ENVIRONMENTALLY FRIENDLY CITIES, Proceedings of PLEA'98, Lisbon, Portugal, June 1998
Pages 463-466 © 1998 James & James Science Publishers Ltd

Climate change and passive cooling in Europe

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Abstract

Climate modellers estimate that global warming will significantly increase summertime temperatures in Southern Europe by 2-3 K by 2030 if greenhouse gas emission rates continue to grow at close to their present rate. The generation of electricity for air-conditioning and mechanical ventilation making an increasing contribution to emissions. Passive and low energy cooling strategies have the potential to reduce these emissions but their effectiveness is very sensitive to climate, and hence to climate change. Maps of mean maximum air temperature in July in Europe are presented for the current epoch and for 2050. Thresholds for the viability of daytime comfort ventilation and nocturnal convective cooling are identified and the regions of Europe for which these systems may no longer be viable are shown. The reasons for the recent rapid growth in air-conditioning use in commercial buildings in temperate climates are addressed and the role of "mixed mode" buildings in countering this trend is discussed.

INTRODUCTION

There is now a consensus amongst meteorologists and climate modellers that increasing atmospheric concentrations of carbon dioxide and other gases with significant absorptivity in the far infra-red ("greenhouse gases") will lead to significant changes in the climate of the world [1]. Simulation studies predict a general warming trend, superimposed on the considerable natural variability of the climate. A large fraction of the increase in the concentration of greenhouse gases is attributed to human activity [1].

An increasing component of the "anthropogenic" carbon dioxide emission results from the demand for electricity for air-conditioning, and this component is expected to increase further as a result of global warming, producing a positive feedback effect resulting in the increased use of air-conditioning fuelling global warming. Passive cooling and other low energy cooling techniques give rise to much lower emissions, but the effectiveness of these techniques is much more sensitive to climate, and hence to climate change. This paper looks at ventilative passive cooling in Europe in relation to global warming.

PREDICTIONS OF CLIMATE CHANGE

Over the last 100 years the global mean of the temperature of the air at the earth's surface has increased by 0.3-0.6 K and around 0.2-0.3 K over the last 40 years. While this change is consistent with the predictions of climate models, it is potentially within the natural variability of the climate. Observations of the climate over the next couple of decades will be needed to determine unequivocally the existence of global warming

Predictions of global warming depend on assumptions regarding future emission rates of CO_2 and other greenhouse gases. In the studies reported in 1990 [1], the best estimate for the "business-as-usual" scenario, in which there is only a modest reduction in the rate of increase of greenhouse gas emission rates, is that there will be a global mean warming of 1.8 K by 2030, relative to the pre-industrial temperature. Significant geographical and seasonal variations are predicted: summer-time temperatures in Central North America and Southern Europe are estimated to rise 2-3 K by 2030. Estimated temperature rise for Southern Asia and Australia is 1-2 K. Predictions of changes in humidity, cloud cover and wind speed are uncertain, as are predicted changes in the variability of weather, including the frequency of extreme conditions. A recent report [3] presents a range of possible future climates.

ESTIMATES OF CLIMATE CHANGE IN EUROPE

Figures 1 and 2 are maps of mean maximum air temperature in July for the southern half of Europe for the current epoch (1951-1990) and for 2050 based on the business-as-usual scenario.

CLIMATE DEPENDENCE OF PASSIVE COOLING SYSTEMS

As noted in the Introduction, passive cooling systems are much more sensitive to climate than active systems. A consequence of this sensitivity is that it is possible to determine thresholds in particular climate variables above which particular systems cease to be viable. These thresholds are approximate in that they depend on the details of the design, the internal loads and, most importantly, on the comfort requirements. However, they are useful for assessing the effect of climate change on system viability. Givoni [5] presents thresholds for the operation of different types of passive cooling system. Here we consider only ventilation strategies:

Comfort ventilation to produce human comfort, mainly during the day, with no reliance on thermal mass

Nocturnal convective cooling: ventilation to cool the thermal mass of building during the night in order to improve comfort during the day.

The threshold value of the maximum ambient air temperature for the viability of comfort ventilation is given as 28-32°C at indoor air speeds of 1.5-2.0 m/s, depending on the comfort requirements. This is based on the observation that the indoor air temperature approaches the outdoor air temperature as the ventilation rate increases. (For comparison, the upper limit of the extended ASHRAE comfort zone is 28°C at 0.8 m/s air speed [6].) In office or similar environments, a combination of higher internal loads and restrictive expectations concerning dress would produce a reduction in the threshold that depends on the particular situation but which may amount to several Celcius degrees.

Givoni's rule of thumb for nocturnal convective cooling is that the indoor maximum temperature is less than the outdoor maximum temperature by nearly half the diurnal range in outdoor temperature, providing the envelope and internal gains are modest and the thermal capacity is high. Nocturnal convective cooling is applicable if the maximum ambient temperature is too high for comfort ventilation and the diurnal range is sufficiently large to bring the indoor maximum temperature down into the comfort range.

If the diurnal swing is insufficient to bring the maximum internal temperature into the comfort range then an alternative strategy involving radiant cooling, evaporative cooling or earth coupling is required. In order to illustrate the effect of global warming, we consider two examples of ventilative cooling systems:

A) A comfort ventilation system in which the design maximum indoor temperature is 28°C.
B) A nocturnal cooling system in which a design maximum indoor temperature of 29°C is achieved with a maximum outdoor temperature of 34°C and a minimum outdoor temperature of 23°C.

The temperature maps presented here show averages for the month of July. Making the simple approximation that design conditions are 3°C warmer than average July conditions, the threshold average July temperatures for the two examples are:

A) Maximum outdoor temperature: 25°C
B) Maximum outdoor temperature: 31°C, minimum outdoor temperature: 20°C

EFFECT OF CLIMATE CHANGE IN EUROPE

The areas of Figure 1 and Figure 2 for which the temperature is less than 25°C indicate the regions of Europe for which comfort ventilation is viable now and in 2050 using the criteria given above. The areas where the temperature is less than 31°C provide a good indication of the regions where nocturnal cooling is viable, since an inspection of the minimum temperature maps shows that the limit of 31°C for the maximum temperature is almost always more restrictive than the limit of 20°C for the minimum temperature (i.e. the average diurnal swing is not significantly less than 11°C throughout the marginal areas).

The regions where each system will cease to be viable by 2050 are extensive enough that designers should anticipate the likely effects of global warming in order to pre-empt the later installation of air-conditioning. Comfort ventilation will not be viable throughout the life of the building in some areas and here provision for nocturnal cooling should be included in the design. Where nocturnal ventilation will cease to be viable an alternative strategy involving radiant cooling, evaporative cooling or earth coupling is required. Because of the limitations in the meteorological data noted above, the absolute position of these bands is somewhat uncertain.

Other factors that affect future design requirements include comfort criteria and the thermal performance of particular buildings. The need for change could be reduced by any behavioural adaptation to climate change. The analysis presented here applies to well shaded buildings where the internal loads are relatively small (e.g. residential). The indoor temperatures are then determined primarily by the outdoor temperatures and it is possible, therefore, to define threshold values for the outdoor temperatures.

In buildings where the loads are significant compared to the heat that can be stored in the thermal mass with the available temperature swings, the threshold for viability depends on the loads and the effective thermal mass as well as the outdoor temperatures. Such cases can be treated using computer simulation.

BUILDING DESIGN AND THE DECISION TO AIR-CONDITION

A matter of increasing concern because of its impact on greenhouse gas emission rates, is the rapid spread of air-conditioning for reasons unconnected with climate change. For example, almost all new speculatively developed office buildings in the South of England are air-conditioned. It is assumed by property developers that office buildings must be air-conditioned or they will be very difficult to let. This is in spite of growing evidence that occupants dislike air conditioning, or more particularly, they dislike the lack of proximity to an operable window that is associated with a deep plan air-conditioned building.

While increasing standards of living must account for a significant amount in the increase in the global use of air-conditioning, the reasons why it is being universally adopted in a temperate climate like Britain are worthy of further research.

It is becoming clear that internal gains in commercial buildings are often significantly overestimated. For example, "nameplate" ratings for electrical equipment typically exceed the actual heat output by a factor of three. A recent study has shown that with good design no supplementary cooling is required in a well designed UK office with personal computer densities of one per desk [7].

The poor thermal performance of many commercial buildings can be attributed to inappropriate building form. A deep plan is incompatible with most daylighting and natural ventilation strategies for multi-storey buildings. Highly glazed, unshaded facades give rise to problems of overheating and glare. The isolation of thermal mass by suspended ceilings and raised floors limits its ability to moderate internal temperature swings.

Market perceptions of air-conditioning are beginning to change significantly due in part to a perceived association with Sick Building Syndrome. Many owners are anticipating changes in building regulations and a carbon tax that would make high energy consumption a serious liability. Legislation introduced in the Canton of Zurich in 1986 that restricts the use of air-conditioning has forced architects and engineers to acquire new skills and has already resulted in a number of innovative low-energy cooling system designs [8].

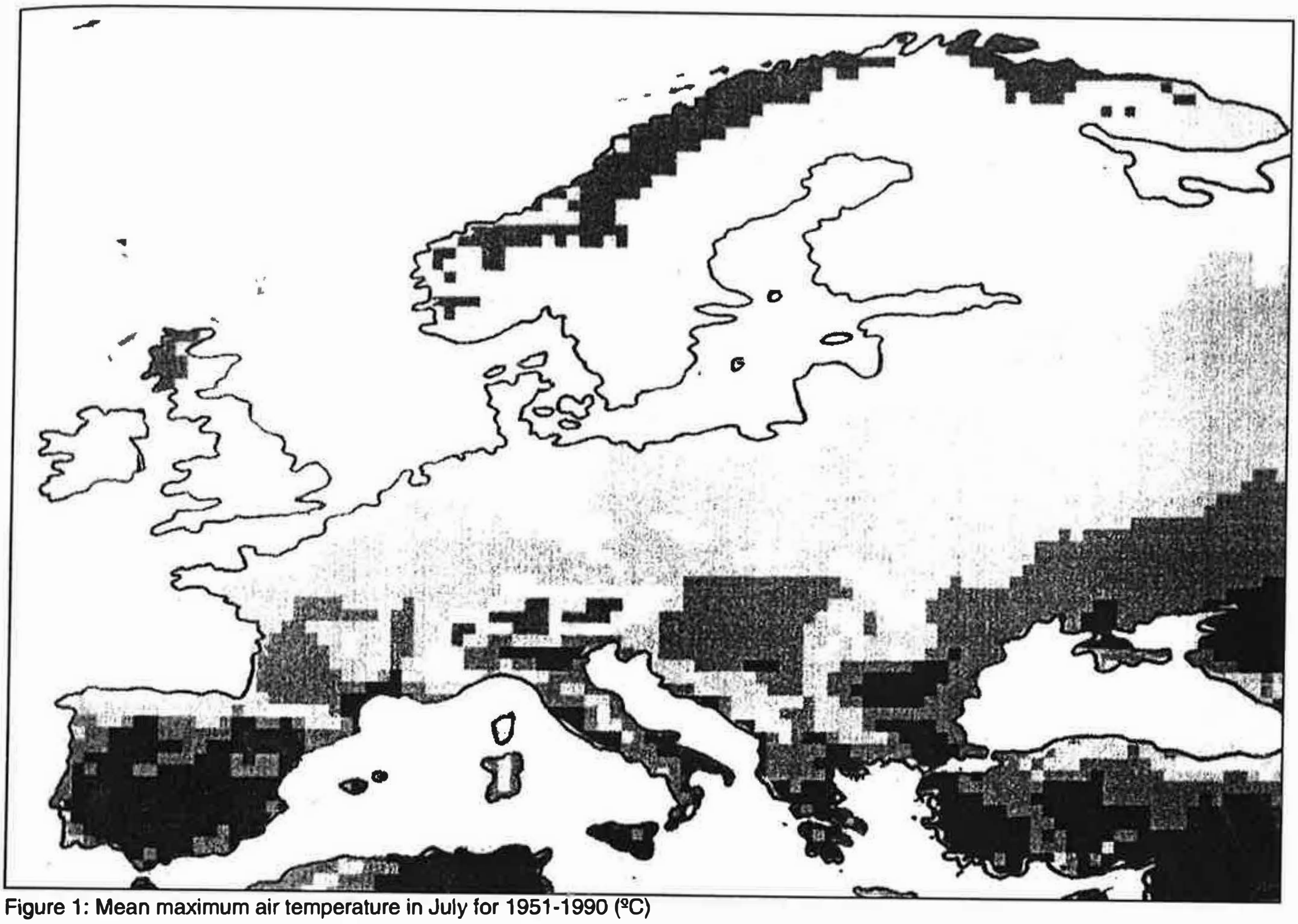

Figure 1: Mean maximum air temperature in July for 1951-1990 (ºC)

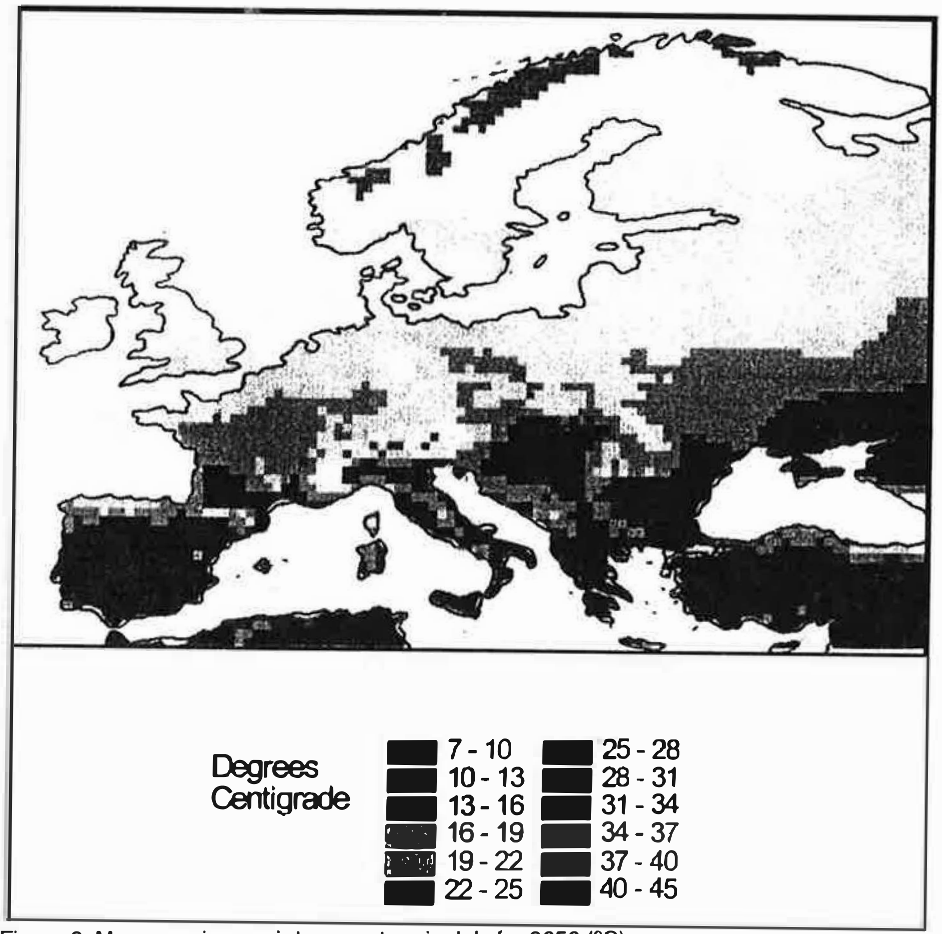

Figure 2: Mean maximum air temperature in July for 2050 (ºC)

THE MIXED MODE APPROACH AND THE USE OF HYBRID COOLING SYSTEMS

Recent developments in the use of low energy cooling strategies in commercial buildings in a number of European countries are based on three significant departures from conventional air-conditioning practice; air-conditioning is installed only in the spaces where it is actually needed, and is used only when it is actually required ("mixed mode"); the space is cooled mainly by radiant coupling and displacement ventilation is used in preference to mixing the supply air with the air already in the space.

So-called "mixed mode" buildings make the maximum use of natural ventilation and to minimise the use of mechanical cooling. The challenge for the designer is to make the natural ventilation so attractive and effective that there will rarely be a call for the air-conditioning to be switched on. The use of cool radiant ceiling panels is common in Scandinavia and is now being adopted in the UK. These panels are particularly applicable to low energy cooling in that they use water at 15-20°C, which can often be produced by evaporative cooling without the use of refrigeration equipment [8]. Air is supplied to the space primarily to maintain air quality and regulate the humidity. Desiccant dehumidification systems can be used to complement evaporative cooling systems when there is a significant latent load [9]. Displacement ventilation, in which cool fresh air is supplied at floor level at low velocity and exhausted at ceiling level offers significant air quality advantages over the conventional fully mixed approach. There are also thermal advantages in that natural buoyancy removes heat from the occupied strata, allowing air to be exhausted at temperatures higher than those prevailing in the occupied region of the space. This allows low energy cooling systems, such as indirect evaporative cooling, to function more effectively by raising the minimum temperature of the air that is supplied to the space. These approaches, and related approaches such as indirect evaporative cooling, are significant in that their use has arisen within the architectural and engineering mainstream. In particular, the mixed mode approach provides reassurance to sceptical developers, letting agents and occupiers, since the building can still be marketed as "air-conditioned", but with the added benefit of low energy bills.

CONCLUSIONS

The use of mechanical cooling, especially vapour compression air-conditioning, contributes to global warming and other climatic changes predicted to result from increased atmospheric concentrations of CO_2 and CFCs. The problem of CO_2 emissions resulting from the use of fossil fuels is likely to produce regulatory action (e.g., a "carbon tax"), although the severity, timing and uniformity of this action are unclear at present. Nevertheless, whatever form such action takes, it can be expected to require, or at least favour, the use of technologies and approaches that minimise the use of primary energy, and avoid the use of refrigerants that contribute to the greenhouse effect (as well as depleting the ozone layer) when discharged into the atmosphere. However, the performance of passive and low energy cooling systems is, by their very nature, much more sensitive to climate than is the performance of refrigeration-based systems and the likely effect of global warming on their performance should be taken into account by designers. Global warming is expected to give rise to increases of 2-3 K in summertime temperatures in Southern Europe by 2050 if significant action to reduce the emission of greenhouse gases is not taken. In particular, the regions where particular passive cooling strategies would cease to be viable over the expected lifetime of new buildings are of significant extent, although their exact location of these regions depends on the details of the particular design.

The use of air-conditioning is spreading rapidly due to a number of factors other than long term climate change. The mixed mode approach, combined with the observation of passive design principles and the use of low energy cooling systems, has the potential to overcome these factors in many cases. The resulting buildings can be expected to cost less to build and less to operate, as well as providing a more congenial environment for their occupants.

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