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Improving the sustainable development of building stock by the implementation of energy efficient, climate control technologies

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Abstract

It is the aim of this article to explain the testing procedures developed at the University of Technology, Sydney (UTS) and to evaluate the potential natural ventilation and daylighting applications that have arisen from this research. The objectives for research into this field were to reduce energy costs and increase the sustainability of building stock. From the results of these experiments actual and potential designs are illustrated and discussed in this article. Multi-storey buildings require substantial artificial lighting, even with glass fronted facades, the shaded depths of multi-storey buildings require daylight supplementation and therefore energy. By supplementing the internal lighting levels with daylight, reducing the internal heat load by shading windows to direct radiation and the utilisation of natural ventilation over air conditioning where possible, significant energy savings are achievable. This article explores the heating and cooling problems associated with some glass faced curtain wall multi-storey facades and proposes design changes such as: delivering daylight above the suspended ceiling into the depths of the building by horizontal light pipes and natural ventilation, utilising stack effect and wind siphonage. © 2000 Published by Elsevier Science Ltd.

Keywords: ecologically sustainable development; climate control; daylighting; natural ventilation; stack effect; wind turbines; energy efficiency; curtain walls

1. Introduction

The need to provide climate control inside buildings to improve comfort levels and hence productivity is very desirable. However, the cost of design or redesign to achieve the desired comfort levels has to be economically evaluated.

With the on going energy/greenhouse emission reduction campaigns and in accordance with Environmental and Ecologically Sustainable Development (ESD) principles, the relevance of implementing sustainable energy technologies is now gaining the attention of building designers around the world.

The problems associated with energy consumption such as cost, material depletion both renewable and non renewable and greenhouse gas emissions have provoked an increased awareness and willingness to strive for technologies that provide ameliorative measures which increase the sustainability of building stock.

An area of research that will contribute to reduced energy costs is building facade design implementing natural ventilation and daylighting. The objective of this paper is to highlight the implementation of the technologies and designs that have arisen from research into natural ventilation and daylighting at UTS.

The Construction Management program at UTS has developed a light inlet test building that represents the curtain wall configuration familiar to multi storey buildings. Various methods and means have been evaluated to bring reflected light in above the suspended ceiling and then distribute this light throughout the building.

The Construction Management program and Mechanical Engineering program at UTS have also

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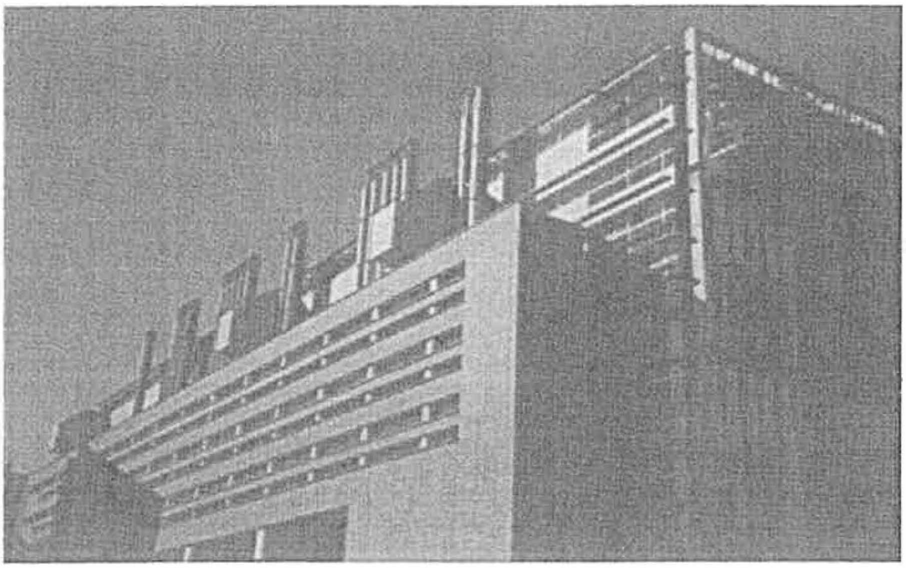


Fig. 1. Science Precinct Building, University of New South Wales, featuring LVT ventilation extraction.

developed a test rig to assess wind driven ventilators. From these results natural ventilation rates can be calculated.

The aim of these projects is to develop a curtain wall panel that provides reduced artificial light dependency, reduced heat load and reduced operating costs, for both air conditioning and lighting.

One of the daylighting devices that has been evaluated involves a solar hood shading device to stop incident radiation from striking the north facing glazing (south in the northern hemisphere) but reflects light through a horizontal light pipe (HLP) above the suspended ceiling and then redistributes that light into the work place (refer to Fig. 2).

2. Background

A curtain wall is usually a non load bearing gl fronted facade hung from the structural frame of building. This project relates to solar control and mc particularly to a method and means for allowing su light/reflected light to be redirected internally ir buildings by improvements to curtain wall design.

There has been recognition for many years tl solar shading using sunhoods/extended eaves e enhances the thermal comfort of a building, and win heating and summer cooling costs are minimised. T standard application is to shade windows from dir radiation during the height of summer while allowi

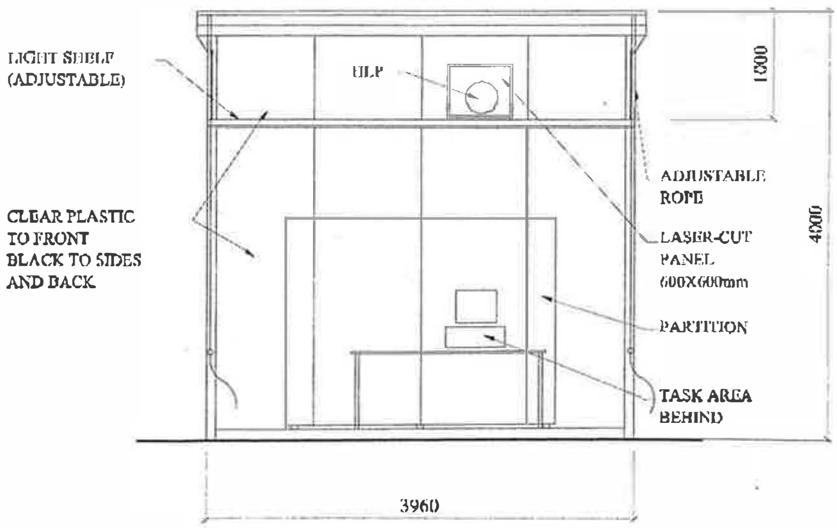


Fig. 2. The Daylighting curtain wall simulation test building, developed by the Construction Management program at UTS.

sunlight penetration during other seasons when the increased heat load is appreciated.

Solar hood and eaves overhang designs can be accurately assessed by comparing the buildings orientation to the solar paths. For example, with a north facing window the extreme sun angles of June 22 and December 22 would be the limits of vertical and horizontal pitch and an appropriate sunhood designed.

One of the major advantages of curtain walling is that it allows excellent undisturbed floor to ceiling views if wholly glazed. If the glazing is unshaded however, full intensity sunlight/radiation enters the building giving rise to unacceptable internal heat loading requiring increased aiconditioning to provide thermal comfort for the buildings occupants.

Direct radiation can be overpowering in the summer months and requires substantial air conditioning and therefore high energy input to lower the temperature to comfortable working levels. As the sunlight enters the building it passes through the glazing as short wave radiation which inturn heats objects within the building and is re-radiated as long wave radiation which cannot pass back throughout the glass and is therefore trapped within the building, commonly referred to as the "Green House Effect".

Currently, daylight cannot be distributed throughout the building because of the ceiling limitations. Therefore, even with the increased sunlight entry capable with curtain wall designs, the internal work space requires considerable artificial lighting even during daylight hours.

The paper evaluates methods and means to combine the principle of solar hood design with borrowed light. Borrowed light can be distributed throughout the building, lessening the requirement for artificial light and this ambient reflected light will not provide heat load as is the case with direct incident radiation.

3. Significance

In the NSW Government Department of Energy report released in February 1996: "Energy use in the NSW Commercial Sector", it was calculated that 18.7% of NSW's total electricity consumption is directed to Commercial operations. The findings revealed that the major areas of electricity consumption are lighting 33.3% and heating, cooling and ventilating 23.5%[1].

Massive savings in energy consumption are possible with current technology, and office buildings have now been constructed that have 50% less energy consumption compared to similar sized commercial spaces. Obviously, enormous cost benefits are attributable to these energy savings and have been widely documented.

Energy auditing and assessment of buildings is a field of building technology that has seen tremendous growth and attention by both government and private sector organisations as the economic and social benefits are evaluated as increasingly essential components for best practice. From the figures provided in the NSW report "Energy use in the NSW Commercial Sector", lighting is emphasised as one of the most important areas to reduce energy consumption. By maximising the level of natural daylighting and using task/ambient lighting, savings of 80% in energy consumption have been documented.

4. Horizontal light pipe technology

As part of the research into daylighting technologies various methods of refracting and reflecting light into the depths of multi-storey buildings have been considered and this must take into account the construction practicalities, that is, positioning and mounting of the facade, solar shading and devices mounted externally on the facade etc.

Specific design requirements such as; buidability and maintenance of any facade attachments are serious considerations. The advantages of mounting a reflecting or refracting panel on the outside of the building envelope, for example, allows for air dissipation of heat before it is transmitted into the building envelope.

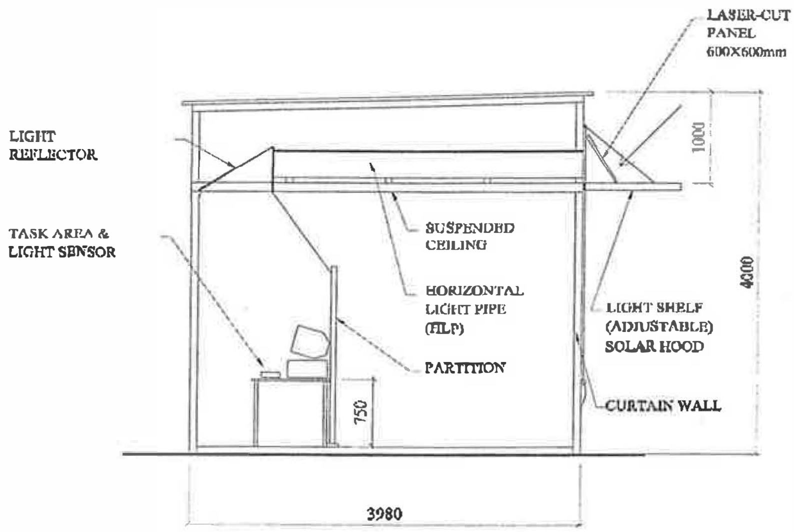
5. Testing the HLP

On the roof of Building 2, city campus UTS a clear unshaded space allowed for the computer assessmentof the daylighting levels achieved in the test building, given various configurations. Light levels were recorded from within the test building and also on the roof of the test building to compare total lux available to those transmitted to the desk top work plane area. One of the HLP tests carried out in 1994 at UTS is shown in Figs. 2 and 3.

Australian Standard 1680.2 1992 recommended lux levels for general office tasks of 320 Lux. From the results of testing, on a bright sunny day over one third of the daylight (320 Lux required) at 3.5 m can be transmitted into the building with the HLP in operation. The effectiveness of the HLP is clearly demonstrated by the light levels achieved when the HLP is in the closed or open position (refer to Fig. 4).

This research involves on-going testing and evaluation of various methods and means of reflecting

[1] NSW Government Department of Energy: "Energy use in the NSW Commercial Sector", February 1996.



SECTIONAL ELEVATION OF TEST RIG 1:50

Fig. 3. The Daylighting curtain wall simulation test building, developed by the Construction Management program at UTS.

light into the work plane area. Research involving optical cable, light shelves, tunnels, mirrors of reflecting glass/film, and infra red/reflecting and absorbing filter materials will be considered.

Percentage increase in lux from various systems are assessed for commercial potential, calculations of potential reduced heat loading will become possible with on going data and design limitations and results will be summarised and perceived benefits assessed by (reduced air conditioning/lighting) with energy savings measured in kW and expressed as monetary savings per annum. The resultant cost benefit analysis incorporating appropriate sensitivity and life cycle analysis of implementing the design improvements is the final stage of development.

6. Vertical light pipe technology

While well known to domestic applications t have roof space to floor area available, vertical l pipes (VLPs) and skylight technologies are now p ing a part in rooftop locations such as supermarl and warehouses where substantial savings in ligh have been achieved (Fig. 5). Solatube Australia Ltd, a manufacturer of tubular skylights has a s stantial testing facility consisting of identical test bu ings. With Solartube Australia Pty Ltd's assistanc vast array of reflective materials and configuration lightpipes have been tested since 1994. One of the c figurations tested and compared was the applicatior a north facing reflector (south facing in the north hemisphere) to its VLPs.

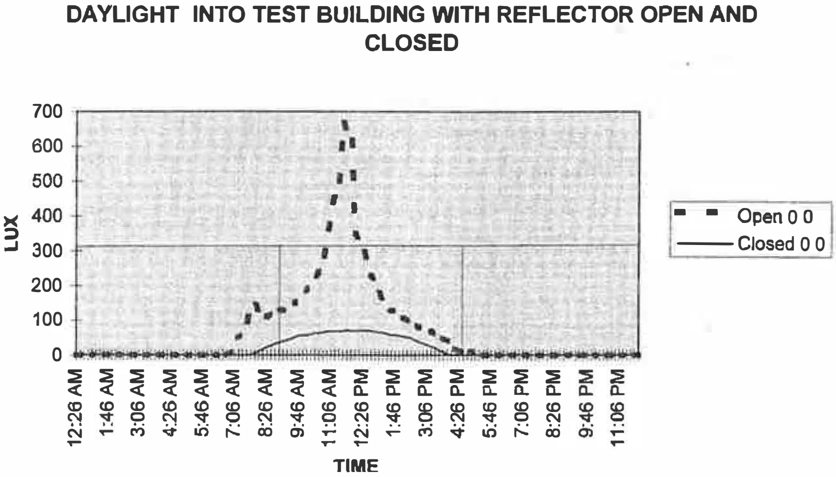


Fig. 4. HLP performance as recorded March 1994.

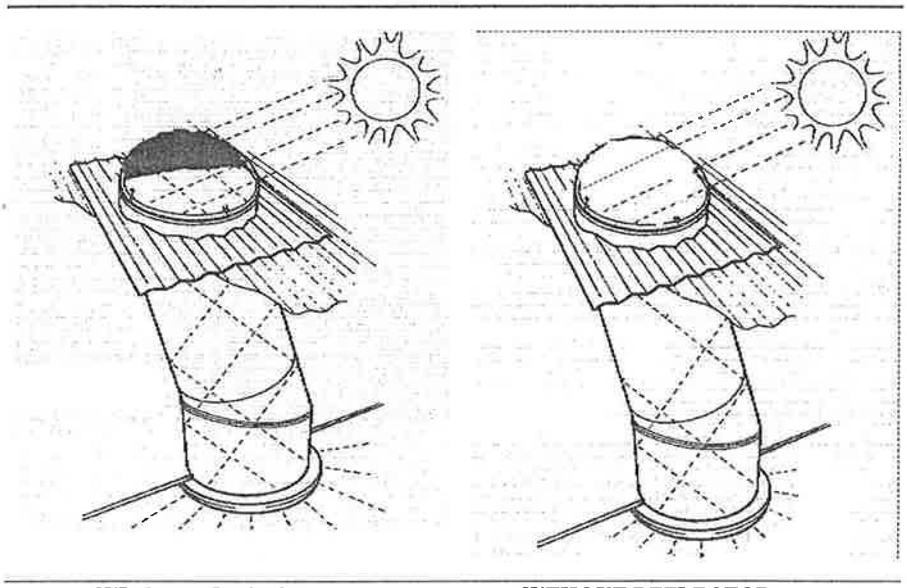


Fig. 5. VLPs, with and without reflectors.

7. Results

From the results of experiments conducted under identical conditions the VLP fitted with the true north facing reflector achieved a 40% improvement over the VLP without the reflector. On a bright sunny day when a sum total of 100,000 Lux of sunlight is considered available and the delivery into the building is only a maximum of 1400 Lux, the need for improved daylighting technologies becomes obvious (refer to Fig. 6).

Australia has led the way with the penetration of VLPs into the residential market and now major developments incorporating VLPs and roof mounted skylights are taking place in residential and commercial projects around the world.

8. Natural ventilation

As previously highlighted in the NSW Government Department of Energy report released in February 1996: "Energy use in the NSW Commercial Sector" stated that heating, cooling and ventilating constituted 23.5% of electrical consumption in the commercial sector[1]. The economic consequence of a few percent re-

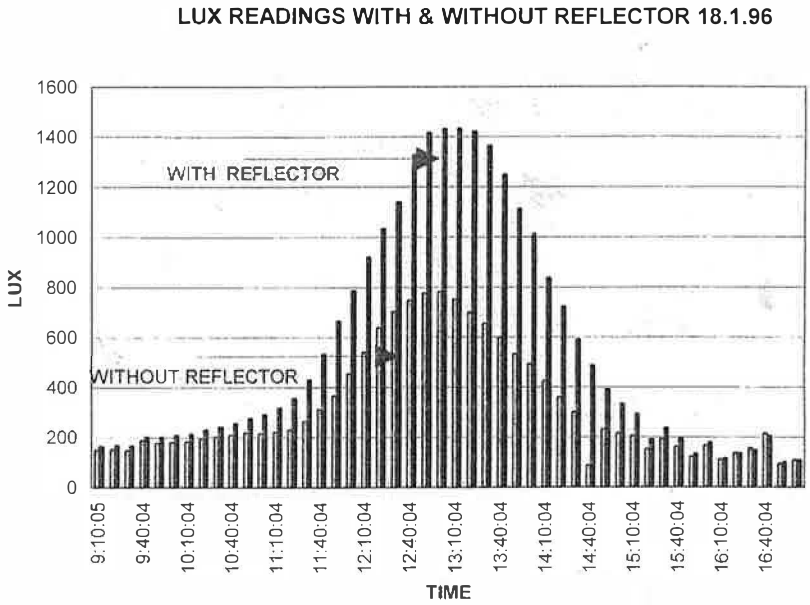


Fig. 6. VLP performance with and without reflector.

duction in consumption would translate into millions of dollars worth of savings.

Building stock in countries having a warm temperate climate with high solar gain and industrial processing operations usually suffer from a common problem of heat gain. The need to reduce or dissipate the heat load inside factories to improve manufacturing processes and comfort levels in offices and hence productivity is an extremely desirable feature that has gained the attention of building designers around the world. The application of natural ventilation into commercial buildings is now being assessed scientifically with advanced computer simulation models that apply the laws of nature to assist with ventilation.

In utilising one of the thermal laws the 'stack effect', buildings are flushed of hot air by inducing a convection cycle which includes the dispelling of hot internal air and replacing it with cooler external air (if available). Ventilation designers employ this stack flow and are now producing sophisticated thermal chimneys and other advanced stack flow systems with varying degrees of success.

Wind driven ventilators also have their place and can assist the stack effect, however when there is no wind the stack effect is the natural ventilation base line. Wind driven ventilators make little contribution to venting when there is no wind present, apart from their exhaust coefficient of discharge due to their throat diameter. It should be stated that stack effect or wind driven turbines applied to domestic housing is also a different issue, especially where sealed insulated ceilings are concerned which will effectively reduce any airflow from within the house to the roof mounted exhaust vents.

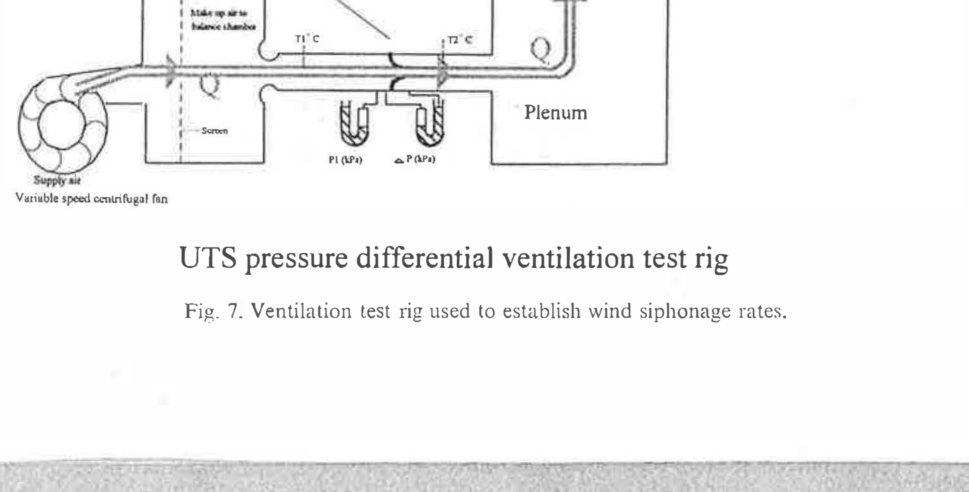
Thermal stacks with the assistance of wind driven turbines are a feature of some new office building signs. The Science Precinct Building at the Univers of New South Wales shown in Fig. 1, is an exam that has applied improved wind driven turbine desi known as long volume turbines (LVTs) tested at U to assist ventilation where a good constant wind sou is available.

9. Testing for wind siphonage

In association with the Mechanical Engineering p gram at UTS a ventilation test rig was developed assess ventilation rates due to wind siphonage. tests were documented by recording the wind veloc with zero pressure differential between the plenum a the ambient air pressure. The results of the testi proved to be very beneficial in establishing ventilati rates for various designs, allowing an assessment the percentage of the airflow induced through the ve throat at various wind speeds.

10. Operation

The fan produces the required wind velocity ov the turbine, opening or wind directional vane (whi ever is being tested) hopefully giving rise to suctic drafting air out of the plenum chamber. Air pressure balanced by an input supply fan to achieve ambie air pressure and measured applying Bernoulli's pri ciple across the metering nozzle (refer to Fig. 7).



UTS pressure differential ventilation test rig

Fig. 7. Ventilation test rig used to establish wind siphonage rates.

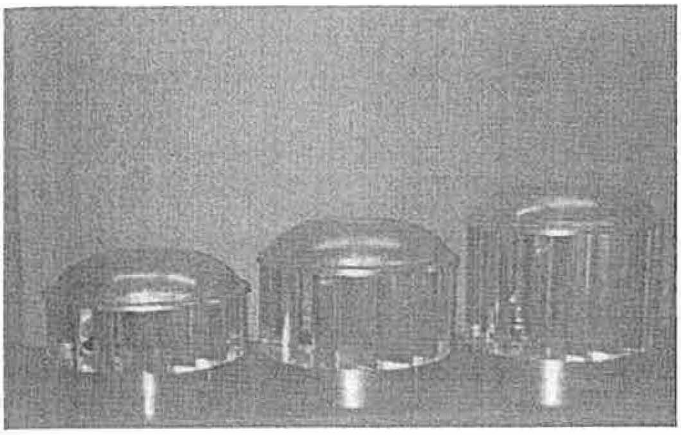


Fig. 8. Variable blade height/LVTs.

11. Variable blade height/long volume turbines

One of the impressive results that came out of our research on ventilator design was the improved performance of turbines labeled LVTs. In consideration of set design variables such as throat diameters to match joist spacing, it was decided to adjust the blade height while the throat diameter remained constant (refer to Fig. 7).

The LVTs were supplied and modified by Edmonds Products Australia Pty Ltd and compared to their normal 250 mm blade height Hurricane model (Fig. 8). With reference to Fig. 9 it can be seen that a 50% increase in blade height gives a 13.5% increase in exhaust flow rate. The increase in height will also have an advantage on pitched roof houses, allowing more blade area to be exposed above the roof ridge line, assisting extraction.

12. Combined daylighting and ventilation technologies

The economic viability of implementing new technologies depends not only on the cost of production and the savings attributable to the technology in use ie its pay back period, but to a large degree, the products aesthetics, ease of use and market acceptance.

The ability to combine the energy saving technologies developed from research relies on the design of the building being sympathetic to its direct application and/or its suitability for retro fitting.

With the advancement of daylighting, ventilation, photovoltaic cells and phase change materials, successful implementation depends on careful design and scientific assessment. The design shown in Fig. 10 represents an eight storey office/retail building incorporating energy saving enhanced technologies which incorporate the following features.

A stepped north facing facade which allows for sunlight to reach the refracting panels on each floor without shading the panel below, while providing sufficient solar shading to protect the recessed windows from direct radiation in the summer months when required.

Mounted on the solar hood is a combination of photovotaic panels and selective wave length reflecting or refracting panels that deliver sunlight (preferably the visible spectrum minus infrared heat carrying component, especially important in summer months for temperate climates). The refracted or reflected daylight is then distributed above an insulated suspended ceiling and reflected into the office space.

The suspended ceiling is insulated to reduce heat flow into the office space and runs uniformly from the glazing to the air stacks/shafts that run the entire

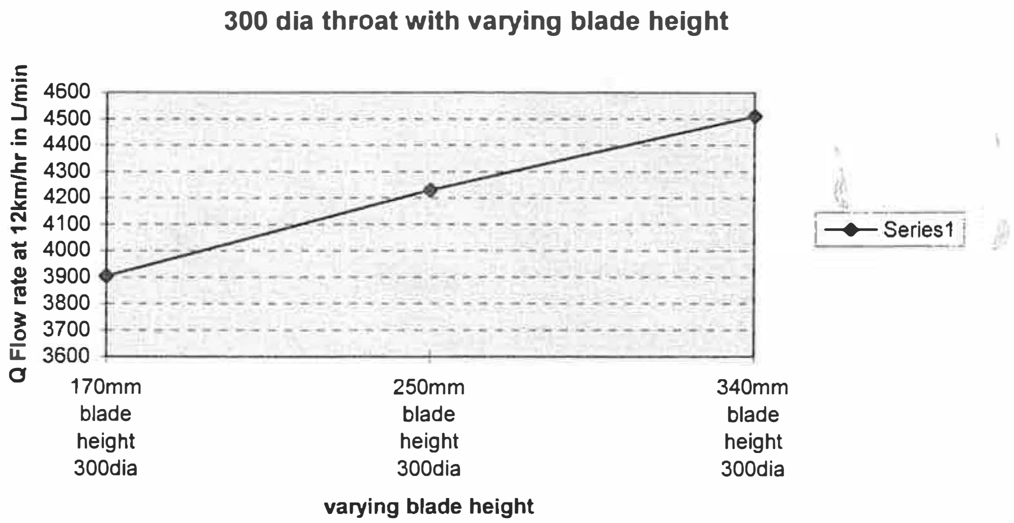
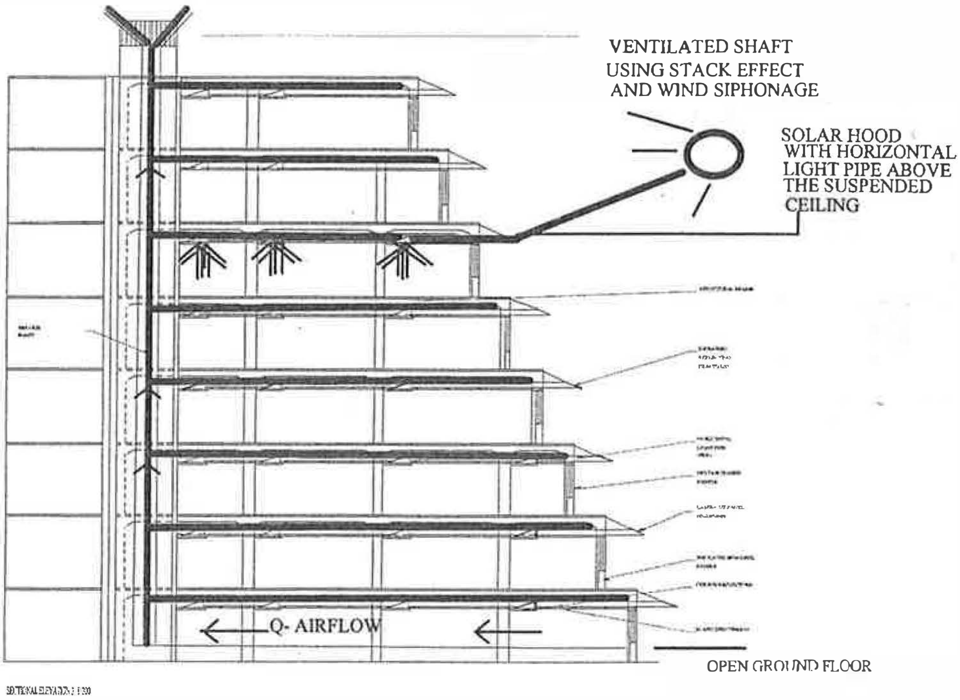


Fig. 9. Varying blade height performance.



ENERGY SAVING SUSTAINABLE CONSTRUCTION
COMBINING DAYLIGHTING AND NATURAL VENTILATION

Fig. 10. Represents the cumulative result of combining the daylighting and ventilation technologies.

length of the building. By insulating and opening the suspended ceiling to an air stack, hot air is siphoned to the core creating a thermal chimney and evacuating the heat from each floor.

The thermal chimney is created by forming air corridors alongside the lift shafts, which operate by employing the stack effect, cooler denser supply air is drawn into the building from the open ground level retail stores. To assist the stack flow by added siphonage, wind turbines such as LVTs can be placed on top of the air stacks such as in the case of the Science Precinct Building at the University of New South Wales (refer to Fig. 1)

13. Conclusion

The results of both the daylighting and ventilation research described in this article have produced a greater understanding of the application and benefits that may be achieved utilising the improved designs which will hopefully be implemented into low energy consuming sustainable office buildings, as depicted in Fig. 10.

Considerable savings have been demonstrated by the HLP and VLP applications and the use of natural ventilation improvements such as the LVT. Only a few of the results of our testing have been highlighted in this article and it could be said that the most signific outcome of this research relates to the collection of liable data that can be used to design systems fror scientific viewpoint.

Both daylighting and natural ventilation are criti climate control components that should be conside for all building stock in efforts to reduce energy c sumption and increase sustainability. Heating, cool and material specification have a crucial part to p in the sustainable buildings of the future and apply some practical building and design science the could make a substantial difference to both the sh and long term viability of businesses operating wit the buildings they occupy.

14. Uncited references

[1–33]

Acknowledgements

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References

[1] Aronsson S, Nilsson P. Learning from experience with energy efficient lighting in commercial building. Netherlands: CADDET, 1991.

[2] ASHRAE. ASHRAE Handbook — Fundamentals. Atlanta GA: American Society of Heating, Refrigerating and Air Conditioning Engineers, 1993.

[3] Australian Standard 1668–1991, The use of mechanical ventilation and air conditioning in buildings, part 2: mechanical ventilation for acceptable indoor air quality.

[4] Australian Standard 1680–1990 Interior Lighting, & 1680.2.0.

[5] Australian Standard 2427–1983, Smoke/heat release vents.

[6] Australian Standard 2428–1983, Methods of testing smoke/heat release vents.

[7] Australian Standard 2665–1983, Smoke/heat venting systems — design installation and commissioning.

[8] Bedford T. Environment warmth and its measurement. London: HMSO, 1940 (reprint 1965).

[9] BRE Digest. Natural ventilation in non domestic buildings. BRE Digest 1994;399.

[10] BRE Publications. Environmental design manual; summer conditions in naturally ventilated offices. BRE Publications, 1988.

[11] British Standard 1042 part 1-1964, Methods of measurement of fluid flow in pipes.

[12] British Standard 5925–1991, Code of practice for ventilation principles and design of natural ventilation.

[13] Cartwright V, Reynolds JS. Daylight, energy conservation, and comfort in an office building. Department of Architecture, University of Oregon, 1999.

[14] CIBSE. Guide, air infiltration and natural ventilation, section A4, volume A, design data. London: The Chartered Institution of Building Services Engineering, 1998.

[15] Commonwealth Department of Science Technology. Daylight at work — occupational health and safety environment series. Canberra: Australian Government Publishing Service, 1981.

[16] Cowling IR, Veevers P. The design and performance of a permanently mounted daylighting device. Architectural Science Review 1999;33.

[17] Cowling IR. General principles and design of daylighting devices at QUT. Queensland University of Technology, 1993.

[18] Croome DJ, Roberts BM. Air conditioning and ventilation of buildings. USA: Pergamon Press, 1975.

[19] Department of Primary Industries Energy. Saving energy through lighting management. Canberra: Australian Government Publishing Service, 1981.

[20] Draft Australian/New Zealand Standard for Comment DR97303, Natural ventilators — classification, construction and performance, issued for comment 1 July 1997, closing for comment 31 August 1997.

[21] Dupreez WP, Howosad RM. Performance test on a whirlybird turbine ventilator. South Africa: CSIR, 1989.

[22] Edmonds IR. Solar energy materials and solar; cells performance of laser-cut light deflecting panels. North Holland, 1993.

[23] Faber O, Kell JR. Heating and air conditioning of buildings. Sixth ed. London: The Architectural Press, 1979.

[24] Fisk DJ. Thermal control of buildings. London: Applied Science Publishers, 1981.

[25] Hassall DNH. Reflective insulation and the control of thermal environments. Australia: ACI Insulation, 1977.

[26] ASHRAE. IAQ proceedings: managing air for health and energy conservation. USA: ASHRAE, 1986.

[27] Littlefair PJ. Innovative daylighting — a review of systems and evaluation methods. Lighting Research and Technology 1900;22(1).

[28] Phillips RO. Sunshine and shade in Australasia. Sydney: Commonwealth Experimental Building Station, 1963.

[29] Pivovonsky M, Nagel MR. Tables of black body radiation functions. New York: McMillan, 1961.

[30] Public Works and New South Wales Government Office of Energy State Projects Division. Building energy manual. Australian Government Publishing Service, 1993.

[31] Shaw CY, Kim A. Performance of passive ventilation systems in a two storey house. National Research Council Canada, 1984.

[32] The Institution of Heating Ventilating Engineers. IHVE guide, book B. London: The Institution of Heating and Ventilating Engineer, 1970.

[33] West STK. Daylighting work at UTS. Royal Architectural Institute of Canada: Advanced Building Newsletter 1995;1(9):5–7.