a,	R134a	R134a	H20, with	H20,

	HCFC, NH3	, HCFC, NH3	, HCFC, NH3	LiBr, NH3 with H20	with LiBr, NH3 with H20
COP	4-6	4-6	Up to 5.5	0.6-0.75	1.2
Range MW	0 to 1.5	0.3 to 7	0.5 to 25	0.1 to 5.8	0.1 to 5.3
Surface on ground m2/KW	0.006 to 0.016	0.006 to 0.016	0.006 to 0.016	0.01 to 0.03	0.01 to 0.03
Weight on ground kg/Kw	5.2 to 9.1	5.2 to 9.1	5.2 to 9.1	8.5 to 22	8.5 to 22
Qrecooling/Q cooling	1.2 to 1.25	1.2 to 1.25	1.2 to 1.25	1.91 to 2.5	1.91 to 2.5

Table 5. Comparison between compression and absorption chillers, (3).

3.1.1.3 Sea Water Systems

Sea water or deep water source cooling, is based on the use of cold water of the sea or of a lake to cool water circulated in buildings. The basic principle is shown in Figure 7, (7). Cold water from the sea is circulated through a heat exchanger, where it cools water that is circulated to cool buildings, Figure 8, (7). The main components of the system are the water supply system, the heat exchanger, and the fresh water distribution system. The heat exchanger is made from titanium to avoid corrosion from the seawater. Counter plate heat exchangers are normally used, where sea water circulates through the primary channel while the water to be distributed fluids in the secondary channel without any mixing. The used seawater is rejected back to the sea.

Seawater cooling has important energy and environmental benefits as the use of energy used is minimum. An interesting comparison between chiller based systems and sea water cooling based systems has been provided in (3), Table 6. As shown, the energy used by the sea water systems is almost 7-8 times lower.

Source	Units	Chiller based system	Deep water source cooling based system
Chiller	KWe/kWc	$186\ 10^{-3}$	0
Chiller water pumps (assumes a 30 m pump head requirement)	KWe/kWc	$20\ 10^{-3}$	$20\ 10^{-3}$
Lake or ocean water pumps, (assumes a 30 m pump head requirement)	KWe/kWc	-----------------	$14\ 10^{-3}$
Condenser water pumps	KWe/kWc	$28\ 10^{-3}$	0
Cooling tower fans	KWe/kWc	$9\ 10^{-3}$	0
Total	KWe/kWc	$243\ 10^{-3}$	$34\ 10^{-3}$

Table 6. Relative energy consumption : Sea water source cooling versus chiller based systems, (3).

3.1.1.4 Adsorption Systems

In adsorption systems the refrigerant is adsorbed by a solid hydroscopic material like silica-gel. This procedure continues until the hydroscopic material reaches a saturation level. Then, the system is switched to heating mode in order to bring the water vapour out of the hydroscopic material.

Hot water of about 80-100 C is mainly used as a primary heat source. The COP of such a system is around 0.7

3.2 Heat Distribution Media

Hot water or steam are the main heat distribution media. European district heating networks are operating using hot water below 150 C, while American networks are mainly based either on hot water or steam above 175 C. Networks using low temperature water, above 90 C, has been tested recently and present a number of important advantages and disadvantages. .

The main advantages of the low temperature networks are the use of low cost distribution and transmission piping systems and the low cost of the connection with the clients. As the temperature of the distributed hot water is low, heat losses are decreased and thus, less insulation for the pipes is necessary while lower cost materials may be used and lower cost installation methods may be employed. In parallel, low temperature distribution networks may be directly connected to the building without the need of a heat exchanger., thus, reducing substantially the connection cost. However, low temperature networks can not supply industrial processes while is expensive to supply buildings fitted for steam distribution. In parallel, to be connected with district cooling networks using absorption technologies, the temperature of the water has to increase considerably.

In moderate hot water distribution networks, the temperature of the water varies between 90 to 150 C. In these systems the temperature of the water varies as a function of the ambient temperature. The higher the outdoor temperature the lower the supply water temperature. As a function of the water temperature, heat exchangers between the network and the consumers may be installed or not , reducing thus the capital cost of the system. In this case, additional pumping stations and pressure-reduction valves may, be installed.

Steam or high temperature water networks, above 150 C, are more appropriate for industrial processes or to supply buildings fitted with steam systems. These systems may be also easily connected with absorption district cooling systems. It is evident that high temperature networks are characterised by higher heat losses thus, the cost of the piping system is higher, while expensive heat exchangers required to supply buildings. Also, the water inside the pipes has to be treated in order to prevent corrosion Steam may be supplied at low, (< 2 bars), medium, (2-8 bars), or high pressures, (above 8 bars).

3.3 Heat Distribution Systems

Heat distribution systems include the piping, pumps, control and the interface with the distribution system inside buildings. As a function of the hot water temperature heat exchangers may be used or not. Important factors that determine the efficiency of the system as well as the economics of the network are the heat demand density, the supply and return temperature and the characteristics of the site. Lower return temperatures can be achieved by linking the space heating and the hot water systems, by use of low-temperature heating systems, etc.

As mentioned above the temperature of the distribution system determines at a large extend the cost of the system. The lower the distribution temperature the lower the cost of the piping system. Also the cost depends on the density of the demand and it is evident that the higher the density of the demand the lower the distribution cost.

4. Advantages and Disadvantages of District Systems

Regarding district cooling systems, the more important advantage has to do with the dramatic decrease of peak electricity load. As buildings served by the district cooling network do not present peak cooling demand at the same time, the peak load line of district cooling systems is much smoother and thus there is no need to over design the cooling capacity of the network. This results in substantial reductions of the capital and operational cost. In parallel, room and central air conditioning systems are designed to meet the peak cooling conditions. Thus, for more than 90 % of the operation period perform out of the nominal conditions, and for sure their efficiency is quite reduced. A good example is given in Figure 13, where the reduction of the peak electricity load in Cleveland is shown prior and after the integration of a district cooling system in the city, (13) . However, the overall economics of district cooling systems are highly depended on the density of the area they have to supply. Such a study, comparing room, (RAC), and central air conditioners, (CAC), with District cooling systems has been performed in the frame of the URBACOOL project, (2). As shown in Figure 14, district cooling techniques present a much lower cost compared to (CAC) and (RAC) for increased urban densities

District energy systems are very efficient as operate at high efficiencies, can increase effective building space, decrease operational, maintenance and capital cost of the user, and can improve indoor air quality as do not generate any chemical or biological pollution in the building. In parallel, district heating and cooling techniques when operated by Municipalities and Community authorities may be the source of important of revenues for the local society. In Europe, most hot water district heating systems operate at temperatures of 90° C-150° C (temperature of primary supply line). Higher temperatures up to 175° C are common in the United States. At temperatures above 150° C heat exchangers are always required.

5. Expected Energy Gains

The potential of district heating and cooling systems when combined with CHP is very high. A recent analysis by Euroheat & Power, (1), has determined that the existing DHC/CHP systems, decrease EU carbon emissions by 6%. It is also estimated that 'expanding DHC and doubling the share of CHP production, according to the Community goal, will further reduce EU carbon emissions 8% by 2010'.

6. Use of Demand Side Management Techniques

Demand side management techniques may be the more appropriate tools to reduce the peak and total energy demand, in cities. During the recent years, some forms of demand side management techniques have been extensively used by the European utilities.

Apart of the use of sustainable district heating and cooling systems, five types of demand side management actions can be identified:

DSM1. Use of more energy efficient air conditioners and heating devices that implies better performance and better design and integration to the building.

DSM2. Application of advanced control systems like inverters, fuzzy logic in order to take into account the operational profiles of urban buildings, like the highly intermittent occupation of residential and commercial buildings in urban areas.

DSM3. Direct load control like remote cycling, by the utilities on the cooling usage as on other usage. This technique is widely applied during peak periods on a few millions of appliances room air conditioners in the US. By limiting the available duty cycle during peak periods, utilities can reduce significantly the peak demand. Attention has to be given on consumer's comfort.

DSM4. Improvements on the building design to decrease their heating and cooling load. This may involve actions on heat and solar protection, heat modulation and dissipation of excess heat in a lower temperature environmental sink.

DSM5. Use of cogeneration techniques. This type of distributed generation of electricity + possibly cold/hot water or steam can reduce peak transportation costs and use of fuel.

Three of the more important demand side management techniques are analysed in the following.

6.1 Advanced Air Conditioners

Technology of cooling systems has been tremendously improved during the last years. Research and new developments have been permitted to create high efficiency A/C systems better adapted to the urban environment. Improvements have been recorded in many components of the systems as well as on their operational characteristics. In principle, improvements can be classified in the five following major categories :

- Those that aim to increase the heat transfer surface. These techniques involve the increase of the frontal coil area, the increase of the depth of the coil, the increase of the fin density, the addition of a subcooler to the condenser coil, etc.

- Those that aim to increase the heat transfer coefficients. These techniques involve the improvement of the fin design, the improvement of the tube design, the spray condensate onto the condenser coil, the improvement of the fan and of the fan motor efficiency, the improvement of the compressor efficiency, the use of variable speed compressors, the use of alternative refrigerants, the use of electronic expansion valves, etc.

- Those that aim to improve the control of the devices. These techniques involve between others the use of thermostatic static control, as well as of the fuzzy logic control.

- Techniques aiming to adapt the load curve of the air conditioning devices in the specific climatic conditions of the urban environments. These techniques permit to the systems to operate under the optimum conditions although the temperature increase in the cities.

- Alternative cooling systems making use of new advanced techniques like indirect evaporative coolers, etc. These techniques permit to operate under high COP values.

In the frame of the EERAC project of the European Commission, (14), an attempt has been made to calculate the potential improvement of the room air conditioning. The considered scenarios as well the calculated scenarios are given in the following Table 9. As shown there is a very important potential to improve COP that may be high up to 30 per cent.

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

Table 9. Possible Improvement of the COP of air conditioners.

In the frame of the OFFICE project of the European Commission, (15), various retrofitting strategies and design options to promote successful implementation of passive and energy efficiency retrofitting actions to office buildings have been studied. Among the other studies specific exercises have been carried out regarding the application of passive cooling techniques and the improvement of HVAC systems. Studies have been performed for five types of buildings : a) Free standing, Core Oriented with mostly open plan and a heavy structure, b) Free standing, Skin oriented, mostly cellular, heavy structure, c) Free standing, Skin oriented, mostly cellular, light structure, d) Enclosed, Skin Oriented, cellular, heavy structure, and e) Enclosed, Skin Oriented, cellular, light structure.

For the first category of buildings it is found that in the Mediterranean area, improvements of the building envelope may decrease the cooling load of the reference buildings by 6.6 kWh/m2/year or 15 % of the cooling load. In parallel, application of passive cooling techniques may decrease the cooling load by 4.4 kWh/m2 or 10 %, while retrofitting of the artificial lighting may reduce the load by 6.6 kWh/m2, (10 %), and finally improvements in the HVAC system may decrease the load by 13.2 kWh/m2 or 30 % of the total cooling load. If global retrofitting techniques are applied then the cooling load is reduced by 24.4 kWh/m2 or 55 % of the initial cooling load.

For the second category of buildings, (Free standing, Skin oriented, mostly cellular, heavy structure), it is found that in the Mediterranean area, application of passive cooling techniques is the more important retrofitting measure and may decrease the cooling load by 5 kWh/m2 or 25 of the cooling load.

For the third category of buildings, (Free standing, Skin oriented, mostly cellular, light structure), it is found that in the Mediterranean area, improvements of the building envelope may decrease the cooling load of the reference buildings by 8 kWh/m2/year or 8 % of the cooling load. In parallel, application of passive cooling techniques may decrease the cooling load by 31 kWh/m2 or 46 %, while improvements in the HVAC system may decrease the load by 19.2 kWh/m2 or 32 % of the total cooling load. If global retrofitting techniques are applied then the cooling load is reduced by 20.4 kWh/m2 or 30 % of the initial cooling load.

For the fourth category of buildings, (Enclosed, Skin Oriented, cellular, heavy structure), it is found that in the Mediterranean area, improvements of the building envelope may decrease the cooling load of the reference buildings by 106 kWh/m2/year or 40 % of the cooling load. In parallel, application of passive cooling techniques may decrease the cooling load by 133 kWh/m2 or 50 %. If global retrofitting techniques are applied then the cooling load is reduced by 189 kWh/m2 or 71 % of the initial cooling load.

Finally, for the fifth category of buildings, (Enclosed, Skin Oriented, cellular, light structure), it is found that in the Mediterranean area, improvements of the building envelope may decrease the cooling load of the reference buildings by 7.5 kWh/m2/year or 28 % of the cooling load. In parallel, application of passive cooling techniques may decrease the cooling load by 15 kWh/m2 or 57 %, while improvements in the HVAC system may decrease the load by 1 kWh/m2 or 4 % of the total cooling load. If global retrofitting techniques are applied then the cooling load is reduced by 15 kWh/m2 or 56 % of the initial cooling load.

6.1 Advanced Control Systems

Building Management Energy Systems contribute to considerable reduction of the energy consumption of large area buildings and improvement of the indoor environment. As reported, (16), revenues for new building control systems and retrofit HVAC systems in USA were an estimated $1.17 billion in 1989, and were projected to grow to $2.49 by 1996. Actually, the building automation business, in the United States had exceeded 725 millions dollars by 1995, and is expected to exceed 1.1 billions of dollars by the year 2000. The European market of building automation business is close to 800 millions of US Dollars or 670 MECU's, (17), Modern control systems provide an optimized operation of the energy systems while satisfying air quality needs, (18). Significant energy gains and better use of solar and ambient gains are reported when efficient control systems are used, (19). Recent research developments based on artificial intelligence techniques, offer several advantages compared to classical control systems, (19). Thus, current industrial research on energy management systems deals mainly with software development based on recent artificial intelligence technologies, i.e fuzzy logic, neural nets, genetic algorithms, (18). In parallel, recently developed Operating Networks, technology for data transmission and for remote control of the global building energy system, offers a powerful means for implementing distributed systems that perform sensing, monitoring, control and other applications. Advanced operating networks allows intelligent devices to communicate with one another through an assortment of communications media using a standard protocol. Smart card techniques combined with the energy management system can contribute considerably to energy conservation. Smart card terminals can contribute as interface between the users and the central control system, while a limited number of "human comfort units" i.e. thermal units for the winter, air-conditioning units for the summer can be charged in the memory of the smart card according to the comfort needs of the average human, (20).

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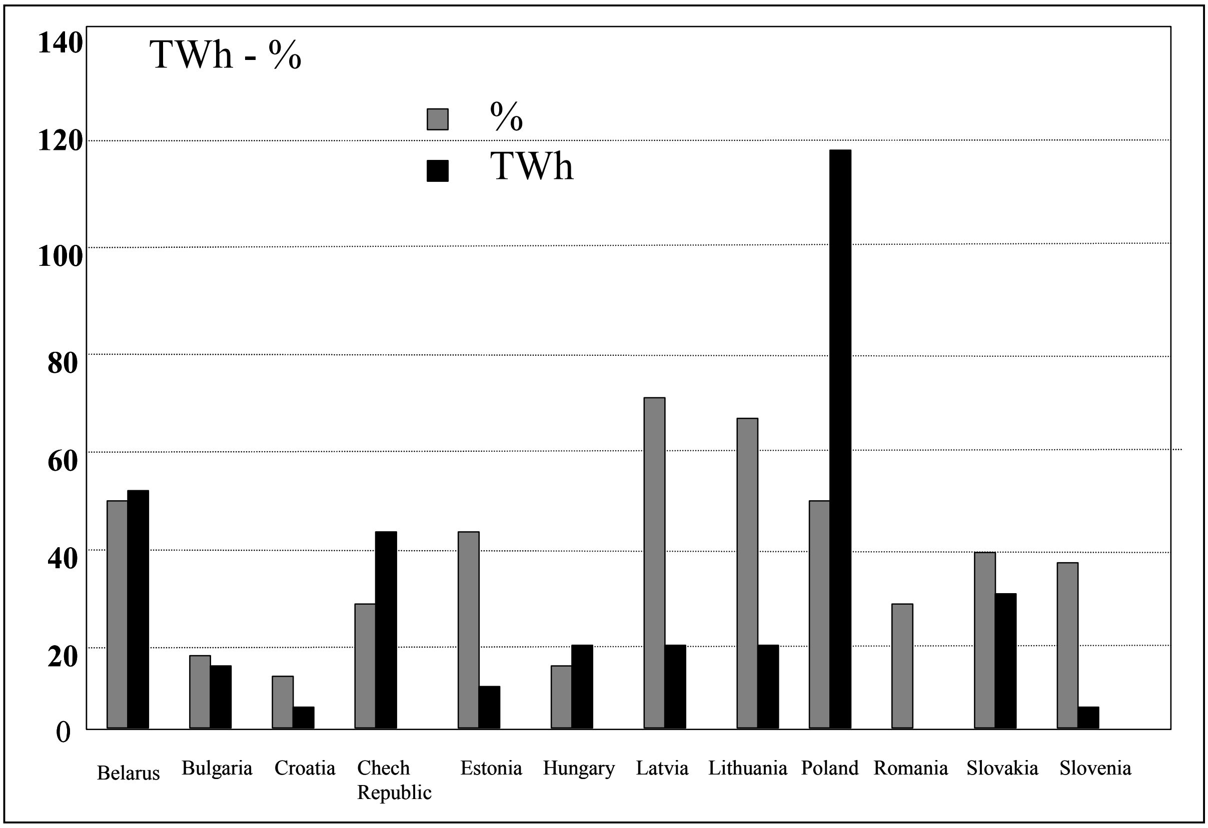
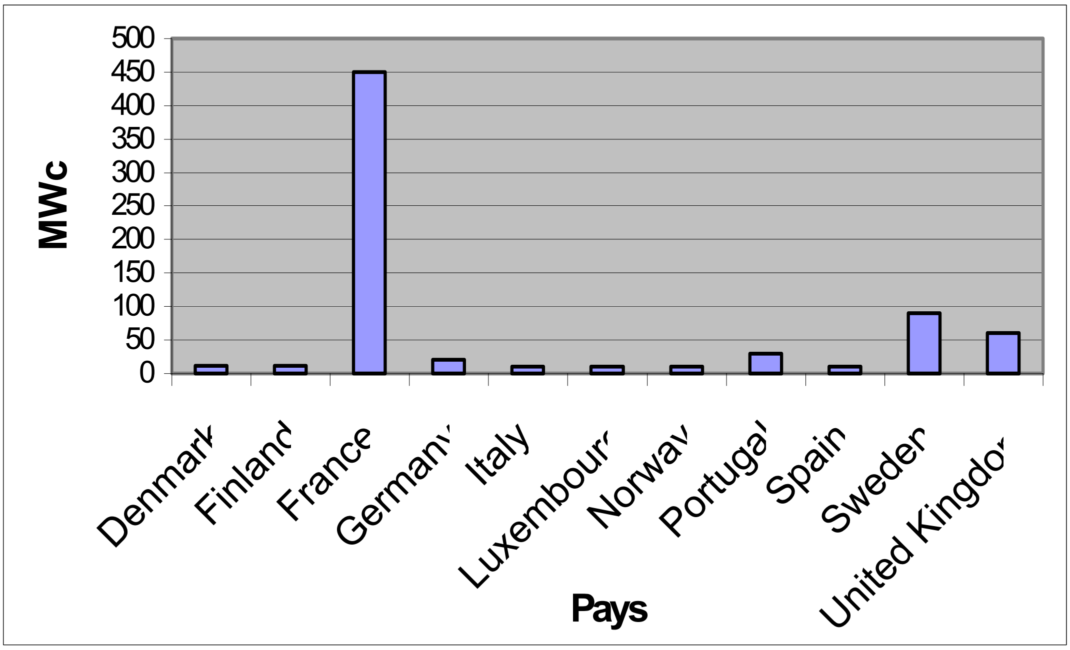
22.

Figures


TWh - %
%
TWh
140
120
100
80
60
40
20
0
Belarus
Bulgaria
Croatia
Chech Republic
Estonia
Hungary
Latvia
Lithuania
Poland
Romania
Slovakia
Slovenia


MWc
500
450
400
350
300
250
200
150
100
50
0
Denmark
Finland
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Norway
Portugal
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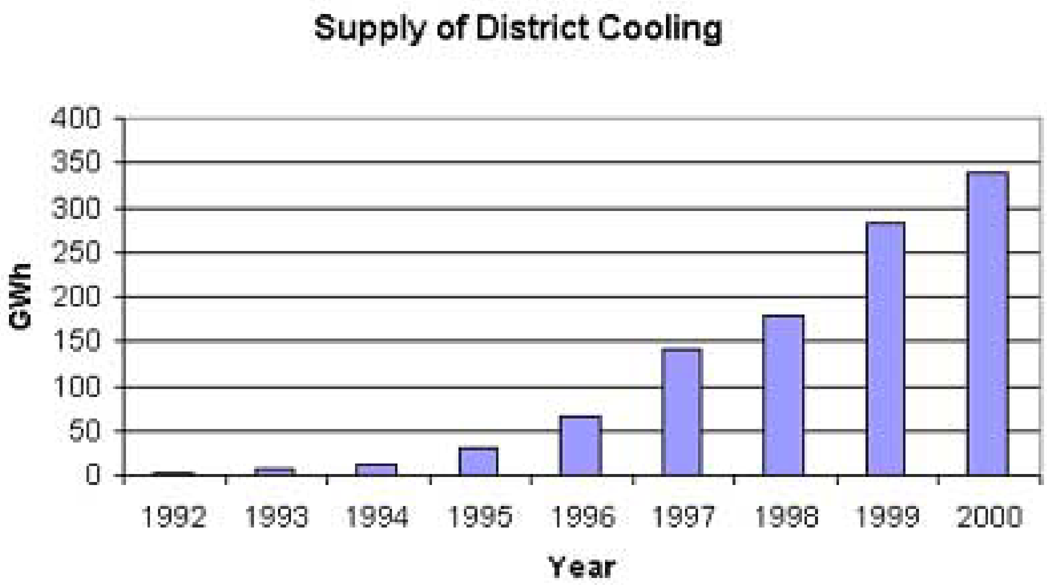
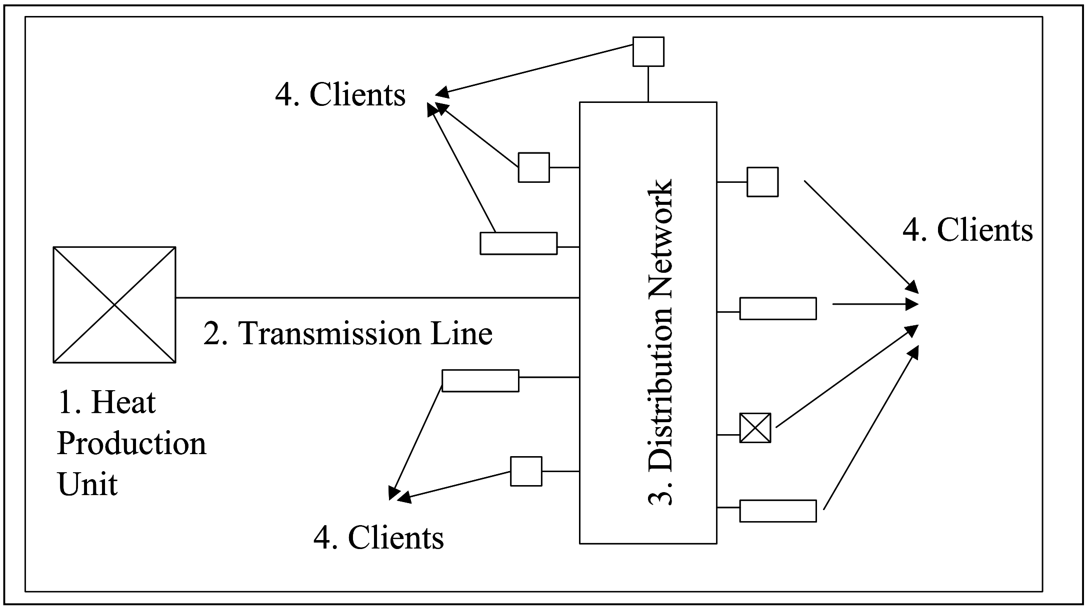
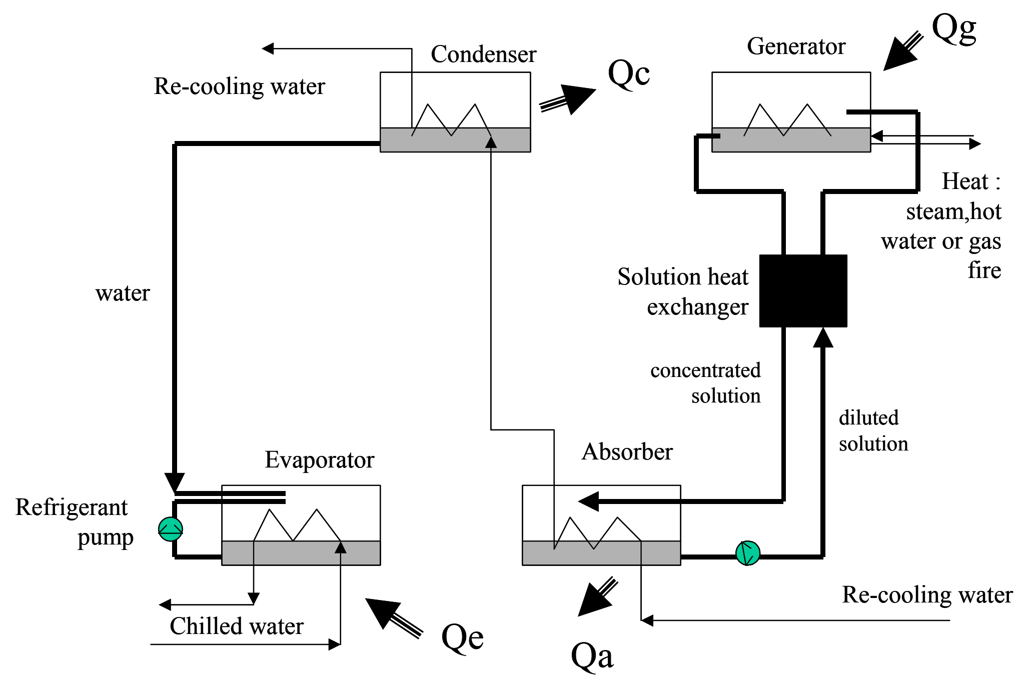
Sweden
United Kingdom
Pays



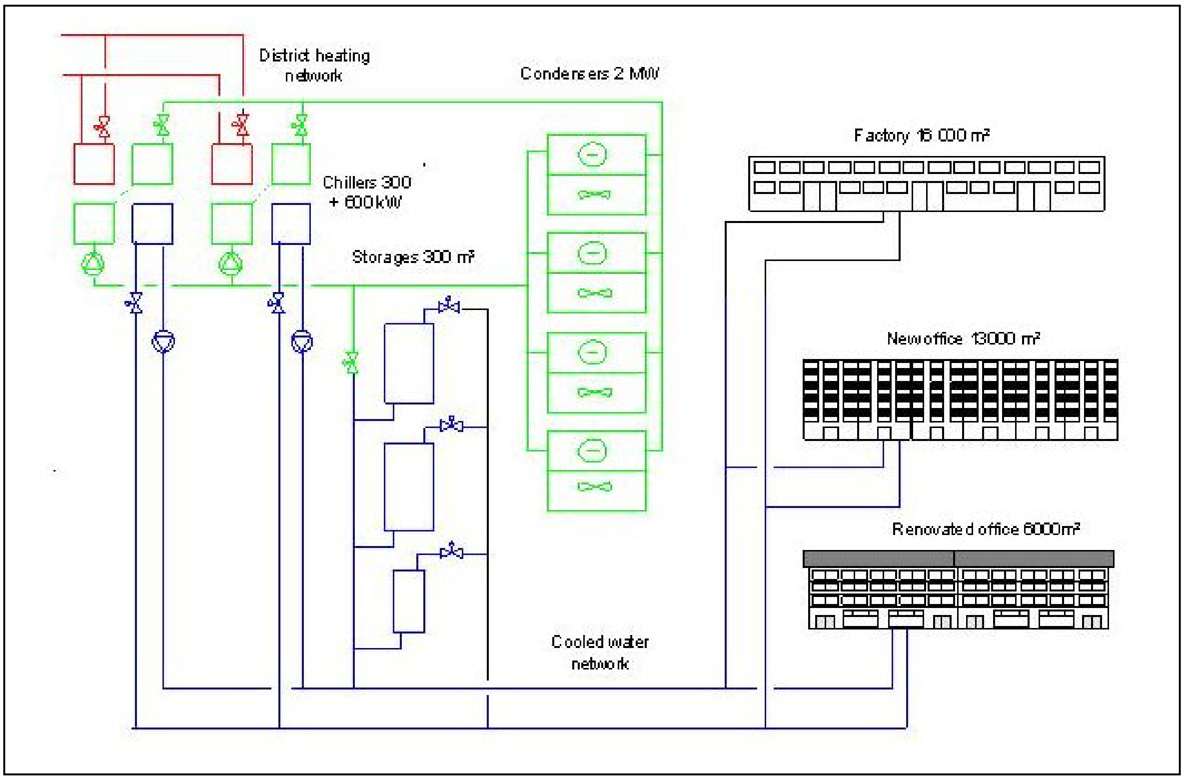
Supply of District Cooling
400
350
300
250
200
150
100
50
0
GWh
1992
1993
1994
1995
1996
1997
1998
1999
2000
Year

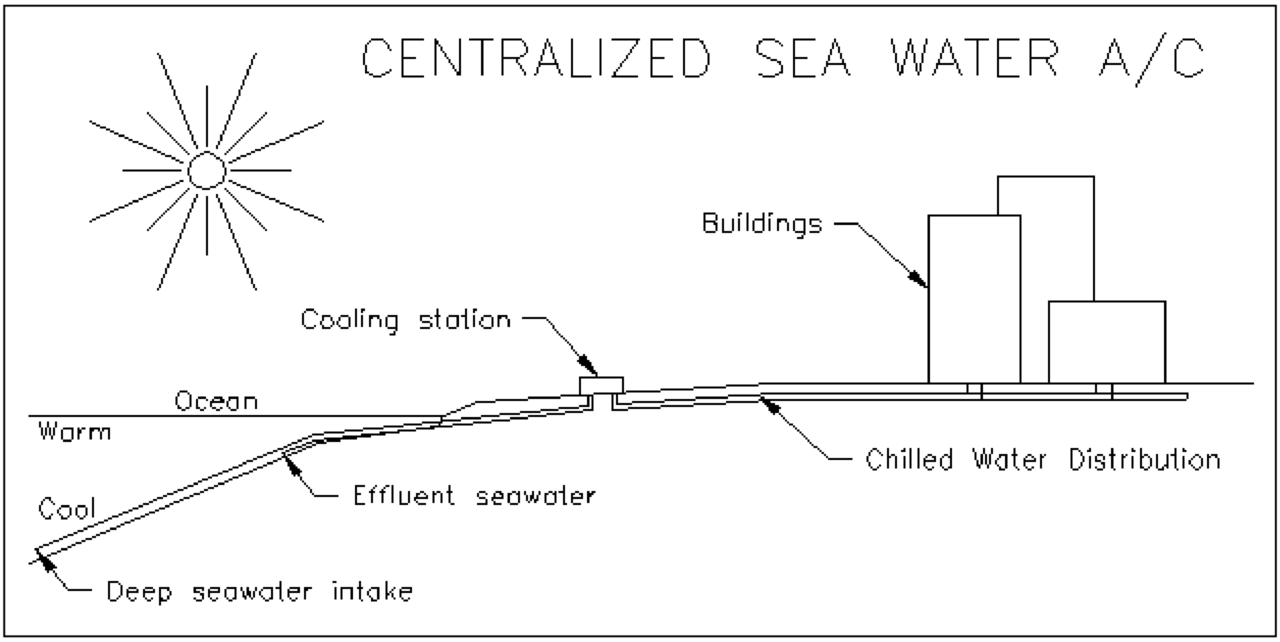


4. Clients
4. Clients
1. Heat Production Unit
2. Transmission Line
3. Distribution Network
4. Clients

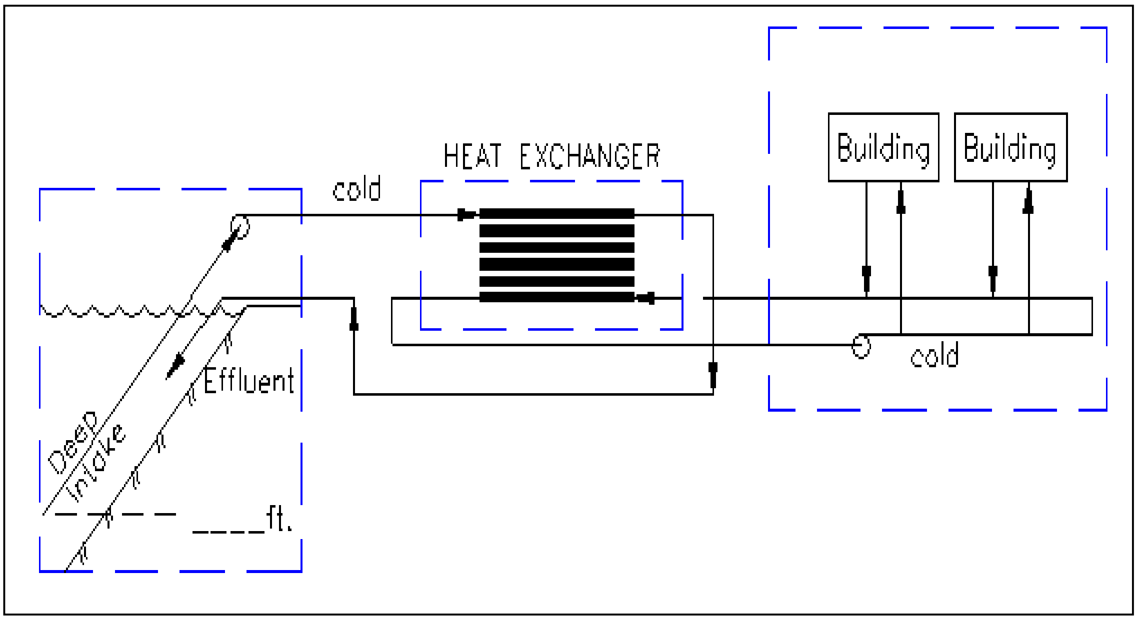


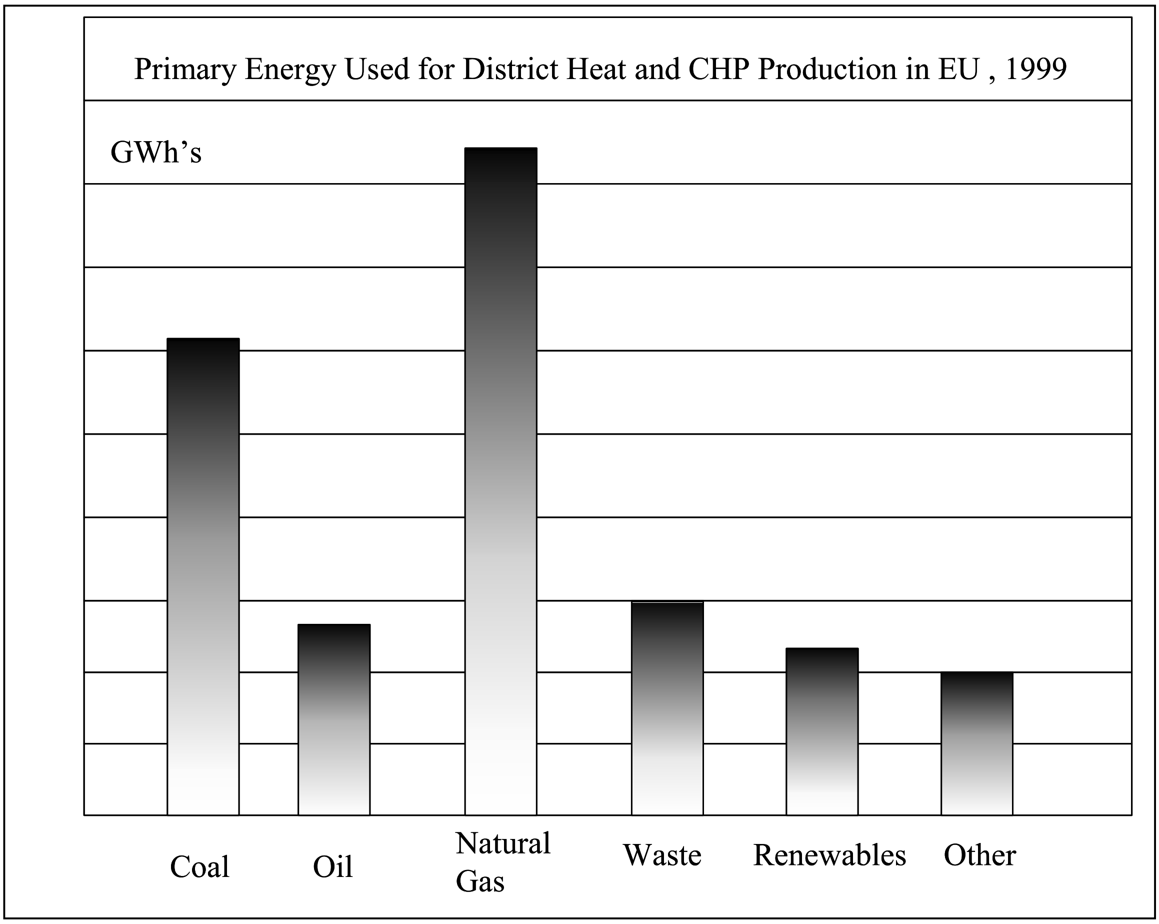
Qg: Thermal Energy in generator, Qe : Thermal Energy in Evaporator, Qa : Thermal Energy in absorber, Qc : Thermal Energy in condenser

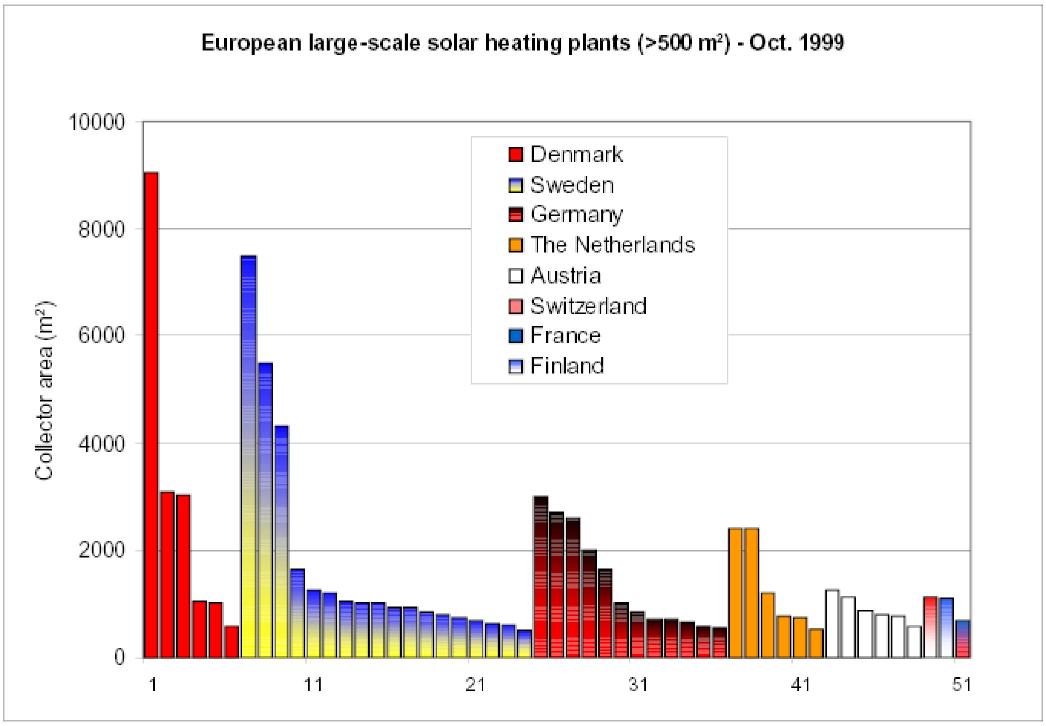

District heating
network
Condensers 2 MW
Factory 16 000 m²
Chillers 300
+ 600 kW
Storages 300 m³
New office 13000 m²
Renovated office 6000m²
Cooled water
network

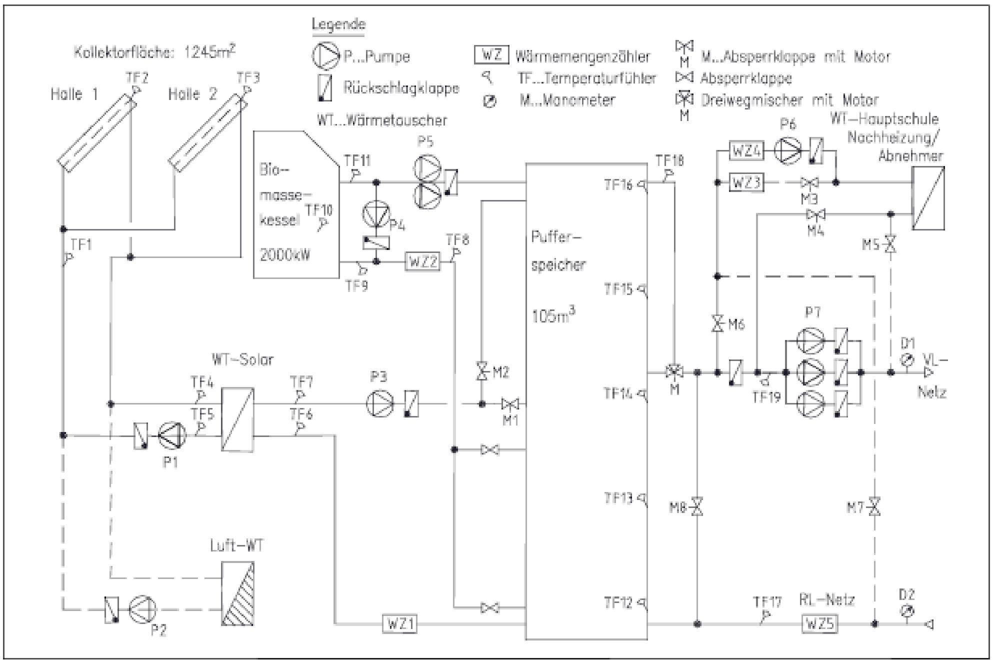


CENTRALIZED SEA WATER A/C
Buildings
Cooling station
Ocean
Warm
Chilled Water Distribution
Effluent seawater
Cool
Deep seawater intake


HEAT EXCHANGER
cold
Building
Building
cold
Effluent
Deep
Intake
____ft.


Primary Energy Used for District Heat and CHP Production in EU , 1999
GWh's
Coal
Oil
Natural Gas
Waste
Renewables
Other


European large-scale solar heating plants (>500 m²) - Oct. 1999
Collector area (m²)
10000
8000
6000
4000
2000
0
1
11
21
31
41
51
Denmark
Sweden
Germany
The Netherlands
Austria
Switzerland
France
Finland



Legende
P...Pumpe
Rückschlagklappe
WT...Wärmetauscher
WZ Wärmemengenzähler
TF...Temperaturfühler
M...Manometer
M...Absperrklappe mit Motor
Absperrklappe
Dreiwegmischer mit Motor
Kollektorfläche: 1245m²
Halle 1
Halle 2
TF1
TF2
TF3
Bio-masse-kessel
2000kW
TF4
TF5
TF6
TF7
TF8
TF9
TF10
TF11
P1
P2
P3
P4
P5
P6
P7
WZ1
WZ2
WZ3
WZ4
WZ5
WT-Solar
Luft-WT
M1
M2
M3
M4
M5
M6
M7
M8
M
Puffer-speicher
105m³
TF12
TF13
TF14
TF15
TF16
TF17
TF18
TF19
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D1
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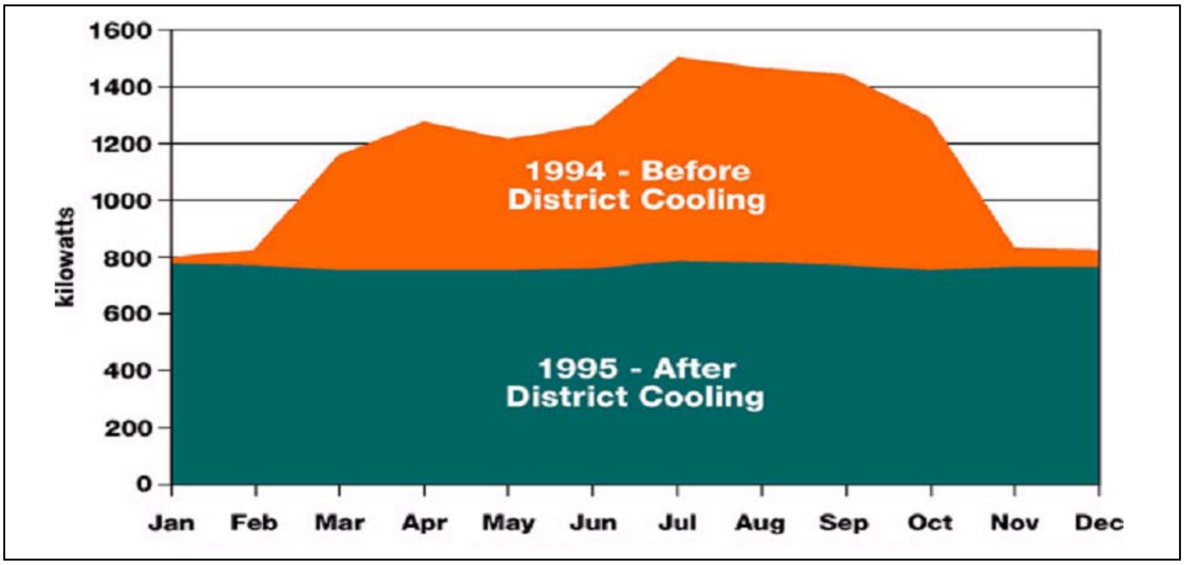
RL-Netz


1600
1400
1200
1000
800
600
400
200
0
kilowatts
1994 - Before
District Cooling
1995 - After
District Cooling
Jan
Feb
Mar
Apr
May
Jun
Jul
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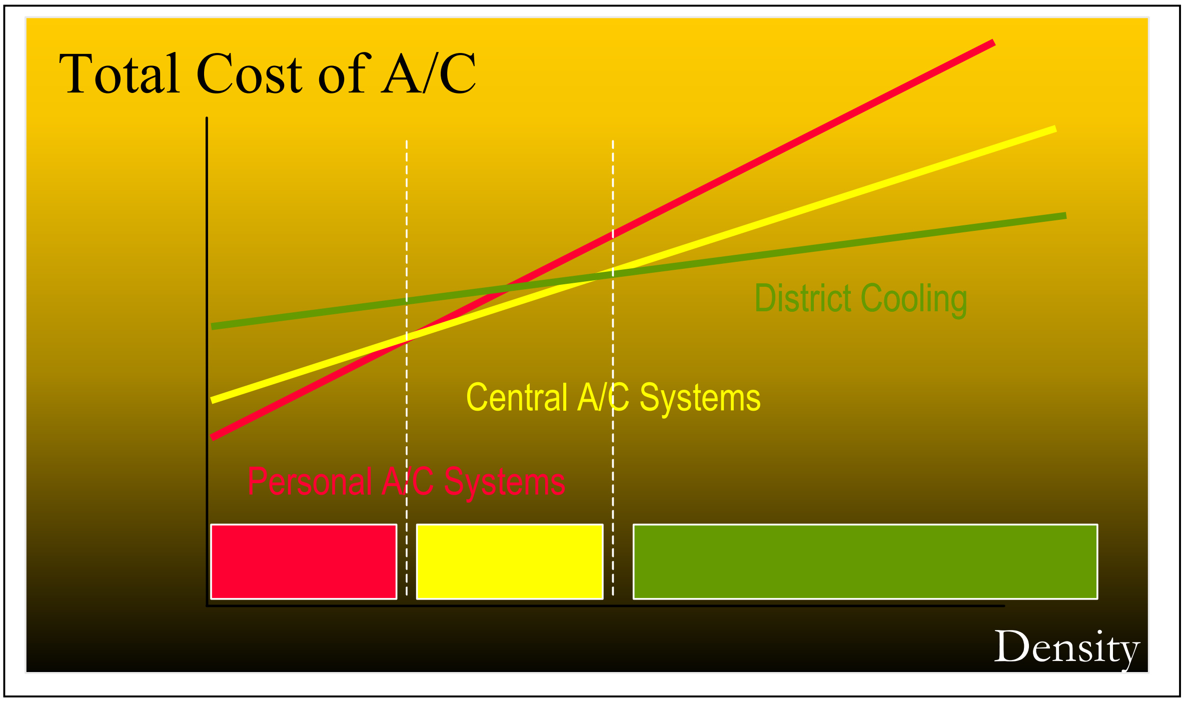
Sep
Oct
Nov
Dec



Total Cost of A/C
District Cooling
Central A/C Systems
Personal A/C Systems
Density