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Recent progress on passive cooling techniques Advanced technological developments to improve survivability levels in low-income households

M. Santamouris [a,*], K. Pavlou [a], A. Synnefa [a], K. Niachou [a], D. Kolokotsa [b]

[a] Group Building Environmental Studies, Physics Department, University of Athens, Athens, Greece
[b] Technical Educational Institute of Crete, Chania, Greece

Abstract

Low-income households in developed and less developed countries suffer from serious indoor environmental problems such as heat stress, lack of comfort and poor indoor air quality. Passive cooling of buildings and in particular solar and heat protection techniques, heat dissipation and heat amortisation techniques have reached a very high degree of maturity. New technological developments have proven extremely efficient in decreasing the need for cooling and improving indoor environmental conditions. Developments on the field of solar and heat protection, such as highly reflective coatings for the urban environment and the building envelope and new knowledge and developments on the field of ground and convective cooling and ventilation, may help low-income citizens to considerably improve their quality of life during the overheating period. These new developments are characterised by low cost and are easy to apply.

This paper investigates the potential of the more promising new developments on the field of passive cooling, like the cool reflective coatings to improve outdoor and indoor conditions of low-income households in warm areas of the planet, ground cooling using earth to air heat exchangers, and discusses the potential of new ventilation techniques and systems for improving indoor comfort and air quality. Results show a very high potential to improve indoor environmental conditions and contribute towards higher passive survivability levels.

Keywords: Low-income households; Passive cooling, Heat dissipation techniques, Indoor comfort conditions, Indoor air quality

1. Introduction

Buildings are the major economic sector in the world and the quality of buildings, shapes the life of citizens. Although there is an important increase of the budget devoted to construction, the United Nations estimates [1], that more than one billion urban citizens, live in inappropriate houses – mostly in squatter and slum settlements – while in most of cities in less developed countries between one- and two-thirds of the population live in poor quality and overcrowded housing [2,3].

Even in the developed world the percentage of people living in low-income households is quite high. The average percentage of low-income households in the EU is close to 15%, while in some countries like Ireland it may go up to 21% [4].

Inappropriate housing is characterised by poor indoor environmental conditions such as extremely low or high temperatures, lack of ventilation, etc. In parallel, heat island conditions in dense urban areas increase ambient temperatures and the thermal stress to buildings, especially during the summer period [5]. For example, in Athens the heat island increases the cooling load of buildings by about 100% [6], and the heat island is mainly present in city areas where low-income people are living [7].

A research that was carried out in 1100 households in Athens [8], has shown that low-income people live in old construction buildings. The mean age of households of the lower income group is 29 years while for the richest group it is 19 years. In parallel, a very clear relation is found between the income level and the quality of the envelope. Only 28% of people in the low-income group live in insulated buildings, while the corresponding figure for the high-income group is close to 70%. In parallel, it is found that the higher the income the higher the percentage of buildings with double glazing. For the poorest group the percentage of double glazed buildings is 24% while for the

* Corresponding author. Tel.: +30 6932644459; fax: +30 210 7295282.
E-mail address: msantam@phys.uoa.gr (M. Santamouris).

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richest group the corresponding figure is 67%. Finally, insulated buildings with double glazing are quite rare for the lower income groups (8%), but this increases to 60% for the high-income group.

Concerning the use of air conditioning, it is found that although there is a very high increase in the installed a/c per household as a function of income the density of installed air conditioners per square meter is much higher for the lower income people than for all other groups. Although middle and high-income people use more air conditioning, the relative cost of comfort during the summer period is much higher for the lower income people as they live in buildings with limited thermal protection and also because low-income housing is located in areas of Athens where the heat island has maximum intensity. In parallel, it is found that the use of air conditioning significantly increases the annual electricity costs especially in the low-income groups. While as a mean value, the use of air conditioning increases the annual expenses by about 100 Euros/household, the increase is much higher for the low-income groups, where the relative increase of the cost because of the use of air conditioning is close to 195 Euros/household.

The inappropriate design of buildings that results in increasing urban temperatures, and the improvement of living standards, have contributed to a spectacular increase in the penetration of air conditioning in the residential sector. According to the IEA [9] energy demand for cooling of residential spaces accounted for 6.4% of total electricity demand in the OECD in 2000 and there was a 13% growth from 1990 to 2000. As reported by Waide [10], almost 46% of OECD households have some air conditioning, but this varies widely from continent to continent and country to country. In the USA, up to 80% of new homes have central air conditioning systems, while the share of air-conditioned houses increased from 23% in 1978 to 77% in 2001. In Europe, the penetration is quite low, around 0.02 per household on average, but there was a sevenfold increase over the 1990s and now a/c use could be around 5–7% of households.

Increased use of air conditioning creates a serious peak electricity load problem to utilities and increases the cost of electricity. According to EEC [11], the mean European cost of a kWh off peak is close to 3.9 cents, while the mean cost during peak is 10.2 cents. In parallel, the average cost of a saved kWh is 2.6 cents. In addition, demand greatly increases during heat waves. As reported during the July 2006 heat wave in California, the average homeowner used about 28% more electricity [12].

Increased energy loads in order to satisfy appropriate indoor environmental conditions in poor households, combined with increased energy prices, put a serious strain on low-income people. When more than 10% of the family income is spent for energy, the family can be characterised as ‘energy poor’, while when energy expenditure exceeds 20% of the income, the family is under ‘severe energy poverty’. In the UK alone almost 5.2 million people are considered as ‘energy poor’ [13]. In Ireland, estimates show that 17.6% of households are energy poor [14]—about 226,000 houses. About 27% of the fuel poor households, around 4.7% of the total housing stock, are suffering from chronic fuel poverty. Also, 12.7% of the households suffer from intermittent levels of fuel poverty, i.e. occupants are occasionally unable to condition their homes. In the USA a report published recently by the National Fuel Funds Network [15] found that at the end of the 2000/2001 heating season, at least 4.3 million low-income households were at risk of having their utility service cut off because of an inability to pay their home energy bills.

The situation regarding the environmental condition of households in less developed countries is far from acceptable. As reported by the United Nations [16], ‘in cities of the less developed world, one out of every four households lives in poverty; 40% of African urban households and 25% of Latin American urban households are living below locally defined poverty lines’.

It is evident that alternatives to the conventional air conditioning techniques have to be adopted in order to improve the environmental conditions of low-income households. The idea is not to maintain temperatures within the ASHRAE-defined comfort zone of (20–27 °C) using energy driven systems, but to create buildings that will not threaten the lives of their occupants under adverse ambient conditions even when power is lost or if citizens can not afford to pay for it [17].

Passive cooling relies on the use of techniques for solar and heat control, heat amortisation and heat dissipation [18,19]. Solar and heat protection techniques may involve: thermal improvement by the use of outdoor and semi-outdoor spaces, layout and external finishing, solar control and shading of building surfaces, thermal insulation, control of internal gains, etc. Modulation of heat gain deals with the thermal storage capacity of the building structure, while heat dissipation techniques deal with the potential for disposal of excess heat of the building to an environmental sink of lower temperature, like the ground, water, ambient air or the sky.

Very important research on the field of passive cooling has been undertaken recently. The most important progress has been in the fields of appropriate materials for the building envelope and the urban environment as well as on the field of heat dissipation techniques. The present paper discusses the applicability and investigates the potential contribution of both techniques for low-income households faced with problems of overheating and poor indoor environmental quality.

2. Heat and solar protection techniques

2.1. Improving the urban microclimate

The increase in urban temperatures caused by the heat island effect mainly affects low-income people. During the summer period high ambient temperatures and heat waves cause dramatic problems to vulnerable people living in overheated households. According to Eurosurveillance [20] an estimated 22,080 excess deaths occurred in England and Wales, France, Italy and Portugal during and immediately after the heat waves of the summer of 2003. In addition 6595–8648 excess deaths were registered in Spain of which approximately 54% occurred in August and 1400–2200 in the Netherlands of which an