

Alternative Cooling Techniques for Buildings

M. Santamouris

Group of Building Environmental Research, Physics Department, University of Athens, Greece

Mail : msantam@phys.uoa.gr

Note : The present paper is based on the article ‘ Passive Cooling – The State of the Art’,
Published in Advances in Solar Energy, 2005, Earthscan, London

Abstract

The present paper presents the recent progress on the field of passive cooling technologies for buildings. Given the very rapid penetration of air conditioning all around the world and the important energy and environmental impact it causes, alternative cooling techniques have received a very important attention and important developments have been achieved. The paper discusses some of the actual progress on techniques to improve urban microclimate, heat and solar control, thermal comfort and heat inertia techniques as well as heat dissipation methods.

Introduction

The increase of family income in developed countries has made the use of air conditioning systems highly popular. In Europe the main commercial market for cooling and air conditioning systems totals 8 billion Euros. Almost 6% of office, commercial and industry buildings are cooled, making a total volume of about 20 million cubic meters (Adnot, 1999). The volume of air-conditioned buildings in Europe is expected to increase four times by the year 2010.

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

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

1. Adaptation of buildings to the specific environmental conditions of cities in order to efficiently incorporate energy efficient renewable technologies to address the radical changes and transformations of the radiative, thermal, moisture and aerodynamic characteristics of the urban environment. This involves the use of passive and hybrid cooling techniques to decrease cooling energy consumption and improve thermal comfort.
2. Improvement of the urban microclimate to fight the effect of heat island and temperature increase and the corresponding increase of the cooling demand in buildings. This may involve the use of more appropriate materials, increased use of green areas, use of cool sinks for heat dissipation, appropriate layout of urban canopies, etc.

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

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

- a) Solar and Heat Protection Techniques. Protection from solar and heat gains may involve: Landscaping, and the use of outdoor and semi-outdoor spaces, building form, layout and external finishing, solar control and shading of building surfaces, thermal insulation, control of internal gains, etc.
- b) Heat Modulation Techniques. Modulation of heat gain deals with the thermal storage capacity of the building structure. This strategy provides attenuation of peaks in cooling load and modulation of internal temperature with heat discharge at a later time. The larger the swings in outdoor temperature, the more important the effect of such storage capacity. The cycle of heat storage and discharge must be combined with means of heat dissipation, like night ventilation, so that the discharge phase does not add to overheating.
- c) Heat dissipation techniques. These techniques deal with the potential for disposal of excess heat of the building to an environmental sink of lower temperature. Dissipation of the excess heat depends on two main conditions: 1) The availability of an appropriate environmental heat sink; and 2) The establishment of an appropriate thermal coupling between the building and the sink as well as sufficient temperature differences for the transfer of heat. The main processes of heat dissipation techniques are: ground cooling based on the use of the soil, and convective and evaporative cooling using the air as the sink, as well as water and radiative cooling using the sky as the heat sink. The potential of heat dissipation techniques strongly depends on climatic conditions. When heat transfer is assisted by mechanical devices, the techniques are known as hybrid cooling.

Heat Dissipation Techniques

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

During the summer the soil temperature at certain depth is considerably lower than the ambient temperature, thus, the ground offers an important opportunity for dissipation of the buildings' excess heat. The concept of buried pipes involves the use of metallic or PVC pipes buried at 1 to 4m in depth. Ambient or indoor air is delivered via the tubes where it is precooled and then delivered to the building. When outdoor air is circulated into the pipes the system is characterized as an 'open loop system'; when the indoor air is circulated from the building through the tubes the system is known as a 'closed loop system.' The performance of the buried pipes is a function of the inlet air temperature, the ground temperature, the thermal characteristics of the pipes and soil as well as of the air velocity, the pipe dimension and the pipes' depth. Application of buried pipes cooling techniques in buildings has shown that the energy benefits are very important. Advanced modelling techniques have been developed quite recently that permit a very accurate sizing of the system under different boundary conditions, (Mihalakakou et al, 1994).

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

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

Different hybrid ventilation systems have been proposed and applied in various types of buildings. An extended review of these systems and their existing applications is provided by (Delsante and Vik, 2001). Results from first generation of hybrid ventilated buildings, show that such techniques have great potential. Hybrid systems were found to be quite effective in providing good IAQ and thermal comfort, while the energy performance was good but not excellent. Hybrid ventilation is proved to be suitable for schools and cellular offices while in open-plan offices there were some complaints. Hybrid ventilation is a very new and promising technology but several problems still remain. Design tools and methodologies as well as more robust control strategies and sensors for demand control ventilation must be developed in the future.

Solar Control and Heat Protection

Important research has been carried out to improve the global thermal and visual performance of solar control devices, which are commercially available (Wilson, 1999, 2000). Switchable glazing technology has been considerably improved and electrochromic glazing is commercially available. Multifunctional façade components able to provide ventilation, daylight, solar control and other energy benefits have been designed and tested and are expected to enter the market soon (Cromvall, 2001). According to the European Glass Industry, replacement of single glazed windows in Europe with double low-e glass, will save almost 75 x 10¹⁵J, 10.4 million Euros, and 57.7 million tons of CO₂ (GEPVP, 2001). Similarly, replacement of simple double glazed windows with low-e glass will contribute to save almost 340 x 10¹⁵J, 3.95 million Euros and 24.6 million tons of CO₂.

Improving the Urban Microclimate and Fighting Heat Island

Various mitigation techniques to decrease the impact of heat island have been proposed. Among the most important techniques are : the use of green spaces and cool sinks as well as the extensive use of cool materials. Appropriate materials used in the urban scale can decrease seriously the surface and ambient temperatures, improve thermal comfort and decrease cooling loads of buildings. Extensive research described by Akbari et al, (2005), has permitted to develop cool materials presenting high solar reflectivity combined with high emissivity coefficients. White and colored cool materials have been recently developed and tested in Southern Europe and it has been proved that present extremely interesting optical and thermal performances.

Synnefa et al, (2005), have performed a comparative study of 14 types of white reflective coatings, aiming to investigate the thermal effect of white reflective coatings on lowering surface temperatures of buildings and other surfaces in the urban environment, and thus test their suitability to lower ambient temperatures and fight the heat island effect. All materials have been tested during August to October 2004, on a 24 h basis. The thermal as well as the optical characteristics of all materials have been measured.

Measurements have shown that during the day time the thermal performance of the samples is mainly affected by their surface solar reflectance, while emissivity has a lower impact compared to reflectance. During the night, emissivity becomes the predominant factor affecting the thermal performance of the tiles. It was found that the mean nocturnal surface temperature and the infrared emissivity value of the samples was well correlated with a correlation coefficient close to -0.84), and this verifies the previous statement.

Measurements have also shown that during the daytime period, the white colored coatings in general had the ability to reduce highly the surface temperature of the concrete tile on which they were applied. The maximum temperature decrease was observed for a white acrylic elastomeric coating, a white acryl-polymer emulsion paint, a white alkyd, chlorine rubber coating and a white acrylic, ceramic coating that reduced the mean concrete tile's surface temperature by 5 °C, 4.3 °C, 4 °C and 4 °C, respectively during the experiment. The maximum surface temperature of a tile coated with a white elastomeric coating was by 7.5 °C cooler than the uncoated tile.

All coatings have been compared against two natural cool materials, a white marble and a white mosaic tiles. It is found that during daytime, the white acrylic ceramic coating, the two acrylic elastomeric coatings, the alkyd, chlorine rubber coating, the acryl-polymer emulsion paint, the acrylic latex and the acrylic paint presented lower mean surface temperatures than both the marble's and the mosaic's mean surface temperature. The maximum difference in mean surface temperature was found to be between the acrylic ceramic coating and the marble tile (3.8 °C) and between the acrylic elastomeric coating and acrylic emulsion paint and the mosaic tile, (4.1 °C).

Synnefa et al, (2006, 2006b), have reported measurements of the solar spectral properties as well as of the thermal performance of 10 prototype cool colored coatings, developed at the National and Kapodistrian University of Athens. The coatings have been developed using near infrared reflective color pigments in comparison to color-matched, conventionally pigmented coatings. Special infrared reflecting color pigments, have been used in order to develop the prototype cool colored coatings. These complex inorganic pigments exhibit high reflectance in the near infrared portion of the electromagnetic spectrum. In total, 10 prototype cool colored coatings were tested in comparison to color-matched, conventionally pigmented coatings. In particular, an orange, a light blue, a blue, a green, two black, one anthracite, one brown, one chocolate brown and a light brown coatings have been developed and tested.

Coatings have been developed, in order to be used in the urban environment to fight heat island effect. The spectral reflectance and the infrared emissivity were measured and the solar reflectance of the samples was calculated. The surface temperature of the tested coatings applied on concrete tiles was monitored, using surface temperature sensors and a data logging system, on 24h basis from August to December 2005 in an effort to investigate the ability of the cool colored coatings to maintain lower surface temperatures than conventionally pigmented color-matched coatings.

It is found that for the first and the second month of the experimental period, mean daily surface temperatures ranged between 36.4°C and 31.6°C (for cool orange) and 49.4°C and 40.9°C (for black (2) standard), respectively. As expected, the coatings with the higher values of solar reflectance demonstrated the lower surface temperatures. During the day, all the cool colored coatings had surface temperatures lower than the colored matched standard ones. The best performing cool coatings were black (2), chocolate brown, blue and anthracite that maintained a difference in mean daily surface temperature from their standard color matched coatings by 5.2, 4.7, 4.7 and 2.8°C respectively, for the month of August. The highest temperature difference was observed between cool and standard black (2) and was equal to 10.2°C. The lowest temperature difference was observed between cool and standard green (2) and was equal to 1.6°C.

Some Conclusions

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

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

References

- Adnott, J., (Ed.) 1999. Energy Efficiency of Room Air-Conditioners (EERAC) Study. Directorate General for Energy (DGXVII) of the Commission of the European Communities.
- Akbari H., Levinson R., Miller W., Berdahl P. Cool colored roofs to save energy and improve air quality. Proc. International Conference "Passive and Low Energy Cooling for the Built Environment", Santorini, Greece, 2005
- Cromvall, J., 2001. Final report of AIRLIT-PV research project. European Commission, Directorate General for Research, Brussels, Belgium.
- Delsante, A., Vik, T.A., 2001. Hybrid ventilation—State of the art review. IEA Energy Conservation in Buildings and Community Systems Programme. Annex 35: Hybrid Ventilation and New and Retrofitted Office Buildings, Paris, France

GEPVP, (Groupent Europeen des Producters de Verre Plat), 2001. Low e- glass in buildings. Impact on the environment and on energy savings. Report published by GEPVP, Brussels, Belgium.

Ghiaus, F. Allard, Y. Mansouri, J. Axley : Natural ventilation in urban context, In 'Solar Thermal Technologies – The State of the art', M. Santamouris (ed), James and James Science Publishers, London, UK, 2003.

Heiselberg, P. (Ed.) 2002. Principles of hybrid ventilation. IEA [international Energy Agency], Energy Conservation in Buildings and Community Systems Programme. Annex 35, Hybrid Ventilation and New and Retrofitted Office Buildings, Paris, France

Mihalakakou, G., Santamouris, M.,and Asimakopoulos, D.N. 1994. Modelling the thermal performance of the earth to air heat exchangers. Solar Energy, 53 ,3 No 2, p.p. 301-305

Santamouris M and Assimakopoulos D. (Eds) : 'Passive Cooling of Buildings', James and James Science Publishers, London, UK, 1996.

Synnefa A., M. Santamouris, I. Livada : A study of the thermal performance of reflective coatings for the urban environment. Solar Energy, 2005.

Synnefa A.and M. Santamouris : Development and performance of cool colored coatings, Proc. Conference EUROSUN, Edimburg, 2006, UK.

Wilson H. "Solar Control Coatings for Windows", Proceedings of the Conference EUROMAT 99, 27th to 30 Sep 1999 in Munich, Germany, 1999.

Wilson H., A: Gombert, A. Georg, P. Nitz, 2000, "Switchable Glazing with a Large Dynamic Range in Total Solar Energy Transmittance (g-value)", in Sayidh (Ed), Conf. Proceed. World Renewable Energy Congress- VI (WREC 2000), July 1st to 7th 2000 in Brighton, England