Implementing the Results of Ventilation Research
16th AIVC Conference, Palm Springs, USA
19-22 September, 1995

Automatic Control of Natural Ventilation and Passive Cooling

Andrew Martin

BSRIA, Old Bracknell Lane West,
Bracknell, Berks RG12 7AH, UK

AUTOMATIC CONTROL OF NATURAL VENTILATION AND PASSIVE COOLING

Andrew Martin, BSRIA, Old Bracknell Lane West,
Bracknell, Berkshire, RG12 7AH, U.K.

Natural ventilation has the potential to replace or supplement air conditioning, comfort cooling and mechanical ventilation. Whilst there are obvious environmental advantages, there are problems of achieving adequate control. The flow of air must be controlled to ensure a comfortable environment in the building whilst limiting energy consumption and maintaining indoor air quality.

Several UK buildings now use natural ventilation in conjunction with automatic control systems. This technique has a number of important benefits including:

- reduced building energy consumption
- potentially lower equipment costs
- lower operation and maintenance costs
- improved temperature control (primarily in passive buildings), especially during hot periods
- possible integration with mechanical ventilation systems.

This work was carried out as part of the Department of the Environment's EnREI (Energy Related Environmental Issues in Buildings) programme and was managed by the Building Research Establishment. The material presented in this paper highlights some aspects of two research projects, 'The Control of Natural Ventilation'[1] and 'Night Cooling Control Strategies'.

The research undertaken has led to the development of generic control strategies. These have evolved from consideration of the control strategies used in naturally ventilated buildings utilising Building Management System (BMS) control together with experience obtained from monitoring three naturally ventilated buildings. The site monitoring has also led to recommendations being provided for commissioning and fine tuning procedures.

1 INTRODUCTION

1.1 The decision to use automatic controls

The decision to use automatic controls is primarily based on the expected heat gains in the occupied space. If the heat gains are expected to be below approximately 25 W/m^2[2] throughout the year then manual opening of windows will generally allow summer comfort conditions to be maintained. The use of automatic controls fitted to the inlet and outlet ventilation path within the building can extend this, through the use of night-cooling control strategies and an appropriate building design, to heat gains of approximately 40 W/m^2 or more. These cooling strategies allow the inlet and outlet vents to be opened during the night thus allowing the cool night time air to flow through the building, cooling the fabric, furniture and fittings. In this way the heat that has built up during the previous day is removed and storage of the cool air ('coolth') within these components is achieved, consequently providing a cooling effect the following day. The building fabric may be designed to have exposed concrete ceilings or other exposed mass to facilitate the storage of additional 'coolth', thus enhancing the effect.

The use of a lighting control system may extend this even further since it will reduce the heat gains during the peak cooling season (perhaps by 10 W/m^2) when natural light levels will be at their highest. Above heat gains of approximately 45 W/m^2 mechanical ventilation in conjunction with comfort cooling or air conditioning is more likely to be used.

Automatic controls are not only used to ameliorate heat gains. Some buildings may not be suited to manual operation of windows especially public buildings where damage may occur to the vents when opened by occupants unfamiliar with their operation. Other buildings may not have accessible windows such as atria, sports halls, etc.

Automatic control of the windows and vents may take place in conjunction with manual control. Research has been carried out[2] showing that where occupants of a space have control over their local area they are more willing to accept a wider comfort band. This may be in the form of two separate ventilation components, one under manual control and the other under BMS control (for night-cooling). Alternatively, an occupant controlled pushbutton may be used to electrically drive a window or vent open during the day with the BMS overriding this at night.

1.2 Open/closed or modulating control

Modulation of the vents is advantageous since it allows a reasonable level of ventilation to take place when there is rain or high winds present. This is achieved by restricting the opening of the vents to a position to prevent the ingress of water and high air velocities. Other building designs allow ventilation in poor weather conditions by protecting the air inlet path by the use of shades, grilles, cowls and baffles, thus allowing some or all of the vents to remain open.

Modulation of the vents may not be necessary as opening and closing the device in steps can be acceptable, or alternatively, the successive opening of ventilation devices in sequence may be possible until the ventilation demand is satisfied. The air flow rate through the device will, in any case, be generally coarsely controlled due to the fluctuations in the wind speed. This renders close control of air flow rates impracticable. However, if ventilation openings with a large 'free area' are provided relative to the volume of the space, it is likely that they will be required to have modulating control in order that some control of the air flow rate can be achieved.

The research carried out has led to the development of generic control strategies for buildings with automatic control of natural ventilation only, buildings with mechanical and natural ventilation control (mixed mode) as well as two generic control strategies for night cooling. These evolved from consideration of the control strategies used on ten sites together with experience from monitoring three of these sites.

2 MIXED MODE CONTROL STRATEGY

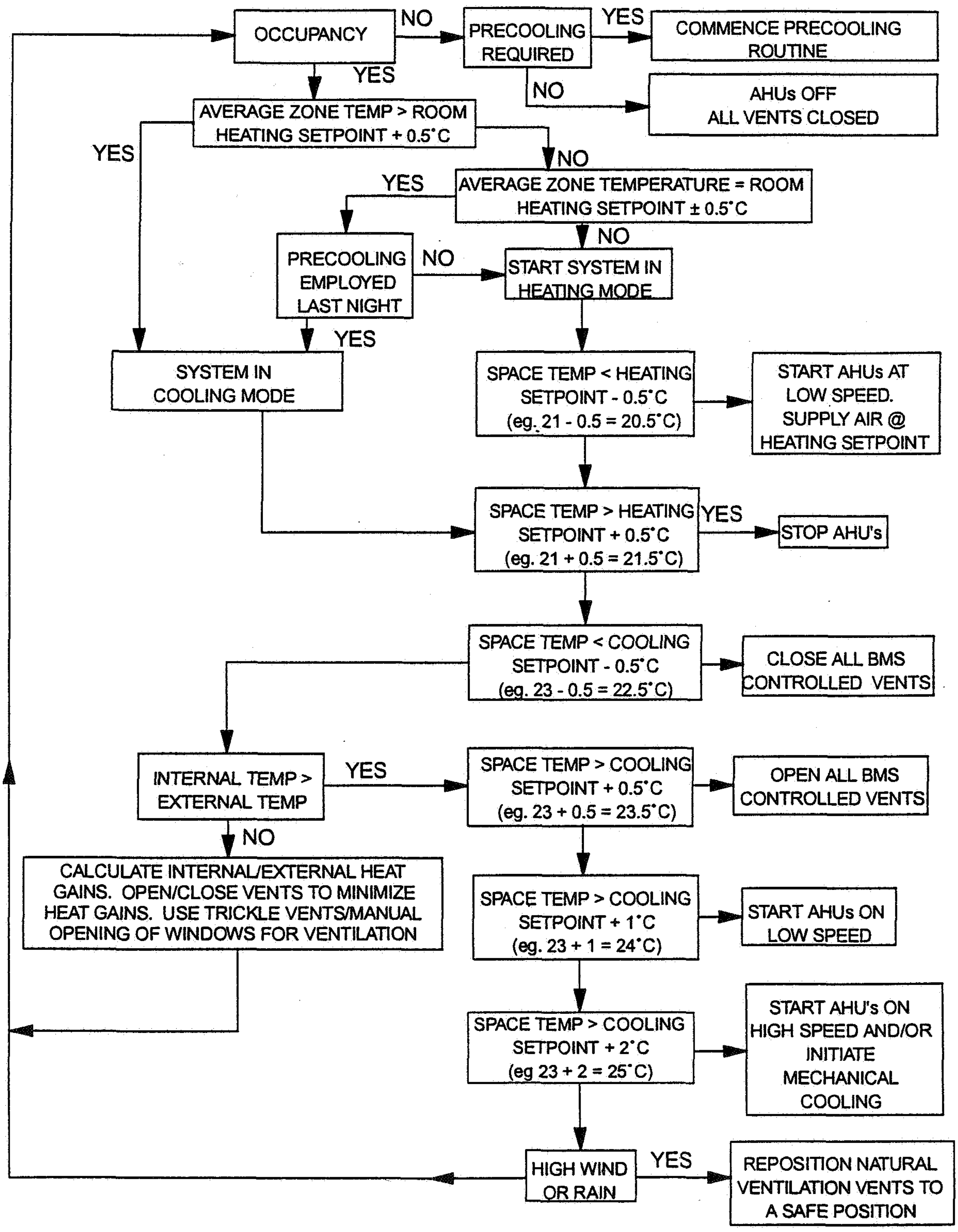
The control system determines whether heating or cooling is required depending upon the average zone temperature and selects the appropriate ventilation system following the logic presented in figure 1. In the event that mechanical cooling is not available and both the internal and external temperatures rise above say, 23°C, then the optimum control strategy (ie whether to open or close the vents not required to satisfy the minimum fresh air requirement) is dependent upon a number of issues:

i) Selecting the minimum source of heat gain - ie the external air will supply a heat gain to the space depending upon the external air temperature and the number of air changes per hour. This is approximately 0.35 W/m^3 for each 1°C difference between internal and external temperature.

ii) Maintaining the inlet and outlet vents open will maximise the air movement in the building, but at the cost of increasing the rate of internal temperature rise. However, the increased air movement will be beneficial to comfort in preference to slightly lower internal temperatures and less air movement. The extent of the perceived benefit of air movement on people has been discussed by Oseland[2] who suggests that " the graphs and algorithms used in current standards (CIBSE, ASHRAE Standard 55 and ISO 7730 [1993]) which show the increase in temperature required to compensate for an increase in air velocity can equally well be used to show the increase in summer temperature that will be tolerated with an increase in air velocity." This would suggest that an air velocity of 1 m/s will correspond to a perceived temperature decrease of about 2°C.

iii) A further consideration is that the requirement to manually close vents, especially windows, is counter-intuitive to human nature when it is hot in countries where air conditioning is not prevalent. The benefit of providing mechanical ventilation plant simply to increase air flow under hot conditions should also be carefully considered. The use of a 'punkah' fan is likely to be more beneficial.

Figure 1 - Mixed Mode Ventilation Control Strategy



3 NIGHT-COOLING CONTROL STRATEGY

The choice of a night-cooling control strategy is dependent upon achieving the optimum transfer of cool night air into the building fabric, furniture and fittings. One control strategy for allowing this is presented in figure 2. This strategy aims to measure the daytime heat gains in the space and then remove the equivalent amount of heat at night, thus maintaining the equilibrium between the building fabric temperature and the space temperature. The method of quantifying the daytime heat gains is based upon measuring the number of hours that the internal space temperature is above room temperature setpoint, totalled for all the hours in this period. The cooling gain in degree hours is defined as the number of hours that the internal temperature is below the room temperature setpoint, totalled for all the hours in the period.

The decision as to night-cool or not is based upon the number of degree hours that the internal temperature is above the room temperature setpoint. If, at the end of the occupied period the internal temperature has been above the room temperature setpoint for more than say, three degree hours and the internal temperature is higher than the external temperature, then the decision is made to cool the building that night. The normal wind, rain and low external temperature interlocks still apply. In the event of these interlocks occurring the ventilation openings will either close or they will be limited, if possible, to a practical operating position. A multiplying factor may be provided so that the amount of cooling degree hours can be varied above or below the monitored daytime heating degree hours.

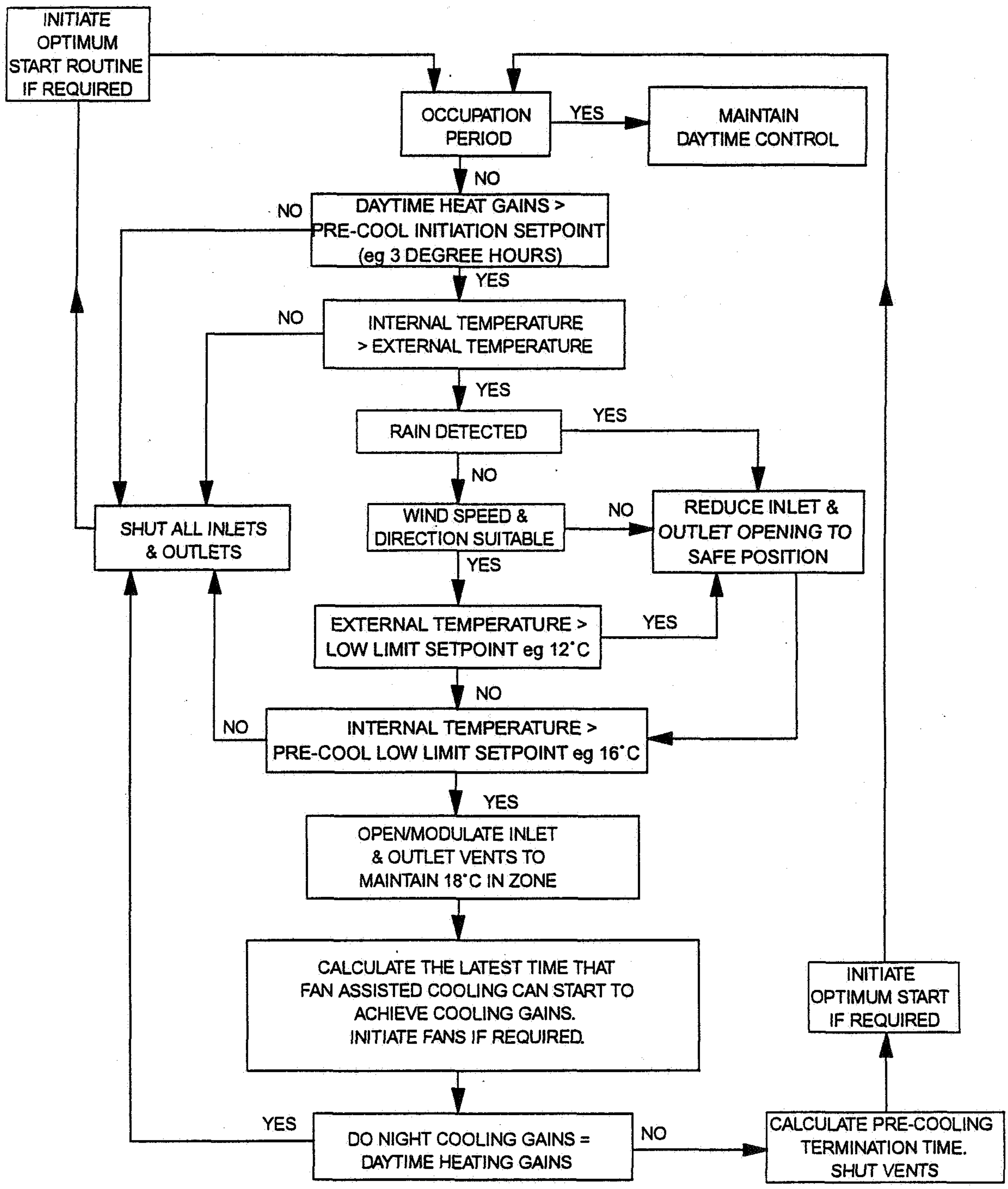
Other night cooling control strategies allow the internal temperature to fall to a lower value (eg 14°C) thus increasing the amount of passive cooling provided. This may add an additional control problem - when to terminate the night cooling. Typically, an exposed ceiling slab will still be at a temperature of approximately 20 - 23°C even after a full night of cooling (it is unlikely that a concrete slab will change temperature by more than 1°C overnight and 0.5°C is more likely). This exposed slab thus provides a heating source capable of raising the internal air temperature towards the room heating temperature setpoint. If the night-cooling is not completed then the optimum time to terminate the night-cooling strategy is not clear. The two possibilities are:

a) disabling the night-cooling earlier in the morning thus allowing the space to be heated by the heat re-emitted from the building fabric or,

b) extending the night-cooling and initiating the heating system for a short period. This is believed to provide additional stored cooling for use later in the day.

In option a) the control system calculates the time that the ventilation system should shut down in order that the heat gains re-emitted from the building fabric will provide sufficient heating to raise the space temperature to the setpoint by the start of the occupation period. The intensity of this heating effect is typically expected to be in the region of 1 to 1.5 K per hour and will depend in particular, upon the effectiveness of the night-cooling strategy in conjunction with the thermal characteristics of the fabric, furniture and fittings. If there is insufficient passive heat available then it may be

Figure 2 - Night Cooling Control Strategy



necessary to provide heating. It is, in any case, recommended that the conventional optimum start algorithm is provided to initiate the heating if the building is unlikely to achieve the space temperature setpoint by the start of the occupation period. This is analogous to option b) and the efficacy of this is based on the requirement that the internal temperature is at the space temperature setpoint by the start of occupancy. The comparatively small amount of heat input necessary to reach this state is expected to be justified by the additional cooling stored in the slab, which will benefit the space with a reduced air temperature during the ensuing day. It is, of course, necessary that the space temperature (heating) setpoint is below that of the slab temperature to prevent the slab absorbing the heat given out by the terminal heat emitters.

Where mechanical ventilation is available a separate algorithm calculates the latest time that the supply and extract fans should start in order that night-cooling can be completed. There may be an interlock that only allows the fans to run during the low tariff period thus minimising electricity charges.

Three buildings were monitored as part of the project, one of which is presented below.

4 MONITORING OF A MIXED MODE BUILDING

The building is a three storey office building built around a central atrium. The building utilises BMS control of the casement vents with manually controlled centre pivot windows beneath. A mechanical ventilation system can provide either 2 or 4 air changes per hour to the open plan office space. The building utilises the generic ventilation control strategy presented in figure 1. The night-cooling strategy is based upon ventilating all night using natural ventilation to obtain a calculated slab temperature setpoint. This setpoint calculation is self learning according to the deviation from the setpoint at the start of the following day and is based upon equalising the slab temperature, the room temperature and the slab temperature setpoint. An adjustment factor is provided in order that towards the end of the occupancy period a cooling effect is still available from the slab. Mechanical ventilation is initiated during the low tariff period if necessary. The mechanical ventilation system is also initiated in the event of the high wind and rain interlocks operating.

Monitoring of this building highlighted the following:

- Night-cooling of the exposed concrete slab enabled the average space temperature to be held at 26°C with an external temperature of 31.5°C (windows open),

- Bad weather (high wind or rain) prevented the natural ventilation system from operating for approximately 30% of the time. Consequently the mechanical ventilation system ran thus increasing the energy use of the building. Fine tuning of the control setpoints will help to alleviate this,

- However, mechanical ventilation to assist cooling during the daytime was initiated on only 9 of the days during the 4 month monitoring period. On 7 of these days the outside air temperature was above the internal temperature and therefore the mechanical ventilation was not suitable for cooling. This would suggest that if passive winter ventilation was provided together with either an improvement in the building design to facilitate natural ventilation during poor weather conditions and/or fine tuning of the weather control setpoints, then there is little requirement for mechanical ventilation,

- The use of night-cooling using natural ventilation appeared to provide more effective cooling of the exposed slab (and the space temperature) than the use of night-cooling using mechanical ventilation. This is despite the natural ventilation working with higher temperature external air. This effect may be due to fan pick up. A better technique may be to use the extract fans to 'drag' air through the casement windows in order to cool the space,

The initiation of the heating system following night-cooling occurred on 25% of the monitored days. The night-cooling and heating controls were not linked other than to inhibit the optimum start routine if night-cooling was applied. It is suggested that for this building consideration should be given to linking the strategies in order to reduce the hours of operation of the heating system.

The analysis carried out regarding the eleven buildings utilising automatic control as part of this project suggests that the buildings would benefit from further fine tuning of the control systems in order to enhance their performance, both in terms of the internal temperature as achieved and in a reduction in energy consumption. This fine tuning should be an additional contract following completion of the building and should be undertaken throughout the year following handover, perhaps involving three site visits. The additional cost of this can often be justified by the energy savings that can be achieved as well as the improved comfort conditions that will result. However, it is important that the contractor has a pre-conceived plan for the fine tuning method.

ACKNOWLEDGEMENTS

BSRIA acknowledge the financial support and project guidance provided by: the Department of the Environment of the U.K. Government (via the Building Research Establishment), Caradon Trend Ltd, Colt International, Landis & Gyr (Europe) Corporation, Oscar Faber Applied Research and Vent Axia Ltd.

REFERENCES

1) MARTIN A J. *Control of Natural Ventilation.* TN11/95. 1995. BSRIA. ISBN 0 86022 406 6.

2) Building Research Establishment Digest 399. *Natural Ventilation in non-domestic Buildings.* October 1994.

3) OSELAND N. *A review of thermal comfort and its relevance to future design models and guidance.* Proceedings of BEPAC Conference. York. 1994. pp205-216.