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# Design curves for the application of night cooling ventilation

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A thermal simulation model and suitable weather data were used to generate design curves for the application of night ventilation cooling to office buildings. The work was carried out under the programme of the International Energy Agency (IEA) Annex 28 on 'Low Energy Cooling'. The generated curves show the potential reduction in internal peak day temperatures throughout the cooling season, the free cooling provided by night ventilation and the number of hours that a fan would run during the night for mechanical systems to achieve this free cooling. The advantages of using internal exposed thermal mass is clearly demonstrated in the graphs through the achieved temperature reductions, and the higher amount of free cooling available. However, they also demonstrate that night ventilation is a worthwhile cooling strategy to follow even in standard internally lightweight buildings.

## INTRODUCTION

It has been established over recent years through research work and built examples that night ventilation is an effective low energy cooling technique for appropriately designed modern buildings, especially in climates with relatively low peak summer temperatures during the day and medium to large diurnal temperature differences such as that of the UK. Such weather combination allows the thermal mass of the building to use the cool night air to discard the heat absorbed during the day. Therefore, cooling using night ventilation is particularly suited to office buildings which are usually unoccupied during the night so that relatively high air flows can be used to provide maximum cooling effect. Buildings using night ventilation for cooling have been evaluated and reported with encouraging results [1-3].

In order to help designers to explore the application of night ventilation cooling in the early design stage, pre-design computer tools have been developed [4-6]. These are based on various simplified theoretical and empirical models and typical design days or user defined weather (typically for one week). Such tools provide the opportunity to explore quickly various scenarios in terms of internal heat gains, ventilation rates, occupancy patterns and external temperatures. They predict peak temperatures or daily temperature profiles and they can give an indication of expected energy benefits by extrapolation of data to the whole cooling period.

The data presented in this paper, however, have been derived from simulating the performance of a 'typical' office module throughout the summer period using full weather data and a finite difference thermal simulation model. In this way, more detailed analysis is provided but is focused to the SE England weather. In addition, the potential energy savings have been derived by comparing the hourly temperatures achieved in the night cooled office with an identical office controlled to the same conditions by an active cooling system.

## THE MODEL

### Building model and control strategy

The building model is based on a typical cellular office with dimensions 10m width, 6m depth and 3m floor-to-ceiling height. It is positioned in the middle of a row of offices on the middle floor of a 3-storey office block and has 0.2m$^2$ glazing per m$^2$ of floor area. This module has been derived as a suitable office for night cooling through previous research work [7]. A thermally heavyweight and thermally lightweight construction were simulated as the two extremes for creating the curves. In both constructions the thermal conductivity of the external wall was kept similar with 100mm mineral fibre insulation while the internal partitions, floor and ceilings were assumed adjacent to spaces with similar temperatures to the simulated space. The required exposed thermal mass is provided by 75mm exposed concrete on the ceiling and 100mm plastered concrete block on the external wall. In contrast, the reference (internally lightweight) module has a false ceiling and 400mm air gap underneath a 150mm concrete slab. The external wall is insulated framed construction with lightweight plaster on the internal face. In both cases the floor is carpeted and the internal partitions are lightweight plasterboard.

Occupancy is assumed between 8.00 and 18.00 hrs during weekdays only; during this time day ventilation is operated. Night ventilation, at a constant flow and temperature dependent on the external conditions, is operated between 24.00 and 7.00 hrs. The controls are as follows based on work by BSRIA [8]:

- the time is between midnight and 7 am
- inside air temperature > 18°C
- outside temperature > 12°C
- outside air temperature < inside air temperature

**Thermal model and weather data**

The two constructions and the control strategy have been programmed into the thermal model APACHE and simulations were performed for the four summer months of June to September. Heathrow weather data were used for the simulations as they are generally accepted as more suitable weather conditions when assessing overheating risks. Heathrow weather data are characterised by a peak temperature of 29°C and solar radiation values typical for SE England. A number of simulations were performed and from each run temperature frequency distributions were created and related energy data were predicted for the four summer months.

**RESULTS**

**Peak Temperatures**

Figure 1 shows the peak day internal dry resultant temperature exceeded for 30hrs over the four month period. The temperatures are shown as a function of the following parameters:

- combined solar and internal heat gains
- exposed thermal mass
- day ventilation rate
- night ventilation rate

From Figure 1 it can be seen that the lowest temperatures are achieved in the case of high day ventilation rates and exposed thermal mass office. In general, there is a 2°C temperature difference between the reference and the exposed thermal mass office. In both constructions the largest reduction in peak temperatures, (when using night ventilation), are achieved when the day ventilation rate is low.

**Calculation of solar and internal gains**

In order to use the graphs of figure 1, an estimate of the likely solar and internal gains is required. Internal gains will depend on the design of the office and occupancy patterns. Typical good practice values are 5-25 W/m$^2$ for occupants, 5-10 W/m$^2$ for lighting and 10-15 W/m$^2$ for IT equipment.

Solar gains are more difficult to estimate and will depend on orientation, area and type of glazing and type and extent of solar shading. However, as a rule of thumb the values in Table 1 are provided for the case with no shading. Again, as a rule of thumb, it can be assumed that solar gains are proportional to the glazing area and to the shading coefficient. The values presented in Table 1 have been derived from simulations using the reference office with the same weather and occupancy conditions as described above.

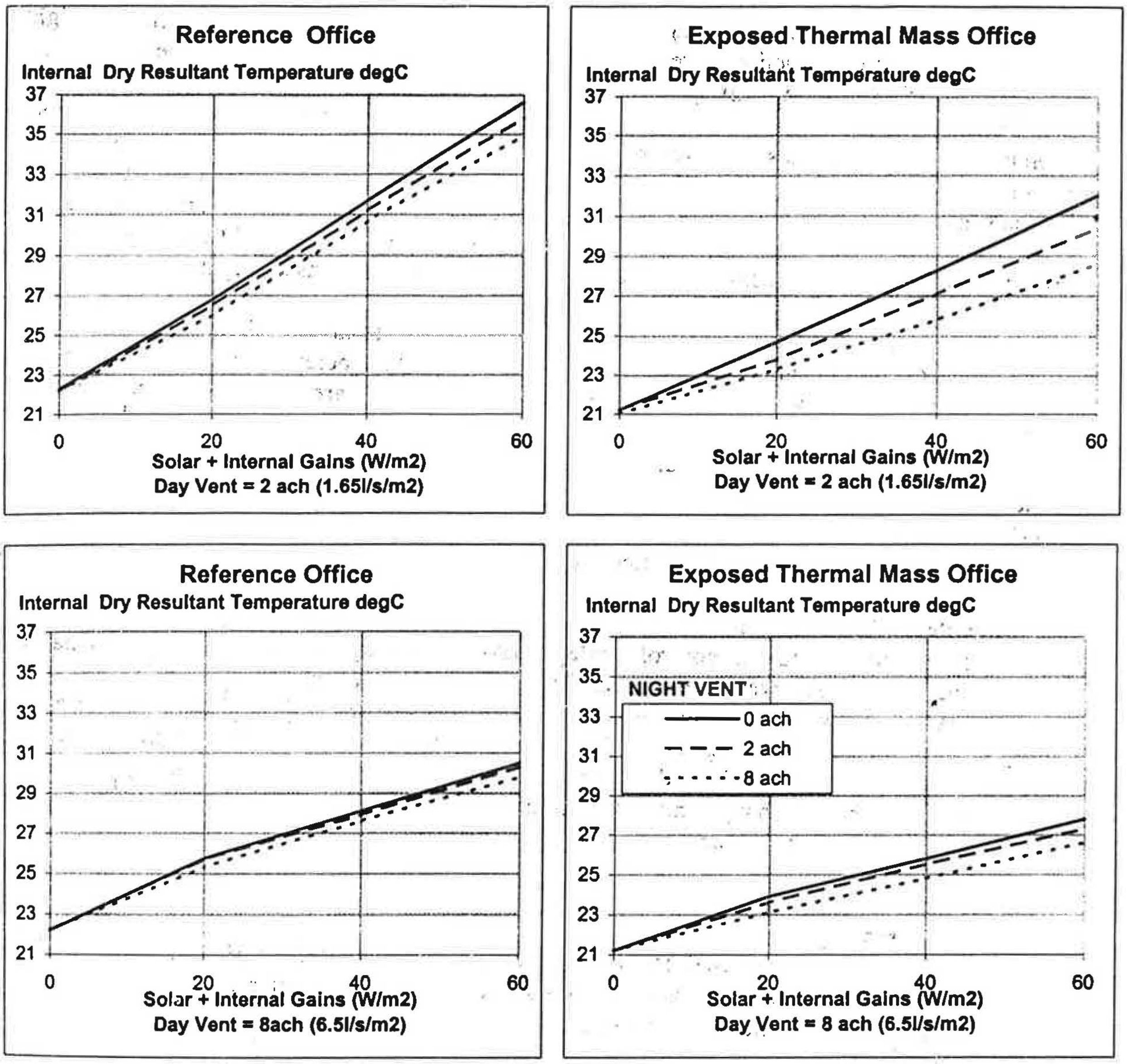


Figure 1: Presents the internal dry resultant temperatures that were exceeded for 30hrs in a reference and exposed thermal mass office using Heathrow weather data. Maximum space temperatures were predicted higher by aprox. 1.5 to 2.0°C for the reference case and 1.0 to 1.5°C for the exposed thermal mass case. It should be noted that in mechanical systems and in particular when high ventilation rates are utilised, fans will increase temperatures by about 0.5 to 1.0°C.

**Table 1**: Predicted solar gains using Heathrow weather data.

| Orientation | North ($W/m^2$) | East ($W/m^2$) | South ($W/m^2$) | West ($W/m^2$) |
|---|---|---|---|---|
| Low gain glazing (eg reflective double glass) | 7 | 12 | 20 | 20 |
| High Gain glazing (eg single clear glass) | 10 | 24 | 35 | 35 |

**Free cooling provided**

It should be noted that Figure 1 presents peak temperature reductions only. In many cases, larger reductions are achieved during other times of the occupied period especially during the morning hours as presented schematically in Figure 3. This effect is taken into account for the calculation of total free cooling provided during occupancy hours as presented in Figure 2.

The free cooling has been quantified in terms of energy saved per unit floor area during the summer months of June to September. It is clear that the free energy provided by night ventilation is a worthwhile strategy in the exposed thermal mass office, providing between 6 and 20 kWh/m$^2$/annum of free energy. However, there is some benefit in night ventilating a reference type building as the free energy provided ranges between 2 and 5 kWh/m$^2$/annum. In the second case, the benefits might be offset by the energy required to run a fan in mechanical systems, so night ventilation may be a worthwhile strategy if it is provided by natural means.

**Fan energy required**

If the night ventilation is provided through a mechanical system, some energy is required for the fans during the night. An indication of the required energy is presented in figure 4 in terms of hours that fans would run to provide the same cooling. These estimated fan hours can be multiplied by the fan power to obtain fan energy consumption as follows:

$$E_{fan} = SFP \times Q_a \times hrs$$

where:
$E_{fan}$ = fan energy consumption (Wh/m$^2$/annum)
SFP = specific fan power (W/l/s)
$Q_a$ = air flow rate ((l/s)/m$^2$)
hrs = fan run hours during summer

Table 2 provides some example calculations for a case with internal + solar gains of 25W/m$^2$. It can be seen that the energy required by advanced and best practice (SFP=0.75-1+) fans is only a small percentage of the free cooling provided by night ventilation. It could be a worthwhile strategy for exposed mass building when using less efficient fans but the benefits might offset the energy consumption for the reference case and higher ventilation rates.

**Table 2:** Example calculations for fan energy consumption (internal + solar gains 25W/m$^2$)

| Building Type | Day V. ach | Night V. ach | Temp °C (fig 1) | Cooling kWh/m$^2$/a (fig 2) | Fan Run hrs (fig 4) | Fan energy kWh/m$^2$/a SFP=0.75 | Fan energy kWh/m$^2$/a SFP=1 | Fan energy kWh/m$^2$/a SFP=2 |
|---|---|---|---|---|---|---|---|---|
| Ref. | 2 | 2 | 28 | 3 | 275 | 0.35 | 0.45 | 0.9 |
| Ref | 2 | 8 | 26.5 | 3.25 | 125 | 0.6 | 0.8 | 1.6 |
| Exp | 2 | 2 | 25 | 11 | 450 | 0.55 | 0.75 | 1.5 |
| Exp | 2 | 8 | 24 | 13 | 315 | 1.5 | 2 | 4 |

**DISCUSSION**

One reference and one exposed thermal mass typical office modules were used and simulations were carried out using the APACHE thermal simulation model and Heathrow summer weather data. The predictions have been presented in terms of peak internal dry resultant temperatures exceeded for 30hrs over the four summer months of June to September, free cooling provided when using night ventilation and energy required for fans during the night in mechanical systems. It was shown that, in general, there is a 2°C temperature difference between the reference and the exposed thermal mass office. In both constructions the largest reduction in peak temperatures when using night ventilation is achieved when the day ventilation rate is low. Free cooling is three to four times higher in the exposed thermal mass office than in the reference office. The required fan energy is a low percentage of the provided free cooling in the exposed mass office and a higher percentage in the reference office. Therefore, an exposed thermal mass construction will provide the most benefit in terms of temperature reduction during the day and free cooling.

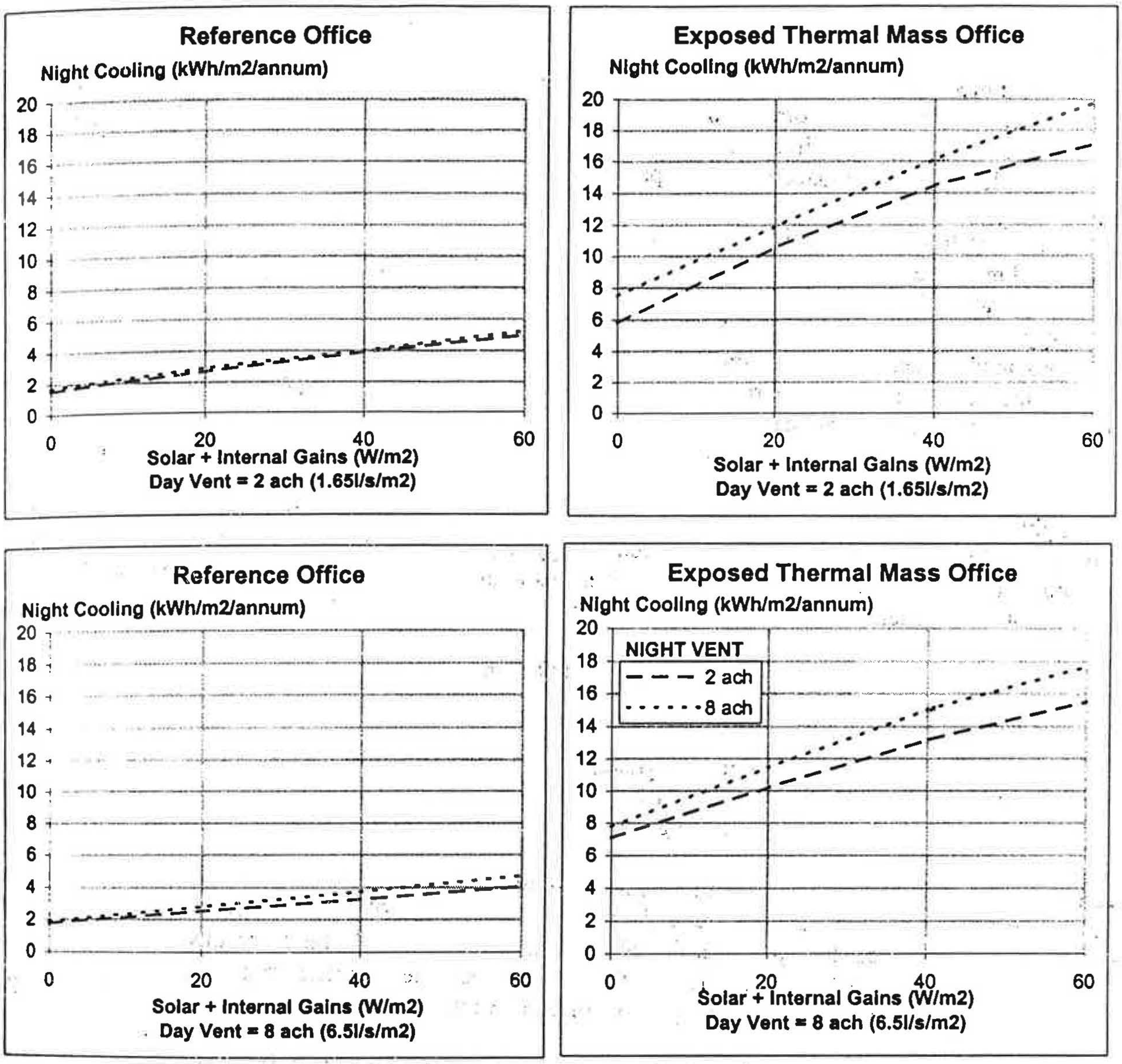


Figure 2: Free cooling provided with night ventilation in a reference and exposed thermal mass office using Heathrow weather data.

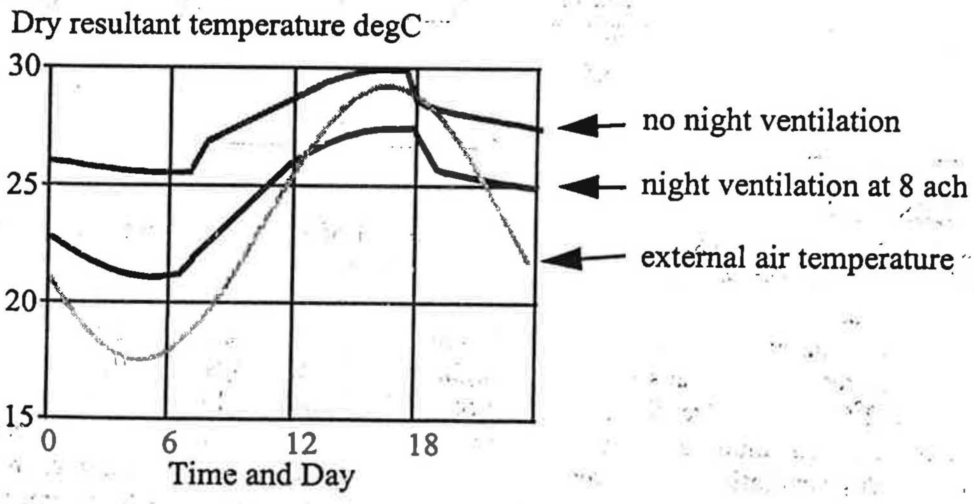


**Figure** 3: Schematic of hourly temperature in an exposed thermal mass office with and without night ventilation. Internal gains are set to $25w/m^2$, infiltration to 0.4 ach and day ventilation to 2 ach

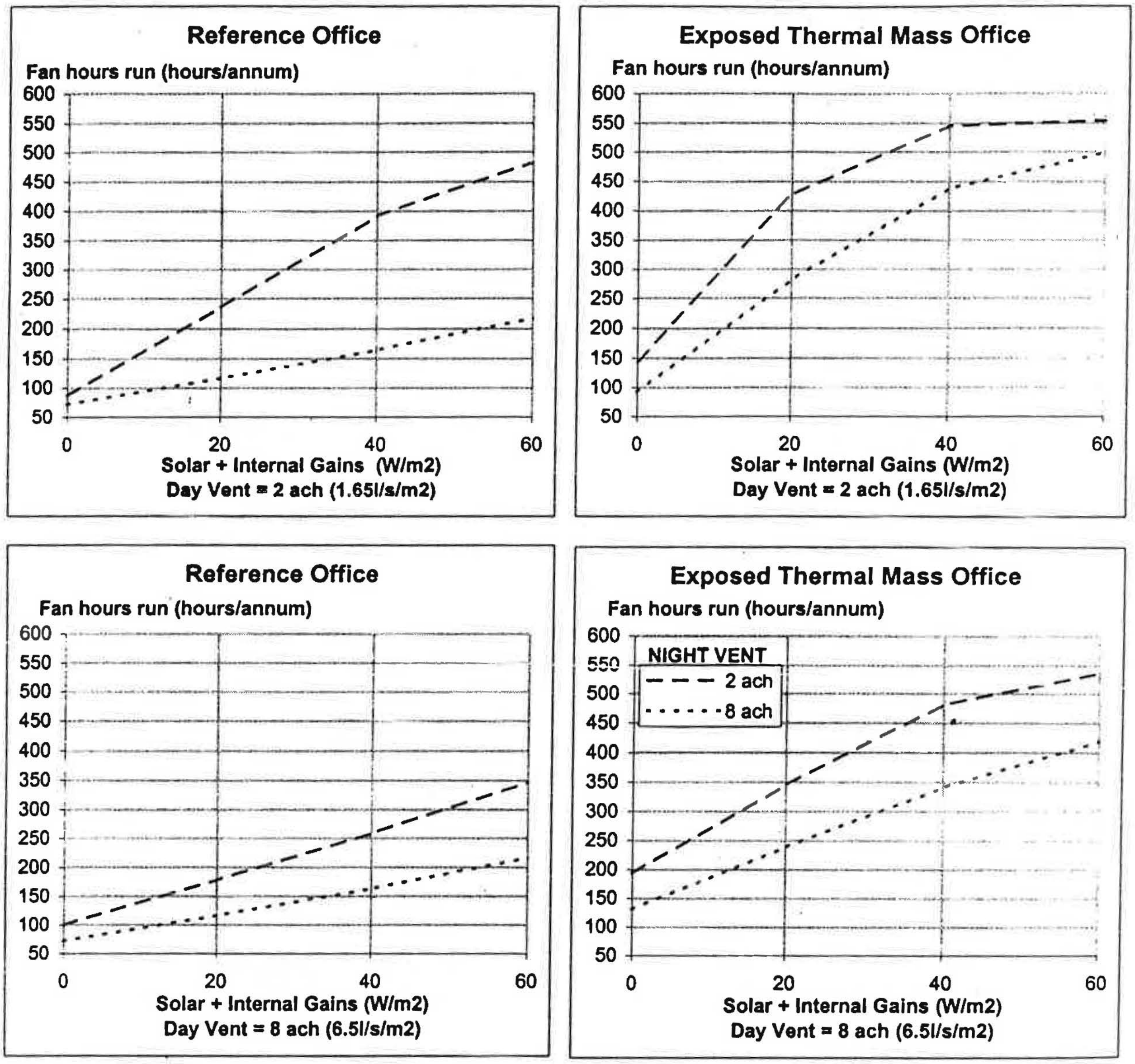


Figure 4: Number of hours that a fan need to run during the night in the summer in order to provide the free cooling predicted in Figure 2.

## ACKNOWLEDGEMENTS

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