CHILLED BEAMS IN NATURALLY VENTILATED BUILDINGS

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There has been a recent growth of interest in the use of passive cooling in buildings, particularly in the use of chilled ceilings, including both beams and radiant panels. However, there is still concern about the risk of condensation on cold surfaces and water dripping onto occupants or furnishings, especially where there is no control over the level of humidity for instance in naturally ventilated buildings. This paper reports on practical experience gained from the design, installation, commissioning and "running in" of four installations, completed in the early summer of 1995, in different buildings. The paper describes some of the problems encountered, during the "running-in" period and, how they were resolved.

INTRODUCTION

Over the last two or three years there has been a rapid growth in interest and, use of, direct space cooling such as chilled beams, chilled ceilings and even chilled radiators. In most cases the direct cooling element has been installed as a component part of an "air conditioning" system, taking the place of an indirect space cooler such as a fan coil unit and, coupled with some form of mechanical ventilation air treatment system. The ventilation systems are usually designed to dry the supply air sufficiently to reduce the dew point of air in the space to about 2K below either, the temperature of the coldest surface of the cooling element or, the temperature of chilled water supply(1). This overcomes any risk of condensation and, the consequences of water dripping on occupants and furnishings. However, there are installations in other countries, notably Sweden and Switzerland, that appear to ignore this risk and use chilled beams and ceilings in naturally ventilated spaces with chilled water inlet temperatures as low as 14°C. Clearly there are initial and running cost savings if mechanical ventilation is not really necessary for other reasons and this begs the question - Can chilled beam systems work in naturally ventilated buildings in the UK?

This overview case study concerns four buildings in London belonging to one client. All of the buildings had opening windows and two had "background" mechanical ventilation/cooling systems. Each of the buildings had a history of overheating in summer but the client did not want to install "full air conditioning." The company has a maximum temperature target for their buildings. Two criteria must be met, a) an internal temperature of 25°C should not be exceeded for more than 19 days and, b) 27°C should not be exceeded for more than 10. The internal temperature is the maximum that exists for more than 15 minutes.

COOLING NATURALLY VENTILATED SPACES

Installing direct space cooling in naturally ventilated buildings cannot replace air conditioning as, at best, it can only deal with one parameter, temperature. But, if the only reason for providing air conditioning is to avoid excessive temperatures then, direct space cooling is an appropriate solution. This superficially simple change in the design objective, avoiding excessive temperatures as opposed to maintaining a constant temperature, can mean a significant change in the approach to the design solution.

Excessive temperatures can be avoided by designing the cooling system to either a) actively attempt to maintain a constant temperature in the space at all times when the external design conditions are not exceeded i.e. like air conditioning or, b) passively complement the thermal response of the enclosure to ensure that the space temperature does not exceed certain temperature limits for more than a predetermined number of hours in a given period i.e. like a free running building.

In the active case it is a matter of choosing the warmest, sunniest, design day, estimating the heat to be removed from the space and, selecting the appropriate cooling element for the internal temperature. With the passive case it is a matter of matching the performance of a space temperature dependant cooling element against the thermal dynamic response of a space for each hour of each day and determining the frequency and duration of excursions of temperature above predetermined values. Determining whether or not a particular selection of cooling element will meet the specification can only be estimated using dynamic techniques. Fortunately, experience has shown that it is usually only necessary to do this for representative. It has been shown that using this dynamic approach the cooling power necessary can be reduced by 25 to 30%(2). Obviously the thermal parameters must be satisfied within the constraints of overcoming the potential problems of condensation.

CHILLED BEAM COOLING

This particular client had an environmental policy for cooling that includes, among other criteria, the following:

> To limit the frequency of occurrence of excessively high temperatures to within the defined maximum temperature criteria.
>
> Avoid attempting to maintain constant temperatures, i.e. not full air conditioning.
>
> Allow occupants a degree of control over their own environment.
>
> Only use energy for cooling when really necessary.
>
> Use water as the primary means of distributing cooling, not air.
>
> Use the simplest technology.

The alternative solutions were to install either fan coil units or chilled beams. The advantages and disadvantages of chilled beams were identified as follows:

Advantages	**Disadvantages**
More energy efficient	Risk of Condensation
Low maintenance	Lower cooling power
Self adaptive control	Limited experience in UK

The dynamic thermal analyses had shown that, on the basis of limiting temperatures, adequate cooling could be provided using either chilled beams or fan coil units. The chilled beams appeared most attractive in terms of, matching the client's environmental policy, energy efficiency and, maintenance. Self adaptive control is a feature common to direct space cooling elements where the surface temperature is close to the space temperature. Basically the rate of cooling diminishes as the temperature in the space falls and is attractive as fewer local controls are necessary. The only serious drawback, with chilled beams, was the uncertainty of the risk of condensation.

CONDENSATION RISK ANALYSIS

The potential problem of condensation with chilled beams was considered in two ways. Firstly, how often was it likely to occur and, secondly, what should be done to avoid adverse consequences when it does occur.

The risk of occurrence of condensation on chilled surfaces in naturally ventilated buildings is obviously dependant on the surface temperature and how often the internal dewpoint temperature exceeds that value. The internal dewpoint temperature closely follows the external if an allowance is made for moisture released within the space. This is typically 0.5 to 1.0 g/kg (4), approximately equal to an elevation of 0.5 to 1.0 K in dewpoint temperature. Figure 1 shows the frequency of occurrence of higher dewpoint temperatures for London Airport for a period of 15 years (5). It can be seen that the risk of condensation can, largely, be eliminated if the surface temperature is maintained above 20°C at all times. Allowing for a temperature difference between the chilled water and the surface of 1 to 2K and internal moisture generation this restricts the chilled water to a minimum temperature of about 20°C. This is too high to provide adequate cooling so a decision was taken to develop the design on the basis that condensation would be allowed to form but that measures would be taken automatically to either, eliminate further condensation or, any adverse consequences.

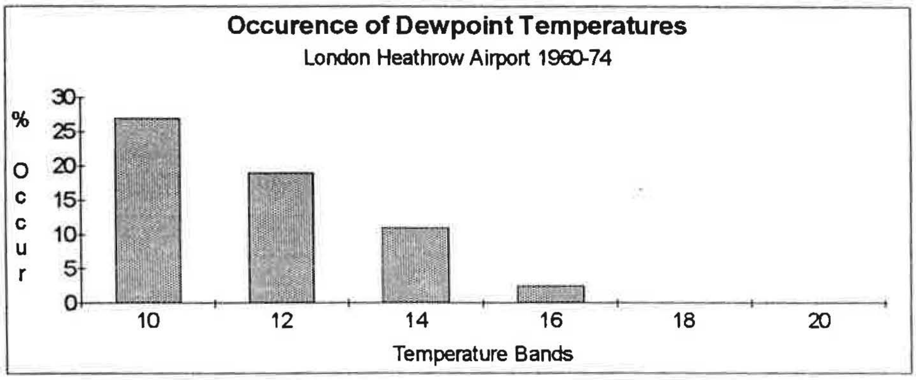

Figure 1. Frequency Occurrence of Dewpoint Temperatures

This means that firstly, detectors are necessary to detect moisture forming on chilled surfaces and secondly, that a method is required to either collect condense or, once detected prevent more forming. Whilst certain chilled beams are fitted with drip trays the possibility of collecting condensation in them would raise the possibility of micro-biological growth and this option was not considered further. In a naturally ventilated building the only way of preventing further condensation forming on chilled surfaces is to raise the temperature of the surface above the internal dewpoint. The options are to raise the temperature of the chilled water supply or to stop circulating chilled water until the dewpoint temperature falls.

The thermal analysis indicated that a chilled water supply temperature of 15 to 16°C would be necessary to physically install sufficient cooling in the space available with chilled beams and, achieve the maximum temperature limits of the client's brief. This water supply temperature results in a minimum surface temperature of approximately 17°C. Making an allowance of 1K for internal moisture generation means there is a risk of condensation on the cooling element whenever the external dewpoint exceeds 16°C. Comparing the frequency distribution in figure1 with this temperature results in a risk of occurrence of condensation, to a greater or lesser extent, for less than 3% of the hours of a typical summer. It was decided that as the likely occurrence was so low that the most simple and expedient solution was to use the signal from the moisture sensor to stop circulation of chilled water and allow the thermal inertia of the spaces to limit excessive excursions of temperature.

On the basis of the analysis chilled beams were selected to provide the cooling in each of the four buildings. Each system was fitted with moisture detectors fitted to the coldest surface on each sub-circuit.

Table 1. Buildings and Systems

No.	Floor Area m2	Cooling	Ventilation	Windows	Condense Control
1	5,000	Concealed Ch. Beam	Mech.	Opening	Moisture Detection
2	2,000	Concealed Ch. Beam	Natural	Opening	Moisture Detection
3	2,000	Concealed Ch. Beam	Mech.	Opening	Moisture Detection
4	200	Exposed Ch. Beam	Natural	Opening	Moisture Detection

PRACTICAL EXPERIENCES

The four systems were commissioned during the early summer of 1995. Three of the buildings, numbers 1,2, and, 3, were visited regularly to monitor the internal temperatures, the use of windows and the occurrence of condense on chilled surfaces. Internal temperatures for the three buildings are shown in figure 2. The temperatures are the average for each floor during each visit. This shows quite clearly that the rate of rise in internal temperature is approximately one quarter of the rise in external temperature. Estimates from thermal models indicate that the internal temperatures are about 4K less than without cooling. Each of these buildings were pre-conditioned to reduce the temperature at the beginning of the day and maintained under thermostatic control in the evening to prevent post occupancy overheating. This was necessary because the relatively low cooling power, typically 45 to 60 W/m^2, does not provide the ability to deal with large "pull down" loads at the beginning of the day.

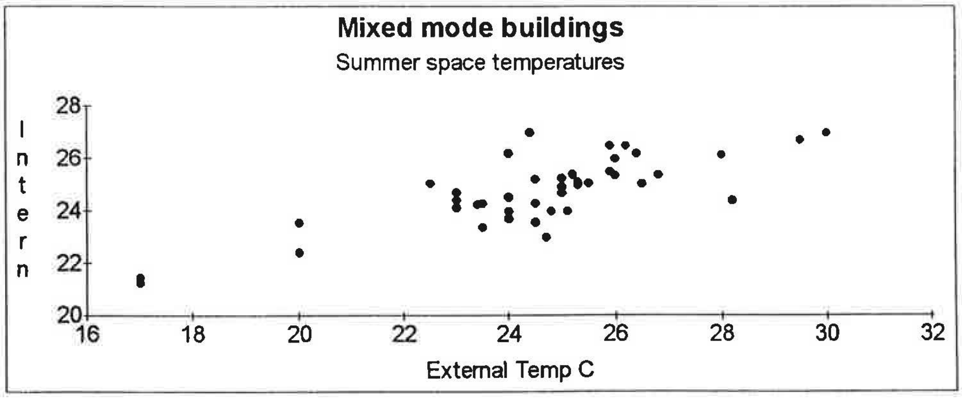

Figure 2. Typical space temperatures on warm days.

Installation Problems

Each of the projects suffered, to a greater or lessor extent, from installation problems. The worst was building number 1, it had continuous failures of the refrigeration plant, apparently a result of inadequate quality control by the manufacturer. In addition there were teething problems with the controls and, to make matters worse, the installation contractor failed to install the moisture detectors.

As these problems coincided with the onset of unusually hot weather it took some time to bring the building back under control. Unfortunately, these problems created a poor image initially. Monitoring of the temperatures started when these problems had been resolved.

Condensation

Condensation of moisture on the cool surface of the chilled beams occurred twice at building number 1 and once at building number 3. In each case the installed moisture detection devices closed the systems down before the condensation caused a problem. On each occasion it was consistent with a high external humidity. As shown in figure 3. the summer of 1995 was more humid than had been anticipated, during the design, but condensation occurred less often than expected. Strangely, it was the two mechanically ventilated buildings that experienced condensation. The naturally ventilated buildings, 2 and 4, did not encounter the problem at all. The conclusion was that the existing cooling coils in the ventilation plants at these buildings perform virtually no dehumidification and introduce larger quantities of moist (non-dehumidified) outside air than in the naturally ventilated buildings, resulting in a higher internal humidity.

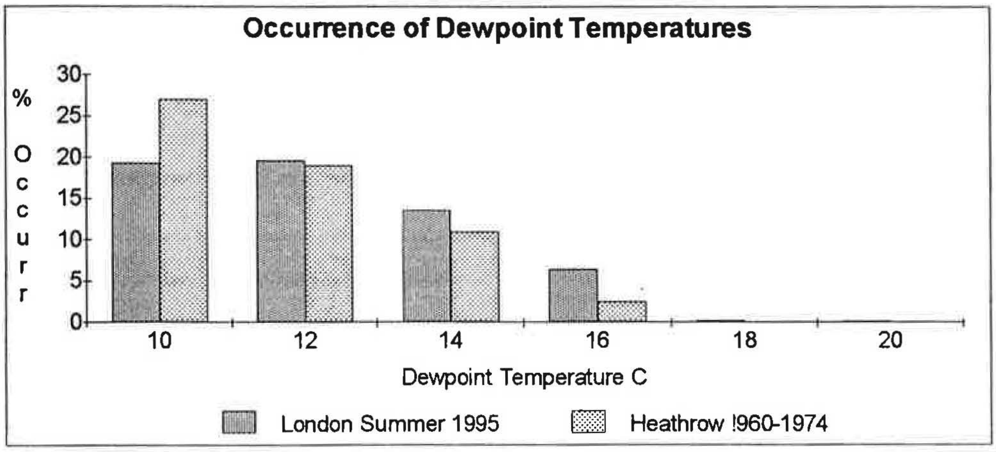

Figure 3. Comparison of design and actual dewpoint occurrence

Window Opening

One of the key issues with this type of cooling, in naturally ventilated offices, is to avoid staff throwing open the windows when the weather is hot. This has the effect of "throwing the cooling out of the window" and making the office as hot or hotter than it is outside. Our experience from these projects was that once we had overcome the teething problems most staff, soon realised the advantage of avoiding opening windows unnecessarily. Visits to the buildings comparing the situation before the cooling was installed and after showed that before they opened nearly every window and, even fire escape doors, to try and keep cool. Afterwards wide open windows were almost eliminated apart from a small number of people that either smoked or just preferred open windows irrespective of the temperature.

CONCLUSIONS

The post installation monitoring visits to these buildings during the hot and relatively humid summer of 1995 showed:

a) building users soon learn to keep windows closed and retain the *coolth* on hot days,

b) when systems failed there appears to be a critical temperature around 27^{O}C above which people will open windows regardless of the consequences, ie to obtain some air movement,

c) as these systems have limited capacity it is important to avoid starting the day with an overheated building,

d) condensation is not a major problem and, of the three buildings monitored, there was less risk of condensation with the naturally ventilated one than the mechanically ventilated building. This was due to the lack of dehumidification in the existing systems,

e) once installation and commissioning problems were resolved the building users appreciated the provision of passive cooling.

Our experiences from these buildings in a very hot summer have convinced us that year round comfort can be provided without the capital, energy and maintenance costs of full air conditioning.

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