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Performance of radiant cooling surfaces with respect to energy consumption and thermal comfort

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ABSTRACT

The intensive use of electrically driven vapour compressor air conditioning is accompanied by an analogous environmental impact and the imposition of a severe stress on the electric grid. Still, the decarbonisation of the latter, by the increased utilisation of renewable energy sources, and the implementation of smart grids could help in overcoming those issues, if a different approach in thermal energy storage and thermal comfort in the cooling of buildings can be achieved. Hydronic radiant building surfaces address those issues providing thermal comfort by cooling directly the building and the people, utilising high temperature cooling water, that increases the efficiency of cooling systems, while they present the feature of thermal energy storage embedded in their construction. The present study compares radiant and convection systems with respect to final energy consumption and thermal comfort in a test cell representing an office room. The results highlight the issues of proper control of radiant systems in order to take full advantage of their specific features and of the appropriate evaluation of thermal comfort conditions provided by those systems.

1. Introduction

The quest for coolness in warm climates occupied people for thousands of years. Several ancient architectural practices (high thermal mass walls, high room ceilings, shading and natural cooling techniques) have been employed to adjust buildings to local climatic conditions, while several cultural practices developed to help people adjust (e.g. clothing). The natural, or passive, cooling techniques have therefore a centuries' long record of being used. Mechanical cooling emerged only during the 19th century, but boosted by the electrification of cities it expanded to the current point where today it is considered to be the standard way of cooling. That wide availability and intense operation of electricity driven vapour compression cooling systems resulted in a twofold effect. It led people and buildings to loose or abandon their acclimatisation features and produced a significant environmental impact and a huge stress on electricity grids, especially during hot periods.

However, if electricity generation is about to be proliferated by renewable energy sources' (RES) contribution and transmitted and distributed through smart grids, a big challenge emerges: to successfully implement demand responsive schemes, that will force building operators to run their electricity driven cooling equipment when RES-generated electricity is available, in order to minimise the environmental impact and relieve the grid from peak mismatches between supply and demand. For this to be realised two issues should be resolved: how to provide uninterrupted cooling, when the availability of the respective equipment is intermittent following the availability of RES, and how to provide thermal comfort in an indoor environment where occupants do not have full control over time of their conditioning equipment.

Thus, a different approach in the perception of thermal comfort, energy efficiency and thermal energy storage is required during the cooling of buildings. Hydronic radiant building surfaces provide that different approach since they achieve thermal comfort by cooling directly the building and the people and not the indoor air and, in addition, they utilise high temperature cooling water that increases the efficiency of cooling plant equipment, while they also present the feature of thermal energy storage embedded in their construction. By using such systems a totally different view on the building as a system is possible, where the building elements themselves act as terminal cooling units and thermal energy storage facilities.

The present paper, following an investigation of the reasons that cause increased cooling demand in today's built environment and an introduction to the main parameters of thermal comfort, compares radiant and convection systems with respect to their energy performance and the thermal comfort conditions they are establishing in a building during cooling conditions.

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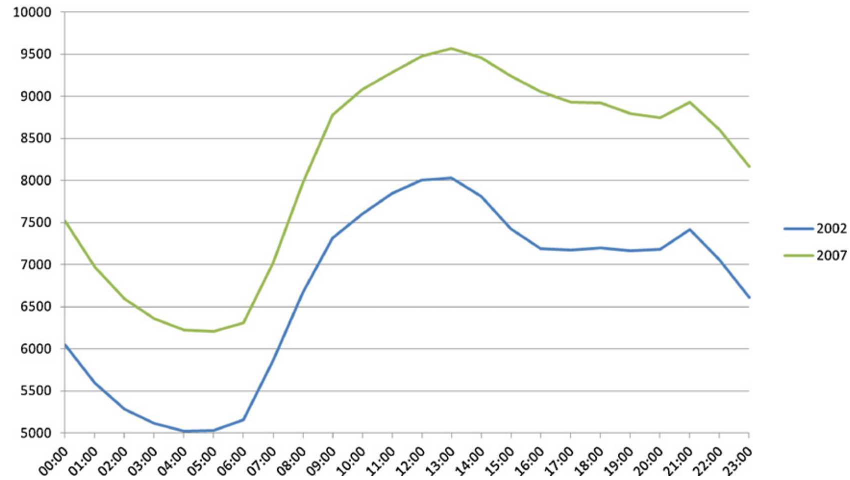

Fig. 1. Average electricity load during July weekdays [3].

2. The increasing cooling demand

Greece was, at least until the deep recession started in 2009, a typical example for the increasing cooling, which was reflected at the increased electricity demand during the summer months. The microclimatic change, with the overheating of the big cities due to the heat island effect, the increased glazed surfaces of buildings, as a result of "architectural globalization" and the drastic drop of the initial cost of air conditioning systems resulted in a huge increase in the electric peak load of the interconnected system [1,2]. During July weekdays the average electricity load increased from 2002 to 2007 about 1500 MW, most of it due to air conditioning loads (Fig. 1). In 2008, the contribution of air conditioning load to the maximum electric load was estimated at 2500 MW (about 25%).

It is indicative that between 2003 and 2009, demand shedding schemes were activated during heat waves, in order to keep peak loads below the stability safety level of the interconnected electric system. The strong correlation of daily maximum air temperatures in Athens, which accounts for more than a half of the interconnected system's load, and the maximum electricity peak load during the weekdays of July 2006, is impressively depicted in Fig. 2.

In a more systematic approach of analysis, four different categories of causes can be identified, that contribute to this increase of cooling demand; they are depicted in Fig. 3.

2.1. Climatic causes

Urban heat island is probably the single most important factor considering the increased cooling demand. The intensity of the urban heat island in Athens has been calculated at 5–15 °C [5] while in Thessaloniki at 8 °C [6]. The elevated temperatures not only increase the cooling load of buildings but also affect negatively the efficiency (coefficient of performance) of cooling systems leading to a vicious cycle. According to Papadopoulos in a typical street canyon in Thessaloniki the air temperature can rise up to 6 °C higher when the canyon buildings are air-conditioned by split units with their outdoor units installed on the buildings' facades [7]. Santamouris et al., estimated the efficiency deterioration of air conditioners up to 25% due to urban heat island in Athens [5].

In addition, the features of urban microclimate degrade the passive cooling potential of buildings. Ventilation cooling which is the most common form of passive cooling is restricted due to increased air temperatures and low wind speeds met in urban street canyons

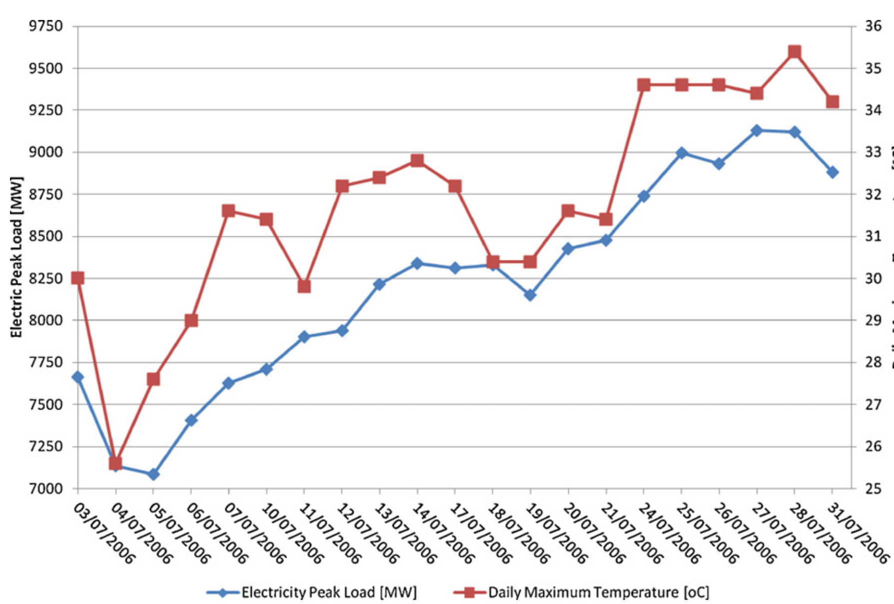

Fig. 2. Correlation between daily maximum outdoor temperature and daily maximum electricity load [3].