INNOVATIONS IN VENTILATION TECHNOLOGY

21ST ANNUAL AIVC CONFERENCE
THE HAGUE, NETHERLANDS, 26-29 SEPTEMBER 2000

The role of simplified ventilation modeling for the application of low energy design: a library case study

S C Rufus* and M Kolokotroni♦

*Dorset County Council, UK
♦Department of Mechanical Engineering, Brunel University, Uxbridge, UB8 3PH, UK

The role of simplified ventilation modeling for the application of low energy design: a library case study

S C Rufus* and M Kolokotroni♦

*Dorset County Council, UK
♦Department of Mechanical Engineering, Brunel University, Uxbridge, UB8 3PH, UK

Abstract

This paper discusses how simplified thermal and ventilation tools could be used during the feasibility study of buildings to demonstrate the advantages of natural and low energy ventilation strategies. The paper focuses on local authority library buildings in South-East England and two simplified tools were used; one using a dynamic thermal simulation and ventilation method and another based on the admittance method. The prediction of both tools were compared with measured temperatures from an existing library that has a known overheating problem. Having gained confidence in the tools' predictions, the dynamic thermal simulation and ventilation tool was used to modify the design of a proposed library building at the feasibility stage, as a way of demonstrating how the design of the building could be change to benefit from natural ventilation. The paper concludes that using the results of user-friendly dynamic thermal simulation and ventilation models, local authority engineers would be able to adapt the concept of the building to low energy design principles. The need to develop simple adaptable and accurate tools for natural ventilation applications for a variety of building types is highlighted.

Introduction

In recent years, natural ventilation has gained momentum as a suitable passive design strategy for non-domestic UK buildings. Design guidance and documented case studies have been published by professional institutions [for example 1-5] and results of European projects have emerged [for example 6 and 7]. In addition, details about naturally ventilated buildings including post-occupancy evaluations have appeared regularly in professional journals [for example 8-10].

The application of natural ventilation for public funded buildings has also emerged for two reasons:

(a) purpose design natural ventilation will help in providing good internal air quality and comfort at a reduced capital and most importantly running cost. Running costs are a considerable burden for public funded buildings in contrast to commercial building where energy is submerged relative to staff costs.
(b) low energy buildings will help to demonstrate the environmental impact commitment of local authorities and will directly contribute to the Government's CO_2 reduction targets for 2012.

School buildings are a good example of centrally driven initiatives. A recent publication from the Department of Education encourages natural ventilation in such buildings [11].

Public libraries are another example where natural ventilation could be a suitable strategy. As in many public funded buildings, building related budgets for libraries are restricted and costs need to be kept at a minimum both capital and operational. Therefore, they are based on standard designs with a low percentage of them provided with air-conditioning. The consequence is either uncomfortable internal conditions during summertime or expensive and energy intensive retrofits.

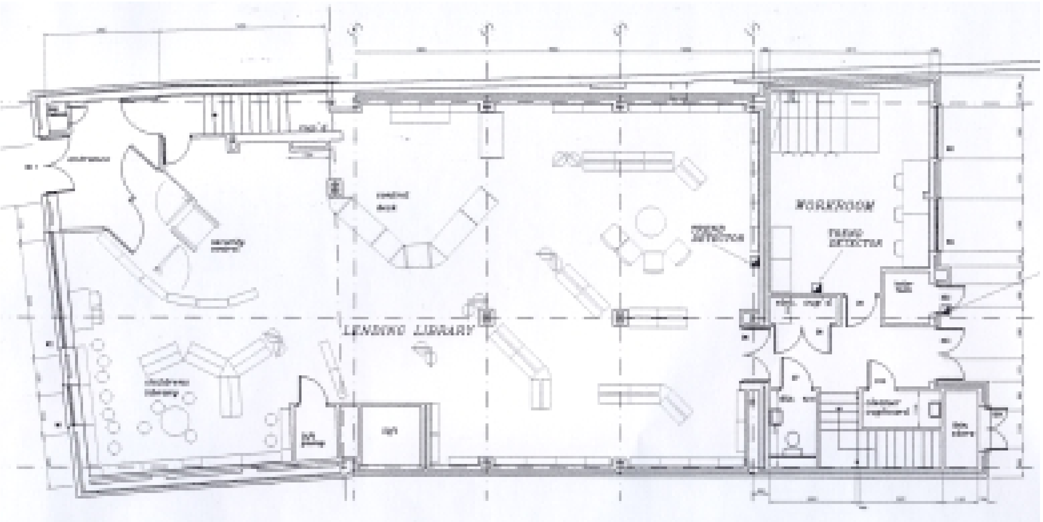
The aim of this paper is to illustrate how simplified thermal and ventilation tools would help local authority estates departments to provide information to their finance colleagues and users of buildings on the benefits of purpose designed natural ventilation strategies together with good practice low energy simple design strategies for their library buildings. A ventilation simplified computer tool was used for the analysis; (BRE's NiteCool [6 and 12]). NiteCool uses a dynamic thermal simulation model [13] and natural ventilation calculations set out in CIBSE's AM10 [1]. The tool is developed for office buildings but in the present study has been used for library spaces. This tool will be referred to as SDT&V tool in the following sections (Simplified Dynamic Thermal and Ventilation). In addition, a tool based on the admittance method was also used to carry out some comparative analysis, as this method is the basis of many simplified tools. This tool will be referred to as 'design-day' tool because the predictions are carried out for one day at a time. First the prediction of both tools were compared with measured temperatures from an existing library that has a known overheating problem. Having gained confidence in the tools' predictions, they were used to modify the design of a proposed library building at the feasibility stage, as a way of demonstrating how the design of the building could be change to benefit from natural ventilation.

Existing naturally ventilated library building

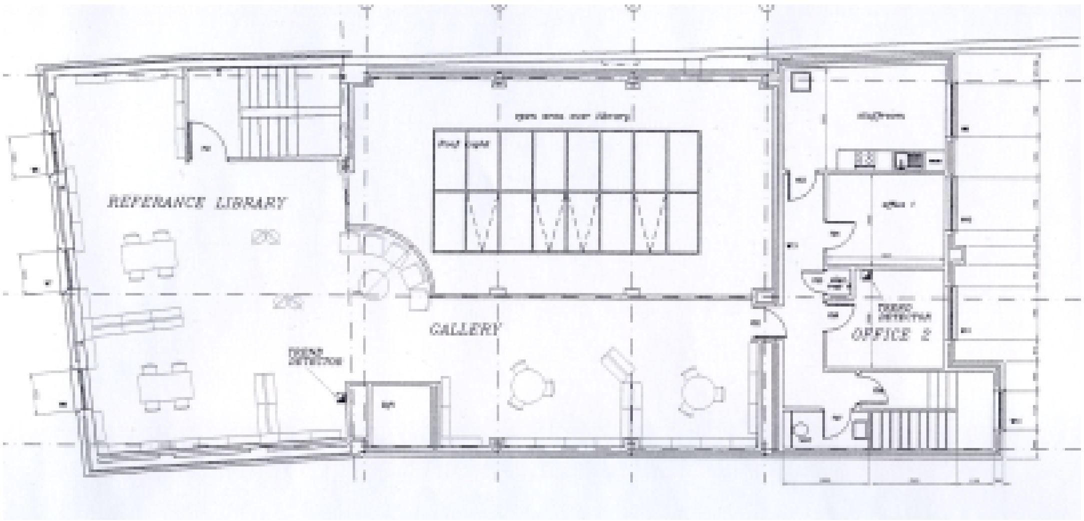
Building and existing ventilation strategy description

The case-study building is a two storey library located in a quite road of the main thoroughfare in a rural market town in south-east England. The plans of the building together with photographs of the front and back elevations are shown in Figure 1. The area around the building is relatively lightly developed with open area to the rear of the site. The building is approximately three miles from the coast so is influenced by south westerly sea breezes during most of the year. The main frontage of the building was originally constructed in the late 18th century as a private dwelling house. The whole building and especially the rear section has been altered over the years to suit varying uses. The conversion to the present library was completed in June 1997. The overall floor area of the new building is 462m^2.

The library area has a balanced mechanical ventilation system installed on the ground floor only for indoor air quality purposes and not for cooling. The maximum total capacity of the system is 1250 m^3/hr.(347 l/s) calculated to provide 8l/s per person for a maximum occupancy of 40 occupants. Due to security problems (theft of books) the client requested that none of the windows in the main library area should be openable. All windows are fitted with trickle ventilators in the window heads, these are difficult to reach on the tall windows



Ground Floor Plan



First Floor Plan

Front Elevation

Back Elevation

FIGURE 1: Floor Plans and Elevation Photographs of existing library

on the ground floor of the library. On site investigation all the trickle ventilators were closed. The staff did not know they were installed or how to use them. The original design relied on the use of high level opening roof lights to provide the main source of rapid ventilation to the library. There are 4 of these opening roof-lights each unit being 1m wide x 2m long with a maximum opening of 0.45m. The original roof light was to have full solar control glazing and to be controlled through the building management system in conjunction with temperature, rain and CO_2 sensors. This was cut from the design due to budgetary constraints. The system actually installed comprises of slightly tinted glazing with a basic control system based on a temperature sensor to open and close the windows at a set point of 24°C coupled with a rain sensor over ride and a link to the intruder alarm which automatically closes the roof-lights when the alarm system is set. The opening roof lights were designed to dissipate any excess heat that occurred during the summer months. The original ventilation concept included ducts that were to run from the rear of the library at first floor ceiling level through the rear offices to the external wall. The ideal was to use these ducts to introduce fresh air into the main library at ceiling level allowing the full stack ventilation effect to be utilised. These ducts were taken out of the design at some stage due to the fire officers request for compartmentation of the building in conjunction with a cost cutting exercise.

Perceived and measured summer overheating

Since its occupation in the summer of 1997 both staff and visitors complained of the building being very warm especially in the reference section on the first floor. During the autumn, winter and spring months the occupants were very happy with the environment throughout the building. During the summer of 1998 complaints of over heating and ‘stuffiness’ again came to light. So it was decided to log the temperatures that were occurring in different areas of the library during July and August.

From the recorded temperature plots, it was observed that the temperature in the main library starts to rise quickly from 10 am. When the CIBSE AM2 Window Design Manual [14] Sunpath diagrams were applied to the building they show that the roof glazing would theoretically be in direct sunlight between 10 and 11 a.m. which would indicate that the main solar gain at this time of day is through the roof light. From 10am the temperature steadily increases until the peak temperature is reached at approximately 6 p.m. From the temperature plots it was observed that the internal temperature of the building drops very slowly. On a typical day when peak day time temperatures of 28.8^oC on the ground floor and 27.8^oC on the first floor were recorded, the night time internal temperature did not drop below 23^oC when the external minimum temperature dropped down to 12^oC. This indicates the building is well insulated and has a fairly “tight construction” with not much air leakage. The decay of the internal temperature in the library is very slow, on average less than 0.25^oC per hour. It is also suggested that the books in the library may act as a heat sink and store heat which is released over night back into the building. This may change the characteristics of the building from light weight to a heavy weight structure. Another indication that the building is acting as a heavy weight structure is the delay of the maximum internal temperature compared to the outside temperature, this delay is on average about 4 hours which is much longer than would be expected from a light weight building [15].

Modelling results

The question to be answered using simplified modelling was what can be done for this building and what can be done for future buildings so that similar mistakes are not encountered. It is not possible to carry out detailed studies using advanced thermal and ventilation simulation models because of the resource implications. What is needed is a reliable tool that would give fast results in the right order of magnitude so that comparisons of different design options can be made.

As mentioned before the SDT&V tool to be used is a software package developed for the investigation of passive and low energy ventilation for cooling in office buildings. But how accurate the predictions are for overheating summertime periods in a mostly naturally ventilated library? This was investigated by comparing the simulation results to measured temperatures. The same would apply for the 'design day' tool.

All input for the model have been estimated as realistically as possible. Some additional calculations were carried out for the estimation of natural ventilation rate because the tool is based on a 'typical' office module and adjustments had to be made for the actual volume of the library.

Figure 2 presents a comparison between measured and predicted internal temperatures by the two tools. The external weather is assumed 'typical' of SE England (8% risk factor [16]) with a maximum temperature of 25.2°C and a minimum temperature of 15.9°C. It can be seen that both methods overestimate the maximum internal temperature. It is also observed that the correlation between the shape of the temperature trace between SDT&V predictions and measured values is very good with the peak temperature predicted within one hour of the actual recorded results. Also, the shape of the curves during the night is extremely close, with the rate of decay of temperatures matching very well. This indicates that the minimum temperature calculations do follow the recorded results very well.

It should be noted that the building is assumed as a lightweight structure because of its construction. Some additional simulations were carried out where the thermal capacity of the building was changed to heavyweight in both models. This had the effect of reducing the maximum temperatures by $2.5^{o}C$ of the SDT&V tool's predictions. This brings the predicted temperature closer to the maximum recorded temperature, again indicating that the library is acting as a heavy weight building. The effect on the predicted temperatures was negligible when using the 'design day' tool; the only effect was to shift the peak temperature by one hour.

The above results indicate that the use of simplified dynamic thermal simulation models has an advantage over design-day procedures because they take into the account the accumulative effect over a number of days. This becomes very important in cases that passive ventilation for cooling is considered. Also the effect of the internal thermal capacity of the building (in the forms of books) could be taken into account for more accurate predictions of the internal environment. It should be noted that the effect of books on the temperature and humidity of space has received attention by researchers and practitioners for the design of libraries and similar buildings such as archive buildings [17].

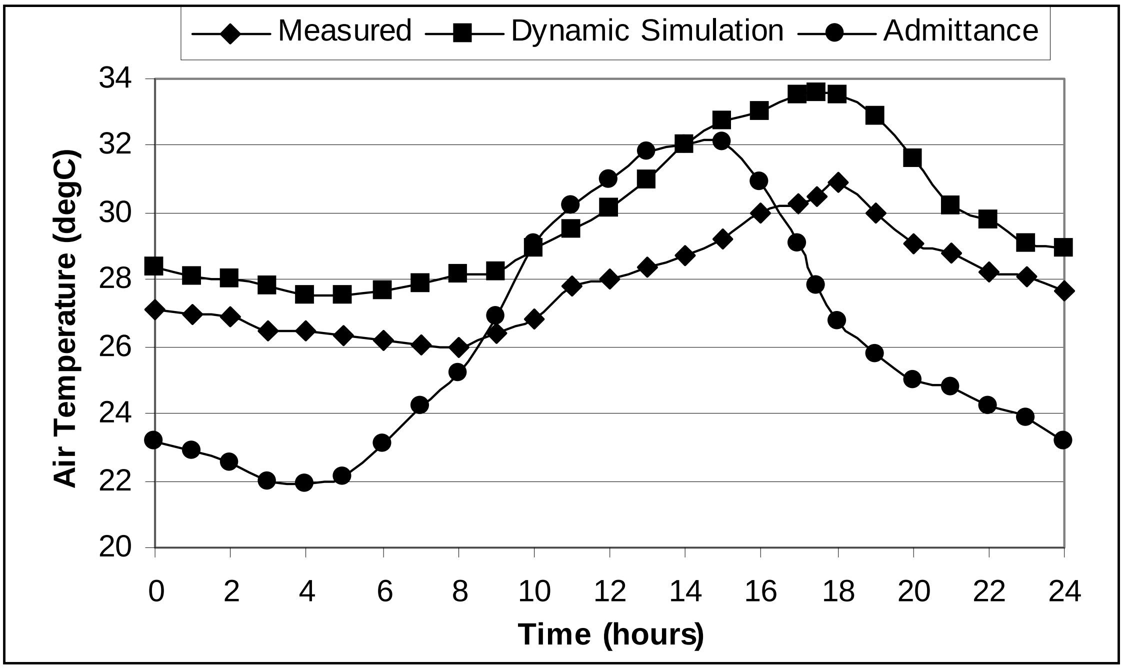


FIGURE 2: Measured and Predicted values for air temperature in the library.

Application of results to a new library building

The previous section has increased confidence on the predictions of internal temperatures using the SDT&V model. In this section, the model is used to demonstrate how the design of a new library at the feasibility stage would be improved in line with low energy design principles in order to make the specification of an air-conditioning system unnecessary. The library considered was at feasibility stage so is in an ideal situation to be considered for modification to use natural ventilation.

The proposed building is to be three stories high and will accommodate both the library and ancillary offices. The plan of the ground floor and a section of the proposed building is shown in Fig 3. The offices (400 m^2) are located on the south and east side of the building on all three floors. The library area (550 m^2) occupies the west and north sections of the library. The existing design did to some extent consider natural ventilation for the building but has not progressed beyond this initial point. The section will focus on the predictive performance of the main library area which includes large amount of west facing glazing so potentially it may have an over heating problem. With the layout of this area stack ventilation could be applied.

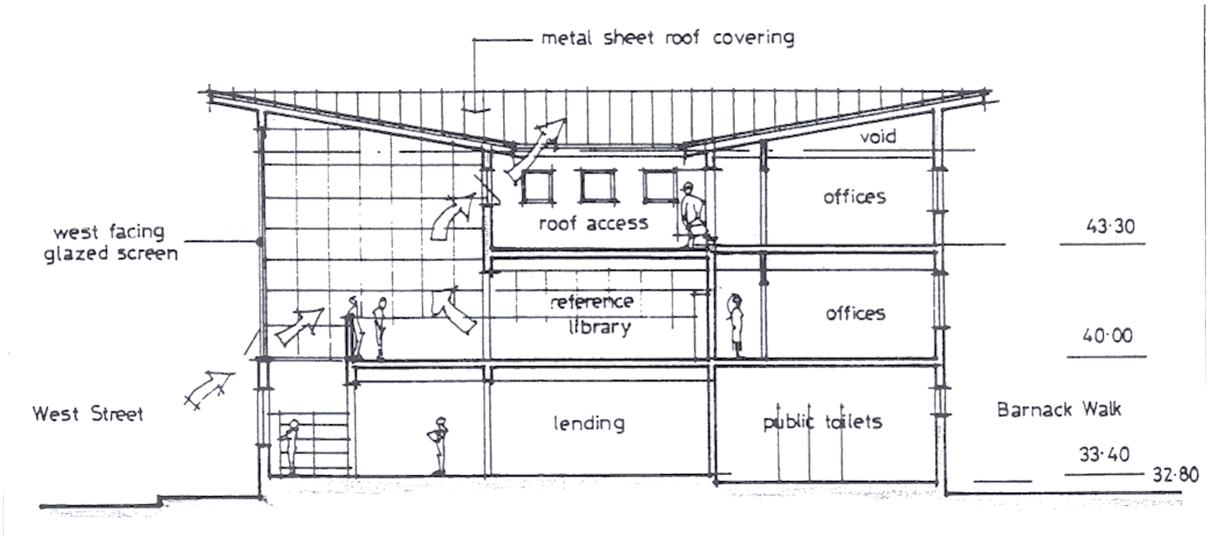


Figure 3: Cross section for the proposed library building as originally proposed

Modelling results

First the SDT&V model was used to simulate the internal conditions in the main library area in the proposed design. The model will then be developed to try and reduce the peak predicted temperatures for the main library. The system will be used to calculate the required free areas for the proposed ventilation methods and the way they could be practically incorporated into the building will be discussed. The main library area has been selected using the west facing area as the base model. As the library building is in fact 11 times larger than the standard office model this will be taken into consideration when calculating free areas for ventilation rates. The design of the library allows the use of stack ventilation to be modelled. The specific parameters used for the library model are shown below:

Internal Load:- The figures used are based on the information obtained from the Bridport library survey and information given by the client. The equipment load in this library is be higher than the Bridport Library as the use of information technology services is expected to be greater. The loads have been averaged over the whole area of the library as it is being treated as one large space. The lighting load has been left in as the lights are usually left on during the day, even if adequate natural lighting is available.

Lighting Load 8 W/m^2, People and Equipment 14 W/m^2, Total 22 W/m^2. Use figure of 20 W/m^2

Infiltration: a figure of 0.5 air changes per hour has been used. A slightly higher figure has been used than Bridport due to the larger area of exposed wall and glazing giving more chance on unintentional infiltration.

Glazing Ratio:- As a large area of the building is glazed a figure of 0.8 has been used. When shading is used a shading coefficient figure of 0.4 is used on east and west facing windows due to the difficulty in protecting the windows from the low sun angles. 0.2 is used for south facing windows with adjustable external blinds.

Night Ventilation:- The base model will not be using a night ventilation strategy. This will be one of the parameters changed later in the model.

Day Ventilation:- A figure of 1.5 air changes per hour has been used for the standard model. The library is 11 times larger than the standard model . This will be taken into consideration when any calculations are made. The height difference for the stack ventilation system is set at 8m. As the library is open plan the internal area was set at 10m^2. If larger areas than this were simulated they did not appear to make any significant difference in the results.

With the above inputs which were selected to shown the worst case situation, the internal temperature in the main library is predicted as 46 ^{o}C.

The first set of results in the Table 1 show the variation in peak temperature when shading is applied in conjunction with day and night time ventilation for the standard west facing module. The calculations were carried out with 5 air changes per hour which was indicated as the optimum rate from the 'design-day' method calculations.

Table 1: The effect of ventilation rate during day and/or night

Changes to base model	Predicted Peak Temperature ^{o}C
West facing with 1.5 ach during day time only	46
West facing with 1.5 ach during day time only and shading	35
West facing with 5 ach during day time only	38
West facing with 5 ach during day time only and shading	31.5
West facing with 5 ach during night & day	37
West facing with 5 ach during night & day and shading	31

With 5 air changes per hour during the night and day and shading on the west facing windows a considerable reduction in temperature can be achieved, with a reduction of 15^{o}C down to 31^{o}C. Next the parametric results available through the SDT&V tool were used to ascertain the optimum flow rates for night and day ventilation. The parametric results indicated the optimum flow rates are between 8 and 9 air changes per hour. Above these figures although extra cooling can be achieved the advantage becomes marginal and the free areas required would be very difficult to locate in the building. Comparing the results between shaded and unshaded does show a slight variation. With the unshaded option and day time ventilation only indicating that increasing the air change rate to 20 air changes per hour may give a reasonable reduction in temperature. From these results the next set of calculations were carried out. The air change rate was set at about 9 air changes per hour. This figure was calculated by the SDT&V tool with the set building parameters and a high level opening of 0.4m^2 and low level of 0.3m^2. Figures were also calculated for a heavy weight building construction.

Comparing the unshaded models it can be seen that the extra ventilation over night and day gives a predicted reduction in temperature of 2^{o}C for a light weight building and 6^{o}C for a heavy weight construction. This shows the importance of the combination of night time ventilation and a heavy weight construction. The amount of extra cooling due to the heavy weight construction is quite surprising as most of the examples quoted in the guides [1, 15, 18,19] indicate reductions of between 2-3^{o}C. This may be due to the fact that the figures are being compared to models that have not had their solar gain controlled were the heavy weight construction will be more effective. If the figures for the shaded cases are compared the difference is about 3.5°C which is more in line with the best practice guides and application manuals.

Table 2: The effect of exposed thermal mass and shading

Changes to base model	Predicted Temp. °C
West facing with 5 ach night & day. Light weight. With shading.	31
West facing with 5 ach night & day. Light weight. No shading	37
West facing with 9 ach night & day. Light weight. No shading.	35
West facing with 9 ach night & day.Light weight. With shading.	30
West facing with 9 ach night & day.Heavy weight. No shading.	31
West facing with 9 ach night & day.Heavy weight. With shading.	27

Now the optimum day and night flow rates have been obtained the parametric analysis will be used to consider the orientation of the building along with the glazing ratio and the effect of the building weight. The parametric results have shown the difference the orientation has on the building with and without shading on the glazing. As would be expected the variation in temperature is more pronounced when shading is not used. The temperature difference between north and south west with shading is 2°C compared to 6°C without shading. A very similar difference can be seen when comparing the glazing ratio with and without shading. It was also observed that a heavy weight construction has a major effect on the building when it has a cyclic load such as through solar gain. With shading the temperature difference between light and heavy weight construction is 2.5°C, but when shading is not used moving to a heavy weight construction reduces the temperature by 4°C. With this particular room it appears that rotating the main area of glazing to the north will produce considerable temperature reductions. As the windows are north facing no shading has been applied. This is very important consideration for library buildings where high percentage of glazing areas are usually specified to promote daylighting.

Table 3: The effect of orientation and glazing area

Changes to base model	Predicted Temp. °C
West facing with 1.5 ach day & night	38
North facing with 1.5 ach day & night	35.5
North facing with 9 ach night & day. Light weight.	30
North facing with 9 ach night & day. Heavy weight.	27.5
North facing with 8.7 ach night & day. Light weight. Reduce glazing ratio from 0.8 to 0.4	28.5
North facing with 8.7 ach night & day. Heavy weight. Reduce glazing ratio from 0.8 to 0.4	26

As a check on the optimal ventilation rates for the north facing glazing and a reduction in the glazing ration of 0.4, parametric analysis was carried out. The results show that the figure of 9 air changes per hour still appears to be the optimal night and day time ventilation rates.

The SDT&V tool has been used to calculate the free area openings required to achieve the stated ventilation rates of 9 air changes per hour during the night and day. The corrected areas take into account that the library volume is 11 times larger than the standard model. The ventilation openings required to feed the stack ventilation system are relatively large (4.4 m2 for high and low level openings during day and night) and require very careful selection to minimise draughts, allow controllability by the staff or an automated systems and be able to be made secure if they are to be used for night ventilation. Consideration also needs to be given to the ingress of rain, noise, fumes large insects and birds. The effect of unintentional ventilation during the winter months needs to be considered to reduce heat losses. The system also needs to be able to control down to very low levels of ventilation for winter use to control CO_2 levels and odours.

The current building design has continuous glazing running around 2 sides of the library with a total length of 30 m. If an opening section could be employed around this whole length it would need to be 150mm high. This could be located behind an external louvre with a mesh to stop large insects entering the building. Internally a second louvre or grille could be fitted to encourage mixing of the air to minimise draughts. The lower intake louvre could be mounted at a height of 2m with the higher discharge louvre mounted at 10m just below roof level. As the low level unit is at 2m it will limit the amount of dust and fumes that may be entrained into the system. Due to the location of these units they would be best suited to automatic control via electric actuators. A simple stainless steel damper arrangement has been utilised at the Elizabeth Fry Building at the University of East Anglia [9] a similar systems could be used in this building. The air is best draw in from the northerly side of the site as this is were the air is coolest. In this case if the building is rotated by 90 degrees to the east as recommended the longest side of intake will be on the northerly side.

Conclusions

This paper described work carried out with the objective to evaluate whether purpose designed natural ventilation will help alleviate overheating problems in two public libraries operated by Dorset County Council by using user-friendly and minimum input pre-design ventilation and thermal simulation models.

The first building is an existing library with documented overheating problems. The monitored data was first used to built-up confidence on the suitability of the software for use in library buildings. It was shown that the effect of books is major in library building and they many change the characteristics of the building to heavy weight. In order for this effect to be modelled accurately dynamic thermal simulation is required.

The principles developed in the first model were then used to evaluate a proposed library currently at feasibility stage. By changing the construction of the original building, which had vast amounts of glazing and introducing day and night time natural ventilation the predicted internal temperatures, were reduced by 13°C making the proposed installation of an AC system redundant.

The results indicated that by using simple design tools it can be demonstrated to the clients that natural ventilation can improve internal conditions and avoid active cooling. This will influence the design of buildings at the critical initial stage when the brief is formulated.
For the SDT&V tool, it could be said that the ability to size the free area openings is an invaluable tool in trying to ascertain the suitability of natural ventilation strategies and can help to decide if the system is practical or not. The only draw back to the system is the simplistic methods used to simulate external and internal loads and the use of the standard size office module. As a comparative tool it gives very repeatable results.

References

1 CIBSE, Application Manual 10: Natural Ventilation in Non-Domestic Buildings, CIBSE, 1997.
2 CIBSE, Application Manual 13: Mixed Mode Ventilation Systems, CIBSE, 2000.
3 DETR, New Practice Final Report 102: The Queens Building De Montfort University - feedback for designers and clients, Best Practice Programme, BRESCU, June 1997.
4 DETR, New Practice Final Report 114: The Inland Revenue Headquarters, Nottingham - feedback for designers and clients, DETR, London, March 2000.
5 DETR, General Information Report 48: Passive refurbishment at the open University - Achieving staff comfort through improved natural ventilation, DETR, London, March 1998
6 BRE, Natural Ventilation for office - NatVent a better way to work, BRESCU, Watford, March 1999.
7 Allard F (Ed), Natural Ventilation in building: A design Handbook, James & James, 1998.
8 PROBE 11: John Cabot City technology College, Building Services Journal, pp 37-42, October 1997.
9 PROBE 14: Elizabeth Fry Building, Building Services Journal, pp 37-42, April 1998.
10 PROBE 18: The Portland Building, Building Services Journal, pp 35-40, January 1999.
11 DEFF, Building Bulleting 87 - Guidelines for Environmental design in Schools, The Stationery Office, London , 1997.
12 Kolokotroni M, Irving SJ and Tindale A, NiteCool: Office Ventilation Pre-Design Toll, 18th AIVC Conference, AIVC, 1997.
13 Tindale A., Third order lumped-parameter simulation method, BSER&T, 14(3), 87-97, (1993)
14 CIBSE, Window Design. AM2, CIBSE, 1987.
15 RennieD and Parand F, Environmental Design Guide for Naturally Ventilated and Daylit Offices, BR345, CRC, 1998.
16 CIBSE, Volume A: Design Data, CIBSE 1986.
17 Twinn C D A, Passive Control of relative humidity to +/-5%, Proc. of CIBSE National Conference held in Alexandra Palace, London, CIBSE, October 1997, Vol 2, pp77-89.
18 BRE, Night Ventilation for Coling Office Buildings, IP 4/98, BRE, 1998
19 Willis S, Fordham M and Bordass W, Avoiding or minimising the use of air-conditioning. GIR 31, BRE, 1995