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SUMMER COOLING FOR OFFICE-TYPE BUILDINGS BY NIGHT VENTILATION

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SYNOPSIS

The suitability of night ventilation for cooling for the UK is first assessed by presenting plots of summer weather data on the bioclimatic chart for three locations within the country. These indicate that most of the external weather conditions lie within the thermal mass and ventilation effectiveness areas of the charts. To confirm this, thermal simulations of a typical office module under a variety of internal conditions and summer weather data were performed. Predictions have shown that internal temperatures can be maintained below the external values for solar and internal gains of up to about 50W/m^2. Field measurements in a refurbished natural ventilated office have confirmed that temperatures in night ventilated spaces are generally lower during the following day, especially during the early hours of the working day. Finally, the development of a pre-design tool in the context of IEA Annex 28 on 'Low Energy Cooling Systems' is discussed. The main aim of the tool is to increase the awareness of designers for the energy benefits and the range of parameters for the application of night ventilation as the first means of cooling so that the need for artificial cooling is minimised or avoided altogether.

1. INTRODUCTION

Of the many techniques available to cool buildings, Night ventilation is an appropriate strategy for office buildings in the UK. This is mainly due to the relatively low peak air temperatures which occur during the day during the cooling season and the coincident medium to large diurnal temperature range. Such a combination allows the thermal mass of the building to use the cool night air to discard the heat absorbed during the day.

An initial examination of the weather conditions experienced during the summer months of June to September in the UK indicates that most peak conditions of external weather fall within the ventilation and thermal mass edge of the bioclimatic chart [1, 2]. To illustrate this, the percentage frequency of combination of hourly dry bulb and wet bulb temperatures [3] for London, Manchester (north England) and Plymouth (south west England) have been plotted on the bioclimatic chart. Figure 1 shows that the summer (June to September) climatic envelope is within the heating, comfort, thermal mass and ventilation effectiveness areas of the chart. Although some hours fall within the humid area, these occur at night and the increase in temperature during the day brings the conditions within the comfort zone.

2. MODELLING NIGHT COOLING

To reconfirm the suitability of night ventilation cooling for UK office-type buildings, thermal simulations were carried out using the computer model APACHE [4] taking into account typical construction of office modules, occupancy patterns and other internal heat gains. A parametric analysis was carried out to examine the effect of a number of variables such as orientation and solar gains, internal gains and occupancy patterns, hourly external temperatures and infiltration, day and night ventilation rates as well as simple control strategies to avoid overcooling. Figure 2 presents the result of four simulations during the cooling period of June to September. Internal gains of 20 and 40 W/m^2 were assumed with and without night cooling with an external maximum temperature of 28.5°C. The example in Figure 2 shows that for day and night ventilation of 4 air changes per hour (ach) internal temperatures are reduced by about 1° to 2°C compared to the cases with no night ventilation.

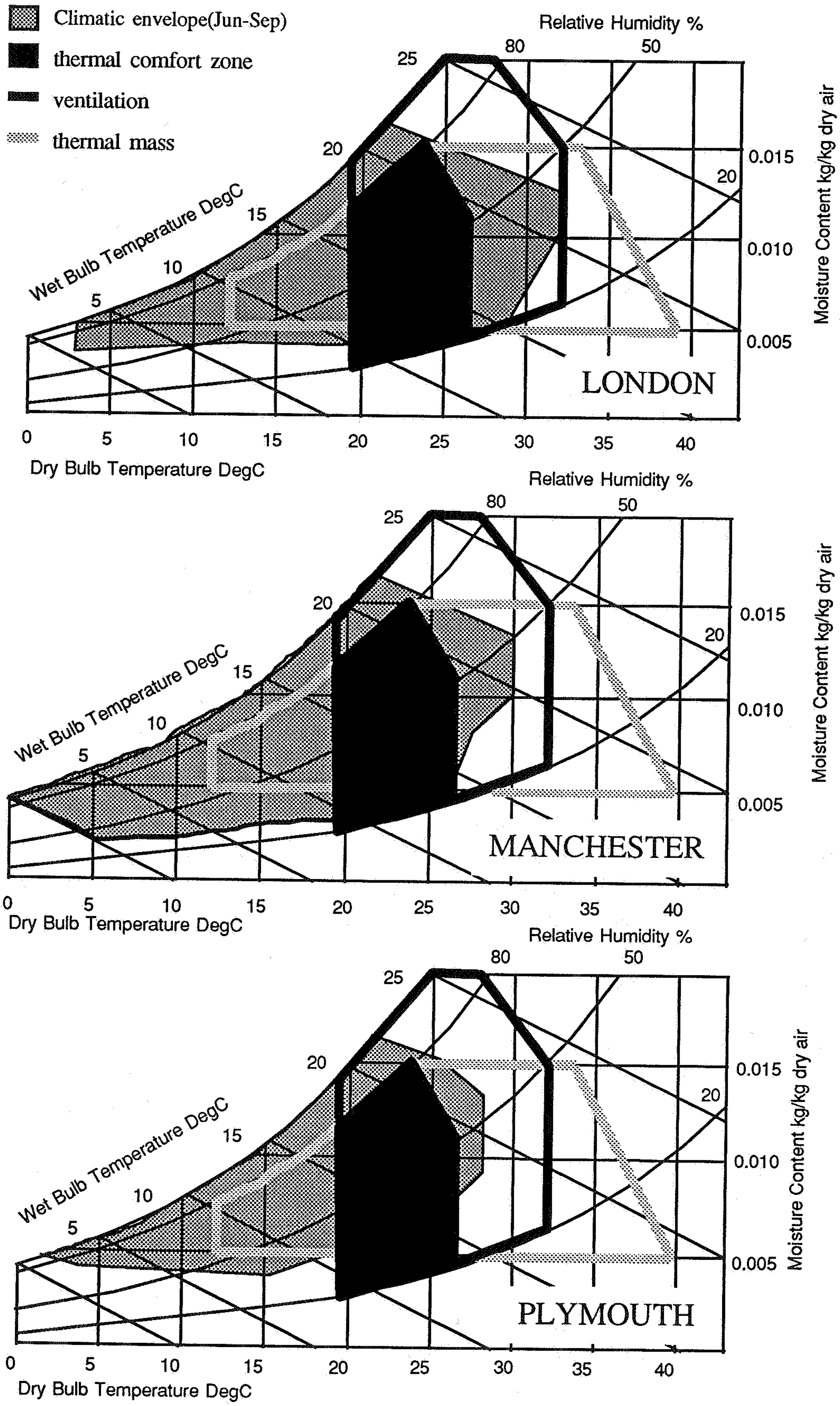

Figure 1: Bioclimatic chart with summer climatic envelopes.

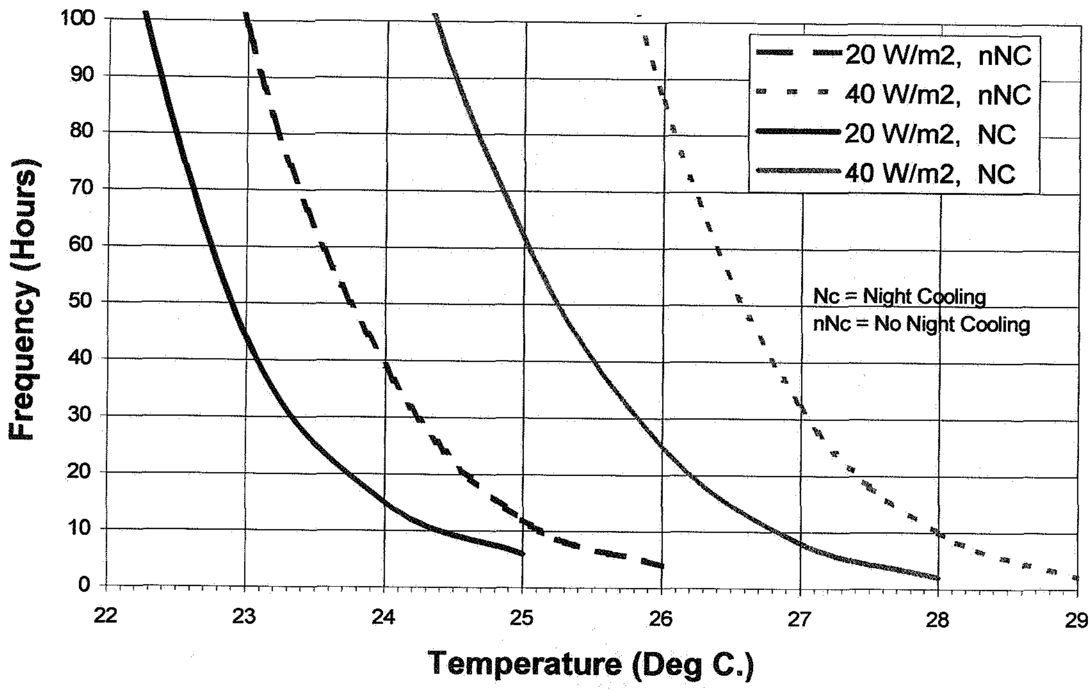

Figure 2: Internal temperature frequency distribution of a typical office module with two levels of internal + solar gains. Day ventilation and night ventilation were 4 ach.

3. MONITORING NIGHT COOLING

A number of recently built innovative buildings in the UK utilising night ventilation for cooling have given encouraging results [5]. However, the potential also exists in older buildings due for refurbishment. Such a building was monitored during the summer of 1995, over a four week period, and the results reported [6]. It follows a summary of the monitoring results in this building for completeness.

The monitored building is a typical 1950's, four-storey office building in west England which had its curtain walling replaced. The project team wanted it to remain a naturally ventilated building, with the users given the option of night cooling. It was assumed that the 'coolth' would be stored in the building mass, i.e. exposed concrete columns, outside wall structure and furnishings. Ventilation was provided by 850 x '600mm bottom-hung ventilators installed around the perimeter of the building. In front of the ventilators was a mesh screen and perforated external louvres, providing 24 hour security and weather protection.

A large open plan office, spanning the width of the building, on floors 1 and 3 was chosen for the study. The offices varied slightly in shape, number of ventilators and amount of glazing. Both offices were cross-ventilated. During each week, Monday to Friday, between 18.00 and 08.00, the ventilators were kept closed on one floor and open on the other.

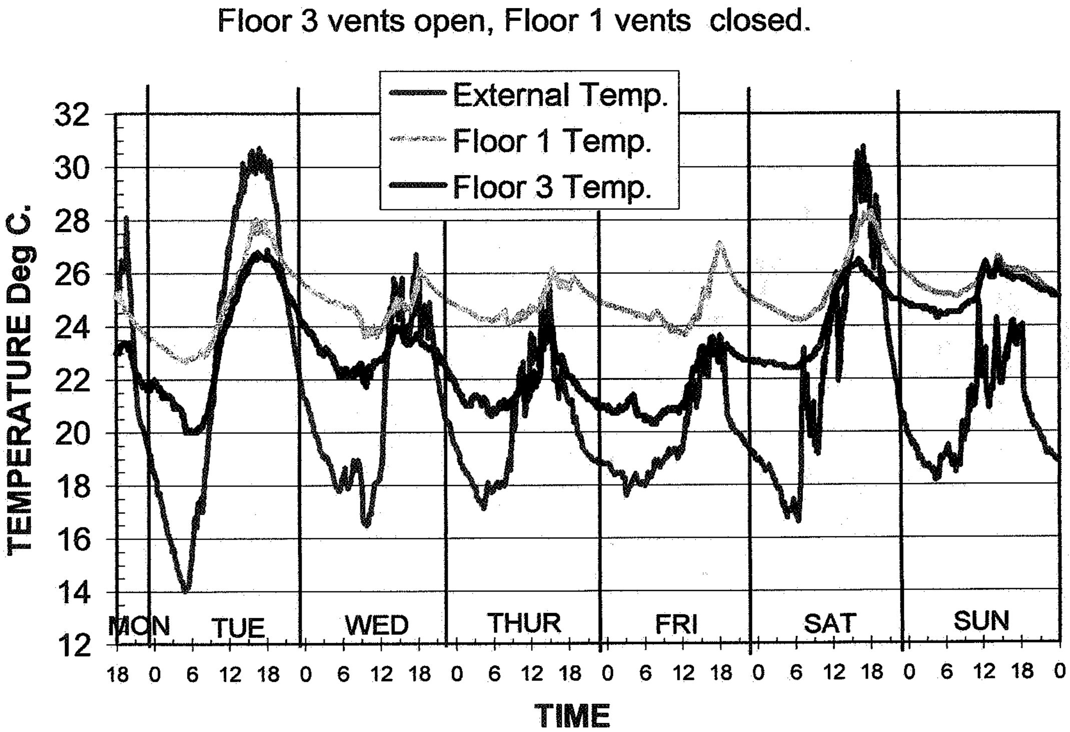

Figure 3: Measured external and internal temperatures in a night cooled and a control office.

At weekends, the ventilators on both floors were either closed or open. For subsequent weeks, and weekends, the conditions were reversed. During the monitoring period the weather was very hot with the external temperature exceeding 30°C on seven days. The maximum external temperature occurred quite often during late afternoon (i.e. 17.00 to 18.00), near to the time when the ventilators would usually be opened (or closed) for the night. If automatic controls were available the ventilators would be opened at an earlier or later time depending on the external temperature so as to maximise the cooling effect.

Figure 3 shows the results of a week, when overnight, from Monday to Friday, the ventilators were kept open on the third floor and closed on the first. The graph compares the mean dry resultant temperatures on both floors with the external temperature. Night cooling is clearly evident on floor 3 with its lower overnight temperatures, and more importantly, the daytime temperatures which remained below those on floor 1 for the majority of the following working day. The ventilators were closed on the weekend days. Figure 3 shows that internal temperatures had reached similar values on both floors by Sunday.

It is easier to compare the night cooling effect between the two floors by determining the difference in the internal mean dry resultant temperatures. Figure 4 shows a plot of the results of two weeks, when the ventilators were closed on floor 1, and open on floor 3. This graph shows that opening the ventilators can reduce the internal temperature overnight, and at the start of the next working day by up to 4°C. However, on some days, towards midday, the temperature on both floors were similar.

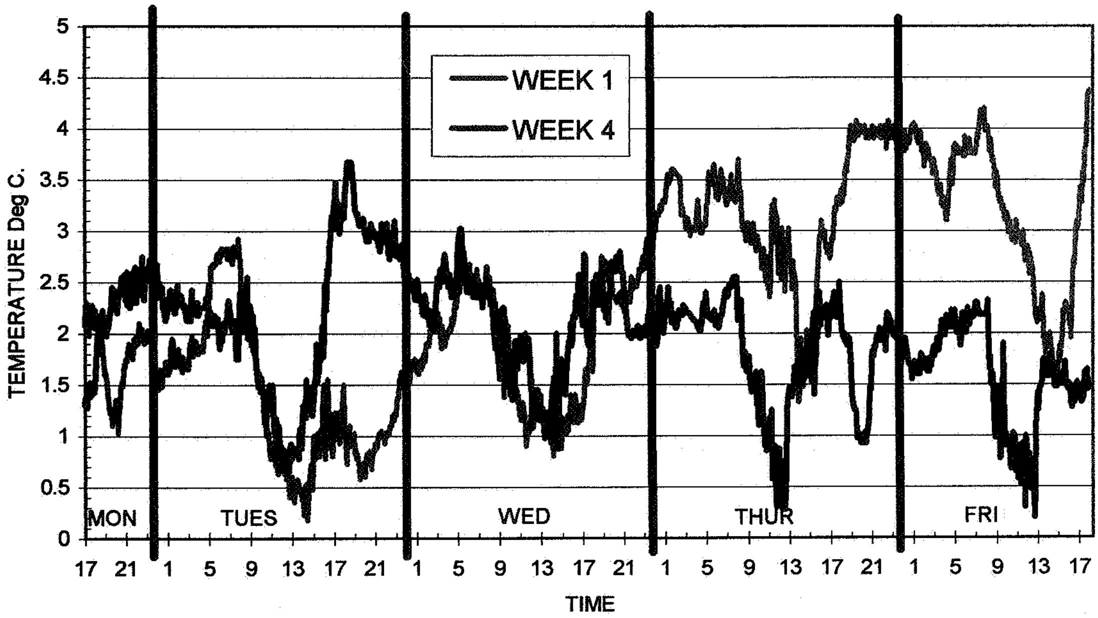

Figure 4: Temperature excess on floor 1 for two weeks. Vents were closed overnight on floor 1 and open on floor 3.

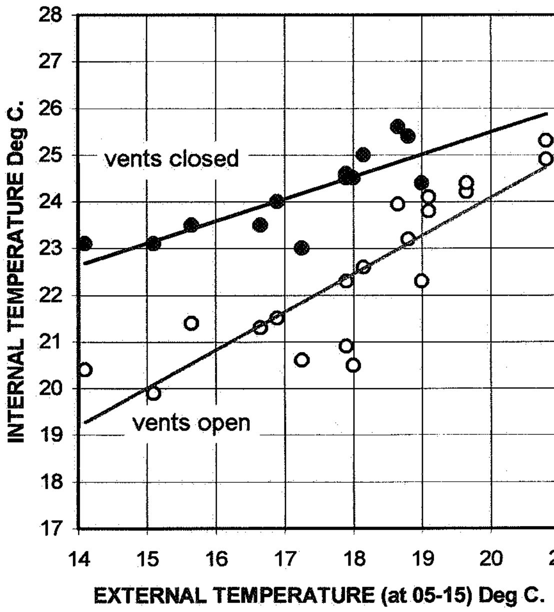

Figure 5: Internal temperatures at 08-00 against external temperature at 5-15 in a night cooled and a control office.

The internal temperature at the start of the working day, 08.00, will give an indication of how effective night cooling was the previous night. It will also have a bearing on peoples comfort level at the start of the day. Figure 5 shows a plot of the internal temperatures, at 08.00, against the external temperature at 05.15 (sunrise, usually the coolest time of the night). The graph shows a linear trend of the internal temperature with external temperature on both floors. The vertical difference between the two lines indicates the night cooling benefit and the degree to which this diminishes at higher external temperatures. At 15°C night temperature, the difference in internal temperature in the morning is 3°C, while at 19°C it reduces to about 1.5°C.

4. DEVELOPING A PRE-DESIGN TOOL

All the interrelated parameters affecting the effectiveness of night ventilation makes it a complex prediction process. Therefore it is necessary for designers to have access to a simple user-friendly and yet accurate model when they are assessing the viability of night ventilation during the initial design stage. We have identified that for such a model, the key predicted output parameters of interest to designers would be:

- maximum dry resultant temperature during the occupied period
- dry resultant temperature at the start of the occupied period
- potential energy savings

Such a tool in the form of design curves has been developed as part of a programme of work within IEA Annex 28 on Low Energy Cooling Systems. The tool is structured as a step-by-step procedure:

- heat gains (Solar + Internal + Day fan pick-up)
- internal / ambient temperature differential for day ventilation only
- night fan pick-up (mechanical ventilation)
- internal / ambient temperature reduction with night ventilation
- peak temperature and frequency distribution
- night cooling
- fan energy consumption (mechanical ventilation)

For night cooling of commercial buildings in the UK, data for the design curves has been generated using a weather year (based on Heathrow weather data) characterised by a peak dry bulb temperature of 28.5°C and suitable for the south-east of the UK . A thermal simulation computer model was used to obtain the data to calculate the curves.

The building model is based on a typical cellular office and positioned in the middle of a row of offices on the middle floor of a typical office block. A thermally lightweight and thermally heavy weight construction were simulated as extremes for creating the curves. Simulation runs included the summer months of June to September. Occupancy is assumed between 8.00 and 18.00 hrs during weekdays only; during this time, day ventilation is operated. Night ventilation is operated between 24.00 and 7.00 hrs. The controls are as follows [7]:

- the time is between midnight and 7.00 hrs
- inside air temperature > cooling setpoint 18°C
- the outside temperature > 12°C
- the outside air temperature < inside air temperature

Figure 6 shows one set of the generated curves where the case with no night cooling and day ventilation rate of 2 ach is plotted for comparison. The curves with night ventilation of 2 and 8 ach demonstrate the reduction in peak day temperatures possible during the cooling season. In addition curves of the free cooling provided in kWh/m^2/annum and the number of hours that the fan would run during the night for mechanical systems are shown. The advantages of using a heavy weight construction with exposed thermal mass is clearly demonstrated in these graphs through the achieved temperature reductions, and the higher amount of free cooling available. It should, however, be noted that the curves demonstrate that night ventilation for cooling is a worthwhile strategy to follow even in lightweight buildings.

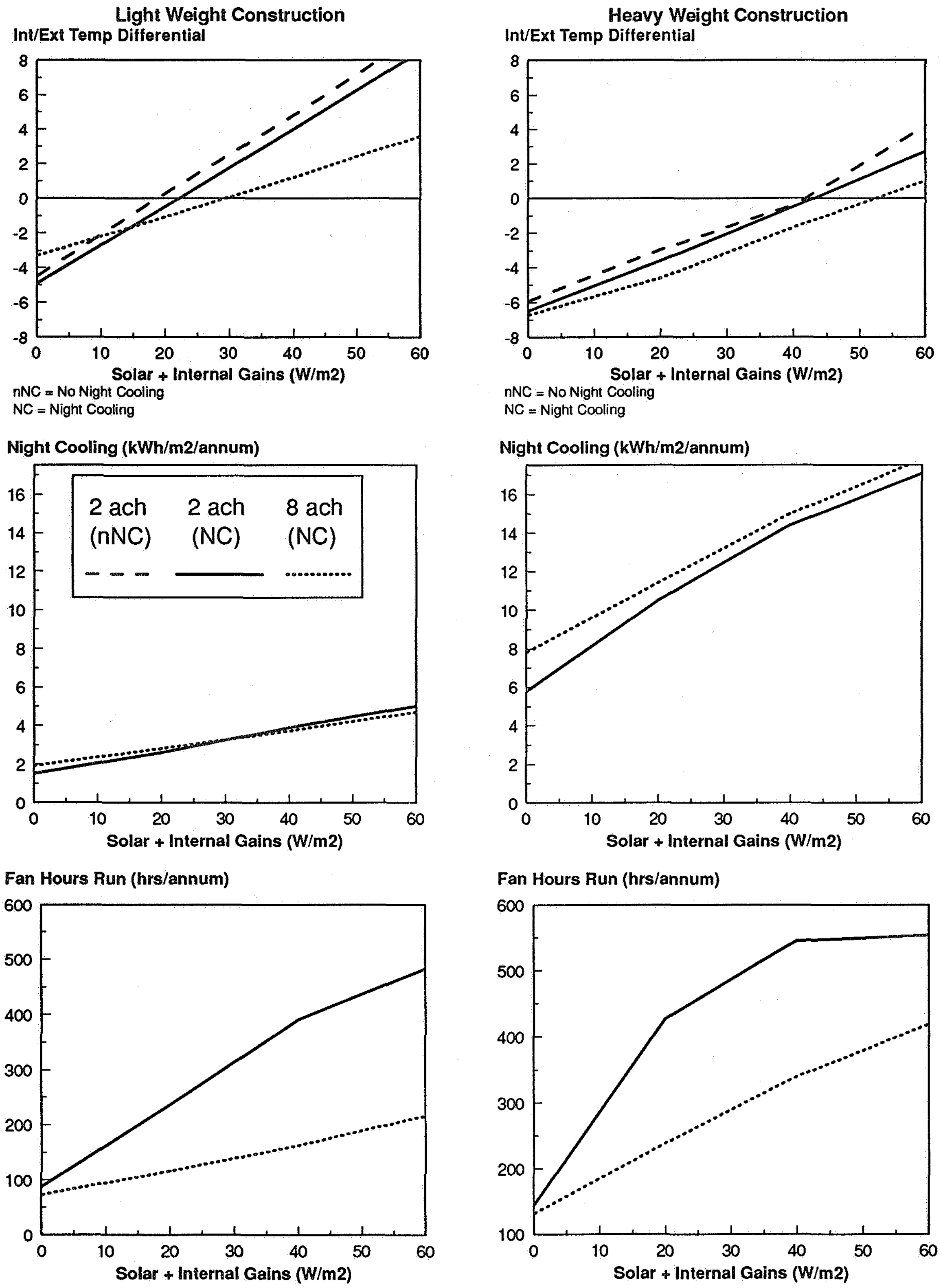

Figure 6: Night ventilation design curves derived using London Heathrow weather data and typical lightweight and heavyweight UK offices. They show the temperature reductions, free cooling provided and the hours a fan would run in mechanical systems.

The design curves so far obtained do provide an indication of maximum expected temperatures during the day and the potential energy savings. However, they do not address the issue of temperatures at the start of the occupied period (when overcooling may be a problem), nor do they give the flexibility of investigating various external weather scenarios and their effect on the internal conditions. To remedy this, a spreadsheet-based pre-design tool which is currently been developed can provide the degree of flexibility required in the initial design stage [8,9]. It is anticipated that the tool will be available before the end of 1996.

5. CONCLUSIONS

The work reported here has assessed the effectiveness of night cooling UK buildings. The study has included desk assessments using bioclimatic charts, thermal prediction procedures using typical office construction and occupancy profiles and field measurements in the office buildings with night-cooling strategies. Results from these studies show that night-cooling is a viable method for addressing the issue of summer overheating in many UK office type buildings.

It is recognised that simplified and pre-design tools either in the form of hard copy design curves or simple computer based calculations will allow the wider uptake of this low energy cooling technique by design and building facilities managers. This paper reports the development of such tools within the current activities of IEA Annex 28 on Low-Energy Cooling Systems.

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