Natural Cooling Techniques

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ABSTRACT

This paper presents the state of the art on the natural cooling techniques.The development on the evaporative,radiative and earth contact cooling techniques and components is discussed.A classification of the existing systems and techniques is attempted and the knowledge on the more important of them is presented.Advantages and disadvantages of the classified systems are evaluated and their suitability for European climates is discussed.The luck of information as well as the existing scientific gaps on the subject are identified.Finally,future research actions are proposed for each topic.

INTRODUCTION

Dissipation of heat from buildings by the processes of radiation,convection,conduction and evaporation to a lower temperature environmental sink like air,sky,water and ground is referred to as Natural Cooling,(fig.1).Natural cooling is characterized as passive whenever the processes used do not require the expenditure of any nonrenewable energy,while when motor driven fans or pumps are used the word hybrid

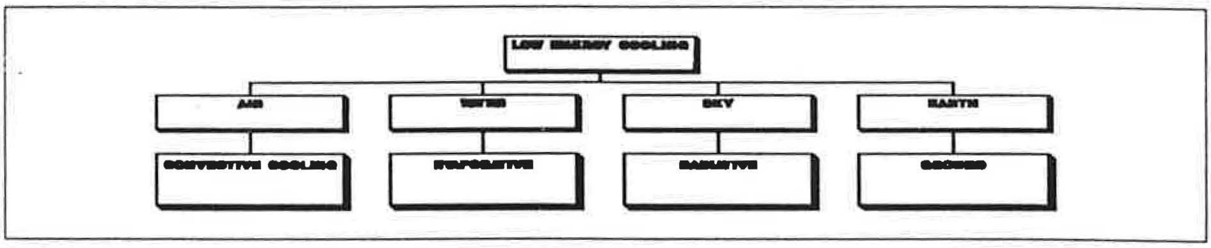

Figure 1: Heat Sinks and cooling modes

characterize the processes.

Techniques of thermal energy rejection from the building to the ambient atmosphere or to the adjacent earth were well known from the ancient years.Underground buried ceramic pipes were used in Delos,while similar systems were used in the ancient Percian architecture as well as in traditional dwellings in northern Italy [1].Fountains,pools and ponds were also extensively used to provide evaporative cooling.

The development ,in the 30s of inexpensive ,reliable Carnot cycle refrigeration systems,using electrically driven compressors,has made cooling widely feasible.During the last years,air conditioning became widespread in residential and commercial construction while annual purchases of air conditioning equipment easily exceeded the $20 billion mark by the end of the 80 s [2].At the same time,the world trade in air conditioning and industrial refrigeration equipment has more than tripled in real terms during the decade 1976 to 1985,[3].

However the impact of air conditioning usage to electric demand has became,in some industrialized countries,a serious problem.The resulting highly peaked demand profiles oblige utilities to build additional power plants,thus increasing the average cost of electricity.

The problem is very serious in USA where the total megawatts of air conditioning induced electric peak load is estimated to be 175 MW or 38 percent of non coincident peak demand.

With the increase of family income in Europe ,the use of air conditioning has become highly popular.Annual purchases of air conditioners in Greece have increased by approximately 900 per cent during the last three years,(fig 2).

Calculation of the air conditioning purchases,using the method proposed in [4],has shown that sales of air conditioners Italy and Spain go side by side,(fig 3).

Therefore strategic management of air conditioning load growth appears to be an important exercise for European countries planners.
Environmental problems associated with the use of ozone-depleting CFC refrigerants are providing also an impulse for the definition of a new "cooling policy" in Europe.
Strategies based on an improved thermal protection of the buildings envelope,as well as on the dissipation of

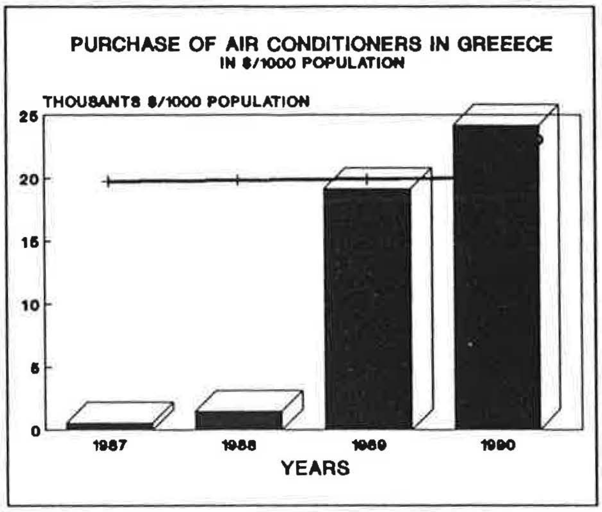

Figure 2 : Annual purchases of air conditioners in Greece

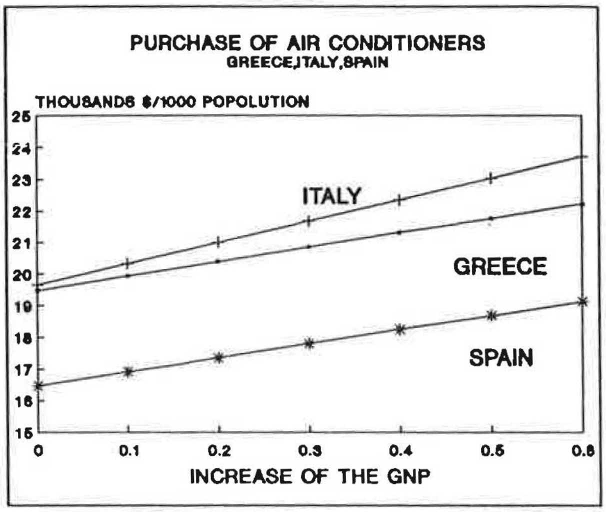

Figure 3 : Estimated annual purchases in GR,E,I.

the buildings thermal load to a lower temperature heat sink,appears to be very effective.
Preliminary research,especially on the second topic,has provided us with new effective techniques as well as with new high performance industrial components.
It is widely believed that evaporative,earth contact and radiative cooling techniques present an important potential to anticipate the air conditioning impacts.The amount of scientific and industrial effort that will be allocated on the topic will build the future growth of these new technologies.

EVAPORATIVE COOLING

Evaporation occurs whenever the vapour pressure of water,in the form of droplets or a wetted surface,is higher than the partial pressure of the water vapour in the adjacent atmosphere.The phase change of water from liquid to vapour is accompanied by the absorption of a quantity of sensible heat from the resulting in a lower dry bulb air temperature and an increase of its moisture content.Evaporation is characterized by a displacement along a constant wet bulb line AB,(fig 4).Where the decrease in the dry bulb temperature is accompanied by an increase in the moisture content of the air,a process commonly known as "direct evaporative cooling".
The potential for direct evaporative cooling is characterized by the saturation efficiency of evaporation which is defined as :

$$\text{SaturationEfficiency} = \frac{T_{d1} - T_{d2}}{T_{d1} - T_{w1}}$$

where T_{d1},T_{d2} are the dry bulb temperature of the air before and after the evaporation and T_{w1} is the wet bulb temperature of the air.

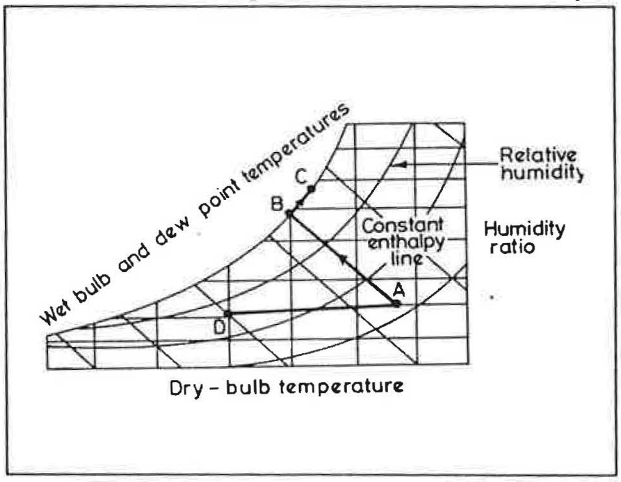

Figure 4 :Evaporative Cooling

When the evaporation taking place inside a tube or on a surface results in a decrease of surface temperature,the temperature of the adjacent air is decreased without

an increase its moisture content.In this case the process is known as indirect evaporative cooling and is characterized by a displacement along a constant moisture content line AD,(fig.4).
As it is mentioned natural cooling techniques are grouped in two major categories,Passive and Hybrid.Therefore four major categories of systems and techniques are obtained.
-- Passive direct systems and techniques
-- Passive indirect systems and techniques
-- Hybrid direct systems and
-- Hybrid indirect systems.

Passive direct systems and techniques

They include the use of the vegetation for evapotranspiration,the use of fountains,sprays,pools and ponds as well as the use of the volume and tower cooling techniques.
Vegetation is a natural form of evaporative cooler.Trees and other plants transpire moisture to reject sensible heat.The energy transfer by plant evapotranspiration is close to 2320 KJ per Kg of evaporated water [5].
The cooling potential resulting from evapotranspiration by plants is important.A full sized deciduous tree evaporates 1460 Kg of water during a sunny summer day.The corresponding energy consumption is 870 MJ a cooling effect equal to five average air conditioners [6].Also one acre of grass can transfer more than 50 GJ on a sunny day while evapotranspiration from wet grass can result in a temperature drop of 6-8 C when compared to that over exposed soil [6].
Current knowledge on the role of vegetation results mainly from observations and theoretical analysis.Observations reported in [7] indicate a temperature reduction of 2-3 C due to evapotranspiration by plants.Also in [8] it is found that temperatures in the San Francisco heavily vegetated Golden Gate Park average 8C about cooler than nearby less vegetated ones.
Theoretical analysis on the role of evapotranspiration by plants given in [9] indicates that evapotranspiration from one tree can save 250 to 650 Kwh of electricity used for air conditioning per year.
Fountains,sprays,pools and ponds for evaporative cooling are particularly effective.Famous applications are the Shah Jahans Taj Mhal in Agra,the Moorish Place and the Alhambra in Granada.
The rate of evaporation from a wetted surface depends upon the air velocity and the difference between the vapour pressure of the moisture and the air adjacent to the moist surface.Calculations based on mean summer climatological conditions give an evaporation rate between 150-200 W per square meter,which is the cooling potential of this technique.
Evaporative cooling in open spaces is particularly effective in areas that have dry bulb temperatures below 21 C.The limits for evaporative cooling as defined in [5],are given in fig.5.

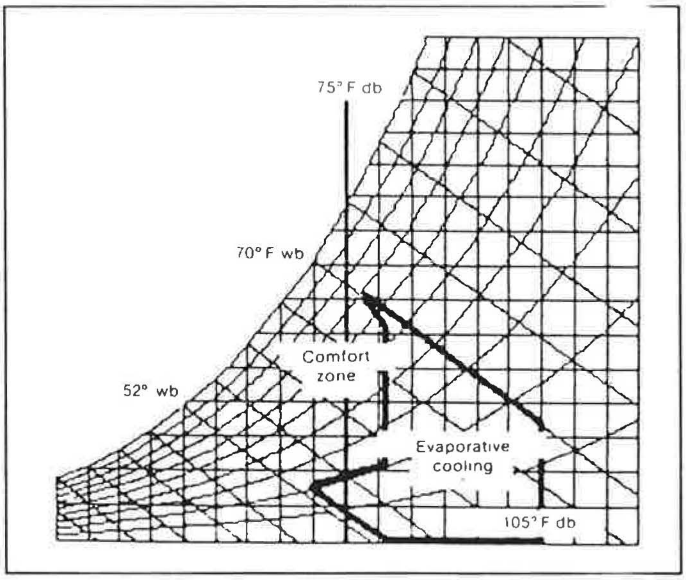

Figure 5 : Limits of evaporative cooling

Volume cooling techniques are known from traditional architecture.The system is based on the use of a tower where water contained in a jar or sprayed is precipitated.External air introduced into the tower is cooled by evaporation and then transferred into the building.
A contemporary version of this technique was presented in [10].Here a wet cellulose pad is installed at the top of a downdraft tower ,below the roof,where the air is humidified.Measurements have shown that with a dry bulb temperature of the incoming air of 35.6 C and wet bulb of 22.2 C the exit air temperature was close to 24 C.

Knowledge on this technique is coming from organized experiments described in [11],as well as from theoretical analysis referred to [12].

Passive Indirect Evaporative Techniques

They includes mainly the following techniques :Roof spray,Open water pond and Moving water film.
In the roof spray technique,the exterior surface of the roof is kept wet using sprinklers.The sensible heat of the roof surface gets converted into latent heat of vaporization and the water evaporates.A temperature gradient is created between the inside surface and the outside surface causing cooling of the building.A threshold condition for the operation of the technique is that the temperature of the roof should be higher than the wet bulb temperature of the air.
Experience with this type of technique has been acquired through many commercial applications in USA,[13],and from experimental work described in [14,15].The observed reduction in cooling load is close to 25 per cent [16-18].However there is no information on the performance of the system in Europe.There may be large variations from one installation to another.
There is a number of problems associated with this type of technique.Studies,[13],have shown that it is not cost effective and that improving the thermal insulation of a roof may be a better alternative.Also there are problems associated with the appearance of the exposed piping,likely damage to the roof,associated with pipe freezing etc.
A roof pond consists of a shaded water pool over an uninsulated roof.Evaporation of the water to the dry atmosphere occurs during night time.The temperature of the roof follows closely the ambient wet bulb temperature,while the ceiling acts as a radiant convective cooling panel for the space under it.Thus, the indoor air, and radiant temperatures can be lowered without elevating indoor humidity levels.
A threshold condition for the application of the system is that the temperature of the roof should be higher than the wet bulb temperature of the air.According to [12],a wet bulb temperature lower than 20 C is the necessary threshold condition.
Knowledge on this technique has been developed through experiments described in [19-21].Important information is also coming from theoretical analysis described in [12-22]
According to [12],a decrease of 2-3 C of the ceiling temperature was achieved while in [22] a decrease of 13 C is reported.However there are no evaluations of the system for European conditions.
The limitation encountered with this technique is that it is restricted to single storey building with flat concrete roofs or to the upper floor of multistorey buildings.Also the capital cost could be high while there is again a question of whether a well insulated roof of conventional construction should be more appropriate.
The moving water film technique is based on the flow of a water film over the roof surface.Therefore the evaporation process is enhanced by an increase in the relative speed between air and water surface.The cooled water is stored in the basement and then is circulated within the room to cool it.
The threshold condition for the operation of the system is that the roof temperature should be higher than the wet bulb temperature of the air.
Knowledge on this technique has been developed through limited experiments described in [23].However there is very little information and limited data on the system while it appears to be useful only in humid climates.

Hybrid direct evaporative systems

In a direct evaporative cooler water is supplied to a small reservoir and then flows through fibrous pads.A fan draws large volumes of outdoor air through the pads,where it is cooled by evaporation and then is supplied to the building interior.Thus its dry bulb temperature is reduced while its moisture content is increased.The principal types of coolers are the "Drip type cooler",the "spray type cooler" and the "rotary pad cooler".Detailed description of these systems are given in [24].
There are many manufacturers of direct systems in the USA,Australia and Europe and there is considerable experience with these system over the last 50 years.The direct evaporative cooler can be a useful cooling device in places characterized by a low wet bulb temperature.A threshold value for the use of such a system is that the ambient wet bulb temperature should be lower than 24 C.A plotting of the design summer dry and wet bulb temperatures for some European locations [25],is given in fig.6.In the same figure the curvescorresponding to a cooler with a saturation efficiency of 60 and 80 per cent are drawn.As it is shown the design temperatures of an important number of locations are out of range permitting application of direct evaporative cooling techniques.
The main problems associated with direct evaporative coolers is the increase of the moisture content of the air.Hence their use should be always combined with a humidity control system.Other problem may arise due to the porosity and the capillarity of the cooler,the filter capacity,etc.

Hybrid Indirect Evaporative cooling systems

They are based on the use of a heat exchanger where the indoor ventilated air passes through the primary circuit where evaporation occurs while the outdoor air passes through the secondary circuit.This decreases the temperature of the air without any moisture increase.There is an important industrial development of this type of system with more than 10 manufacturers worldwide.There are three main types of indirect coolers: the

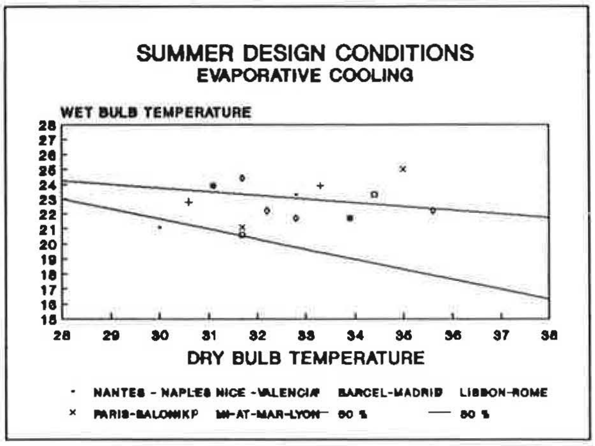

Figure 6 :Design dry and wet bulb temperatures

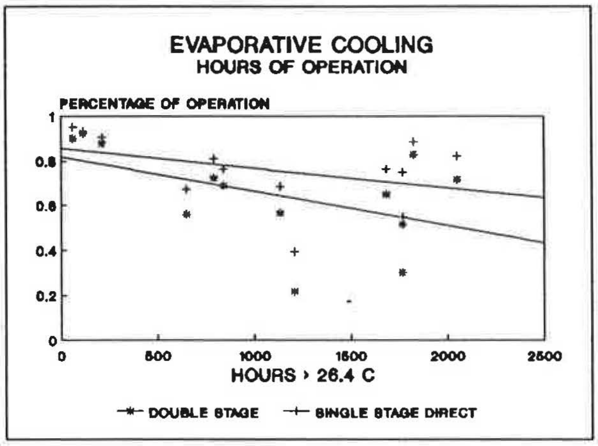

Figure 7 :Percentage of possible working hours

plate,the tubular and the rotary type coolers.Detailed description is given in [24].

The threshold value for the operation of the system is that the indoor air wet bulb temperature should be lower than the outdoor dry bulb.In practice,the indoor wet bulb should be lower than 21 C.According to the reported data ,[26],the performance of the system is quite satisfactory.

Energy savings of up to 60 percent compared to compression refrigeration systems may be achieved in hot dry regions [24].However,the efficiency of the system is strongly influenced by the wet bulb temperature of the outside air.

As indirect evaporative systems do not add moisture to the building,no humidity control is required for their operation.Corrosive components should be avoided for maintenance reasons.Effective filtering is necessary to reduce the number of dust particles.

Where the ambient air is too high,a two stage evaporative system can be used.This consists of an indirect cooler coupled with a direct one ,or/and an indirect cooler.They may be coupled with a refrigerative A/C unit.

There are many applications of these systems,especially in California,and there is a number of established manufacturers,also in USA.Energy savings for such a system have been reported at close to 50 percent compared to an equivalent A/C system [24].

The association of a direct with an indirect evaporative cooler results in lower temperature threshold values reducing thus the possible working time of the equipment.However a double stage cooler offers lower dry bulb temperatures than a single stage,resulting thus in increased indoor comfort levels.Figure 7 shows the percentage of possible working hours of a single (+),as well as of a double (*),stage cooler as a function of the period where cooling load exist.A performance statistics has been derived after extensive calculation for 14 South European locations.Similar data are also presented in a monthly basis in figure 8 for Athens.As it is shown single stage direct evaporative coolers can operate 5 to 20 per cent longer than the double stage equipment.

However the use of direct evaporative coolers increase the indoor humidity levels,and decreases comfort.In figure 9 the range of the relative humidity of the exit air from a single direct and a double stage cooler in Athens is given.As it is shown the use of double stage coolers should result in lower indoor humidity levels.Therefore the percent of time that direct coolers will deliver air cool enough to maintain the effective space temperature as specified by the user ,comfort index,is limited.Figure 10 shows the mean monthly comfort index achieved in Athens using a single direct and a double stage evaporative equipment.It is clear that under these climatic

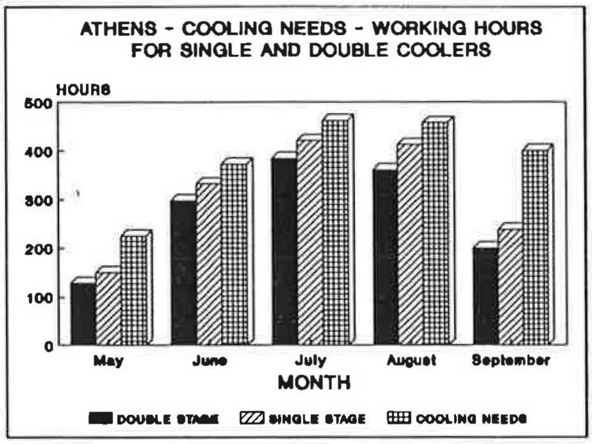

Figure 8 : Needs and working hours of the coolers

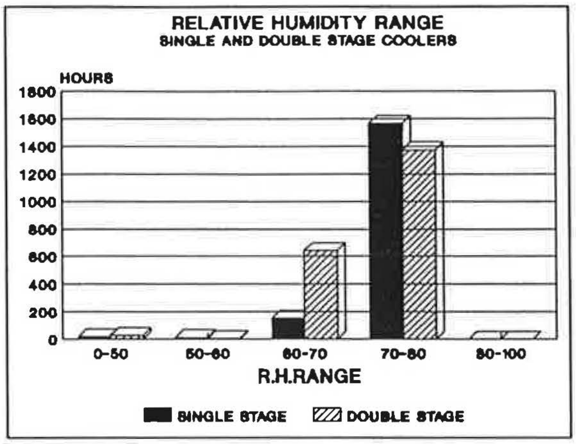

Figure 9:R.H.output from single and double stage coolers

conditions direct evaporative coolers are of limited ability to provide effective air conditioning.The mean summer comfort index for 14 South European cities resulting after the use of direct evaporative coolers is given also in fig. 11 as a function of the 1 % wet bulb temperature.As it is shown higher w.b. temperatures correspond

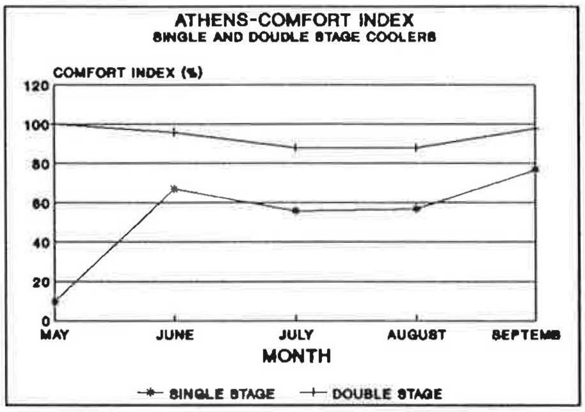

Figure9: Mean monthly comfort index in Athens

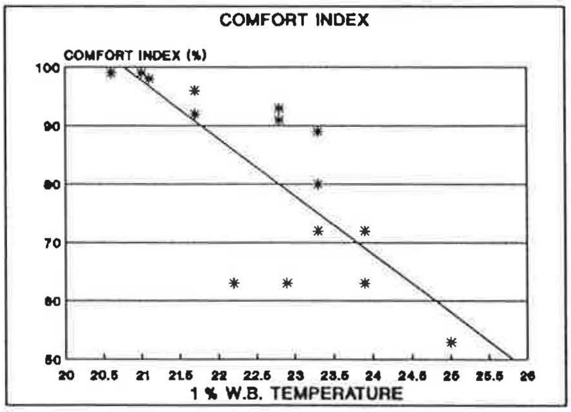

Figure1I : Mean monthly comfort index for 14 locations

to lower comfort indexes

Future Research Actions.

A future research action on evaporative cooling should be focused on six main areas :

1.Collection and classification of relevant climatological data for Europe.
2.Assessment of the utilisability and benefits of evaporative cooling techniques for European conditions.
3.Development and validation of software for the calculation of the performance of selected systems and techniques.
4.Experimental study of promising passive techniques and assessment of the main design parameters.
5.Development of appropriate coolers in conjunction with European industry.
6.Production of a handbook describing the applicability of evaporative cooling techniques and systems in Europe.

EARTH COOLING

During the summer,the soil temperature at certain depth is considerably lower than the ambient temperature.Therefore ground offers an important source for the dissipation of the buildings excess heat.Seasonal variation in earth temperatures decreases with depth,moisture content,soil conductivity and with the surface covering.The relative ranges of the soil temperature as function of depth for various types of soil is given in figure 12 [27].

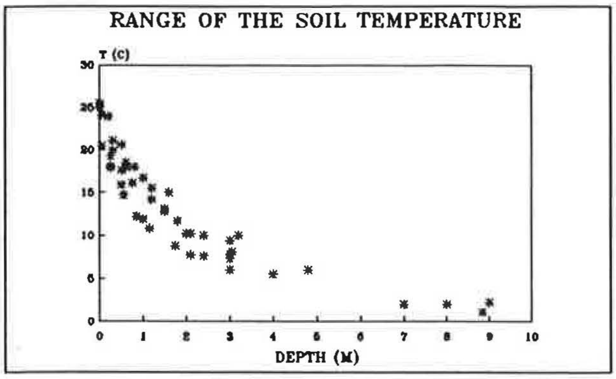

Figure 12 : Variation of the soil temperature with depth

At the same time ground can contribute to the reduction of the heat gain from the exterior,offering effective solar and heat protection.

There are two main strategies for the dissipation of the heat to the ground.The direct earth contact cooling which involves partial or total placing of the buildings envelope in direct contact with the soil,and the earth pipes technique which involves the use of a buried pipe where air from the building or from the outside is circulated through the pipe where it is precooled and then is brought into the building.

Direct Contact Buildings

The transfer of heat from the building to the earth through the walls ,the floor and possibly the ceiling is a well known technique.

Earth coupled techniques have been used at different times in history and in different parts of the globe.Important underground dwellings,villages and communities have been also developed in the Mediterranean region,[28-31].

During the last years the use of the earth as a heat sink for climate control has become popular.Estimates of the number of earth sheltered houses in USA in 1982 range from 4000 to 8000 [32].In Europe there is an large number of one or two story buildings which are set into hillsides,placed partially or completely below grade.

Knowledge on the performance of earth sheltered buildings comes mainly from measurements of traditional buildings,[33],from monitoring of new constructions,[34-35],as well as from theoretical analysis,[32].Energy gains of about 50 to 90 percent are reported for various monitored earth sheltered buildings,[34-35].

Earth contact buildings offer various advantages i.e limited infiltration and heat losses,solar and heat protection,reduction of noise and vibration,fire and storm protection and improved security.Also they present important environmental and land use benefits while their maintenance and operation cost is low.

However they are not free of disadvantages.Inside condensation,slow response to changing conditions,poor daylighting and poor indoor air quality are frequent problems.In addition high cost reduces the potential for a wide scale constructions of such buildings.

Buried Pipes

Underground cooling tunnels is a concept that can be traced back several centuries.Applications of these techniques at different times and in different parts of the world are described in [1,36,37].

The concept involves the use of a metallic or a PVC pipe buried at 1 to 3 m depth.Ambient or indoor air is delivered inside the tubes where it is precooled and then is delivered to the building.When outdoor air is circulated into the pipes the system is characterized as an open loop system while when indoor air is recirculated from the building through the tubes the system is known as a close loop system.

The performance of the buried pipes is a function of the inlet air dry bulb 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.

Techniques to estimate the efficiency of such systems have been developed by various authors and a review of the existing methods is given in [38].

Knowledge on the topic is coming mainly from single pipe experiments [39-46],as well as from theoretical analysis.Results reported in [47],show that for a 30 m long PVC pipe buried under shaded soil at 1.5 m depth,the maximum temperature drop inside the tube was 18 C,(Fig. 13).However the temperature reduction is time variable.The inlet and exit air temperature for 120 hours of continuous operation,taken in the previous

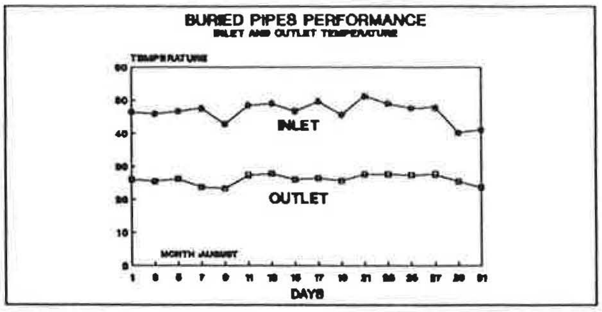

Figure 13:Inlet and outlet temperature from a buried pipe

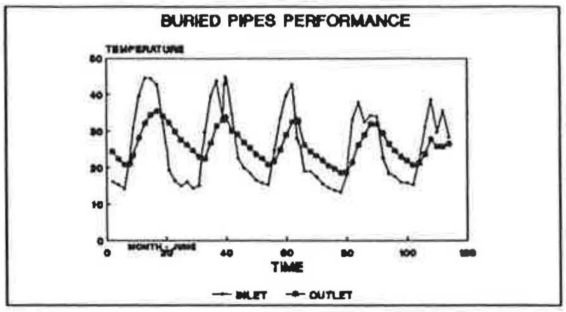

Figure 14:Continuous operation.Inlet and outlet

experiment are given in fig 14,[47].The exit air temperature was significantly lower than the inlet one,during daytime and significantly higher during night.is indicates that buried pipes can be used for precooling as well as for preheating of the building.

Special problems related to this technique is the limited potential for dehumidification,reducing thus the possibility for latent cooling.Condensation inside the tubes can occur only with very low air flow and high ambient dewpoint temperatures.Also in damaged tubes water,is possible,to enter into the tubes.Moisture accumulation can lead to biological growth and resulting odour problems.However no such problems have been reported.

Future Research Actions

Suggested future research actions on the field of ground cooling are the following:

1.Collection of relevant climatological data,especially on ground temperature for different types of soils.

2.A review of the literature on earth sheltered buildings which could be followed by selected short term field studies and occupant interviews.

3.Development of an evaluation method for the prediction of the performance of partially covered buildings and validation of the method.

4.Experimental activities on the technique of buried pipes under different type of soils,materials etc.

5.Development of a model for the prediction of the efficiency of buried pipes and validation of the model.Studies on the control of the systems and on the coupling of the system with the building and with conventional cooling systems.

6.Practical guides regarding the application of those systems and dissemination of information.

RADIATIVE COOLING

Radiative cooling is based on the effect when heat is lost by a body due to its long wavelength radiation to the night sky.The net radiant heat loss from the body is the balance between the emitted energy flux and the absorbed incoming atmospheric radiation.Atmospheric radiation depends mainly on the level of cloudiness.Under cloudy sky conditions the atmospheric radiation reaches its maximum minimizing thus the net radiant heat loss.Vapour content and increased aerosol concentration tend to increase also the sky radiation [48].However the net energy loss from a body is the balance between the net radiative loss and the convective heat exchange between the radiator and the ambient air.

Convective heat transfer from the radiator is a function of the wind speed near the radiator and is proportional to the temperature difference between the radiator and the ambient air.

Radiative cooling techniques were well known from the ancient years and they were used to produce ice and to cool the buildings. During the last years radiative cooling has been investigated for a variety of building cooling methods. Existing cooling techniques can be classified as passive or hybrid. Passive systems, mainly involve the use of the building roof as the radiative component, while hybrid systems involve the use of special metallic surfaces characterized by high emissivity in the longwave range. Important techniques for passive radiative cooling is the "white painting"of the roof the use of the concrete roof associated with operable insulation and the "Skytherm" system.

Passive Systems

The colour of the roof influences the thermal performance of the building significantly because it governs the absorption and reflection of the incident short wave radiation during daytime and the emission of longwave radiation during night time. Painting the roof white increases the reflectivity of the roof to the solar radiation reducind thus its temparature. This technique is traditionally followed in the Mediterranean region and more especially in the Greek islands.

Measurements of the performance of this technique reported in [49] give a cooling potential of 0.014 KWH per square meter per day. Experiments also reported in [50], using different roof colours, give a temperature difference of 3 C and 1 C ,when measured 0.1 m below the roof and 1.2 m above the roof , respectively for grey and white roofs. However, the effect of colour is more important with light structures than with structures of high thermal capacity.

The main problems associated with this technique is the high rate of heat loss during the winter imposing for a new change of colour, the high indoor temperatures during daytime in the summer and that is effective only in single storey buildings.

In conclusion, this technique is of poor performance and it should be considered as a solution only in warm regions.

Exposing the cold storey mass to the sky during the night while protecting it during the day by a movable insulation optimises the potential of radiant cooling.

Operable insulation can be in the form of horizontal movable panels or hinged panels positioned vertically during the night.

Measurements of the performance of this technique reported in [49,50] give a cooling potential of 0.266 KWH per square meter per day. The minimum recorded temperature of the surface was 14 C while the maximum was 19 C . Also the minimum indoor temperature was 15.2 C and the corresponding maximum 22.4 C [49].

The main problem associated with this technique is that is effected only in single storey buildings while the horizontal operable insulation requires storage spaces for the night,and the hinged panels cover an area of the radiant roof corresponding to their thickness.Also it should be pointed out that the system require important man or mechanical operation.

The "Skytherm" system proposed by H.Hay involves the use of water bags which are placed on the roof.A movable insulation is placed above the bags during day to keep the solar heat away from the water and is removed during night where the water loose heat by convection,radiation and evaporation and thus the water cools the living spaces.

Various other types of architectural integration of this system are proposed in [51].

Knowledge on this topic comes from experiments of Hay,[52],at Atascadero House in California.The results of this experiment are reported in [53].It was observed that on a typical summer day,the variation in outdoor temperature was from 13 C to 34 C,while the corresponding indoor temperature ranged from 21 C to 23 C only.

However the Skytherm system present important limitations.Some of these are :

I t is applicable only to one storey buildings or to the upper floor of multistorey buildings

A deterioration of the plastic with time,is observed reducing thus its transparency.

There is an accumulation of dust and

The cost of the system is important.

Hybrid Systems

Hybrid radiative cooling systems involve the use of specialized metallic longwave radiators which can reach temperatures below those achieved when the roof is cooled directly.The radiator should be lighweigh and possibly insulated underneath to avoid heat flow to the radiator from the roof below.Th n e operation of the system involves the flow of a transfer medium,water or air,flowing above ,under or within the radiator which is cooled and then is used directly or it is stored in order to cool the building.

Storage can be achieved circulating the cool water into the concrete floor,which serves as combined cold storage and radiant convective cooling panel,[54].Cool water can be also stored in water tanks,[55],for later use.

The potential of metallic radiators for radiant cooling is a function of the possible depression of the radiative surface temperatureTh.e maximum depression is achieved under stagnation conditions,i.e when the radiant heat loss is not used.The corresponding temperature of the surface is refered as stagnation temperature and

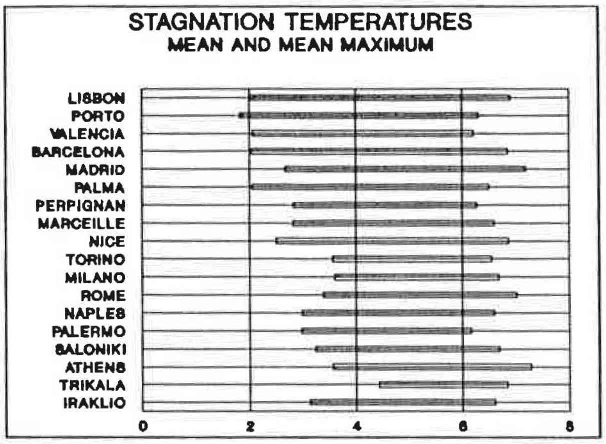

Figure 15 : Mean and maximum stagnation temperatures

express the potential for radiant cooling for any climatic conditions.

The mean temperature depression under stagnation conditions for 18 Mediterannean locations is given in figure 15.Stagnation temperatures have been calculated using the method proposed in [56].As it is shown under mean climatic conditions the expected temperature depression ,under stagnation conditions,rarely exceeds 3 C.In the same figure the possible maximum temperature depression is also given.In this case the corresponding stagnation temperatures have been calculated using optimum climatological conditions,i.e clear sky ,low wind speed etc.The calculated maximum depression temperature range from 5 to 7 C.

Improvement of the performance of metallic radiators can be achieved using high emissity's selective surfaces and infrarent transparent windscreens to reduce convection from the surface.

Selective radiators present a high emissivity in the 8 -13 microns wave band while are highly reflective above and below this wavelenght band.However selective radiators are advantageous only when its temperature is lower than the effective sky temperature.In this case the intensity of the atmospheric radiation above and below 8 - 13 microns is higher than the radiation emitted by an ordinary surface in these spectral region.However when the radiator's temperature is higher than that of the sky the emitted from the surface radiation exceeds that of the atmosphere at all wavelenghts,and thus selectivity does not offer any advantage regarding ordinary radiators.

Experiments with selective surfaces,and more especially with anodized aluminum of 4 and 10 microns,aluminum with sodium silicate layer and aluminized tedlar sheet,described in [57-61] report temperature's dempression from 5 to 17 C.Comparisons with ordinary surfaces have shown however that the difference between them is negligible.Also when the temperature depression is important,condensation occurs on the surface and thus the surface lose its selective radiative properties.

Wndscreens transparent to infrared radiation decrease the convective heat from the ambient resulting thus in lower radiator's temperature.The material commonly used is polyethylene without U.V. inhibitors.Polyethylene is characterized by a transmissivity to longwave radiation equal to 0.75 ,a reflectivity equal to 0.1 and an emissivity equal to 0.15 [62].Polyester and fiberglas films have been tested also without sucess [57].

Experiments ,[62-63],report that a radiator covered by a windscreen was 3-4 C lower than the corresponding temperature of an ordinary radiator.However when the temperature of the polyethylene film drops below the ambient dew point ,dew is formated over the windscreen ,and thus the transmissivity of the polyethylene to the infrared radiation is reduced significantly.

Future Research Actions

The suggested future research in the field of radiative cooling may be classified in the following actions :

Collection of the sky temperature for various sites in rope in order to realize a sky temperature map.Improvment of empirical models to calculate the sky temperature.

Development of an evaluation method for the performance of radiators taking into account condensation,convection,dust covering and thermal coupling with the buildingExperimental validation.

Development of low cost ,efficient selective surfaces

Integration of radiative systems in the building design

Guideline on the use and the sizing of these systems.

CONCLUSION

The state of the art on the natural cooling techniques is presented.The more important techniques and componentsof evaporative,earth contact and radiative cooling are presented and their performance is discussed.Future research actions are proposed for each topic.

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