CHILLED CEILING AND BEAMS - BRE RESEARCH

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There is increased interest in using chilled ceilings and beams for cooling in UK buildings, on account of their perceived advantages over traditional air or chilled water based systems. However, there is currently limited knowledge or experience of the use of chilled ceiling and beam systems in the UK, and there is no proper professional guidance. Designers are particularly concerned to avoid condensation occurring on the exposed cold surfaces that could cause a health problem or lead to the so-called "office rain" effect. BRE has monitored the performance of operational chilled ceiling and beam cooling systems in four buildings during the summer of 1996 as part of a larger CIBSE research project to develop guidance on the design and operation of chilled ceiling and beam systems. This paper reports some preliminary findings from the building monitoring, and discusses the need for condensation control strategies.

THE BUILDINGS

Four buildings were monitored during part of the 1996 cooling season. The objective was to observe how the installed chilled ceilings and beams responded in practice to their individual control strategies and operating loads, and how their effectiveness was viewed by the building occupants. Only limited results were obtained for Building 4 due to the intermittant occupancy and infrequent operation of the chilled ceilings.

Building 1. Perpetual House, Perpetual PLC, Henley On Thames
A "Cosy" chilled beam system is installed within the suspended ceiling void of Perpetual's new Henley headquarters building. Most of the office space is open plan, with on average about one occupant/ 10m^2 (1 occupant/5m^2 in perimeter areas) and with fairly heavy usage of IT consistent with the needs of a financial services sector company.

Building 2. Queens Building, BAA, Heathrow
A "Cosy" chilled beam system, similar to that in Building 1, is installed within the suspended ceiling void in an open plan office area.

Building 3 Hill Samuel Bank, London
"Flakt Opti 180/1" chilled ceiling panels are installed in an older, mainly open plan, office building. Occupation densities and IT levels are similar to Perpetual House.

Building 4. FC Foreman & Partners, London
A demonstration "Trox" chilled ceiling installed in a "pod" suspended from the existing ceiling in the company's board room. The room is occupied intermittently.

THERMAL COMFORT

The overall impressions from the four buildings were that the occupants were generally very satisfied with the systems and the levels of comfort achieved. Notable features of all the systems immediately noticed by the BRE researchers were the low noise levels and unobtrusive appearance, which could have contributed to the occupants' overall satisfaction levels. Conversely, some may find the lack of noise disturbing as it could restrict the privacy of conversations. Thermal and psychrometric conditions were continuously monitored at a representative location in each building for several weeks during the summer of 1996. The results of a bin-analysis of measured room dry resultant temperatures and relative humidities (for occupied hours only) are presented in Figure 1 Room dry resultant temperatures and RHsFigure 1 (Building 4 is excluded due to the intermittant occupation and infrequent chilled ceiling operation). The results hold no surprises.

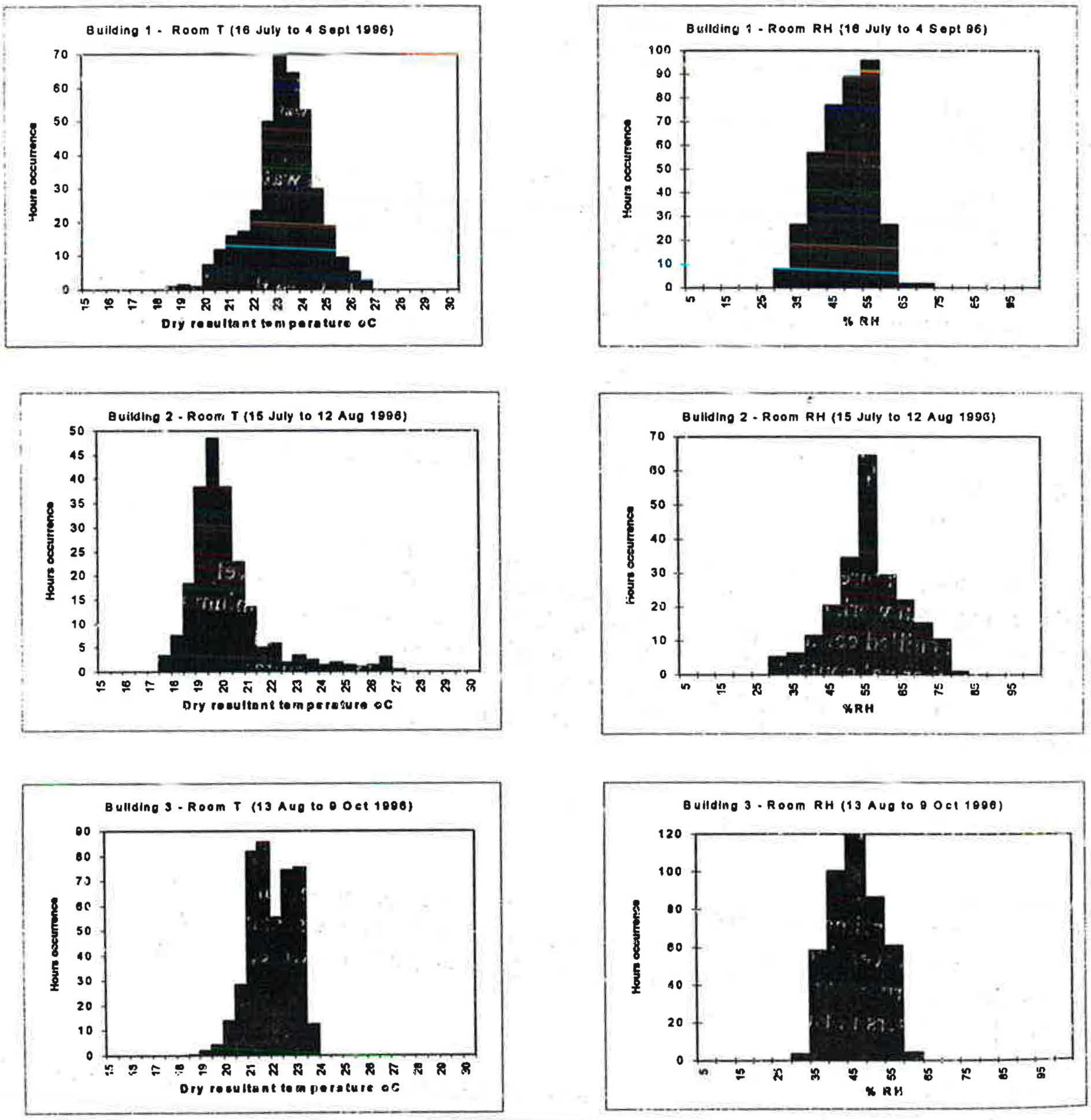

Figure 1 Room dry resultant temperatures and RHs

Building 1 - this building was operated on a mixed-mode basis with an emphasis on minimising chilled beam operation by opening windows on cool days, and allowing room temperatures to drift upwards in the afternoon. Despite this, and some very hot weather during the monitored period, dry resultant temperature only exceeded 26°C on 9hours out of 389hours (occupied hours only). The chilled beams were not operating at these times.

Building 2 - despite periods of hot weather during the monitored period the measured dry resultant temperature was below 20°C for over 50% of the occupied hours, suggesting that the zone temperature set-points were set too low. This is consistent with several informal comments made by female occupants to the BRE researchers that they usually felt uncomfortably cool in the office, even on hot days. The system was probably oversized for the actual loads. It was known that the design allowed for fairly high IT gains, although in practice the occupant density and gains in the monitored area were estimated to be fairly low (around 1 occupant/15m^2 and 10W/m^2 IT gains). A bin analysis of the chilled water inlet temperature (Figure 2 Chilled water inlet temperature - Building 2) shows very little variation during occupied hours which no doubt contributed to the low room temperatures. This suggests a control fault or a defective sensor.

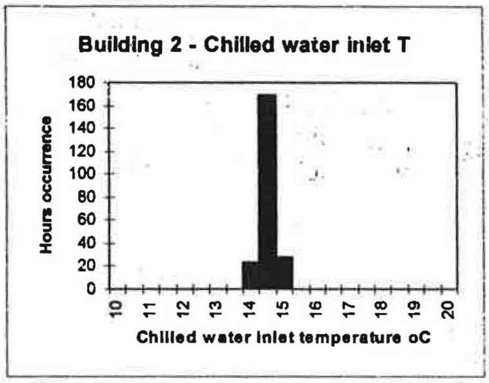

Figure 2 Chilled water inlet temperature - Building 2

A few hours with temperatures in the range 24°C to 27°C were recorded. Here the NW facing glazing allowed low angle direct solar gains in the late afternoon to influence the dry resultant temperature sensor which was located near a line of perimeter workstations.

A wide range of RH% was measured with many hours at 70% or higher (CIBSE recommends that RH% should be within 40% to 70%) - subsequent analysis suggests that there had been no AHU dehumidification.

Building 3 - temperature and relative humidity were effectively and tightly controlled showing that chilled ceilings can work effectively in older heavy weight buildings with relatively high cooling loads. The Flakt Opti chilled ceiling panels are a "metal plank" design (3m long aluminium panels) which achieve better thermal contact with the chilled water pipes (15mm copper) and therefore higher cooling capacity than "lay-in" types of panel using small bore plastic pipe. Dry resultant temperature was maintained at 20 to 24°C, equal to the British Council for Offices recommended range of 22±2°C.

OTHER THERMAL COMFORT CRITERIA

Air velocity

Chilled beams are primarily convective cooling devices. Attempts to measure air draughts below the beams were, however, inconclusive - the measurements were below the sensitivity of the hot wire anemometer instrument used (<0.1m/s). Air velocities around 0.25m/s were, however, measured near the supply diffusers in Buildings 1 and 2.

Vertical temperature profile

There was less than 0.5°C variation in dry resultant temperature from floor to ceiling below chilled ceiling panels and beams operating with an inlet temperature of 14°C.

CONDENSATION CONTROL

A major design issue for designers in the UK has been to avoid the risk of condensation on the surfaces of chilled ceilings and beams. The relatively "wet" climate of the UK compared to continental Europe has led to a belief that the use of chilled ceilings and beams in the UK could cause "office rain". Condensation will start to form if the surface temperature falls below the room air dew point temperature, and various condensation avoidance strategies have been devised to minimise or eliminate the risk of these conditions occurring. One strategy sometimes seen, is to use condensation detectors on the chilled ceiling surfaces to switch off the chilled water flow if condensation has been detected. However, this could lead to the loss of cooling when it is most needed, would be affected by the variation seen in the sensitivity of individual condensation detectors, and is not generally recommended.

A more commonly used method, although not necessarily an energy efficient solution, is to dehumidify the fresh air supply. An alternative method, used in some of the monitored buildings, is to control the chilled water flow temperature to keep it above the room dew point temperature. However, this could also limit cooling output on hot days. The precise methods of condensation control employed in the monitored buildings are discussed and assessed below:

Building 1 - the intended operation is to dehumidify the fresh air supply to limit the building internal dewpoint temperature to 13°C, and to maintain a minimum 1°C difference between the chilled water entering temperature and the room dewpoint temperature. Reheating is achieved by use of runaround coil heat recovery. The chilled water flow temperature is ramped up as necessary to maintain a 1°C difference. The room dewpoint is calculated by the BMS from inputs from RH and dry bulb temperature sensors. However, during BRE's monitoring in this building this differential had been incorrectly set to 2°C. Figure 3 shows a typical day where this control strategy was called into operation. The room dewpoint temperature was approximately 14°C and the chilled water temperature control maintained a 2°C differential, tracking minor variations in dewpoint temperature quite accurately.

The monitored data showed that little or no dehumidification occurred in the fresh-air supply - supported by the results of a bin-analysis of the supply air conditions, shown in Figure 4 Supply air temperatures and RHs, and the fact that the dewpoint temperature often exceeded 12.5°C. Supply conditions (at room diffusers) during hot weather were typically 19°C with RH between 60 and 70%. On one such occassion BRE discovered that the BMS was incorrectly showing a supply RH of approximately 40% and subsequently found that the RH sensor at the AHU was defective.

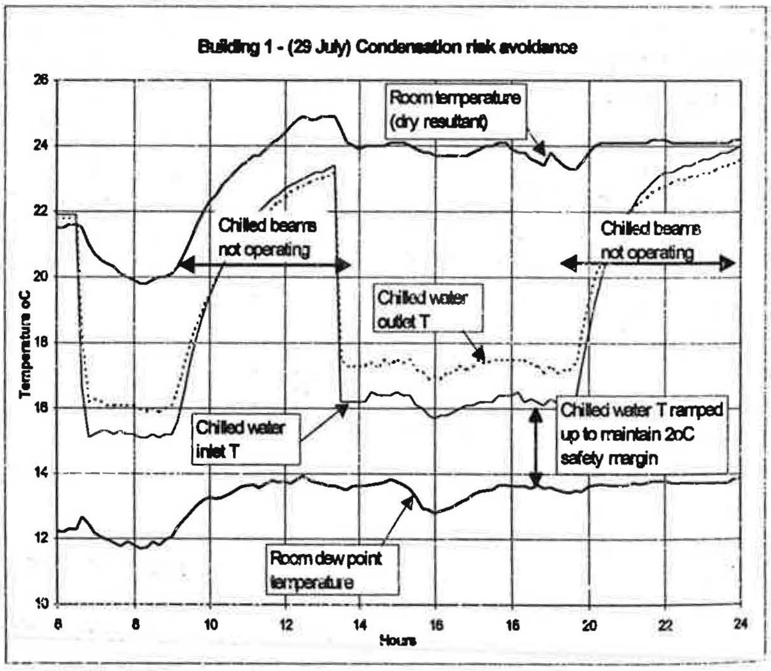

Figure 3 Operation of condensation control strategy in Building 1

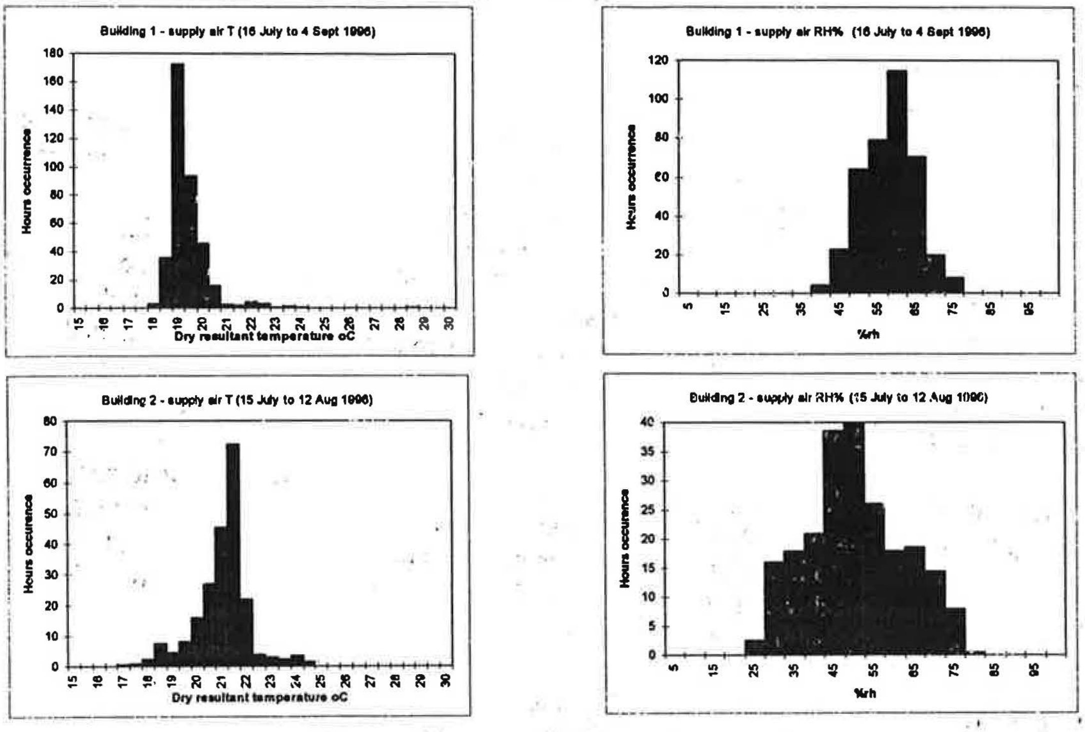

Figure 4 Supply air temperatures and RHs

Building 2 - used a condensation control strategy similar to that in Building 1. However, the monitored data showed that the strategy failed to operate, with room dew point temperature exceeding the chilled water entering temperature by 0.5 to 1.0°C on several occasions, creating a theoretical risk of condensation (although, when questioned, the occupants reported that they had never noticed any condensation). Figure 5 shows this for one such day (29 July), a particulary hot and humid day.

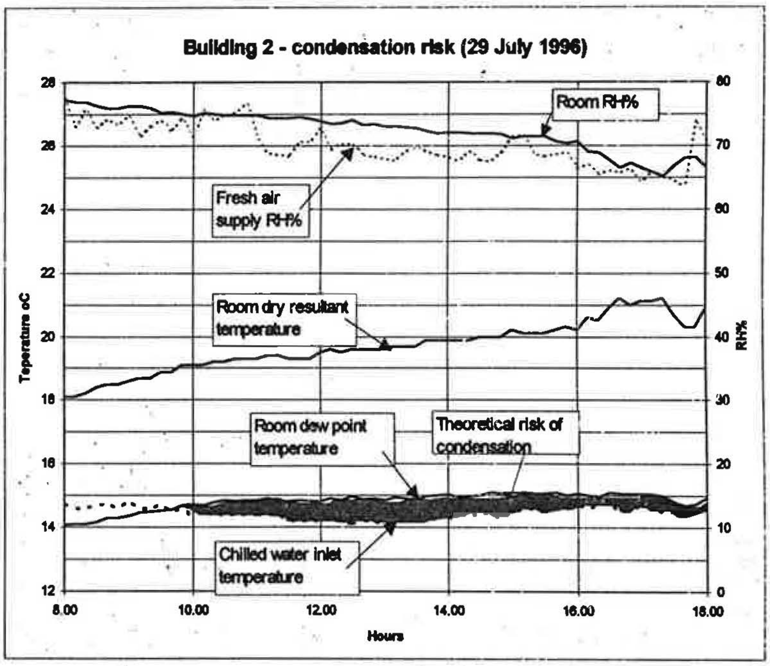

Figure 5 Operation of condensation control stragey in Building 2

Figure 3 shows how, on the same day, the chilled water setpoint in Building 1 was reset to avoid the risk of condensation. The bin-analysis of supply air conditions (Figure 4) shows many hours of supply at over 70% RH%, again suggesting an absence of dehumidification. Further confirmation of this is given by Figure 7 which shows an analysis of the supply air dew point temperature variation. The supply air dew point exceeded 14.75°C on 22 hours during occupied hours. (A dew point temperature of 14.75°C is equivalent to a moisture content of about 10.5g/kg dry air - relatively high for the UK).

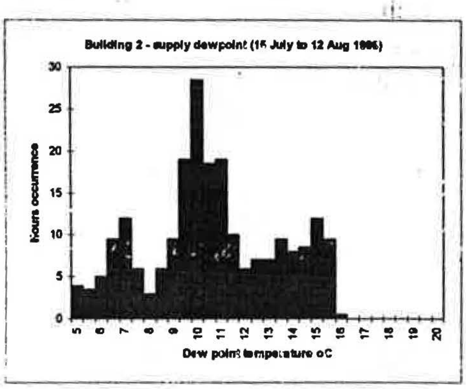

Figure 7 Supply air dew point temperature in Building 2

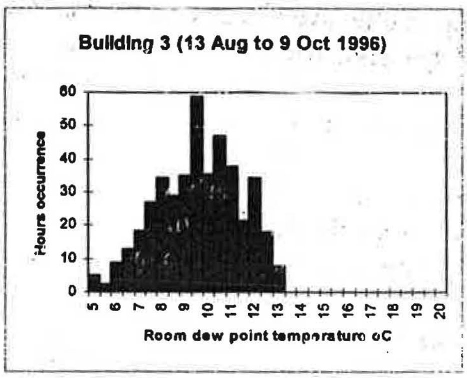

Figure 6 Room dew point temperatures in Building 3

Building 3 - the condensation control strategy in this building is to switch off chilled ceiling panels if the zone RH rises above 65% (a 3-port valve goes into bypass position), and resets when RH falls below 55%. The monitored data (at one representative zone) showed that room RH never exceeded 65%. At the design set point dry bulb temperature of 22°C, 65% RH corresponds to a dewpoint temperature of about 15°. The design chilled water inlet temperature is 14°C, suggesting a slight condensation risk because the chilled water temperature is below the dew point temperature. In practice, however, the ceiling panel surface temperature would be at least 1°C to 2°C higher than the entering chilled water temperature, and there would be no risk of surface condensation. On some hot weather days chilled water inlet temperatures as low as 11 to 12°C were measured, when the room dew point was around 12°C, but the occupants reported no evidence of surface condensation or "misting" on the chilled ceiling panels. Dehumidifying the supply air ensured low room dewpoint temperâtures which were always below the design chilled water inlet temperature of 14°C (Figure 6).

The building plant facilities manager reported that occassional control faults had allowed primary chilled water, at around 6°C, to enter some panels during and immediately after system commissioning. The heavy surface misting that this caused was sufficient to alert engineers to the problem which was rectified before falling droplets or so-called "office rain" developed.

Building 4 - the condensation control strategy is similar to Buildings 1 and 2 in that a minimum 2°C differential is maintained between the chilled water inlet temperature and the calculated room dew point temperature. However, in this system a Staefa condensation detector was also fitted to switch off the chilled water flow in case the control strategy failed. Unfortunately the detector was found to be incorrectly fitted to a return pipe, instead of a flow pipe (the coldest point), and was also in loose contact.

Measurement of coldest surface temperature

Most of the condensation control strategies assume that the chilled ceiling or beam surface temperatures are the same as the chilled water inlet temperature in determining the risk of condensation. This is an incorrect assumption that discounts inevitable temperature differences, and therefore effectively introduces an unnecessary additional safety margin that could limit cooling output on hot days. Preliminary results from additional testing at BSRIA show that chilled ceiling panel surface temperatures are generally around 2°C higher than the chilled water inlet temperature, although this depends on the construction of the panel which determines its thermal efficiency. For chilled beams a much lower temperature difference would be expected because of much more effective heat transfer between the metal fins and the chilled water pipes (chilled beams are similar in principle to a fan coil unit without the fan and with a wider fin spacing). This means that the strategy used in Building 4 could make the difference between the surface temperature and chilled water inlet temperature as high as

4°C, giving an effective 4°C safety margin. Buildings 1 and 2 have chilled beams and would operate with a safety margin nearer to the design value of 1°C in Building 1 and 2°C in Building 2. Even if the surface temperature is the same as the room air dew point temperature boundary layer effects, or localised dehumification, could prevent the formation of significant amounts of condensation.

This said, however, BRE's early view that condensation could still form on the chilled water inlet pipework was confirmed by testing. Whether this moisture forms and re-evaporates unnoticed during normal operation - or may lead to more prolonged wetting of the "unseen" surfaces, is not yet resolved.

Absence of dehumidification in Building 2

The relatively high room RH% levels in this building prompted an investigation of the fresh-air supply conditions. This revealed that the supply fresh-air was being cooled, but with no moisture removal. Figure 8 shows the measured fresh-air supply RH% and the calculated fresh-air supply RH%, based on measured ambient air dry bulb temperature and relative humidity at Garston, and assuming sensible cooling only to the measured fresh-air supply dry bulb temperature. (Figure 8 therefore compares moisture content). The close correlation shows that little or no moisture removal could have taken place - it also shows that ambient conditions at Heathrow were very similar to those at Garston!

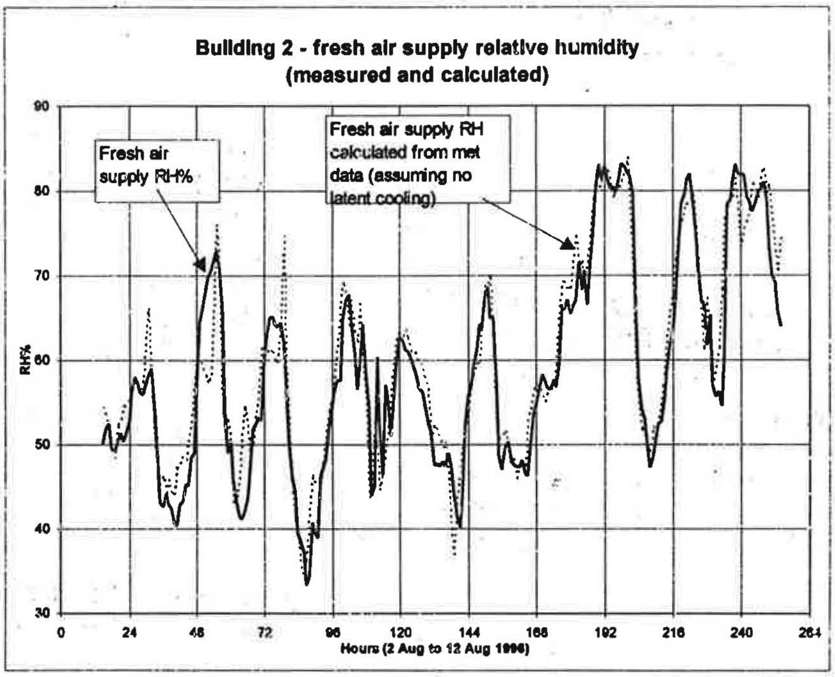

Figure 8 Similarity between ambient and supply moisture content at Building 2

OTHER ISSUES

Aesthetics

The Flakt chilled ceiling in Building 3 was supplied with a painted gloss finish which tended to highlight any minor surface dents caused during installation. The client had subsequently asked for the panels to be resprayed with a matt finish paint which effectively overcame this aesthetic problem. This problem has been reported elsewhere with other types of chilled ceiling and beam units (some types of chilled beam have exposed metal trim panels).

Push-fit flexible pipes

The panels in Building 4 were connected to the supply and return pipes with push-fit flexible pipes. When a chilled ceiling panel had to be hinged down for access to the ceiling void during the monitoring period, a push-fit connection was found to be leaking, causing water to accumulate above the panel and soak the insulation material. Hinging the panel downwards caused a deluge of water to fall on to the board room table!

RH measurement

All of the RH sensors in the four monitored buildings were of the capacitive type. These are known to be potentially unstable over long periods and require regular recalibration - Building 1 RH sensors were recalibrated several times a year - the only building where this necessary maintenance procedure was routinely carried out. More stable RH sensors are available, based on the cooled mirror principle, but are considerably more expensive.

Time clock settings
BRE's monitoring showed that the control time clock in Building 2 was incorrectly set. The chilled beams and mechanical ventilation were operating 24-hours a day and 7 days a week, despite normal 5-day occupancy. Experience suggests that this simple, but very wasteful, fault is quite common in building hvac systems!

OTHER CHILLED CEILING AND BEAMS RESEARCH

The CIBSE chilled ceiling and beams research project involves research by both BRE and BSRIA. BSRIA is testing various chilled ceiling and beam systems in the laboratory to investigate room thermal comfort conditions and the efficacy of control strategies to avoid condensation. BSRIA's laboratory investigation will also assess the formation of condensation under various free-running conditions, which will be related to the findings of BRE's site investigations. BRE is also experimentally assessing the scope for operating chilled ceilings and beams with low energy cooling sources, where a higher limit is imposed on the minimum chilled water temperature, in its own new air conditioning test room. The results of the work will culminate in guidance to be published by CIBSE.

CONCLUSIONS

This study has clearly demonstrated that chilled ceilings and beams have been effective in the buildings investigated. It is not clear whether there is a sufficiently high real risk of condensation with chilled ceilings and beams in UK office buildings to warrant the general use of avoidance control strategies. In the monitored buildings it would seem possibly not. Clearly designers have taken a safe line by including such controls, usually in accordance with manufacturers' guidelines. However, the study has shown no real problems where these have, for one reason or another, been ineffective. If they are not generally necessary then the already elegant simplicity of chilled ceiling and beams could become even simpler to realise in practice, particularly in our imperfect world where getting hvac controls installed and commissioned properly seems a hit and miss affair! However, condensation control may still be necessary where high occupancy levels occur, such as in meeting rooms. Further studies could also be needed to investigate unusual transient conditions, such as the use of office kettles or where staff return from a lunch time walk having been caught in an unexpected shower of rain!

Whenever building hvac systems are monitored, simple, and some not so simple, control or sensor faults are invariably discovered, many having implications for the achievement of occupant comfort or energy efficiency. It is clear that current commissioning and maintenance procedures are still failing to spot these problems.

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