Ventilation Information Paper n° 3

March 2004

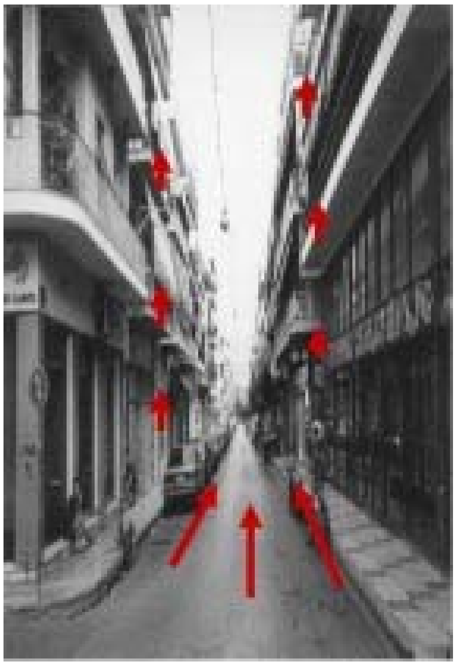
© INIVE EEIG
Operating Agent
and Management
Boulevard Poincaré 79
B-1060 Brussels – Belgium
inive@bbri.be - www.inive.org

International Energy Agency
Energy Conservation in Buildings
and Community Systems Programme

Air Infiltration and Ventilation Centre

Natural Ventilation in Urban Areas

Matheos Santamouris, NKUA



1 Energy in cities

The planet's population is increasing rapidly. More than 80 million of people are added every year, and while the total world population was in 1987 close to 5 billion, it has pass six billion in 2000 and according to the United Nations will continue to grow until the middle of the next century [Ref 1].

Most of the population growth is in cities. Urban population is growing much faster than the rural one; almost 80 per cent of the world's population growth between 1990 and 2010 will be in urban areas and most probably will be in Africa, Asia and Latin America [Ref 2]. This means simply, that there is a current addition of 60 million of urban citizens a year, and as mentioned in [Ref 3], 'is the equivalent of adding another Paris, Beijing or Cairo every other month'.

Energy is one of the more important factors that define the quality of urban life and the global environmental quality of cities.

The urbanisation process dramatically affects energy consumption. It is known, [Ref 4], that a 1 percent increase in the per capita GNP leads to an almost equal (1.03), increase in energy consumption. However, an increase of the urban population by 1 %, increases the energy consumption by 2.2 %, i.e., the rate of change in energy use is twice the rate of change in urbanization.

Increase of the energy efficiency, use of renewables to supply cities, improvement of the urban thermal microclimate and adoption of sustainable consumption policies, seem to be the main tools to reduce the energy consumption in cities.

The energy consumption of the building's sector is high and is expected to further increase because of the improving standards of life and increase of the world population. Satisfying the increased needs, without compromising the environment, clean systems and techniques have to be employed. Natural ventilation and other passive techniques seem to be very appropriate and efficient solution to this problem.

2 Climate in urban areas

Increasing urbanization has deteriorated the urban environment. Deficiencies in development control have important consequences on the urban climate and the environmental efficiency of buildings. The size of housing plots has been reduced increasing thus densities. Increasing number of buildings has crowded out vegetation and trees. As reported, New York has lost 175000 trees, or 20 % of its urban forest in the last ten years, [Ref 5].

As a consequence of heat balance, air temperatures in densely built urban are higher than the temperatures of the surrounding rural country. The phenomenon known as ‘heat island’ is due to many factors the more important of which are summarized in [Ref 6].

Urban heat island studies refer usually to the ‘urban heat island intensity’, which is the maximum temperature difference between the city and the surrounding area. Data compiled by various sources, [Ref 7], shows that heat island intensity can be as high as 15 C.

Higher urban temperatures have a serious impact on the electricity demand for air conditioning of buildings; increase smog production, while contributing to increased emission of pollutants from power plants, including sulphur dioxide, carbon monoxide, nitrous oxides and suspended particulates. Heat island effect in warm to hot climates exacerbates cooling energy use in summer.

In addition to increased energy demand for cooling, increased urban temperatures affect the concentration and distribution of urban pollution because heat accelerates the chemical reactions in the atmosphere that leads to high ozone concentrations. Other sources like transports, industry, combustion processes, etc. contribute to increased pollution levels in the urban areas. In parallel, the roughness of buildings and the urban structures affect wind within the city and slow down wind speeds increasing thus pollutants concentration

3 Wind flow in cities - Basics

The urban wind field is complicated. Small differences in topography may cause irregular air flows. As the air flows from the rural to the urban environment, it must adjust to the new boundary conditions defined by the cities. This results to the development of a two layers vertical structure. Thus, two specific sub-layers are defined. The so called 'obstructed sub-layer', or urban canopy sub-layer which is extended from the ground surface up to the buildings height, while the so called 'free surface layer' or urban boundary layer, is extended above the roof tops (Figure 1).

The obstructed or canopy sub-layer has its own flow field driven and determined by the interaction of the flow field above and the uniqueness of local effects as topography, building geometry and dimensions, streets, traffic and other local features, like the presence of trees. In a general way, wind speed in the canopy layer is seriously decreased compared to the undisturbed wind speed.

Estimation of the wind speed in a city is of vital importance for passive cooling applications and especially in the design of naturally ventilated buildings. Wind speeds measured above the buildings or at airports differ considerably from the speed at an urban monitoring site. As roughness length is greater in an urban area than in the surrounding countryside, the wind speed u at any height z is lower in the urban area, and much lower within the obstructed area.

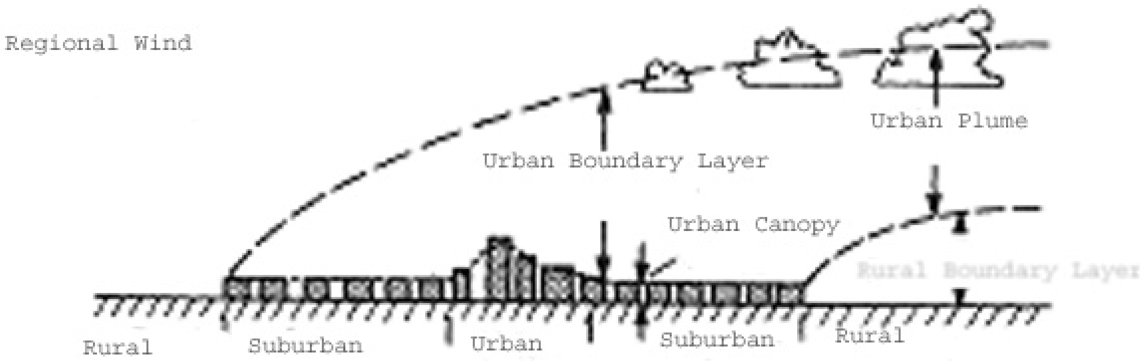


Figure 1: Urban Canopy and Boundary Layer [Ref 7]

4 Wind flow in cities - Canyons

Knowledge of the air flow characteristics in urban canyons is necessary for all studies related to natural ventilation of buildings, pollution studies, thermal comfort, etc.

Urban canyons are characterized by three main parameters, H, the mean height of the buildings in the canyon, W, the canyon width, and L the canyon length. Given these parameters, the geometrical descriptors are limited to three simple measures. These are the ratio H/W, the aspect ratio, L/H and the building density j=Ar/A1 where Ar is the plan of roof area of the average building and A1 is the 'lot' area or unit ground area occupied by each building.

When the predominant direction of the airflow is approximately normal (say ± 30 degrees), to the long axis of the street canyon, three type of air flow regimes are observed as a function of the building (L/H), and canyon (H/W), geometry (Figure 3):

a) When the buildings are well apart, (H/W>0.05), their flow fields do not interact. At closer spacing, the wakes are disturbed and the flow regime is known as "Isolated Roughness Flow".

b) When the height and spacing of the array combine to disturb the bolster and cavity eddies, the regime changes to one referred to as wake interference flow. This is characterized by secondary flows in the canyon space where the downward flow of the cavity eddy is reinforced by deflection down the windward face of the next building downstream.

c) At even greater H/W and density, a stable circulatory vortex is established in the canyon because of the transfer of momentum across a shear layer of roof height, and transition to a "skimming" flow regime occurs where the bulk of the flow does not enter the canyon.

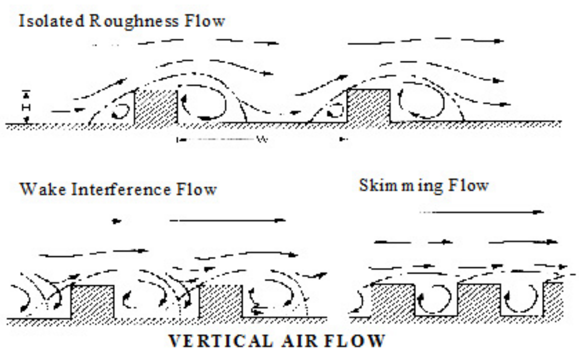


Figure 2: Air flow regimes [Ref 7]

There have been proposed threshold lines dividing flow into three regimes as functions of the building (L/H) and canyon (H/W) geometry. The proposed threshold lines are given in Figure 3.

For parallel ambient air flow, a mean wind is generated along the canyon axis with possible uplift along the canyon walls as airflow is retarded by friction.

For flows at an angle to the canyon axis, a spiral vortex is induced along the length of the canyon, a cork - screw type of action.

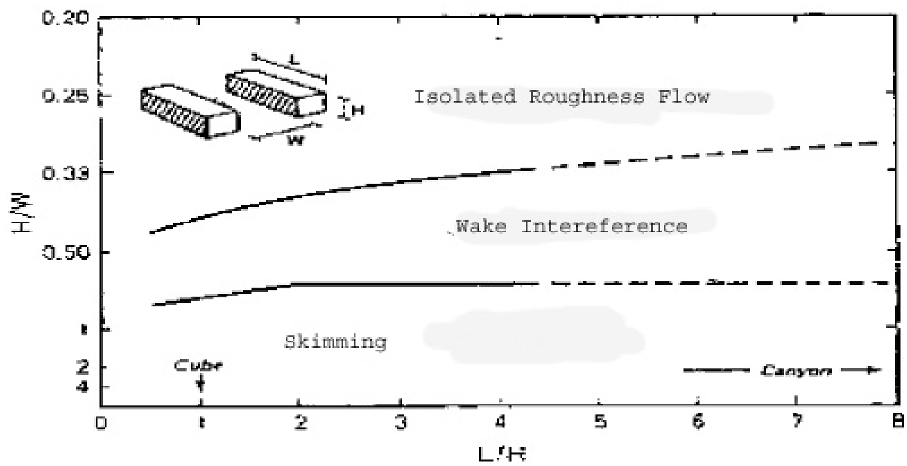


Figure 3: Limits for the different types of fow [Ref 7]

5 Natural ventilation potential

Natural ventilation is one of the most effective passive cooling techniques. Passive cooling in urban areas is highly affected by the wind distribution in the city. Wind speed in urban canyons is seriously reduced compared to the undisturbed wind velocity. Besides, wind direction inside canyons is almost completely different than the one measured by routine meteorological stations.

The serious reduction of the wind speed reduces considerably the potential for natural ventilation in urban canyons. Recent experimental studies in Europe have proposed empirical guidelines to consider natural ventilation in urban canyons:

a) During the day time, when the ambient wind speed is considerably higher than wind speed inside the canyon and inertia phenomena dominate the gravitational forces, the natural ventilation potential in single and cross ventilation configurations is seriously decreased inside the canyon. In practice this happens when the ambient wind speed is higher than 4 m/sec. For single side ventilation configurations the air flow is reduced up to five times, while in cross ventilation configurations the flow is sometimes reduced up to ten times.

b) During the day time and when the ambient wind speed is lower than 3-4 m/sec, gravitational forces dominate the air flow processes. In this case the difference in wind speed inside and outside the canyon, do not play any important role and especially in single side configurations.

c) During the night time the ambient wind speed is seriously decreased and is comparable to the wind speed inside the canyon. In this case the air flow calculated for inside and outside the canyon is almost the same.

d) The calculated reduction of the air flow inside the canyon is mainly a function of the wind direction inside the canyon. When the ambient flow is almost vertical to the canyon axis, the flow inside the canyon is almost vertical and parallel to the window. In this case a much higher pressure coefficient correspond to the conditions outside the canyon, and thus a much higher flow is calculated when the ambient conditions are considered and inertia forces are dominating. When the ambient flow is parallel to the canyon axis, a similar flow is observed inside the canyon, thus the pressure coefficients are almost similar [Ref 8].

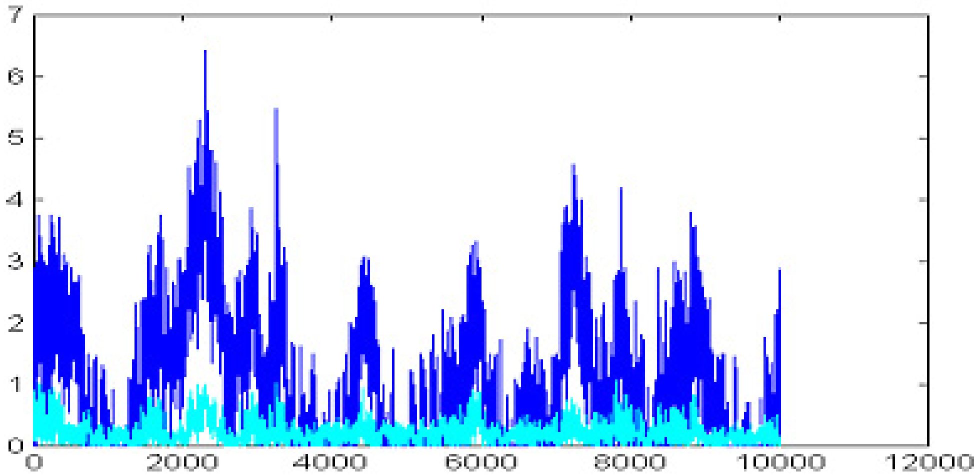


Figure 4: Wind speed (m/s) inside (light blue) and outside (dark blue) the urban canyon

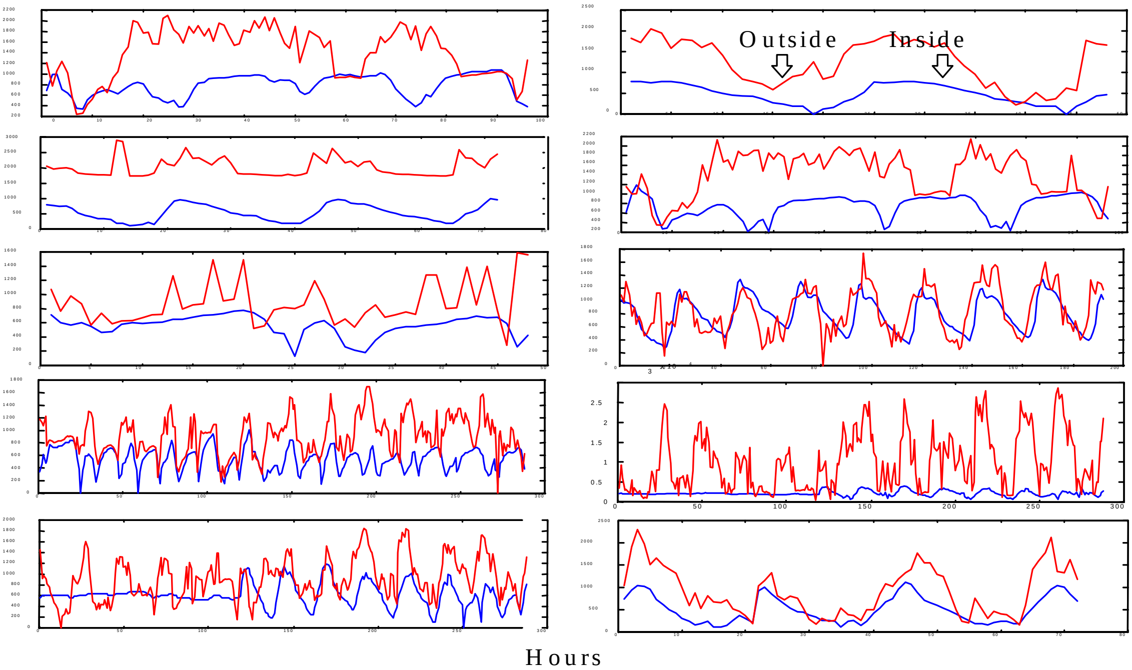


Figure 5: Comparison of the air flow rate (m³/h) in a cross ventilated building located inside (blue), and outside a canyon, (red). Values based on experimental data in 10 canyons in Athens

6 Cooling urban buildings by natural ventilation

Passive cooling techniques present a very serious alternative to conventional air conditioning of buildings. Night ventilation techniques, when applied to massive buildings, can reduce significantly the cooling load of air conditioning buildings and to increase the thermal comfort levels of non air conditioning building.

Night ventilation techniques are based on the use the cool ambient air as a heat sink, to decrease the indoor air temperature as well as the temperature of the building's structure. The cooling efficiency of these techniques is mainly based on the air flow rate as well as on the thermal capacity of the building and the efficient coupling of air flow and thermal mass.

Use of night ventilation techniques in buildings, (for example the Tombazis Office in Athens - Figure 6), has contributed to extremely important energy gains, (see Figure 7), and have decreased the cooling load down to 5 kWh/m².y, [Ref 9].

Because of the serious reduction of the wind speed in the urban environment and the corresponding reduction of the air flow rate, for both single and cross configurations, the cooling load on the buildings inside the canyons is much higher than the one of buildings where wind is not obstructed (Figure 8). In particular, recent studies have shown that in single side configurations the cooling load is higher between 6 to 89 %, while in cross ventilation configurations the cooling load increases by 18 to 72 %. Thus, canyon effect has a very considerable effect on the performance of night ventilation techniques of air conditioned buildings.

Figure 6: Tombazis Office in Athens

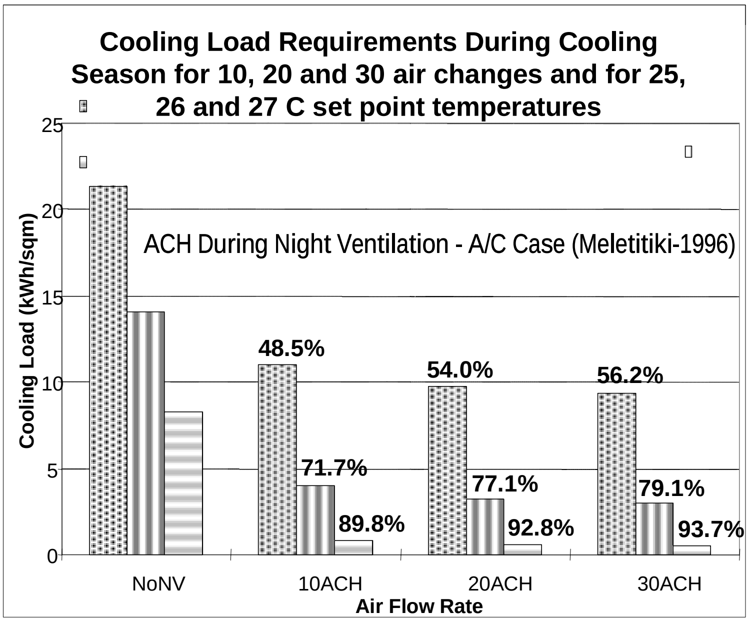


Figure 7: Energy gains in the Tombazis Office in Athens

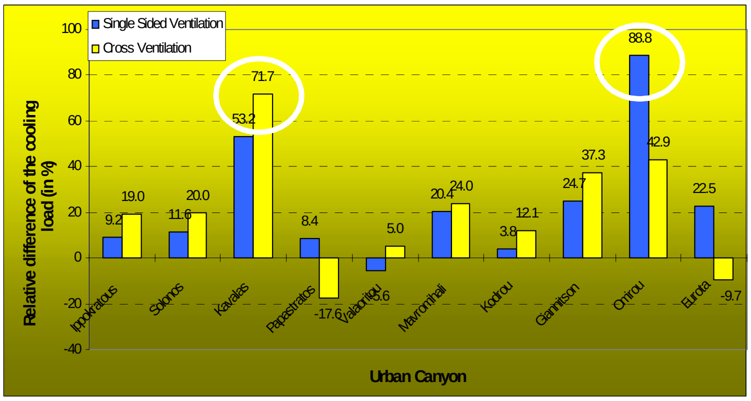


Figure 8: Percentage of Increase of the cooling load because of the canyon effect

Thus, it is very important to consider, other techniques than windows to enhance air flow in urban buildings. Traditional techniques like solar chimneys or wind towers can be easily integrated in urban buildings and may contribute significantly to increase natural air flow through the building.

Other advanced techniques like the PDEC evaporative cooling component or the advanced/intelligent AIRLIT – PV window have been developed recently.

Solar Chimneys are ideal alternative ventilation techniques for the urban environment. They may be used in deep urban canyons to promote air flow through vertical shafts.

In solar chimneys, air flow exits through a vertical shaft because of the temperature difference between the upper and the lower part of the shaft (Figure 9). In order to enhance the air flow, the upper external surfaces of the shaft are heated by solar radiation. Air may enter the building through side windows.

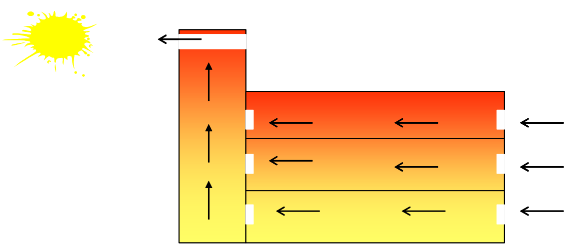


Figure 9: A solar chimney

Recently, many buildings have been designed to use solar chimneys for ventilation. A very interesting and successful building is the Environmental Building of BRE in Garston, UK.

Solar Chimney techniques have been commercialised and aesthetically accepted chimneys are now available for direct and immediate integration to buildings.

Wind Towers are traditionally used in urban areas as they may catch the undisturbed wind flow. Inlets have to be positioned at the windward façade and outlets at the leeward one (Figure 10).

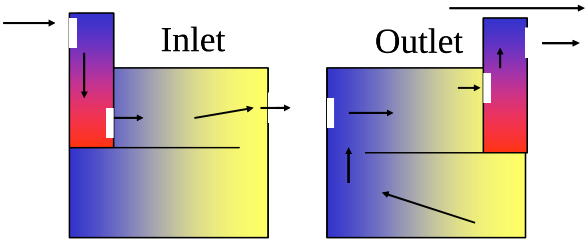


Figure 10: Wind Towers

Passive Downdraught Evaporative Cooling is a technique that has been used for several centuries in parts of the Middle East. In this tradition, wind catchers guide outside air over water filled porous pots, inducing evaporation and bringing about a significant drop in temperature before air enters the interior, [Ref 9]. The technique is very well suited to be applied in an urban context, as the air intakes are in an above-roof position, where the pollutant concentration is lower. At the same time, it is very independent of the air velocity and direction, so that there is no negative influence of eventually existing nearby taller buildings that could disturb the wind patterns.

The Airlit - PV intelligent façade unit is designed recently to face the problem of controlled natural ventilation in urban buildings, [Ref 9]. (Figure 11 – Figure 12)

It incorporates the latest thinking in solar control, natural ventilation, daylighting and photovoltaic power.

The unit has three main sections:

- lower section is a vent for providing fresh air for comfort cooling in peak daytime conditions and night cooling
- central section a conventional view window openable by the occupants in extreme conditions
- upper section of the unit is a high level window which also acts as a ventilation pathway.

The design integrates all of these by the means of a local intelligent controller which operates either in a stand-alone mode or by communication with the building BEMS as part of the building environmental control system

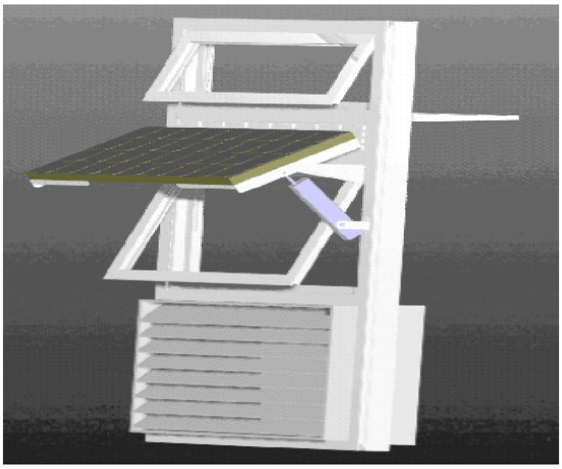


Figure 11: The AIRLIT PV Window

Figure 12: Health Centre Building in North London [Ref 9]

7 Case studies

7.1 Solar chimney air exhaust and mechanical ventilation air inlet

This complex of buildings is located in an urban area next to a railway station. Fresh air is drawn through underfloor ducting and floor grill. This is fan assisted and can be controlled by the occupants. Internal doors to staircases (ventilation towers) are held open and warm air is drawn up by stack effect. Solar gain in tower increases buoyancy [Ref 9]. (Figure 13)

Figure 13: Examples of Solar Chimneys [Ref 9]

7.2 Low pressure mechanical ventilation: Portcullis House, Westminster, London

This building incorporates a low velocity mechanical system with a low pressure loss air handling and duct system without mechanical refrigeration. Ventilation air is cooled by extracting groundwater from two boreholes sunk into a chalk aquifer [Ref 9].

Figure 14: The Portcullis House, Westminster, London[Ref 9]

7.3 Higher Education Building in Portsmouth

Primarily natural ventilated building comprising single-sided and cross- and stack ventilation. Fans are installed in the staircases to assist the stack effect. Night ventilation is an option Air enters via the rooms and exits via a plenum in the corridor ceiling. The plenum connects to the staircase which exhausts air at the top. The staircases form stacks having glazed roofs with selectively opening lights [Ref 9].

Figure 15: The Higher Education Building in Portsmouth [Ref 9]

7.4 Residential Building in Ampelokipi

Cross ventilation, stack effect are used. Summer overheating is reduced implementing cross ventilation though north and south external openings. Overheating in the sunspace zone is prevented by using certain scattered openings in the glazed envelope of the greenhouse and some dampers at the top of it. A fan was to be used in order to recirculate the air, but has never been installed. [Ref 9]

Figure 16: Residential Building in Ampelokipi, Athens [Ref 9]

8 Books on natural ventilation

1. Allard F (Ed), Natural Ventilation in Buildings: A design Handbook, James & James, 1998. (http://www.jxj.com/)
2. Santamouris M. (Ed), Energy and Environmental Quality in the Urban Built Environment, , James and James, 2001, (http://www.jxj.com/)
3. Santamouris M. (Ed), Passive Cooling of Buildings, James and James, 1997, (http://www.jxj.com/)
4. Santamouris M. (Ed), State of the Art on Solar Thermal Technologies for Buildings, James and James, 2002, (http://www.jxj.com/)
5. IEA Annex 35 HybVent: Hybrid Ventilation (http://hybvent.civil.auc.dk/hotel/hybvent/hybvent.htm)
6. BRE Digest 399, Natural ventilation in non-domestic buildings, CRC Ltd, October 1994. (crc@construt.emap.co.uk)
7. CIBSE AM10, Natural Ventilation in non-domestic buildings, CIBSE, 1997. (http://www.cibse.org/)
8. CIBSE AM13, Mixed mode ventilation, CIBSE, 2000.(http://www.cibse.org/)

9 References

1. UNFPA, United Nations Population Fund. 1998. The State of World Population 1998.
2. United Nations, 1998 : World Urbanisation Prospects,. The 1996 Revision, Population Davision, New York
3. UNEPTIE : Tommorrow’s Market : Global Trends and their Implications for Business. 2002
4. Jones B. G. : ‘Population Growth, Urbanization and Disaster Risk and Vulnerability in Metropolitan Areas : A conceptual Framework’. In Kreimer, Alcira and Mohan Munasinghe, Environmental Management and Urban Vulnerability, World Bank Discussion Paper, No 168, 1992.
5. Environmental Protection Agency : Cooling Our Communities. A Guidebook on Tree Planting and Light Colored Surfacing. January 1992.
6. Oke T. R. : 'Boundary Layer Climates', Routledge, 1988b.
7. Santamouris M. (Ed) : Energy and Environmental Quality in the Urban Built Environment, , James and James, 2001
8. V. Geros, M. Santamouris, A. Tsangrassoulis and G. Guarracino : 'Experimental Evaluation of Night Ventilation Phenomena'. J. Energy and Buildings, 29, 141-154, 1999.
9. Sol-Vent website http://www.brunel.ac.uk/research/solvent