LOW ENERGY COOLING STRATEGIES

CLIMATISATION À BAS ÉNERGIE

KÜHLUNGSSTRATEGIEN MIT GERINGEM ENERGIEAUFWAND

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Summary

Environmental concerns such as ozone depletion and global warming are forcing the building design profession to explore new ways of space conditioning. This paper looks at a number of potential low energy cooling strategies, and using dynamic analysis techniques makes an assessment of the ability of such strategies to contribute to the cooling of buildings in the UK climate.

The use of low energy cooling techniques will require a re-evaluation of the acceptable limits for thermal comfort, and so the analysis is presented in the form of frequency distributions at which certain levels of internal temperatures are exceeded. The results indicate that at low levels of internal gains, a number of passive/hybrid technologies are able to provide appropriate levels of cooling, eliminating the need for mechanical refrigeration. At higher levels of gain, these systems can make a significant contribution in offsetting the capacity and energy consumption.

Résumé

Nous examinons un nombre de stratégiés de climatisation à bas énergie, et, en utilisant des techniques d'analyses dynamique, nous évaluons l'abilité de ces stratégies de climatiser les batîments de l'UK.

L'utilisation de ces techniques va nécessiter une ré-évaluation des échelles de confort, et l'analyse a été donc présenté sous forme de probabilités que la temperature interieure dépasse des certains niveux de confort. Les résultats indicent qu'un certain nombre de stratégies passive/hybride peuvent fournir le niveu de confort qu'il faut, pourvu que les apports de chaleur sont bas. A des niveaux plus importants, ces systèmes peuvent réduir la capacité et la consommation de'énergie.

Zusammenfassung

Umweltinteressen, wie die Ozonverringerung und die globale Erwärmung, zwingen die Hochbau-Konstrukteure neue Wege für die Kühlung von Räumen zu erforschen. Dieses Papier und veranschaulicht eine Vielzahl von möglichen Kühlungsstrategien mit geringem Energieaufwand und wendet dynamische Analysetechniken an, die eine Festestellung der Fähigkeiten solcher Strategien ermöglichen, die zur Kühlung von Gebäuden innerhalb des Klimas von Groβbritanien beitragen.

Die Verwendung von Kühlungstechniken mit geringem Energieaufwand erfordert eine Vorabbewertung der annehmbaren Grenzen Für die thermischen Behaglichkeit. Deshalb wird die Analyse in Form von Häufigkeitsverteilungen dargestellt, bei denen bestimmte Niveaus der Innentemperature überschritten werden. Die Ergebnisse zeigen, daβ bei einem niedrigen Aufkommen an interner Wärme eine Anzahl von passiven/Hybrid-Technologien ausreicht, um für ein angemessenes Kühlungsniveau zu sorgen, daβ den Bedarf an mechanischer Kühlung überflüssig macht. Bei höherem Wärmeaufkommen können diese Systeme einen hohen Beitrag zur die Reduzierung der Kühlaggregate und des Energieverbrauches leisten.

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1. Introduction

There is an increasing need to explore alternative cooling strategies for buildings. This need arises because of a number of factors:

a) The Montreal Protocol is having a real impact on the traditional mechanical refrigeration systems, requiring that many systems be modified or replaced at considerable cost.

b) Vapour compression cooling is a significant user of energy in buildings, and its importance as a contributor to greenhouse emissions is enhanced by the fact that these systems are electrically driven.

c) In addition to energy consumption and CO_2 emissions, cooling requirements can result in high electrical demands, with consequent problems for the utility companies.

d) The possibilities of global warming may lead to further increases in demand for cooling, with more CO_2 production, leading to further warming. This circle has to be broken. Increasing use of information technology by organisations is another factor leading to an increasing demand for cooling in the commercial sector.

For these and other reasons, considerable attention is now being given to alternative cooling strategies for buildings. This paper reviews some of these, and makes an assessment of their applicability to the UK climate.

2. Low Energy Cooling Techniques

The various low energy cooling technologies can be sub-divided into a number of different categories; this paper will concentrate on passive and hybrid systems. In examining various alternative cooling strategies, it is recognised that in many cases, a passive method alone may not satisfy the needs of a whole building, and so a mixed strategy utilising some mechanical refrigeration may be required. However such a mixed strategy should result in smaller refrigeration plant with reduced run hours.

In developing a passive/hybrid cooling strategy, the first step is always to minimise the heat gains to the occupied space. This requires careful consideration of building form and geometry, with special emphasis on shading devices to limit solar gain without unduly restricting penetration of daylight. The internal heat sources must also be controlled; for example high efficiency light sources should be used, and an appropriate control strategy adopted to ensure lights are switched off when natural light levels are adequate. As in all approaches to building design, there are compromises which have to be reached, and the importance of the occupant's desire for personal environmental control must not be forgotten.

This paper concentrates on different approaches to providing the cooling effect rather than looking at ways to limit the heat gain. The various strategies examined in this paper are:-

Natural Ventilation uses air movement driven by natural forces (wind and buoyancy) to cool the building. By definition, the degree of cooling obtainable is limited by the diurnal variation in air temperatures. Design methods need a careful analysis of ventilation openings, driving forces and building thermal mass. The main difficulty is to ensure adequate temporal and spatial distribution of air given the variability and unpredictability of the weather. Natural ventilated solutions tend to rely on relatively narrow plan widths, although this also can be utilised to enhance daylight and provide good visual contact with the exterior views. If the system relies on opening windows, due consideration needs to be given to potential noise problems from outside the building. It should be noted that natural ventilation systems need not be restricted to open window strategies. Increasing attention is being given to passive ducts and solar chimneys as a means of providing a more controlled approach.

Mechanical ventilation uses auxiliary energy through the use of fans to provide the necessary flowrates and distribution of outside air to cool the space. As with the natural ventilation option, careful consideration needs to be given to the integration of such strategies with the thermal mass of the building. The problem with ventilation options (natural and mechanical) is that the peak heat gain usually coincides with the maximum external temperature. Consequently, it is important that the building has significant thermal inertia in order to smooth out the temperature swings. The proper integration of the thermal mass is a key design issue.

Evaporative cooling involves using a fan to draw air through a saturated vapour environment (sprays, wetted films etc). This reduces the dry bulb temperature of the air at the expense of increased humidity. Depending on the climate, this cooled air can be used directly to condition the space, or alternatively, used to cool the building exhaust, which then cools the supply air by means of a heat exchanger. Care needs to be taken with such systems to avoid any problems associated with legionella and other health risks.

Earth cooling involves drawing air or water through buried underground tunnels, and using the 'coolth' store of the earth as a means of providing free cooling. Even in the summer months, the average soil temperatures in the UK at a depth of 2 m is around 12°C, and this provides the potential for significant cooling of the ambient air. This approach has the additional benefit of providing the opportunity for pre-heat of ventilation air in winter.

Thermal mass provides the opportunity to store 'coolth' in the building fabric, and thus take advantage of the diurnal variations in outside temperature to minimise the swings in internal temperature during the day. This is usually achieved by having an exposed slab with no false ceiling. The slab can be cooled either at its surface by night time ventilation to the room, or at the core of the slab by passing air or water through flowpaths embedded within it.

Another factor which is providing added benefit to these systems is the desire for improved air quality which leading to increased attention to displacement as opposed to mixed ventilation. Displacement ventilation relies on introducing air at relatively small temperature differences to the room air, and using the convection currents from the heat sources in the room to create plumes of warmer air which remove the pollutant to the extract point rather than dispersing it through the room. The synergy comes from the fact that passive and hybrid systems are able to provide these relatively low supply to room temperature differences, and are therefore well suited to use with displacement ventilation.

Reference 1 contains a more detailed description of these strategies. These various technologies have been evaluated according to a consistent methodology in order to gain an insight into how effective they might be in the U.K. climate.

3. Methodology

3.1 Factors Affecting the Cooling Load

A number of factors influence each of the innovative cooling technologies and the implication of these must be considered under current circumstances and possible future scenarios. These factors include both internal and external issues and the limiting value of each must be identified in order to assess the likely impact on the various technologies.

Required comfort conditions: the perceived comfortable environment is a complicated and to a some extent subjective matter. Rather than specify a single comfort criterion, the ability of each cooling system to maintain a range of comfort conditions was assessed. It is recognised that many factors affect an individual's perception of comfort including temperature, humidity, air speed, radiant asymmetry etc. For the purposes of this analysis, the assessment of comfort was based on the predicted dry resultant temperature, with a secondary limit on the maximum allowable relative humidity. The range of comfort temperatures considered were:-

Low	23°C
Medium	25°C
High	27°C

where the low represents the expectations from a traditional mechanical air-conditioning system and the high represents the level often considered acceptable for a naturally ventilated building. For each temperature threshold, a secondary limit of 65% relative humidity was also established.

External Air Temperature: the external weather conditions or, more specifically, the internal to external temperature difference is a major contributor to the need for cooling. As well as examining the current climatic conditions, it is also important to consider future trends, particularly in view of the possibilities of global warming. The base case external environmental conditions are represented by a continuous sequence of hourly data, measured at Heathrow Airport, that was closest to the 20 year mean. This was determined by the method used to define CIBSE Example Weather Years. To estimate the possible effect of global warming, an additional weather dataset was produced. This was derived from the standard weather tape, but the dry bulb temperatures was increased by 2°C.

Level of Equipment Gains: the need for cooling is strongly influenced by the amount of heat that is generated within the building. Recent trends in information technology have resulted in extensive use of computer equipment and hence higher heat emissions. The range in use of office equipment was represented by three levels:-

Equipment	Low	10 Wm^{-2}
	Medium	20 Wm^{-2}
	High	30 Wm^{-2}

The importance of the values assumed for internal gains from equipment should not be underestimated. Recent work (reference 2) has indicated that 'traditional' assumptions about internal gains have been grossly overestimated, leading to oversized (or even unnecessary) cooling plant being installed.

Although the energy gains from the equipment were the only source for which different levels were considered, other sources, namely from people and lighting were included in the calculations. The gains from people were set at 100 W sensible, 40 W latent per person with a density of 10 m^2 per person. Similarly lighting gains were taken as a constant 15 Wm^{-2}.

The solar gains were calculated as part of the dynamic simulation procedure.

A number of important conclusions can be drawn from the table. It is clear that even in the relatively temperate U.K. climate, passive /hybrid cooling technologies are not able to maintain the level of comfort that has traditionally been associated with air conditioned buildings. However it is clear that these technologies can make a substantial contribution to both a reduction in the required installed chiller capacity, and the hours such chillers are required to run. This may well have significant benefit in terms of both reduced capital cost and reduced energy consumption / CO_2 production.
The table also re-inforces the obvious conclusion that limiting the gains to the space is a very important part of implementing a successful passive cooling strategy. This emphasises the need for a holistic approach to design development, involving the architect and services engineer working together to integrate the cooling system into the overall building concept.

One point which does not come directly from the above analysis is the fact that although hybrid cooling systems utilise 'free' energy sources, they do use ancillary energy to facilitate the capture, storage and distribution of that free 'coolth'. The effect of this ancillary energy must not be ignored if optimal designs are to be obtained. For example, a simplified analysis of indirect evaporative cooling shows that the additional pressure drop caused by the evaporative cooler and the heat recovery device can result in an increase in fan energy greater than the reductions in required chiller energy. Table 2 below indicates the reduction in chiller energy consumption relative to a standard economy cycle free cooling strategy for a range of indirect evaporative cooling systems.

Efficiency of evaporative cooler (%)	70	70	70	90	90	90
Efficiency of heat recovery (%)	50	65	80	50	65	80
Energy savings (%)	17	0	-14	13	-2	-14

Table 2: Percentage energy savings for indirect evaporative cooling as a function of component efficiencies

This table should only be taken as indicative of trends, and not as an indicator of absolute performance. However it does illustrate that maximising thermal efficiency is often at the expense of increased transport energy, and the need for the design to seek global rather than local optima. This emphasizes the need for a total systems approach to design as opposed to a component based approach.

Another important point to emerge from table 1 is the need to question the received wisdom of maintaining 23°C as the space temperature. There are a number of naturally ventilated buildings where space temperatures reach 27°C or more, and yet the occupants express their satisfaction with their environment. This acceptance may be to do with the occupant having some individual control over his environment through the ability to open windows; it may be that naturally ventilated buildings are by definition narrow plan, allowing good visual contact with the outside world; it may be that the temperatures are varying through the day rather than being controlled within tight limits. Whatever the reason, allowing the peak indoor temperature to rise a few degrees will substantially increase the applicability of passive / hybrid cooling technologies. This emphasises the need for more work to be done on the field evaluation of human comfort, and in particular, to generate some insights into the way staff productivity is linked to perceptions of comfort.

5. Conclusions

The results presented above lead to some important implications for the building design professional. Passive and hybrid cooling strategies offer significant potential for reducing vapour compression cooling for many commercial buildings. However in most cases there will still be a need to provide some mechanical cooling, either to provide for the peak gain condition, or to control some localised 'hot spot' in the building. This will demand very careful thought about how to integrate the passive and mechanical cooling systems into a total working concept. Consideration must also be given to the integration of the heating and ventilation systems, and how the dynamics of the building fabric can support the overall design concept.

Other work not described in this paper has also indicated the need for very careful design optimization in order to get the anticipated benefit from passive cooling. For example, pre-cooling the structure requires very careful thought to be given to the relationships with heating systems at morning start up; evaporative cooling needs very careful selection of evaporative cooler and heat recovery device in order that increases in fan energy do not outweigh reductions in chiller energy etc. Particular care will also need to be given to the 'robustness' of the design to changes in building use or operation. Such design optimizations will require an enhanced understanding of building physics, and an ability to apply sophisticated design tools.

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Keyword environment air_conditioning cooling buildings UK energy_conservation thermal_comfort room_temperature passive hybrid natural_ventilation mechanical_ventilation evaporative_cooling models ground

Résumé Nous examinons un nombre de stratégiés de climatisation à bas énergie, et, en utilisant des techniques d'analyses dynamique, nous évaluons l'abilité de ces stratégies de climatiser les batîments de l'UK. L'utilisation de ces techniques va nécessiter une ré-évaluation des échelles de confort, et l'analyse a été donc présenté sous forme de probabilités que la temperature interieure dépasse des certains niveaux de confort. Les résultats indicent qu'un certain nombre de stratégies passive/hybride peuvent fournir le niveu de confort qu'il faut, pourvu que les apports de chaleur sont bas. A des niveaux plus importants, ces systèmes peuvent réduir la capacité et la consommation de'énergie.

Mot-clé environnement conditionnement_d'air rafraîchissement Royaume_Uni conservation_d'énergie confort_thermique température_intérieur_du_local passif ventilation_naturelle ventilation_mécanique modèles_de_simulation sol refroidissement_par_évaporation

Zusammenfassung Umweltinteressen, wie die