ENVIRONMENT DESIGN GUIDE

EMERGING TECHNOLOGIES IN VENTILATION

Dr Mark B Luther and Dr Zhengdong Chen

SUMMARY OF

ACTIONS TOWARDS SUSTAINABLE OUTCOMES

Environmental Issues/Principal Impacts

- Natural ventilation concepts are increasing in Australian and global architecture.
- It is claimed by the International Energy Agency (IEA) Annex 26 and 35 that ventilation will become the major driver for building energy saving in the 21st century.
- In many Australian locations the climate is such that external outside air can be directly applied 40-60% of the occupied building time.
- Synergies of natural ventilation, together with mechanical conditioning, know as hybrid ventilation, are the most promising ventilation systems for buildings.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- an understanding of natural ventilation principles and how they can be incorporated into design
- the hourly climatic data and when natural ventilation can be used outright
- design for hybrid ventilation systems, where natural and mechanical assistance can both have a role
- recognise that people's preferences for air temperature and ventilation rates depends upon the thermal conditions prevailing at their location and vary with the seasons, i.e. employ the 'adaptive model' of comfort (R, de Dear and G, Brager, 2001) wherever possible in building design
- integrate natural ventilation principles together with other thermal and environmental building systems.

Cutting EDGe Strategies

- Consider the benefits of reduced costs of excessive mechanical conditioning and duct work.
- Realise that solar energy (heating) can assist in driving ventilation through chimneys and ventilation hoods.
- Total ESD integrated strategies: water collection used with evaporative cooling to be driven by solar driven ventilation .
- Incorporate duct work, cavities or channels of ventilation within the structural systems and construction details of the building design.
- Consider ventilation strategies as a concept generator for a 'whole of building' design approach.

Synergies and References

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1.0 INTRODUCTION

Innovation in ventilation systems is becoming an increasingly popular and targeted topic of architectural discourse. Architects, consultants and contractors are introducing new products and proposing new systems, subject to client requests for an environmentally responsive architecture. The authors, in compiling the research for this guide, experienced a large increase in Australian constructed buildings that focused specifically on ventilation strategies and systems.

This note presents and discusses the underlying principles of different ventilation techniques. Applications of specific ventilation techniques are demonstrated through building examples constructed in Australia as well as overseas. Although a particular building design may demonstrate several ventilation concepts simultaneously, this note illustrates the most dominant ventilation features in each example.

1.1 Ventilation in buildings: Definition and clarification

Ventilation is the transport of air to provide acceptable indoor air quality in buildings. It is inclusive of wanted fresh external air and suitably treated recirculated air (ASHRAE 2001). Ventilation may consist of forced or natural supply, and the latter is further divided into the 'intentional' (e.g. through opening windows, doors) and 'unintentional' (e.g. through cracks, unintended openings) introduction of air into a space. The two primary functions of ventilation are:

- to provide sufficient air flow to remove indoor contaminants, pollutants and odours and replace with fresh air in order to maintain acceptable air quality.
- to remove excess heat from the building interior in order to maintain a comfortable (26°C maximum) temperature range (CIBSE 1997).

1.2 Capabilities of ventilation technologies

Ventilation technologies are capable of:

- improved energy efficiency (reduced energy consumption)
- improved Indoor Air Quality (IAQ) through removal of pollutants
- utilising solar thermal processes which enhance natural air flow
- increased thermal comfort and safety
- increased occupant productivity.

Building management systems together with climatic (on site) inputs will allow integrated ventilation systems to occur. Pro-active and reactive building controls will permit:

- night purging: high ventilation rates during unoccupied hours
- automatic control of opening and closing vents
- a cross-over between natural and mechanical ventilation strategies
- the operation of the 'economiser cycle', i.e. increasing the flow of outside air above the minimum amount of fresh air (required by the Building Code of Australia), when the outdoor air temperature is less than that inside.

1.3 Management of ventilation

Given the functions of ventilation, it is imperative that the related professions become more familiar with its mechanisms and its control. Put quite simply, ventilation has the potential to become a major liability in building operational efficiency if not properly understood and managed. A mechanical system in operation during periods where external air temperatures are appropriate is such an example. The CSIRO (2001) claims, for instance, for the Melbourne climate, that:

- in a 12 hour a day building, 48% of the time mechanical conditioning is not necessary
- in a 24 hour a day building, 38% of the time mechanical conditioning is not necessary.

The above figures emphasise that an understanding of what is made available under natural climatic means should be embraced and responded to by our architecture. Furthermore, the problems of sick building syndrome may be avoided by ensuring improved air supply into rooms. Natural ventilated buildings have been reported to reduce many of the sick building symptoms observed in some fully mechanical ventilated buildings (Daniels 1994).

Naturally ventilated buildings present substantial challenges to the designer. In addition to the dynamic external climate changes, several potential problems and considerations of naturally ventilated building designs may include:

- an integrated design approach to minimise unwanted heat gains and losses
- speech privacy and noise control in most cross-ventilated buildings
- outdoor air temperature must be less than that inside, to remove heat via natural ventilation.

1.4 Major factors determining future direction of ventilation technologies

The socially responsible movement towards ecological sustainable building and the demands placed upon architects and consultants by government legislation and clients are the drivers of new ventilation technologies. The International Energy Agency (IEA) in its Annex 26 (1996) *Energy Efficient Ventilation of Large Enclosures* as well as Annex 35 *Hybrid Ventilation* have concluded that ventilation and air movement will potentially become the major building energy saving contributors for the 21st century.

1.5 Research in ventilation related areas

Recent IEA research on ventilation in buildings includes:

- Annex 5 *Air Infiltration and Ventilation Centre* (indefinite)
- Annex 18 *Demand-controlled ventilating systems* (1987-92)
- Annex 20 *Air flow patterns within buildings* (1988-91)
- Annex 23 *Multi-zone air flow modelling* (COMIS) (1990-96)
- Annex 26 *Energy-efficient ventilation of large enclosures* (1993-96)
- Annex 27 *Evaluation and demonstration of domestic ventilation systems* (1993-)
- Annex 35 *Control Strategies for Hybrid Ventilation in New and Retrofitted Office Buildings* (HybVent) (1998-2002)
- Annex 40 *Commissioning of building HVAC systems* (2001-2004).

2.0 FUNDAMENTAL VENTILATION PRINCIPLES

2.1 Stack-effect or thermal buoyancy induced natural ventilation

The stack-effect is the phenomenon of temperature difference between the inside and outside of a building, causing pressure differences at openings, resulting as the driver of air flow (see Figures 1 and 2). In the example provided, the indoor air is warmer and thus lighter than the outdoor air. Static pressure changes occur more quickly in colder and denser air. Consequently, the outdoor pressure at the bottom opening is higher than the indoor pressure and cold air is drawn into the building. The reverse is true at the top opening.

Figures 1 and 2 show the possibilities of single-sided as well as cross-ventilation in regards to the stack-effect only. The reader should note that, unlike the

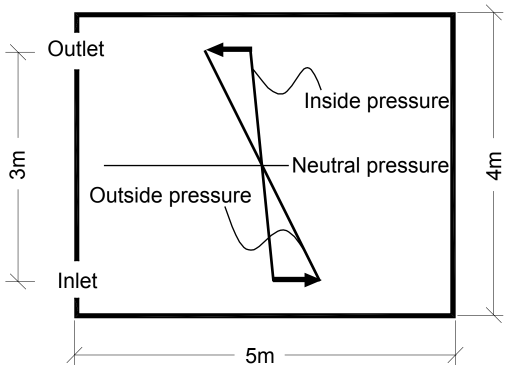


Figure 1. Single-sided ventilation

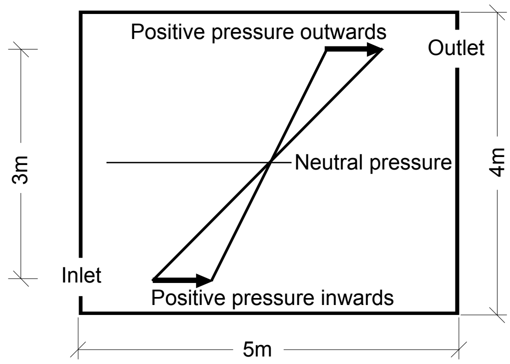
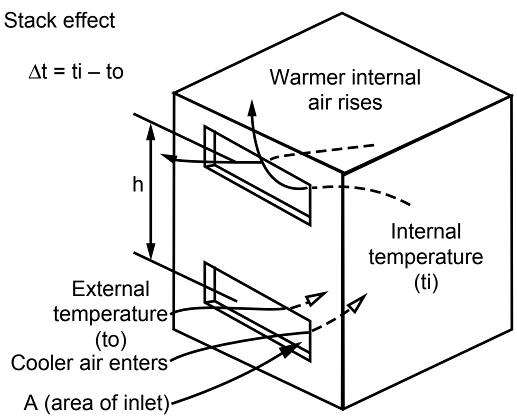


Figure 2. Cross-ventilation

forthcoming explanation of wind driven ventilation, the stack-effect is equally effective for single-sided and cross-ventilation. The ventilation flow rate ($m^3/s/m^2$) induced by two openings with an indoor and outdoor air temperature difference of ΔT as shown in Figure 3 can be obtained by the following equation (Evans, 1980):

$$V = 0.117C_{\text{orrection}} A\sqrt{h \times \Delta T}$$



Area of outlet – area of inlet	Correction factor
5	1.38
4	1.37
3	1.33
2	1.26
1	1.0
0.75	0.84
0.5	0.63
0.25	0.34

Figure 3. Examples of varying ventilations by Evans (1980)

2.2 Wind induced natural ventilation

The mean pressure over time due to wind flow, onto or away from a surface, is defined as wind pressure. Wind pressure varies at different locations along a building envelope subjected to wind flow and results in building ventilation. This is the fundamental mechanism of wind driven cross-ventilation (see Figure 4). Openings designed for cross-ventilation are preferably arranged at windward and leeward sides of a building respectively, relative to the dominant wind direction, so that maximum wind pressure difference can be achieved.

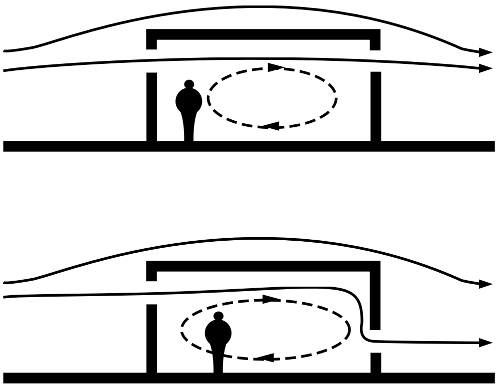


Figure 4. Examples of wind induced cross flow ventilation (M Luther)

In addition to the steady wind pressure, the turbulent nature of air flow encountered in building ventilation also results in transient variations of pressure distributions over a surface. This transient pressure variation is the driving force of wind driven single-sided ventilation in which openings are arranged on one side (only) of the building (Figure 1). It should be noted that wind driven single-sided ventilation could be an order of magnitude less than that caused by cross ventilation (Figure 2) at the same wind speed.

2.3 Comparing natural ventilation forces

Figure 5 shows a comparison of natural ventilation induced by wind and that of thermal buoyancy (stack-effect) for the cross ventilation through two openings of 1m² and a vertical distance of 3m (as in Figure 2 with the wind blowing from left to right). The wind velocity is measured at the building height and the temperature difference is measured between the indoor and outdoor air. It is seen that the thermal buoyancy induced air flow rate for a 10°C difference is roughly equivalent to that induced by wind at 1.3m/s. In a moderate climate, as in Australia, it is relatively easier to have a 1.3m/s wind than a 10°C indoor and outdoor air temperature difference, especially during spring, summer and autumn. Consequently, in practice, wind induced natural ventilation is more effective than that of thermal buoyancy. Typically, when the wind speed at the building height is larger than 2–3m/s, the contribution of the stack-effect may be neglected.

2.4 Hybrid ventilation

It is understood that natural ventilation alone may sometimes be unable to deliver the required ventilation rate. In CBD areas, the use of natural ventilation features such as internal shafts and open areas are very expensive which further limit the use of natural ventilation techniques. In recent years, a new ventilation concept, 'hybrid ventilation', has been developed. Hybrid ventilation is believed to be a very promising ventilation technology for this century. It is a two-mode system which is controlled to minimise the energy consumption, while maintaining acceptable indoor air quality and thermal comfort. These two modes refer to natural and mechanical driving forces. Hybrid systems entirely or partly shut off the mechanical system at periods when natural ventilation systems can provide adequate building ventilation.

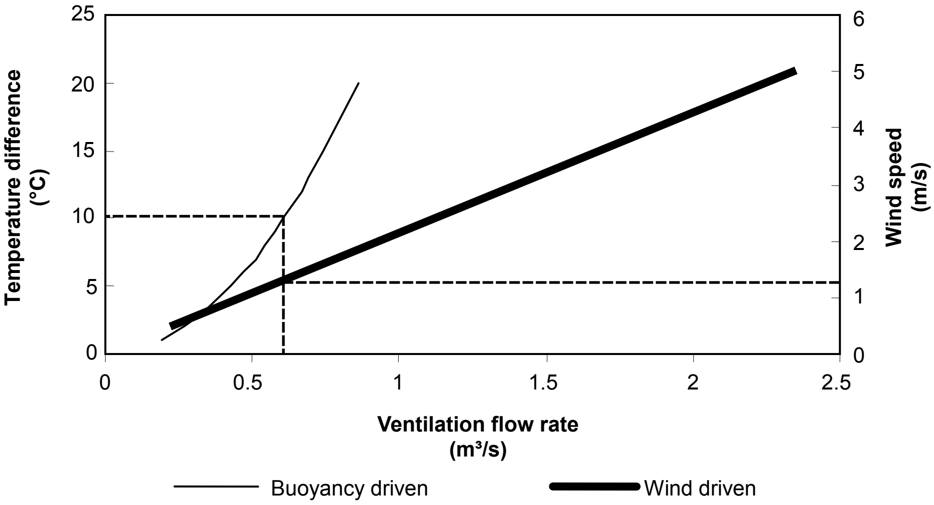


Figure 5. A comparison between buoyancy driven and wind driven air flow rate

The CSIRO is involved in the IEA Annex 35 Hybrid Ventilation project in which 15 countries participate. The objectives of Annex 35 include:

- to develop control strategies for hybrid ventilation systems in new and retrofitted office and educational buildings
- to develop methods to predict the performance of hybrid ventilated buildings
- to promote energy and cost-effective hybrid ventilation systems in office and educational buildings
- to select suitable measurement techniques for diagnosing hybrid-ventilated buildings. A survey of 22 existing buildings (in the 15 participating countries) is being used to identify solutions to specific problems.

These provide architects and building engineers with valuable examples of success and failure, leading to improved ventilation designs. In general, a 20%–60% overall energy saving can be achieved through properly designed hybrid ventilation systems. In recent years, there are a number of buildings in Australia that have implemented hybrid ventilation systems. Examples are presented in the forthcoming sections.

3.0 APPLICATIONS OF VENTILATION PRINCIPLES

3.1 Stack vents

When proper vents are arranged, large atriums or tall vertical spaces can rely on the application of stack ventilation, where there is a large stack pressure difference between the floor and the ceiling. This principle was adopted in the design of Charles Sturt University, Thurgoona Campus building in NSW, Australia (Figure 6), and the ventilated atrium of the 60L Australia Conservation Foundation building of Melbourne (Figure 7). Note that the perimeter single storey spaces allow fresh outside air to pass through them.

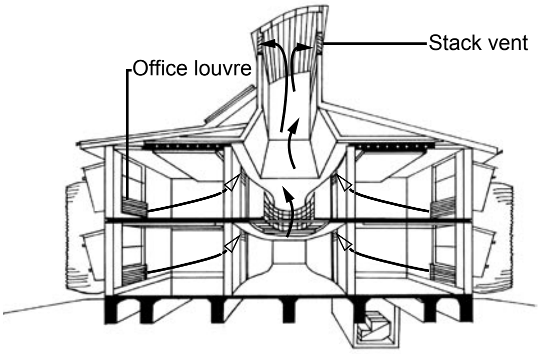


Figure 6. CSU Thurgoona campus building, NSW (courtesy CSU)

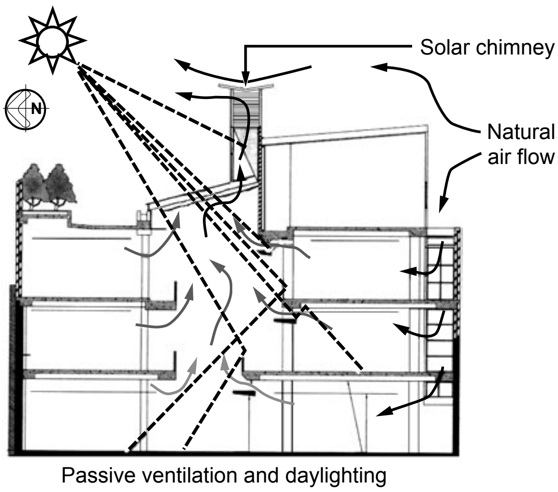


Figure 7. 60L Australia Conservation Foundation, Melbourne (60L brochure)

3.2 Solar chimneys

Solar chimneys are shafts utilising solar radiation to build stack pressure along the shaft. An example can be seen in the Red Centre, University of NSW campus building and the Manly Hydraulic Labs, NSW (see Figures 8 and 9). The use of solar chimneys as ventilation devices can be found in some historical buildings, such as the so-called "Scirocco Rooms" in Italy, which dated back to at least the 16th century, where the solar chimneys were used in conjunction with underground corridors and water features to provide ventilation and cooling (Cristofalo, 1989).

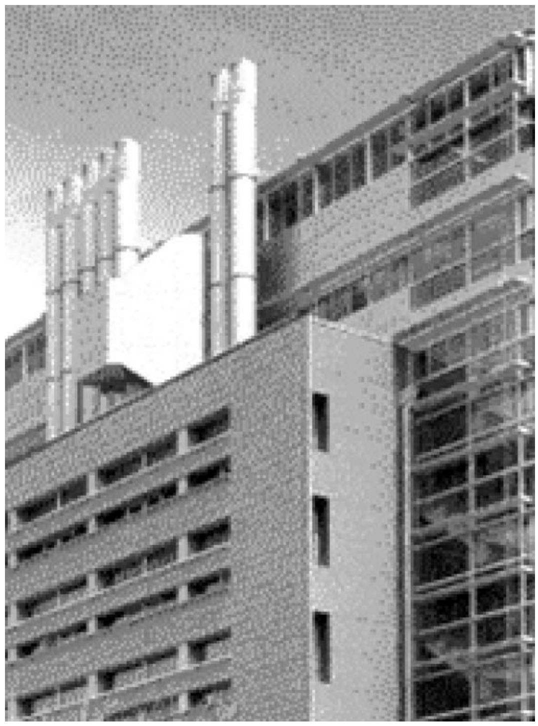


Figure 8. Solar chimneys, Red Centre, UNSW (courtesy, ARUP Engineering)

During the last two decades, increasing awareness of greenhouse gas emissions and the need for effective, efficient and ecologically sound building ventilation, has led to renewed interest in solar chimneys. In recent years, a number of experimental, numerical and theoretical investigations have contributed to the current understanding of solar chimneys. Research by the CSIRO suggests the following requirements for solar chimney designs to achieve good ventilation performance:

- A chimney width (or diameter) to height ratio is preferably around 1/10, but should not be larger than 1/5.
- Restrictions to the chimney inlet should be avoided if possible.

An inclination angle of 30° from the vertical may result in better ventilation performance.

3.3 Ventilation hoods

The large canvas, chimney-like ducts, in the Sydney Olympic Showgrounds function together with solar chimneys (Figure 10). The stack pressure due to the internal heat sources in the building, as well as the solar chimneys above the fabric cones, drive air from the building perimeter horizontally to its centre. Air enters at a low level through the inverted fabric cones. This provides for an effective solution to floor level ventilation conditioning of a space.

3.4 Evaporative cooling ventilation

Evaporative cooling towers could be described as the reversed stack-effect (W Saman, 1996). In this case, warmer air at the top of a chimney is cooled upon natural or wind forced entry through a water spray or saturated fabric. This type of system was applied to the evaporative towers of the Zion National Park Building (Figure 11). The incoming warmer air is conditioned inside the chimneys by evaporative cooling and enters the building through grilles as shown in Figure 11.

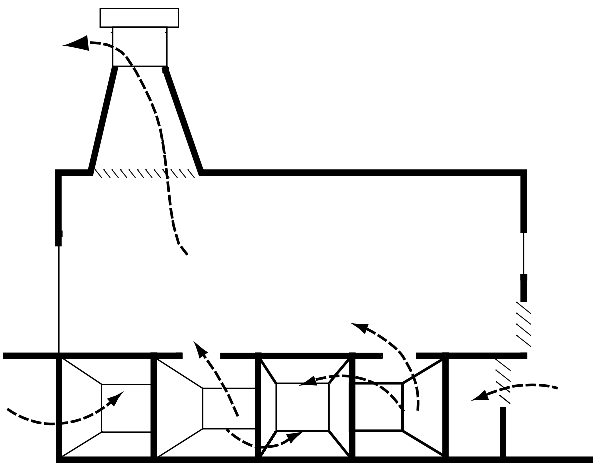


Figure 9. Manly Hydraulics Laboratory, NSW (courtesy, NSW Department of Public Works and Services)

Figure 11. Evaporative Cooling Towers, Zion National Park, Utah, USA (courtesy of D Balcomb).

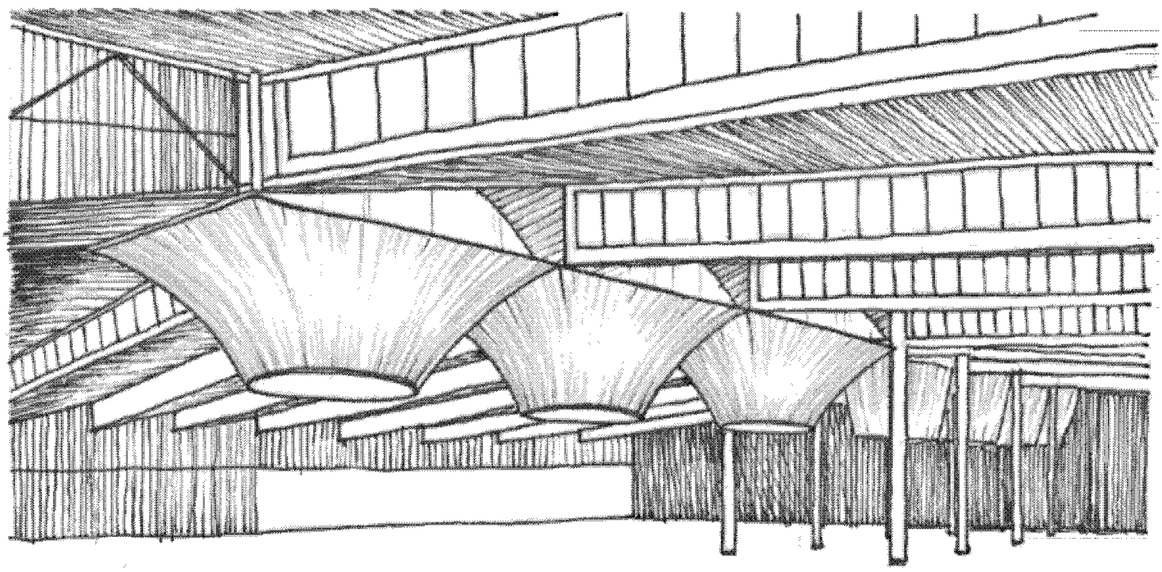


Figure 10. Olympic Showgrounds, Sydney (http://www.dbce.csiro.au/innovation/)

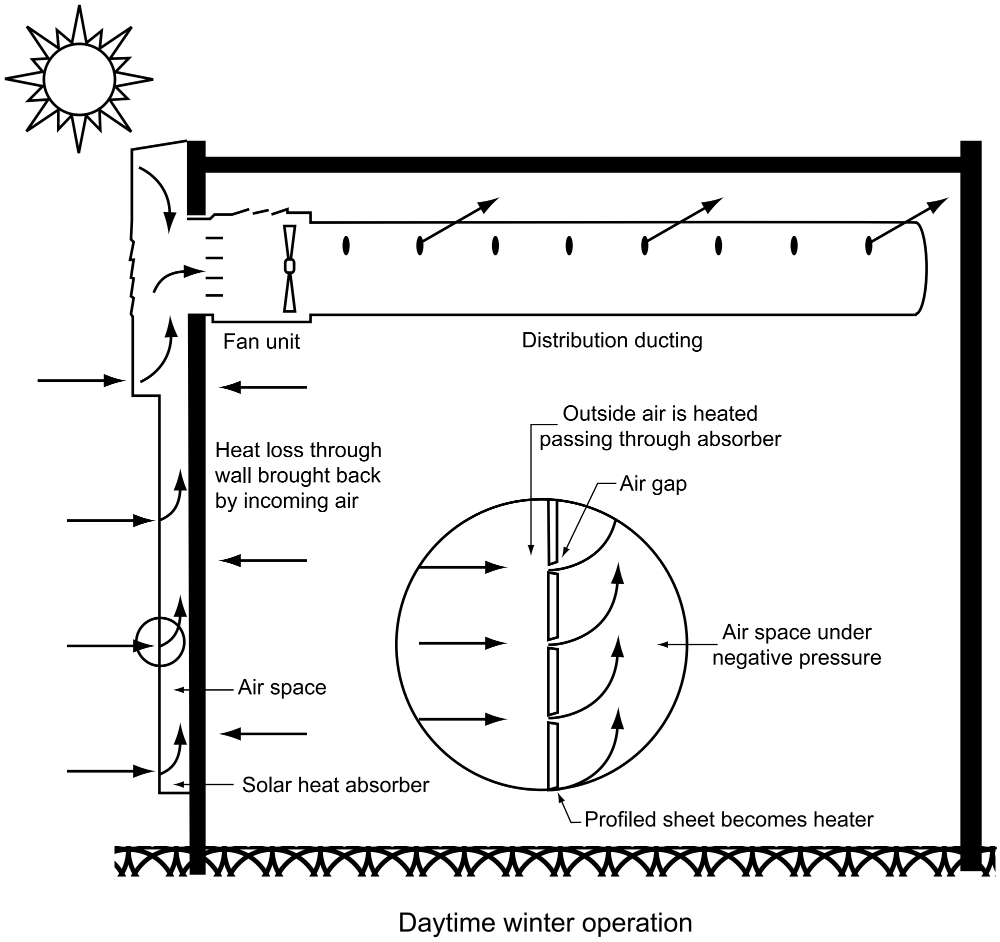


Figure 12. Solar wall used for preheated ventilation (Conserval Engineering Inc brochure)

3.5 Ventilated trombe walls

An innovation to the solar collecting 'trombe wall' (a glazed wall cavity), is that of the 'solar wall'. This product utilises a perforated transpiring metal facade with a cavity acting as a stack shaft (Figure 12). During winter operation, the warmed air in the cavity is drawn into the building and delivered at the ceiling level via the stack-effect as well as through an assisted fan unit. During summer operation, the trombe wall functions as a solar chimney and air can be exhausted back to the outdoors.

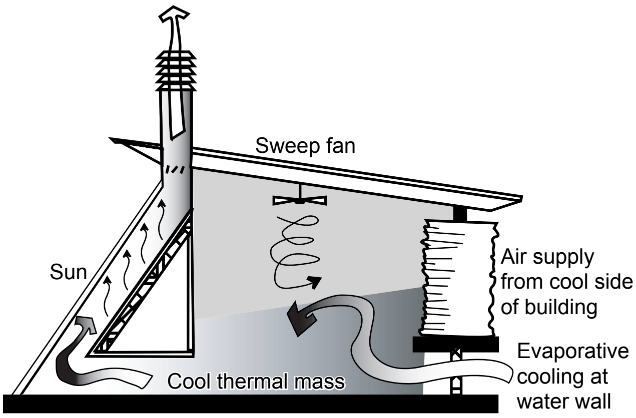


Figure 13. Solar trombe wall with chimney Wesley College, NSW
(Courtesy of Fooks Martin Sandow Anson Pty Ltd)

Wesley College of NSW is an example, using a convective solar heater (a trombe wall) as a driver for natural ventilation flow (Figure 13). The combination of the solar chimney and inclined trombe wall collector create a 'thermal siphon' for natural ventilation. This concept incorporates evaporative cooling as well as a solar chimney making it a very unique building.

3.6 Ventilation cavities, channels and ducts

Air flow or ventilation transportation does not always occur through a window opening or traditional mechanical ducting system. Raised floor and wall cavities are contributors to ventilation air transporting devices, allowing air often to be treated (or conditioned) by the building fabric itself. A prison design by Jebb (1844) used a heat exchanger to siphon cold inlet air at a low level. This air is channeled, entering the prison cell at a high level inlet, heating the cold building mass. Air comes in contact with the cold ceiling and then drops which results in the reversed stack-effect to drive flow downwards to the outlet of the cell. The attic fireplace creates a siphon for air to exit the cell again via a wall cavity (Figure 14). The Language Building of the University of New South Wales achieves room cross-ventilation via wall cavities, which also results in acoustic isolation from the corridors (Figure 15). Air handling units were also installed in the wall cavities, providing a hybrid operation mode of the ventilation system, when natural ventilation is not sufficient.

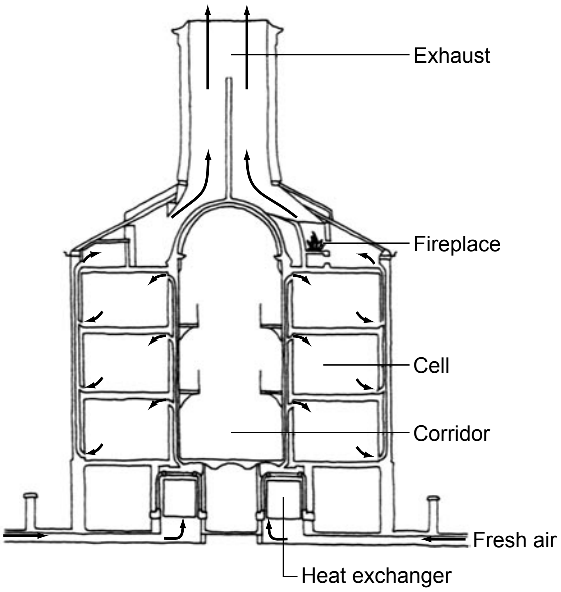


Figure 14. 1844 Prison designed by Joshua Jebb achieved air change rate of 3 air changes per hour (ACH) (K Daniels)

A hollowcore concrete conditioning system is provided in the Science and Technology building of Deakin University (Figure 16). This concept injects either ambient or pre-conditioned air through the cores of the concrete slab. The pre-conditioning of the slab also provides radiant cooling to the space. Cross-ventilation strategies are further provided via an opening through the interior atrium side of each office.

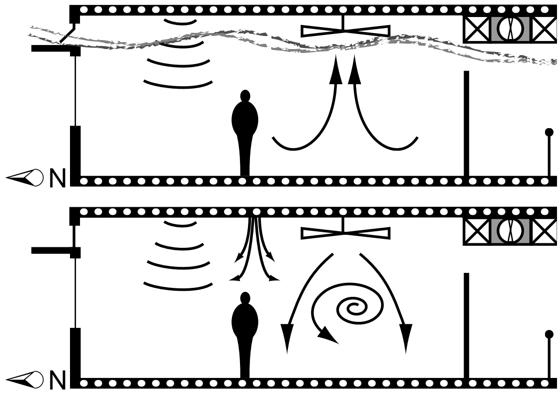


Figure 16. Using a hollowcore panel for a mixed-mode building system (M Luther)

3.7 Convective solar loops

A convective loop operates on the stack-effect and provides a horizontal cavity (or duct) connected to the other side of the building envelope. Solar heated air from one side of the building envelope is distributed to the other (colder) side of the building, through this convective loop, yielding a more uniform heating to the building envelope. A hypothetical example of this concept is illustrated in Figure 17. Other buildings

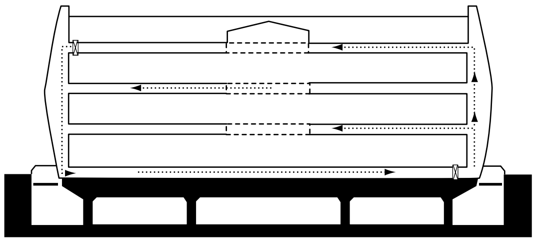


Figure 17. A proposed convective loop with a double envelope system (M Luther)

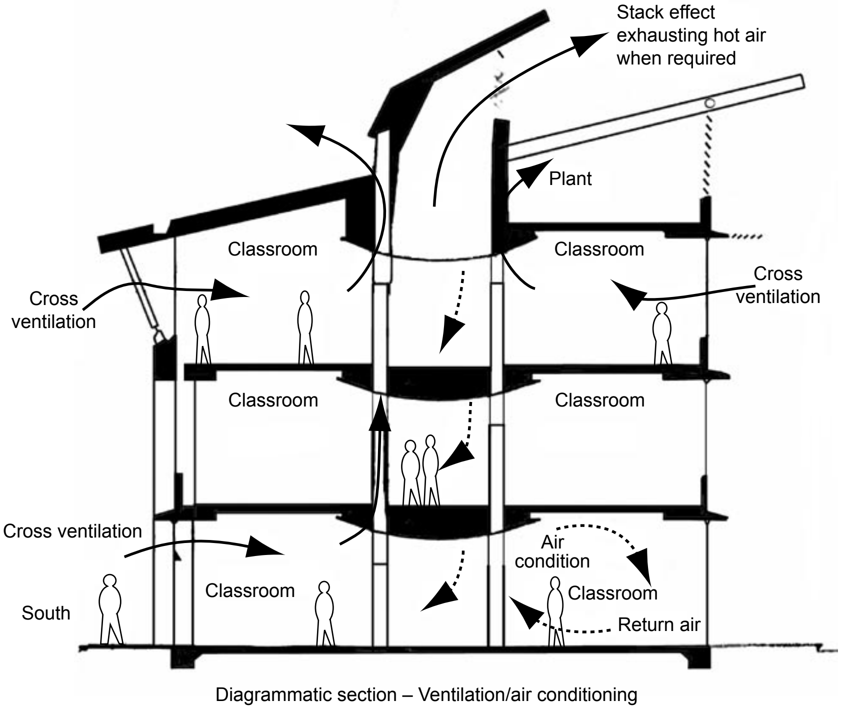


Figure 15. Language Building UNSW, Australia (Courtesy of Steensenvarming Pty Ltd)

relying on the convective loop utilise a double envelope facade system without the existing horizontal channels, similar to the Occidental Chemical building (Figure 18). In this example, air is transported around the perimeter of the building via convection. The double envelope facade is an effective method in the solar heating of air. It can also provide for the stack-effect to take place, siphoning cooler air into its cavity while warmer air is exhausted.

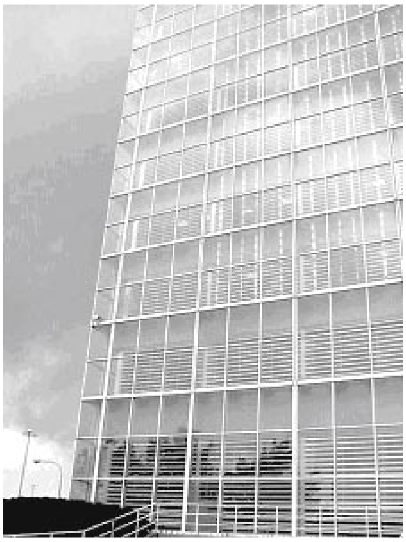


Figure 18. Occidental Chemical building utilising a double envelope and convective loop (photo: M Luther)

3.8 Displacement ventilation

Displacement ventilation occurs when cold air, coming in at low level, displaces hot and polluted air and exhausts it outside the building. Proper designed displacement ventilation is more efficient than a fully mixed ventilation system, i.e. no air temperature stratification, as fresh and conditioned air only needs to be supplied to the lower region where the occupants are located.

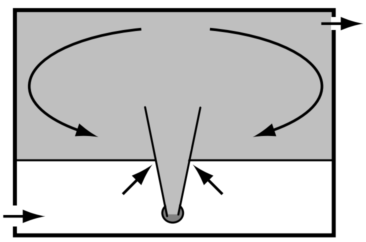


Figure 19. Schematic view of displacement ventilation in buildings (C Zhendong).

For displacement ventilation in a single-zone building with two openings as shown in Figure 19, a buoyancy plume entrains the air around it and rises towards the ceiling. The lighter air in the plume, ascends reaching the ceiling, and spreads towards the sidewalls descending between the sidewalls and the plume. This results in the formation of an upper layer of lighter air in the building. The pressure differences between the air inside and outside induce air exchange through the bottom and the top openings. Lighter air in the upper region exits through the top opening and denser and cooler fresh air is entrained into the building via the bottom opening. When a steady state is reached, a constant level of stratification will be established between the dense fresh air and the light upper layer. The State Emergency Services Building, Melbourne displays an Australian example of displacement ventilation through its floor cavity (Figure 20).

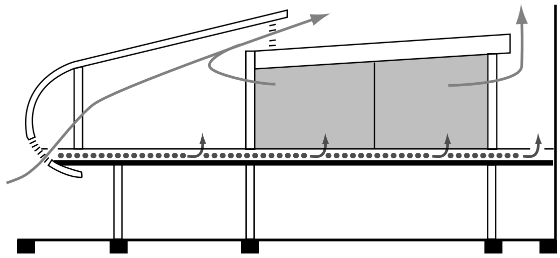


Figure 20. State Emergency Services building (Hyde Engineering)

3.9 Ground buried air ducts and labyrinths

A school in Norway, being studied as part of the IEA Annex 35 'Hybvent' task, is an interesting example of hybrid ventilation in a rather cold climate (Figure 21). One of its interesting features is a large underground insulated concrete ductwork (2 x 2 m²), which acts as a pre-conditioning air supply. Large, low pressure fans in the underground duct and exhaust system are only used if stack and wind effects are not sufficient. Another example of sub-level air conditioning is the concrete labyrinth used at Federation Square to pre-condition air to the mechanical systems.

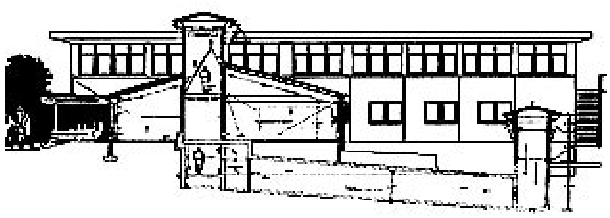


Figure 21. Primary school in Gronge (Norway) by Letnes Arkitektkontor (Wouters et al, 1999)

3.10 Capturing wind-vanes and wind-wells

Some ventilation chimneys combine the use of wind power to turn vanes which create a negative pressure at their outlet to combine with the stack-effect to release the indoor air more effectively. Roof ventilators are generally used to ventilate attic spaces in roofs (Figure 22). More innovative applications of this principle have been introduced to passive ventilation strategies for commercial buildings. A unique example in assuring that there is a negative pressure provided at a ventilation exit is illustrated in the Nottingham University Campus building (Figure 23). The rotating vanes of the ventilation chimney are consistently leeward facing as a result of their 'weather vane' type design. As the wind blows, the vane will always guide the vent opening to the leeward side allowing for a negative pressure zone.

Figure 22. Typical attic roof ventilators (M Luther)

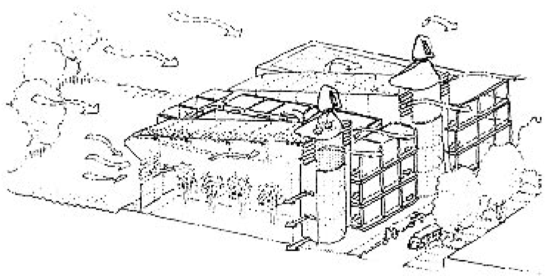


Figure 23. Rotating windvanes, Nottingham University, Jubilee Campus, UK (Arup Engineering)

3.11 Wind screens

One of the most commonly used principles to capture the oncoming wind and to direct it into a building inlet is to apply a wind screen (Figure 24). The wind screen may be secured to the building as a man-made device or strategically shaped and constructed by means of landscaping around the opening.

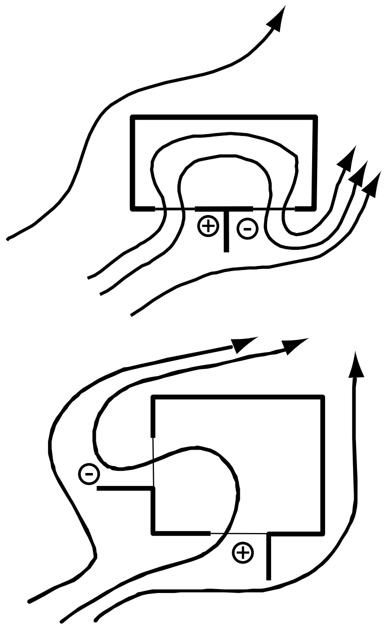


Figure 24. Examples of wind pressurised ventilation through wing-walls (M Luther)

3.12 Independent cellular space conditioning

An independent system for conditioning individual spaces under an occupants control is suggested here (Figure 25). Tremendous energy savings of up to 60% or more over conventional air conditioning systems can be achieved by allowing occupants to have control over their own ventilation and air conditioning system. In the case of the Wilkinson Building at Sydney University, natural ventilation is part of its air conditioning and ventilation system where occupants have control of turning off their fancoil unit and opening a window (D Rowe).

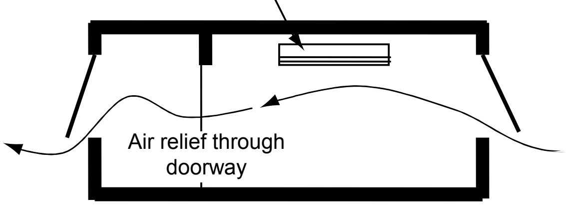


Figure 25. Cross ventilation of a cellular office with occupant controlled reverse cycle split system providing supplementary cooling/heating for use in very hot or cold weather (courtesy, D Rowe)

4.0 CONCLUSIONS

Basic principles of several emerging natural and hybrid ventilation concepts have been described with a number of building examples from Australia as well as overseas. Despite the simplicity in principles, natural and hybrid ventilation systems are often inter-mixed and integrated with each other. The increasing number of natural and hybrid ventilated buildings in Australia and overseas provide valuable examples for architects and building engineers leading towards improvements for these new technologies.

The Australian climate is better suited than where most of the natural ventilation concepts were first developed. It is important to realise that hybrid ventilation, where mechanical assisted systems are designed to work in concert with natural ventilation, require sophisticated engineering and refined control strategies. Examples of control system design and strategies were not considered a part of this note. They are the next step into understanding hybrid ventilation design.

It is encouraging to see such a diversified range of these environmental technologies taking place in Australia. The question remains, however, as to whether the concepts are actually working as planned. A thoroughly monitored reporting of performance is required if we are to expand upon and encourage such practices. Undoubtedly, we are commencing on a new and exciting age of building ventilation technologies which maximise efficiency and performance.

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Buildings

CSU Thurgoona Campus Building, NSW
Architect: Office of Design, Charles Sturt University
I: http://www.netspeed.com.au/abeccs/case%20studies.htm

60L Australia Conservation Foundation, Melbourne
Architect: Spowers Architects
I: http:/www.60lgreenbuilding.com/

Manly Hydraulics Laboratory, NSW
Architect: NSW Department of Public Works and Services

Olympic Showgrounds, NSW
Design consortium:
Scott Carver Architects
SJPH Design Partnership
Timothy Court & Company

Evaporative Cooling Towers, Zion National Park Utah, USA
Architect: US National Park Service I: I: I: http://www.architectureweek.com/2001/0103/building_1-1.html

Wesley College, Chum Creek Outdoor Education Centre, NSW
Architect: FMSA Fooks Martin Sandow Anson (FMSA) Pty Ltd
Solar Wall: Conserval Engineering Inc.
I: http://www.solarwall.com

1844 Prison
Architect: Joshua Jebb

Language Building University of NSW
Design Team:
Steensenvarming Pty Ltd
Jockson Teece Chesterman Willis Architects

Federation Square, Melbourne
Architect: lab + bates smart architects
http://www.labyrinth.net.au/~lerma/federationsquare.htm

Nottingham University, Jubilee Campus, UK
Architect: Michael Hopkins & Partners
http://www.coldhamarchitects.com/greenbuilding/greengrandtour/UK_Jubilee/uk_jubilee_desc.htm

Science and Technology Building of Deakin University
Architect: DesignInc

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