[T06-32] Hybrid Ventilation for Low Energy Building Design in South China

Yingchun Ji*, Kevin J Lomas, Malcolm J. Cook

Institute of Energy and Sustainable Development, De Montfort University, Queens Building, The Gateway, Leicester, LE1 9BH, UK

**Corresponding email: yingchun@dmu.ac.uk*

Keywords: Hybrid ventilation, Low energy building, CFD, Dynamic thermal simulation

SUMMARY

Buildings and their related activities are responsible for a large portion of the energy consumed in China. It is therefore worthwhile to improve the energy efficiency of buildings. This paper describes a low energy building design in Hangzhou, south China. A hybrid ventilation system which employs both natural and mechanical ventilation was used for the building due to the severity of the climate. The passive ventilation system was tested using Computational Fluid Dynamics (CFD) and the results showed that, in the mid-seasons, natural ventilation for the building is viable. The likely thermal performance of the building design throughout the year was evaluated using Dynamic Thermal Simulation (DTS) with local hourly standard weather data. It is concluded that the hybrid ventilation system is a feasible, low energy approach for building design, even in subtropical climates such as south China.

INTRODUCTION

Climate change is one of the major concerns the world currently faces. Increasing evidence has shown that the accumulation of greenhouse gases such as CO_2 in the atmosphere is the main reason behind global warming. Buildings are one of the key contributors to greenhouse gas emissions. For example, in the UK the energy consumed by non-domestic buildings accounts for 44% of the nation's emissions (DEFRA 2006). High CO_2 emissions are often associated with high energy demands and it is also true that the more non-renewable energy is being used, potentially the more CO_2 is emitted. The building stock in China is responsible for 37% of the nation's total energy consumption and by 2020 this figure is projected to rise to 46.7%, and energy consumption per unit treated floor area in China is more than three times higher than in other developed countries such as the US, UK & Japan (IGEEB 2007). Therefore, there is significant potential in China to improve the energy efficiency in buildings. Improving energy efficiency in buildings not only reduces the demands for end use energy but also helps to mitigate the global concerns of climate change by reducing the large amount of CO_2 emissions.

Space conditioning consumes a large portion of the energy used in non-domestic buildings particularly for fully air-conditioned (AC) buildings. Alternative approaches to AC buildings such as natural ventilation (NV) are now gaining popularity. The PROBE studies (Bordass et al 2001) reported the monitored energy use and CO_2 emissions for 20 public and commercial buildings. The monitored results showed NV has the potential for reducing building energy consumption and also offering an improved indoor environment compared with conventional mechanical ventilation and AC systems. NV is the use of the natural driving forces of wind and temperature difference (buoyancy) to achieve ventilation flow for buildings. The simple form of NV is often limited to small scale, shallow plan buildings where the internal environment is exposed to exterior directly through operable vents or windows. The internal air speed, temperature and air quality would have rather quick responses to changes in external conditions. Therefore, in its simplest form, NV is unlikely to deliver acceptable conditions in severe climates characterised by hot summers and cold winters.

Modern non-domestic buildings tend to be large and deep plan with sealed façades for security and noise control. In such cases, where simple forms of NV is unlikely to deliver sufficient ventilation performance, advanced natural ventilation (ANV) strategies should be considered (Lomas 2006). Architectural features such as atria, lightwells, and tall chimneys (stacks) are often used in an ANV system in order to boost the stack effects for natural ventilation. As described by Lomas (2006), ventilation strategies can be classified as Edge-in, Centre out (E-C), Centre-in, Edge-out (C-E), Edge-in, Edge-out (E-E) and Centre-in, Centre-out (C-C). Existing examples of ANV buildings which have used one or more of the above ventilation strategies include the Queens Building at De Montfort University, Leicester, where E-C strategy was used (Simons & Moloney 2003); the Frederick Lanchester Library at Coventry University where C-C and C-E strategies were used (Krausse et al 2007); and the School of Slavonic and East European Studie at University College London where the C-E strategy was used (Short & Lomas 2004). These buildings, being UK-based, are subject to a less severe, temperate climate making natural ventilation a more feasible design option.

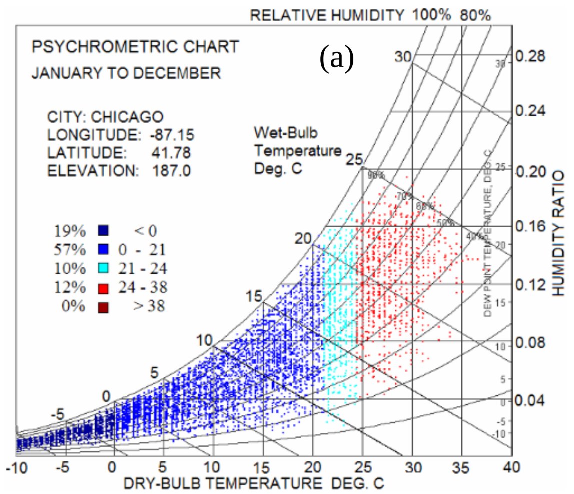

Figure 1. Psychrometric Charts for Chicago (a) and Hangzhou (b).

Although NV on its own is only applicable to a limited range of climates, a hybrid ventilation system, using a NV strategy combined with a mechanical system, can extend the applicability of NV in more severe climatic conditions. A recently completed library building for Judson College near Chicago in the USA has demonstrated the use of this hybrid approach for ventilation (Short & Lomas 2007). The hybrid ventilation strategy was needed to cope with the severe winter cold and summer warmth experienced in the mid-west USA (Fig 1a). The library building uses the E-C approach with localised E-E ventilation for perimeter offices. The Library also shows how the mechanical systems can be integrated without the additional cost of ducts, controls and false ceilings etc, normally associated with AC buildings (Lomas et al 2006). The research of Short & Lomas (2007) has shown that with the hybrid approach the summer time cooling loads were less than half those in a standard US air-conditioned building and the period for which mechanical cooling was needed decreased from seven months to around three months. The climate conditions in Hangzhou are similar to Chicago in the mid-seasons but with a relatively hotter and more humid summer (Fig 1b). Therefore, a hybrid ventilation system which is suitable for Chicago may well be applicable in a climate such as Hangzhou, a city about 110 miles south-west of Shanghai.

The design of a Science and Technology Museum (STM) building at a newly developed industrial base on the eastern edge of Hangzhou City offered the opportunity to explore this hybrid approach for ventilation.

THE BUILDING DESIGN

The STM Building is a four-storey office building with a basement which acts as a plenum for incoming fresh air (Fig 2). The intended operation of the hybrid ventilation system is mechanical cooling/heating mode during hot summer and cold winter periods respectively and during other periods of the year, the building will operate in passive mode.

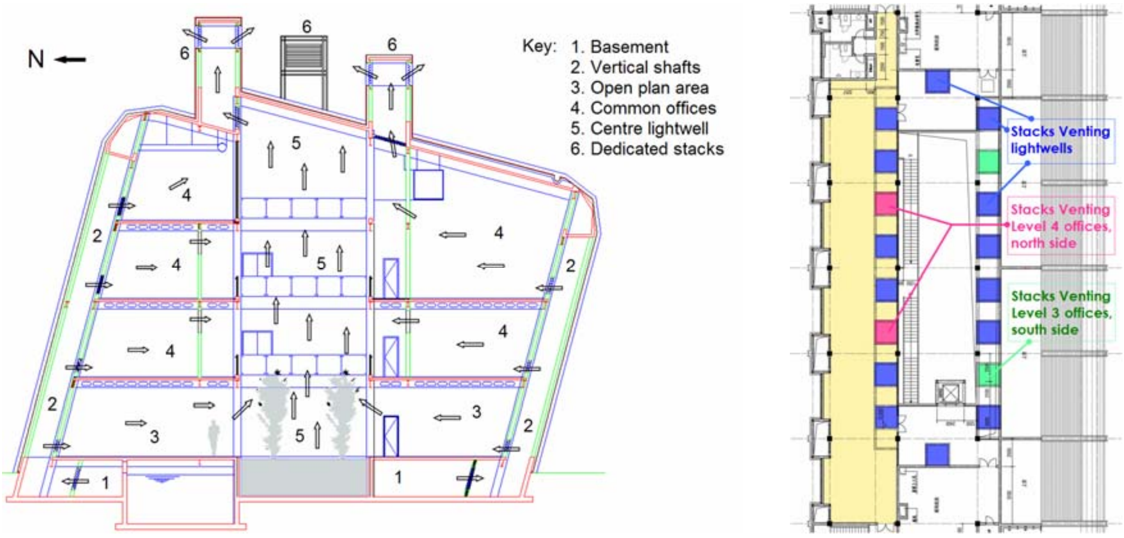

Figure 2. A section view with arrows showing airflow directions in NV mode (left) and roof plan view showing the stack locations and their functions (right).

The architectural features of the STM building are similar to the example buildings mentioned in the introduction in that a combination of stacks and a central lightwell are used to draw air through the building using buoyancy forces. Exposed concrete ceiling which has large thermal mass was used in the building in order to increase the night cooling effects during mid-seasons. The ventilation strategy for this building is ‘Edge in, Centre out’. When the building operates in passive mode (Fig 2, left), cool, fresh air entering the basement and feeding into the 17 vertical shafts naturally; fresh air in the vertical shafts will then enter each ventilation space and stale/polluted air will flow out through the high level vents of each space into a false ceiling surrounding the open centre lightwell; the accumulated warm and polluted air will flow above this false ceiling into the centre lightwell and then be driven out through the designated stacks on top of the building. 14 of the 18 stacks surrounding the central lightwell (Fig 2, right) are used to remove air from the lightwell which ventilates air from different levels. Two stacks on the south and two stacks on the north side are used to ventilate the offices on levels 3 and 4 respectively. This strategy was established following detailed computer simulation work which highlighted problems with the original strategy in which exhaust air from all spaces passed into the centre lightwell and out through the 18 stacks. These problems are discussed later in this paper.

When the STM building operates in mechanical mode, the external vents in the basement will be closed and fresh air, which is cooled in summer and warmed in winter, is driven by fans in air handling units on level 4 at the east and west ends of the building into the same vertical shafts used by the air in passive mode. The basement must be kept as airtight as possible to avoid the loss of conditioned air to the environment. Each occupied room will have its own heating element located close to the air inlet enabling a secondary point of heating when necessary.

AIRFLOW MODELLING AND ANALYSIS

The airflow analysis for the STM building was carried out using the computational fluid dynamics (CFD) program, ANSYS CFX (ANSYS 2007). The analysis involved modelling all the passive ventilated spaces, the supply air shafts and exhaust stacks. The internal heat gains were estimated from the number of people and computers within an individual space, assuming 90W per person and 116W per computer, with lighting loads of 12W/m^2. These gains were distributed to the room surfaces and room air in proportion to their radiant/convective split. The building was modelled assuming that all the spaces were simultaneously fully occupied. The air inlet areas to the basement, from the basement to the vertical shafts, from the vertical shafts to the individual spaces, from the individual spaces to the central lightwell and from the atrium to the exhaust shafts were estimated based on Lomas (2006). These estimates were adjusted on the basis of preliminary CFD results (not shown). In all the analyses reported here, a 20°C external air temperature was assumed. Stack terminals were often designed to avoid wind blowing air back into the stack in an ANV system. The lack of wind at mid-seasons can be the worst scenario for NV. For the cases investigated in this paper the effect of wind was therefore ignored. The aims of these analyses were to:

- identify any hotspots in the building arising from poor ventilation;
- study the degree of vertical temperature stratification within the building as a whole and within individual spaces;
- suggest refinements to the design to overcome any potential hotspots, and to model these; and
- identify any zones where temperatures are unacceptably high (over 27°C).

The preliminary CFD simulations led to a number of modifications to the initial design. High level offices were predicted to be warmer than those on lower levels due to the reduced stack effect. In the original design, Level 4 on the north side and Level 3 on the south side experienced over-heating due to insufficient ventilation. This led to the design suggestion that these rooms be assigned dedicated stacks (Fig 2 right). The duct needs to be internally partitioned so that air can not flow out of one room and into another. Additional shafts were added at the east and west ends of the building because the available cross-section area of the original single shafts at each end was insufficient for the occupied spaces they serve. It was proposed to isolate level 4 from the lightwell to prevent stale air from lower levels spilling back onto level 4 and preventing adequate ventilation of the spaces on this level. In the original design with a single shaft at the east and west ends of the building, the openings to level 1 from these two shafts are expected to bring fresh air into level one. The simulation results showed that the air actually flows into the two shafts from level one. This may be due to the amount of fresh air from the basement into these two shafts is small and the absolute pressure in level one at the inlets opening level is higher than in the shafts. In a natural ventilation design like the STM building, the buoyancy driving force is larger at low levels than high levels. Opening sizes provided by the shafts from north and south sides are sufficient enough to ventilate level one open plan area. Therefore, in the proposed design with added shafts at the east and west ends, there are no inlet openings to level one.

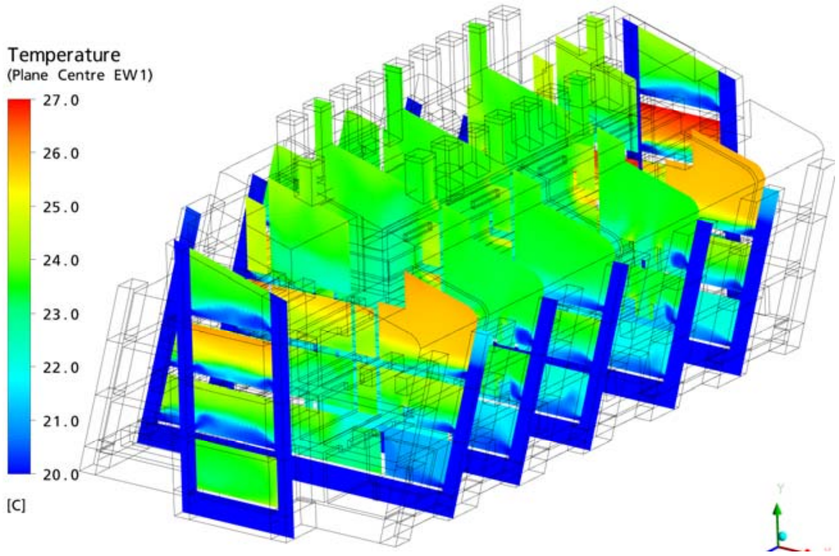

Figure 3. Predicted temperature distribution throughout the building.

The predicted temperature distribution after the design modifications following the preliminary CFD simulations is shown in Fig 3. Most of the spaces in the building are well ventilated as indicated by temperatures below 27C. They show temperature stratification from floor to ceiling ranging from around 20°C to 24°C. Such a 4K temperature difference is to be expected in a displacement ventilation regime such as this. Refinement to the opening areas (i.e. reducing the effective inlet area for level 1 and increasing the effective inlet area for level 3) would result in the flow of air to level 1 being reduced and to level three being increased, therefore diminishing the temperature gradient between floors. Further refinement to the ventilation routes for the east and west end offices at level 3 may still be required to mitigate possible over-heating predicted at high level. Dedicated stacks for these spaces may be necessary.

THERMAL PERFORMANCE

The thermal performance of the building was investigated using IES Virtual Environment (IES 2007) which is a well established tool for analyzing the dynamic responses of a building based on the hourly input of weather data. One-sixth of the whole building was modelled (Fig 4a). The occupancy and the ventilation sizes at all locations are averaged one-sixth of the whole building and the ventilation scheme of this simplified geometry is kept the same as the whole building. A typical room was selected to investigate the energy consumption for different ventilation strategies (Fig 4b).

The occupancy time for the model was assumed to be 8am to 6pm, with heat gains for lighting (12W/m^2), occupants (90W) and computers (116W). The total heat gains for office spaces ranged from 35W/m^2 to 45W/m^2 from Monday to Friday. On Saturday, the heat gains from occupants and computers were reduced by half (lighting gains remained unchanged). An infiltration rate of 0.2 ach was assumed and wind effects were ignored. The heating and cooling set points for the system were 20°C and 26°C respectively.

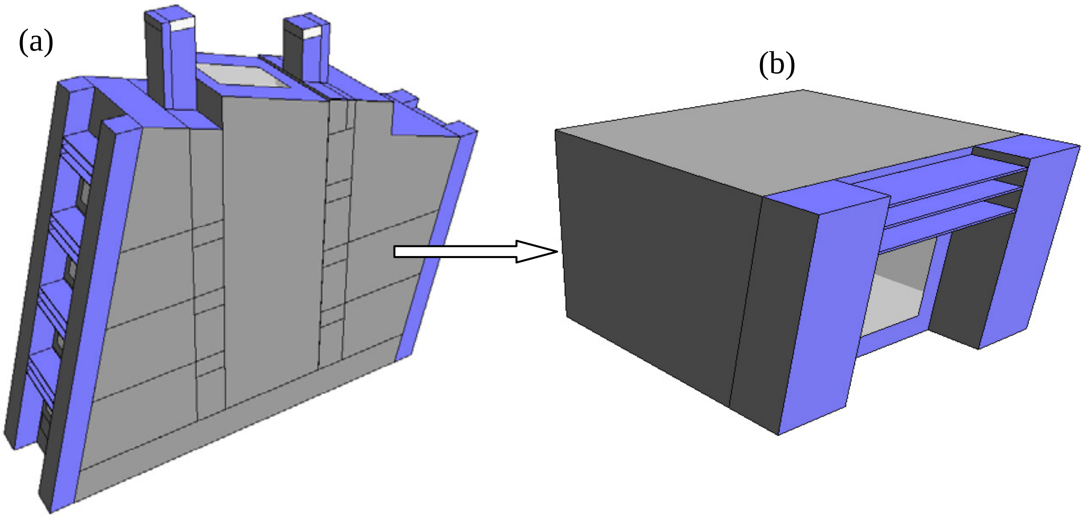

Figure 4. The simplified thermal model (a) and a typical office space (b).

The dynamic thermal behaviour for a typical office space during typical cold winter and hot summer weeks are illustrated in figures 5a and 5b respectively. During these periods, the building operates in mechanical mode. The fresh air supply rates for each individual office spaces were based on their CO_2 level. The control criteria during occupied hours are to maintain the minimum ventilation rate (1 ach) in order to reduce the energy consumption for space conditioning. In a hot summer week such as this (Fig 5b) the use of passive ventilation for cooling the building fabric has little benefit because the external DBT is so high.

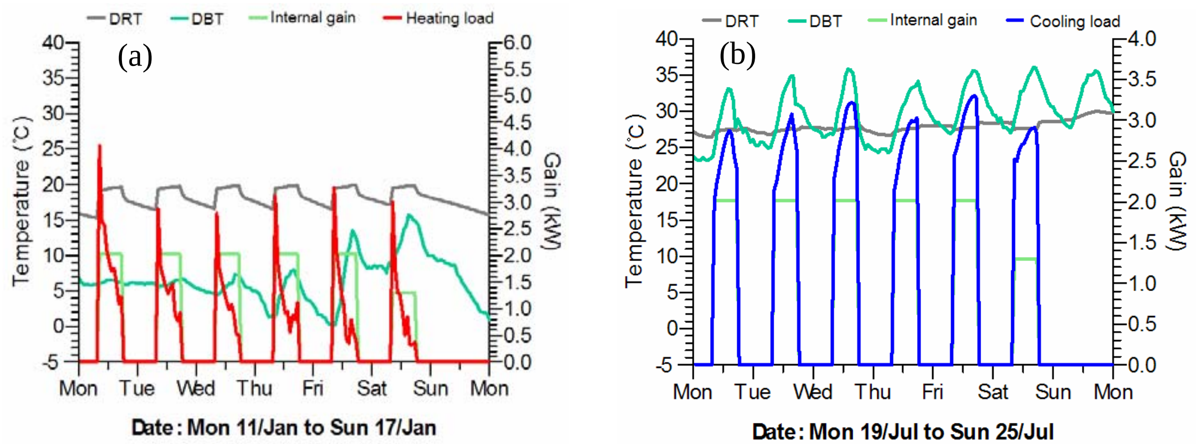

Figure 5. Predicted dry resultant temperature (DRT) showing associated heating load (a) and cooling load (b) for the typical office space with hourly external dry bulb temperature (DBT) and internal gains of the space.

For mid-seasons when heating is not needed, the building can operate in passive mode or passive mode combined with mechanical cooling (Fig 6). On Tuesday in this graph with the moderate external temperature the cooling plant was not activated. The resulting natural ventilation rate for the space was about 3 to 4 ach and the DRT ranged from 21°C to 25°C. On Wednesday afternoon, the external temperature at over 30°C which activated the cooling plant. Once the cooling plant is invoked, the natural vents are closed and the building goes into mechanical cooling with minimum airflow rate. For the following days at night time, the external temperature fell below the cooling set points and is below the internal temperature, so the vents for NV are open to achieve night cooling. The vigorous natural ventilation during unoccupied periods (up to 8 to 9 ach) will cool the building fabric which will reduce the room DRT by about 4K compared with its peak value, and up to 10K compared with the ambient peak. The 'pre-cooled' building fabric with large thermal mass will reduce the cooling load for the next occupied period. This is one of the reasons why the hybrid ventilation strategy has the potential to achieve energy conservation in buildings.

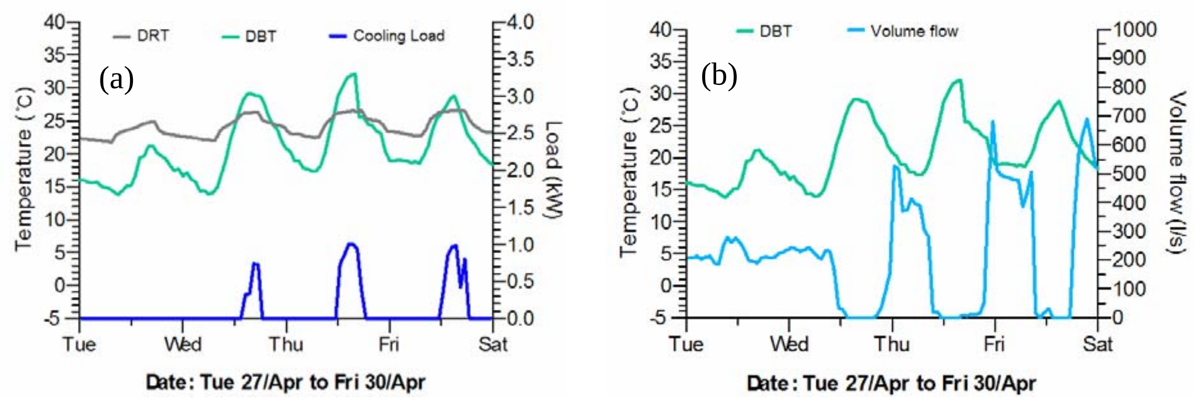

Figure 6. Predicted DRT with cooling load (a) and the associated natural ventilation rate (b).

The annual energy consumptions for different operating mode were investigated for a typical space (Fig 4b). The standard air-conditioning (AC) assumes that, at occupied hours, the space will be maintained at 20°C during heating mode and at 26°C during cooling mode with a ventilation rate of 1.0 ach. The hybrid mode runs at the same set points for occupied hours but the assisted night venting with high ventilation rate (3ach) will be activated for mid-seasons. The resulting annual heating and cooling load for the selected space is shown in Fig 7. The heating loads for the two running modes are similar but the cooling demands are considerably reduced for hybrid ventilation. A total saving of cooling load is up to 35%.

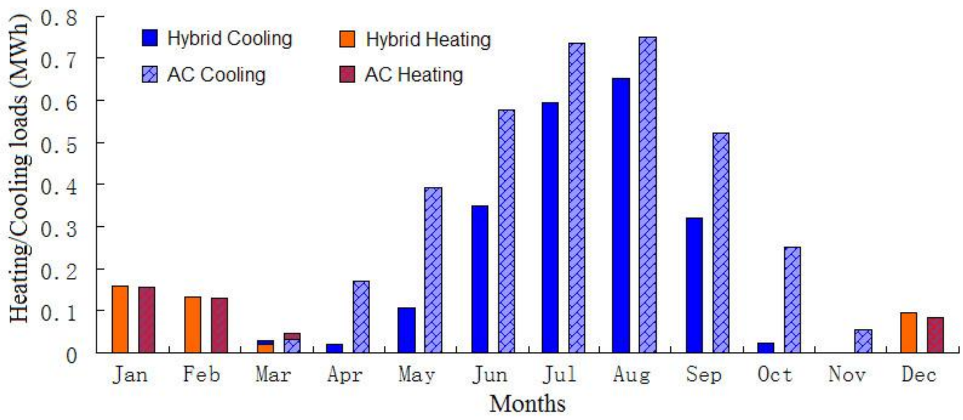

Figure 7. Annual heating & cooling loads of the space for AC & hybrid ventilation systems.

CONCLUSIONS

Computer simulations were used to optimize and evaluate a hybrid ventilation building design in south China. The simulation results have shown that the hybrid ventilation is a feasible low energy approach for non-domestic building design even for sub-tropical climates such as south China.

A full scale CFD model was used to illustrate how well the office spaces can be ventilated in the passive mode for an external temperature of 20°C. Most of the occupied spaces were adequately ventilated by buoyancy driven natural ventilation flow assisted by the centre lightwell and the tall stacks of the building. Spaces at high levels (i.e. Level 3 at south side and Level 4 at north side) should have their own designated stacks, and partitions within the stack may be needed to prevent any potential flow from one room to the other. There is also a need to introduce a new vertical shaft at the east and west end of the building to supply air to the end rooms at levels 2 and 3. Refinement to opening areas would further improve the temperature distribution between floors and prevent any potential over-heating.

Principles of the hybrid ventilation scheme were evaluated using dynamic thermal simulation program IESVE. Results have shown that hybrid ventilation during mid-seasons can maintain thermal comfort as well as significantly reducing cooling load. Mechanical cooling may not be needed when the building runs in passive mode with night time ventilation during mid-seasons. The work has shown that a hybrid ventilation system can reduce cooling demand by up to 35% compared with a standard air-conditioning option.

REFERENCES

ANSYS CFX 2007, http://www.ansys.com/products/cfx.asp, accessed 31/01/08.

Bordass B., Cohen R., Standeven M. & Leaman A. 2001. Assessing building performance in use: energy performance of the PROBE buildings, *Building Research and Information*, Vol 29, No 2, pp 114-128.

DEFRA 2006. e-Digest statistics about: climate change, at http://www.defra.gov.uk/ environment/statistics/globatmos/galocalghg.htm.

IES 2007, Integrated Environmental Solutions ltd, http://www.iesve.com, accessed 31/01/08.

IGEEB 2007. Memoirs on intelligent building and green building 3, *Proc 3rd International Conference on Intelligent Green and Energy Efficient Building*, pp 274-359, Mar 2007, Beijing, China, ISBN 978-7-112-09143-0.

Krausse B., Cook M. J. & Lomas K. J. 2007. Environmental performance of a naturally ventilated city centre library, *Energy and Buildings*, Vol 39, No 7, pp 792-801, ISBN 03787788.

Lomas K. J. 2006. Architectural design of an advanced naturally ventilated building form, *Energy and Buildings*, Vol 39, No 2, pp 166-188, ISBN 03787788.

Lomas K. J., Cook M. J. & Fiala D. 2006. Low energy architecture for a severe US climate: design and evaluation of a hybrid ventilation strategy, *Energy and Buildings*, Vol 39, No 1, pp 32-44, ISBN 03787788.

Short C. A. & Lomas K. J. 2007. Exploiting a hybrid environmental design strategy in a US continental climate, *Building Research and Information*, Vol 35, No 2, pp 119-143, ISSN 0961-3218.

Short C. A., Lomas K. J. & Wood A. 2004. Design strategy for low-energy ventilation and cooling within an urban heat island, *Building Research and Information*, Vol 32, No 3, pp. 187-206. ISSN 0961-3218.

Simons M. W. & Moloney B. J. 2003. Comfort and acoustic monitoring in a large naturally ventilated technically advanced building, *International Journal of Ventilation*, Vol 2, No 1, pp 1-14.