VENTILATION AND COOLING

18TH ANNUAL AIVC CONFERENCE
ATHENS, GREECE, 23-26 SEPTEMBER, 1997

STACK VENTILATION AND COOLING FOR URBAN SITES: Natural ventilation with roof intake for improved air quality

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Synopsis

The paper outlines the value of roof intake air ducts to serve largely passively ventilated and cooled buildings in urban areas. This approach improves air quality, reduces noise pollution and enhances security.

A diagrammatic representation of night cooling using this approach is given followed by a description of experimental work at the Bartlett. This work is directed at establishing methods of starting the ventilation process by overcoming buoyancy, and enhancing the cooling process by providing "mixed mode" cooling.

The author reports on "full size" experiments to establish wind driven ventilation techniques and experiments to establish whether roof planting could provide locally cooled air. Further experimental work on the latter is suggested.

The paper concludes by describing future work aimed at introducing refrigeration as a "mixed mode" ventilation and cooling strategy where passive night ventilation replaces the bulk of the cooling load, and discusses the architectural implications of the research. Further research to establish client attitudes to area loss in buildings as a result of installing large vertical passive stacks is recommended.

List of symbols

t(int)	internal temperature
t(ext)	external temperature
m/sec	metres per second
Pa	pressure in pascals

Introduction

Air conditioned commercial buildings have twice the fuel cost and CO_2 emissions when compared to non-air conditioned buildings. In addition, they are often perceived as uncomfortable and unhealthy. As a result there is a growing trend to avoid active cooling and mechanical ventilation, relying more on a passive control strategy. A new generation of naturally ventilated buildings has recently been constructed. As a result of their form and internal heat gains such buildings would have overheated if they had relied on conventional techniques. These naturally ventilated buildings are currently being monitored under the Sustainable Cities programme and research is currently being undertaken in this area as part of the NATVENT project. [1]

This new generation of naturally ventilated, deep-plan building often encourages natural ventilation by the use of stacks, and cools the building by night venting i.e. drawing cool night air into the warmer building. These techniques are however limited for the following reasons.

1. Stack ventilation normally utilises air drawn in from the perimeter of the building at a low level. Therefore, in urban locations the air inlet is normally located at street level; this results in gaseous, particulate and noise pollution entering the building. This is currently a major drawback in utilising passive ventilation in urban sites as a result of the impact that such pollutants can have on the health and comfort of occupants. Filtration is

Experimental work at the Bartlett

The experimental work at the Bartlett is focused on seeking ways to "kick start" and enhance this approach to passive cooling.

We are fortunate to have guidance from a number of industry partners. These include Monodraught Ltd., Trox UK Ltd and Max Fordham and Partners, Consulting Engineers. We are examining two different approaches:

- to use pressure differences created by the wind to drive air into the intake duct, so that it is cooled down to external air temperature
- to provide a source of cool air on top of or in the intake duct

The former approach will only provide cooling when the external shade air temperature is lower than the internal temperature. The latter offers the possibly of mixed mode cooling where daytime ventilation air can be cooled to comfort levels at times of excessive heat gain. We hope to examine the possibility of combining these approaches at a later stage in our work.

Wind driven ventilation

An obvious model for a wind driven intake stack is the traditional static Middle Eastern "wind catcher". [3] This is simple to build, but has the disadvantage that it will fail to work if the wind is in the wrong direction.

A substantial research project has been conducted jointly by Sir Michael Hopkins and Partners, Ove Arrup and Partners and CSTB in Nantes under the Joule 2 Programme. [4] This examines the feasibility of rotating wind catchers which combine intake and extract ventilation.

The basis of this work is to develop these devices to recover heat from outgoing air through a low resistance heat exchanger and to heat incoming air to a building. The same type of device has potential in passive cooling applications.

The Hopkins research was undertaken using CFD modelling and wind tunnel model tests. Conclusions are:

- hood type intakes are most efficient;
- the intake must be at least 2 metres above an adjoining flat roof to place it above boundary turbulence;
- inlets and outlets should be vertically separated to allow close spacing between ventilators;
- there is doubt that a wind vane will turn a large ventilator in light wind conditions.

We have taken the Hopkins research as a basis for further work. We are addressing the following issues:

- the design of an intake hood which can be shaded;
- strategies to drain rain water entry;
- the use of wind driven servos to turn this type of ventilator.

All our work is being undertaken using "full size" experimental devices. A full size device in this context is a device with airways not less than 200 mm diameter. This allows us to present experimental results giving absolute rather than relative air speeds and pressures.

The first experiment is the corrugated cardboard mock up shown in fig. 2. It has a long shaded intake hood and an intake drum which can be drained. There are seven right angle turns in the airflow through the experiment. The intake is 250% larger than the intake and extract ducts. The device was tested in a wind tunnel at the Building Research Establishment, Garston. Typical experimental results are shown in Table 1.

limited with natural ventilation due to the large pressure drops that filters introduce. In many cases it is impossible.

2. Night cooling involves low level openings which often pose a security risk in urban areas. Also, night cooling has limited impact during the most uncomfortable spells when hot humid conditions prevail and night time temperatures do not drop substantially below day temperatures. However, during cold night conditions there is also a limited degree of available cooling as the structure of the building cannot be cooled below morning comfort temperatures.

Recent research has shown that pollution levels in street canyons fall to background levels at a height of approximately 13 metres. [2] Therefore, by bringing air from roof level or above, levels of pollution can be substantially reduced.

The paper outlines possible strategies for naturally ventilating buildings where the air can be drawn in from an unpolluted roof level site both in the winter and summer, day and night. Without such developments natural ventilation is likely to be limited to "Greenfield Sites".

The basis of any strategy for supplying air from roof level is to reduce intake air duct temperature, and thus buoyancy, to below building air temperature. This principle is illustrated in figure 1. As long as t(ext) is lower than t(int) and duct A is at t(int) and duct B is at t(ext) air will flow through the internal space and cool it down.

The approach has been successfully modelled by Dr Paul Linden at the University of Cambridge, Department of Applied Mathematics and Theoretical Physics. Details of this work will be the subject of a further paper.

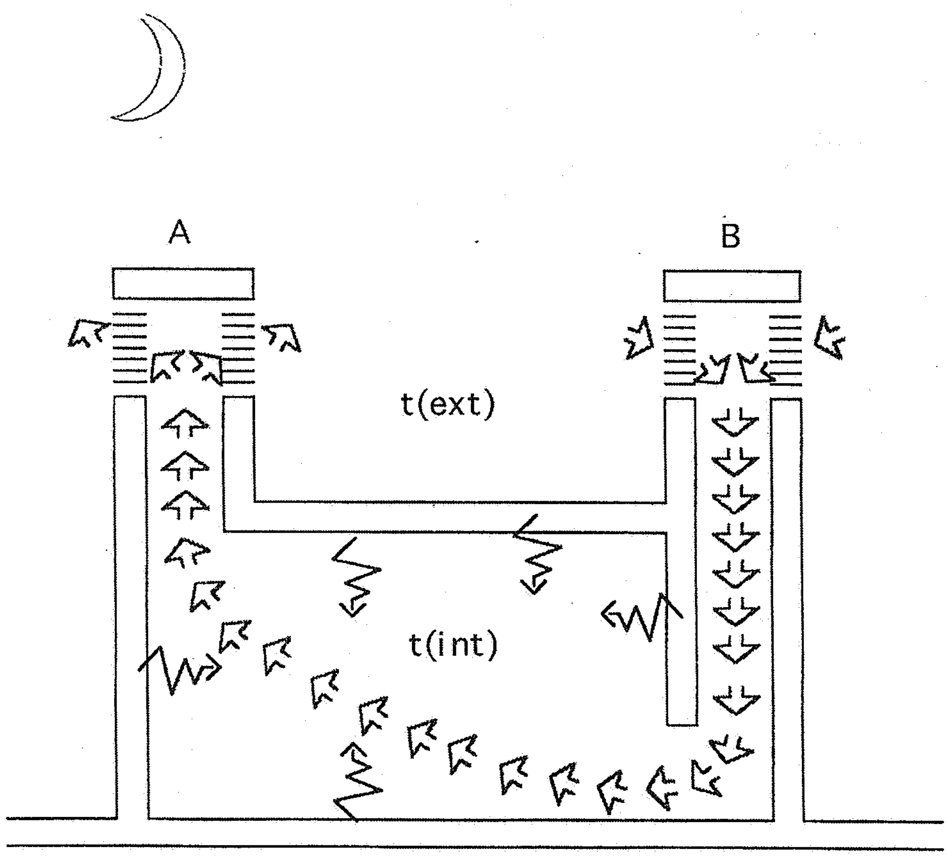


fig.1

PRINCIPLE OF VENTILATION (NIGHT)

Table 1: First wind device.

First series of measurements

Tunnel airspeed (ms^{-1}) (**u**)	0.45	0.90	1.80	2.70	3.60
Reference dynamic pressure (Pa) (m =1.26)	0.13	0.51	2.04	4.59	8.16
Tunnel air pressure (Pa)	1.40	3.50	6.30	*7.60	13.50
Pressure correction (Pa)	-1.27	-2.99	-4.26	-3.00	-5.34

Airspeed in device (ms^{-1}) (w) at position:

A	0.43	0.66	1.60	1.90	2.00
B	0.36	0.64	1.40	1.80	2.70
C	0.22	0.35	1.10	1.40	2.00
D	0.28	0.45	1.20	1.40	1.90

Ratio w/u at position:

A	0.96	0.73	0.89	0.70	0.56
B	0.80	0.71	0.78	0.67	0.75
C	0.49	0.39	0.61	0.52	0.56
D	0.62	0.50	0.67	0.52	0.53

Pressure measurements with plenum ducts closed (Pa) at position:

A (static)	**1.50** (+0.23)	**3.20** (+0.21)	**2.60** (-1.66)	**2.40** (-0.60)	**0.50** (-4.84)
B (static)	**1.60** (+0.33)	**4.20** (+1.21)	**7.80** (+3.54)	**8.30** (+5.30)	**13.70** (+8.36)
C (combined)	**1.70** (+0.43)	**4.10** (+1.11)	**7.90** (+3.64)	**7.50** (+4.50)	**11.90** (+6.56)
D (combined)	**1.40** (+0.13)	**3.20** (+0.21)	**2.10** (-2.16)	**1.20** (-1.80)	**0.02** (-5.54)

Pressure measurements with plenum ducts open (Pa) at position:

A (combined)	**1.50** (+0.23)	**3.20** (+0.21)	**2.90** (-1.36)	**2.70** (-0.30)	**1.30** (-4.04)
B (combined)	**1.70** (+0.43)	**4.20** (+1.21)	**6.50** (+2.24)	**7.10** (+4.10)	**10.70** (+5.36)
C (combined)	**0.00** (-1.27)	**3.00** (+0.01)	**6.90** (+2.64)	**8.20** (+5.20)	**13.30** (+7.96)
D (combined)	**1.50** (+0.23)	**3.80** (+0.81)	**2.70** (-1.56)	**2.20** (-0.80)	**1.70** (-3.64)

NB Pressure readings in brackets show pressures as corrected to atmosphere

* This is an odd figure which correlates with a non-linear arispeed in the device

Air speeds in the device are between 60% and 70% of wind tunnel speeds. We are currently constructing second experimental device to be tested in field conditions (see fig. 3). In this device intake and extract positions are vertically separated. The device will use a wind driven servo to turn it head to wind. The servo is derived from the tail fan wheels used to turn 19th century windmills in the UK.

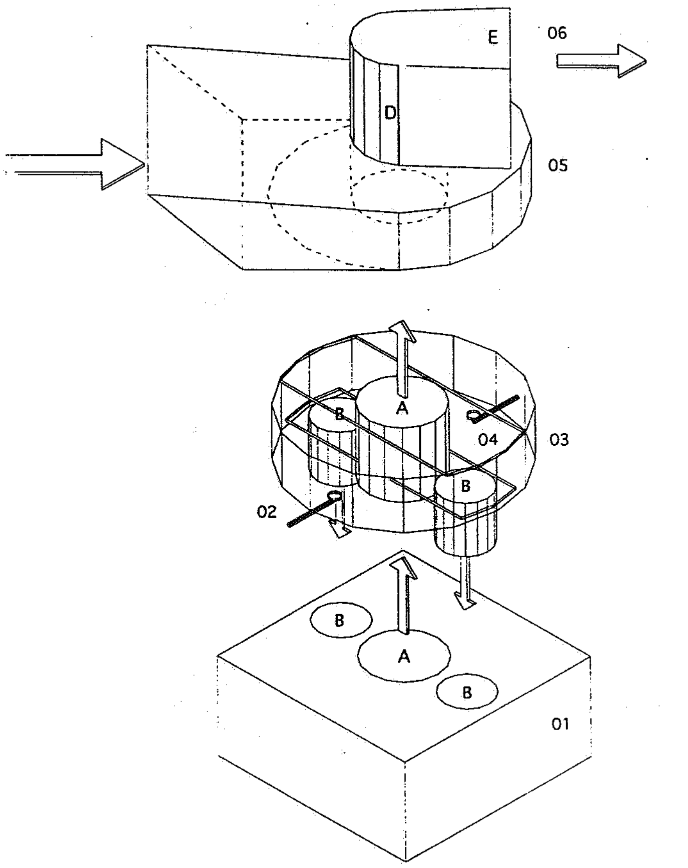


fig.2

FIRST WIND DRIVEN EXPERIMENT

01 plenum box 02 drain off positions 03 base drum
04 rainshield 05 intake hood 06 outlet vent

Refer to table.1

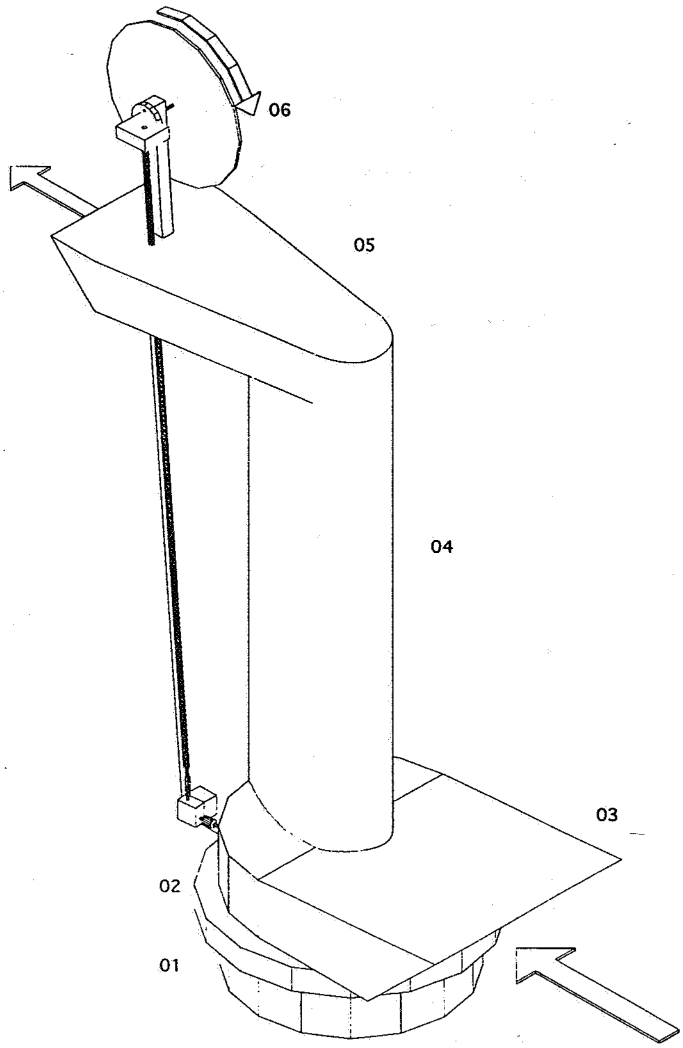


fig.3

SECOND WIND DRIVEN EXPERIMENT

01 base drum 02 revolve 03 intake hood 04 outlet vane
05 outlet vent 06 fanwheel

The initial results of our investigations into wind assisted ventilation and passive cooling systems are encouraging. We believe that intakes can be roof mounted in urban conditions with considerable improvement in indoor air quality and acoustic environment.

Two questions remain unanswered in this approach. What happens when the wind does not blow and what happens when the external shade air temperature is such that a fully passive cooling strategy will not succeed?

A response to the first question is the introduction of large low energy fans into the intake ducts. These are ideally suited to take them. The second question is much more difficult to resolve. We see two possible responses which could lead to mixed mode cooling systems.

Roof garden experiments

Evaporative cooling techniques were used in Middle Eastern wind catchers; water filled unglazed earthenware pots and damp materials were introduced into the intake shafts. This approach has been further explored by Cook *et al* where sprayed water is used both to cool and drive the air. [5] We are concerned that Legionella risks and the problems involved introducing a substantial amount of water into a building will limit the application of this concept.

The undoubted effectiveness of the phase change in water to assist in cooling has also been explored by Giabaklou and Ballinger. [6] We have looked at the possibility of using evapo-transpiration in plants to locally reduce the shade air temperature above intake shafts. The idea that roof gardens could be used to temper the air entering the buildings below them is very attractive because it combines indoor and outdoor amenity for building users.

It is difficult to find the empirical data that would enable a designer to establish the efficacy of this approach. Various researchers have investigated the thermal effects of planting in the built environment. Papers by Parker, [7] Kimura, [8] Euorfopoulou and Arauantinos, [9] Barrosso-Krause [10] and Onomina, Matsumoto and Hokoi [11] all indicate that evapo-transpiration will provide effective cooling. Parker's comments about the role of evapo-transpiration in cooling air are unquantified and all the other authors, with the exception of Kimura, concentrate on the role of vegetation to cool down the fabric of the building below usual (non vegetative covered) temperature levels. Kimura refers to experimental work undertaken at Yamashi where shade air temperatures are shown to be 1 - 2 °C lower in a densely planted garden that than the equivalent shade air temperatures outside the garden.

The subject of evapo-transpiration is also extensively studied by geographers and biologists. Oke, quoting experimental work by Long *et al*, [12] shows how; at 02.00 hours the temperature inside a field crop under an open sky is in excess of 2°C lower than the external air temperature; that at 06.00 hours the temperature is approximately 1°C lower; that at 12.00 hours the temperature is over 1°C higher and that at 18.00 hours the temperature was approximately 1°C lower. He suggests that this process points to an active surface just below the surface of the crop. It should be noted that these experiments took place in the UK, in summer and that the 06.00 measurement can be assumed to be 1.5 hours after dawn.

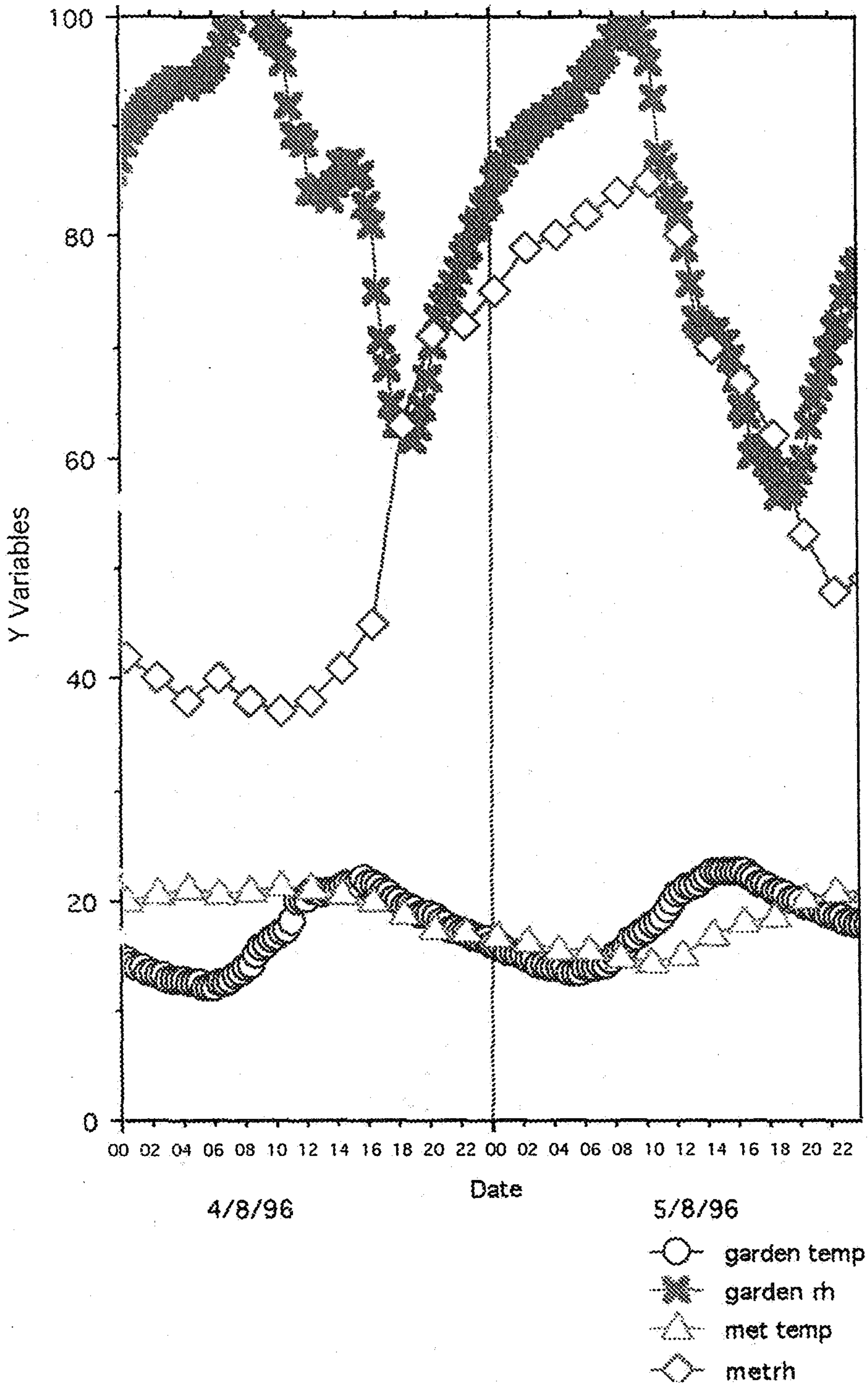
Forests show different characteristics. Oke refers to work by Jarvis to show that at midday the increase in temperature is lifted to the centre of the canopy layer, and that the forest floor temperature is that of the shade air temperature above the canopy.

We constructed an experimental "roof garden" 1.2 metres square and 600 mm deep at the Bartlett, planted with garden shade tolerant plants, placed in pots in a water tray. The high surround was provided to reduce wind effects. In order to mimic the effects of a forest canopy we shaded the garden with an artificial canopy consisting of two layer of white perforated profiled metal decking with an air cavity between them. This is shown in fig. 4.

Typical experimental results are shown in Table 2, which compare two days, 4th and 5th August 1996. Both were sunny but the 5th was a day of exceptionally high humidity. It can be seen that this experiment was only partially successful in that the "artificial canopy" did not stop radiant heat gain. Nevertheless in conditions of low external RH this approach appears to provide an extended morning period where the garden temperature is lower than the external temperature.

Relative humidity is very high when cooling effects are most apparent. This is probably a result both of stomatal evapo-transpiration and of evaporation from the water tray and the growing medium surface. The experiment also shows that, with this configuration heat once gained by the roof garden is trapped in it and that the early evening effects noted by Long do not occur.

Table 2: Experimental "garden".



In hot, dry climates it is probably advantageous to consider enclosed shaded roof gardens under-planted with shade tolerant plants as sources of air for night cooling.

Experimental work should be undertaken to establish temperature profiles in a walled shaded and under-planted roof garden over Spring, Summer and Autumn in a hot, dry climate to establish actual temperature differences in field conditions.

We show a possible experiment in fig. 5. This shows a roof garden approximately 6 metres square surrounded by externally insulated walls 3 metres high. Alternative modes of shading are indicated. A trellis and vine cover may be more advantageous than opening

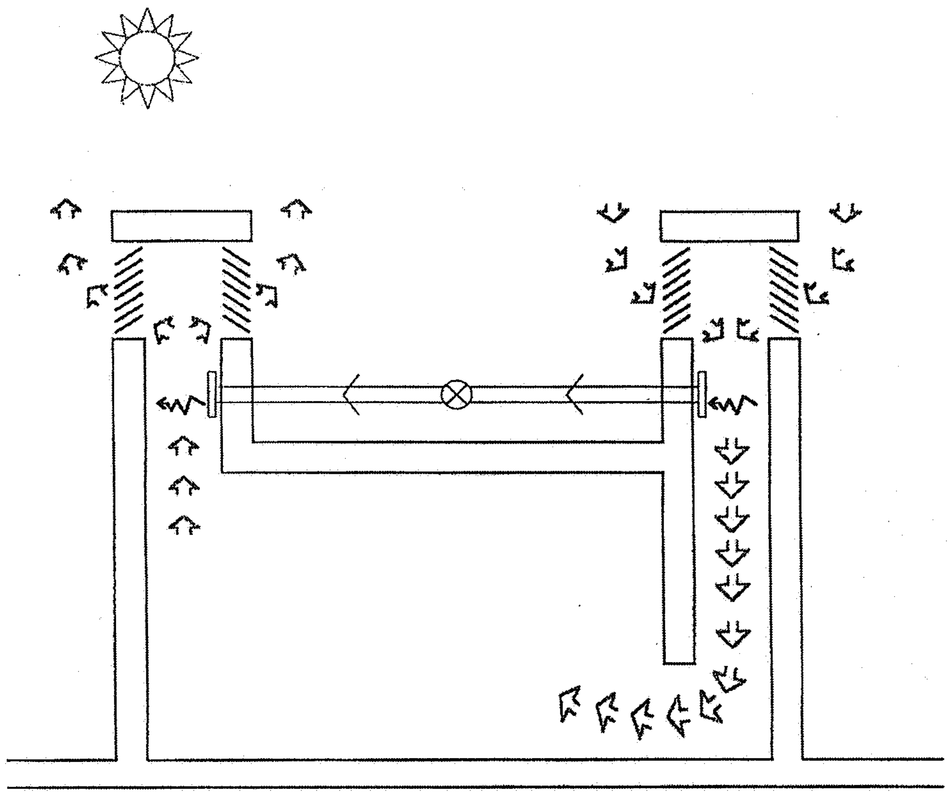


fig.6

PRINCIPLE OF ASSISTED COOLING (DAY)

Architectural consequences of vertical stack ventilation and cooling.

The architectural consequences of this approach to ventilation and cooling are such that it is unlikely to be applicable to buildings exceeding four stories in height. If we assume 10 air changes an hour, a duct speed of 2 m/sec and a floor to floor height of 3.6 metres the combined supply and extract stack area for any floor of a building is approximately 1%. A four storey building will have 4% of its top floor area occupied by stacks. This subject deserves further research. The judgement that no developer will contemplate more than 4% loss of building area is based on the author's experience as a practising architect. It may be that the current commercial climate is more enlightened and a survey of potential clients should be undertaken.

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[1] Report under the NATVENT - European project on overcoming technical barriers to low energy natural ventilation, Kolotroni, Kukudia and Perera, Building Research Establishment, Garston.

[2] LAXEN and NOORDALLY, 1987, "NO_2 Distribution in Street Canyons", *Atmospheric Environment,* Vol. 21, No 9, pp. 1899 - 1903.

[3] RUDOFSKI B, 1964, *Architecture without architects*, Doubleday.

[4] DUNSTER B and PRINGLE J, 1997, "Research into sustainable architecture", *Architectural Design,* Vol 67, no 1/2.

[5] BOWMAN, LOMAS, COOK *et al,* "Application of passive down draught evaporative cooling to non domestic buildings", *Renewable Energy*, Vol 10, no 2/3, pps 191 - 196.

insulated louvres. Our initial results suggest that the air temperature in the roof garden will be lower than the shade air temperature at night, in the morning and the late afternoon. We show a low energy intake fan fitted to the intake duct. This will be necessary if the building below the garden is successfully designed, because ventilation air in the early afternoon will be at a higher temperature than the internal air temperature. It must be driven down the duct. This will heat the inner duct walls which must be cooled down in the late afternoon to allow for subsequent night ventilation. The fan could be powered by photo-voltaic cells.

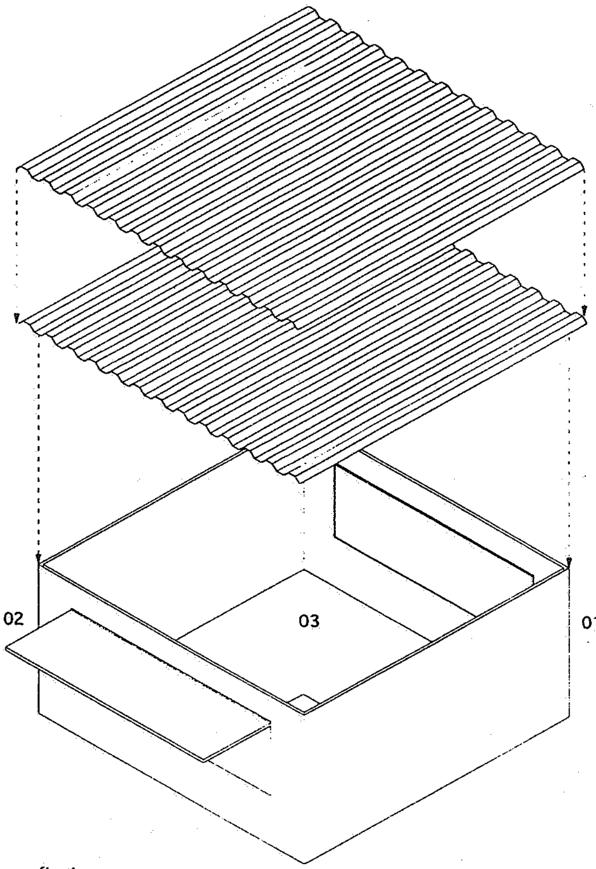

fig.4

SHADED PLANTER EXPERIMENT

01 main chamber 02 access hatch 03 planting
04 first canopy 05 second canopy

CORRUGATED ROOFS WHITE ALUMINIUM, PERFORATED 10% IN CROWN & VALLEYS SEPARATED BY 15mm SPACERS.

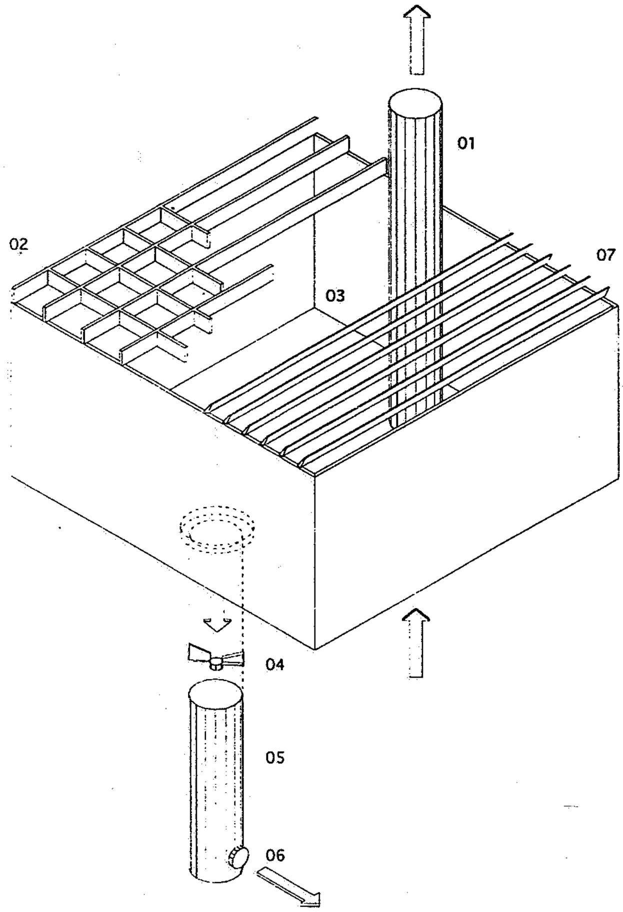

fig.5

POSSIBLE SHADE ROOFGARDEN

01 extract duct 02 trellis & vine 03 underplanting
04 low energy fan 05 insulated intake duct 06 damper
07 rotating insulated louvres

Future work at the Bartlett

Over the coming year we propose to investigate - again using 'full size' experimental devices - the approach shown in fig. 6. This type of "mixed mode" cooling is potentially attractive. The technique used to start night cooling is the same as that which could be used to "top up" cooling in extreme conditions. It should be noted that the vertical stacks designed for cooling must be large to allow for high volumes of air to move relatively slowly. If these are designed for air speeds of 2 m/sec then air speeds during the day will be approximately 0.2-0.4 m/sec in the stacks. The very slow speeds will aid heat transfer from chiller plates. These plates will run colder than the dew point of the incoming air and condensate drainage must be considered.

6 GIABAKOU Z and BALLINGER A, 1996, "A passive cooling system by natural ventilation", *Building and Environment*, Vol 31, pp 503 - 507, .

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8 KIMURA K, "Evaporation in hot and humid urban spaces", *Architecture and Urban Space,* Dover Academic Publishers, pp 631-636.

9 EUMORFOPOULOU E, and ARAUANTINOS D, *Numerical approach to the contribution of the planted roof to the cooling of buildings.*

10 BARROSSO-KRAUSE C, 1993, "Vegetal shelter: is it a good option as a passive cooling strategy?", *3rd European Conference on Architecture,* 17-21 May, pp 395-398.

11 ONMURA S, MATSUMO M, HOKOI S, *A study on evaporative cooling effect by roof lawn gardens.*

12 OKE T R, 1978, *Boundary layer climates*, Methuen & Co. pp 110-157.