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SOLVENT: Development of Strategies for the Efficient Use of Solar and Passive Ventilation in Urban Buildings

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Abstract

In the framework of SOLVENT project, work was carried out to develop strategies and dissemination material to assist the efficient application of solar and passive ventilation in urban buildings. The information gathered during the project is synthesized in a website designed for the 'informed' architect and also useful to HVAC engineers in their discussions with their clients. It includes information on the effect of urban environment on buildings, outlines the principles of solar and passive ventilation and how these could be adapted for application in urban buildings, describes design solutions in the form of case-study buildings and design components and reviews how current regulations encourage/restrict the application of solar and passive
ventilation in urban buildings.

The first section explains basic concepts of how the urban climate is created and some detail information about urban climatology and on the factors affecting the urban climate. The question of interest for the project is 'how does this affect building design' and 'where could a designer find this information'? The next two sections outline how principles of solar and passive ventilation traditionally applied to out-of-town buildings could be adapted to effectively be applied to urban buildings. A last section discusses the role of regulations and presents a summary of current regulations that encourage or prohibit the use of passive and solar ventilation.

The overall structure of the website aims to be understood by the occasional user. The navigation tools are simple and it is easy to find the required information in a number of ways. For example, a search facility is provided as well as a traditional hierarchical menu. The address of the Solvent website is http://www.brunel.ac.uk/research/solvent/home.htm

1 INTRODUCTION

Increasing urbanisation and industrialisation have deteriorated the urban environment. The size of housing plots has been reduced, thus increasing densities and the potential for traffic congestion. Increasing number of buildings has crowded out vegetation and trees. New York has lost 175000 trees or 20 % of its urban forest in the last ten years.

Increased urban temperatures have a direct effect on the energy consumption of buildings. During the summer period, cooling demand increases the but the heating load of buildings during the winter period decreases.

For US cities with population larger than 100'000 the peak electricity load will increase 1.5 to 2 percent for every 0.5C increase in temperature. Taking into account that urban temperatures during summer afternoons in US have increased by 1 to 2C during the last forty years, it can be assumed that 3 to 8 percent of the current urban electricity demand is used to compensate for the heat island effect alone (Littlefair, 2000).

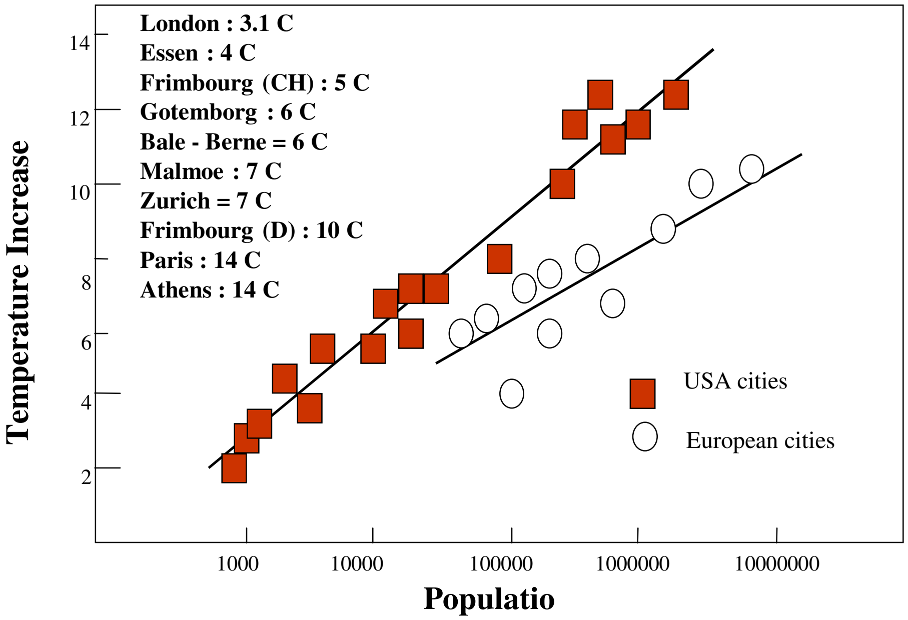


Figure 1: Maximum difference in urban and rural temperature for US and European cities. From [Littlefair, 2000], data from [Oke, 1982].

In the EU countries, buildings consume approximately 40% of primary energy. The percentage of full air-conditioned floor space is also increasing; in the UK, 7.5% of floor area was air-conditioned in 1970, 12% in 1980, 19% in 1990, and 27% in 1994 [Energy Paper 66, 1997]. The values are higher in southern European countries. In Greece, cooling accounts for 12.5% of the delivered energy to office buildings with an annual growth rate in excess to 150% for central air conditioning plant installation and more than double the figure for packaged units. The trend shows an increasing use of air-conditioning split packaged units.

On the other hand, results of studies of energy use in offices have shown that 'good practice' or 'typical' naturally ventilated and passively cooled office buildings consume approximately 50% of the energy used for heating and cooling [for example ECON 19, 1998]. There is, thus, a significant potential to reduce energy consumption in the office building stock in the European Union by encouraging the uptake of natural ventilation while minimising the use of air conditioning.

Solar assisted and natural ventilation use the natural driving forces of solar gains and wind to provide ventilation both in winter and summer without the use (or minimum use) of mains and fans. Solar assisted and natural ventilation can take the form of one of the following modes:

- Single sided and cross ventilation through opening on the façade of buildings and primarily using wind forces.
- Thermal and solar chimneys (and atria) using internal and solar heat gains to create the required buoyancy force.
- Wind chimneys using wind forces and possibly linked with evaporative cooling.
- Double façade ventilation using solar gains to create the required buoyancy force.

Various barriers, including those of external noise and air pollution, have traditionally prohibited the use of solar assisted and natural ventilation in urban buildings. However, recently there has been a considerable amount of scientific and technological effort on advancing the use of solar assisted and natural ventilation, either for improving indoor air quality or for cooling purposes. The EC funded NatVent [BRESCU, 1999] and POLIS [Littlefair, 2000] European projects have shown that solar assisted and natural ventilation is possible for urban buildings. Also, important studies carried out in the USA and Japan have investigated the effects of external surface albedo and wind patterns within the urban environment.

However, the uptake of the technology is still relatively low because of lack of information in the appropriate form to convince a significant number of building professionals of the advantage and practicality of solar assisted and natural ventilation for urban buildings.

SOLVENT had the aim to combine and adapt existing scientific and technological knowledge with examples of engineering and architectural practice to integrate and disseminate the use of solar assisted and natural ventilation in urban buildings. A website has been created based on information available in the public domain.

2 STRUCTURE OF THE WEBSITE

The overall structure of the website is presented in Figure 2 and Figure 3 shows the home page. Considerable effort has been devoted to the creation of an interface, which is easily understood by the occasional user. The navigation tools are simple and it is easy to find the required information in a number of ways. For example, a search facility is provided as well as a traditional hierarchical menu on the left-hand side. The main headings provide all sub-headings only when selected so that the users are not confused from the very beginning by having all the complex information available to them.

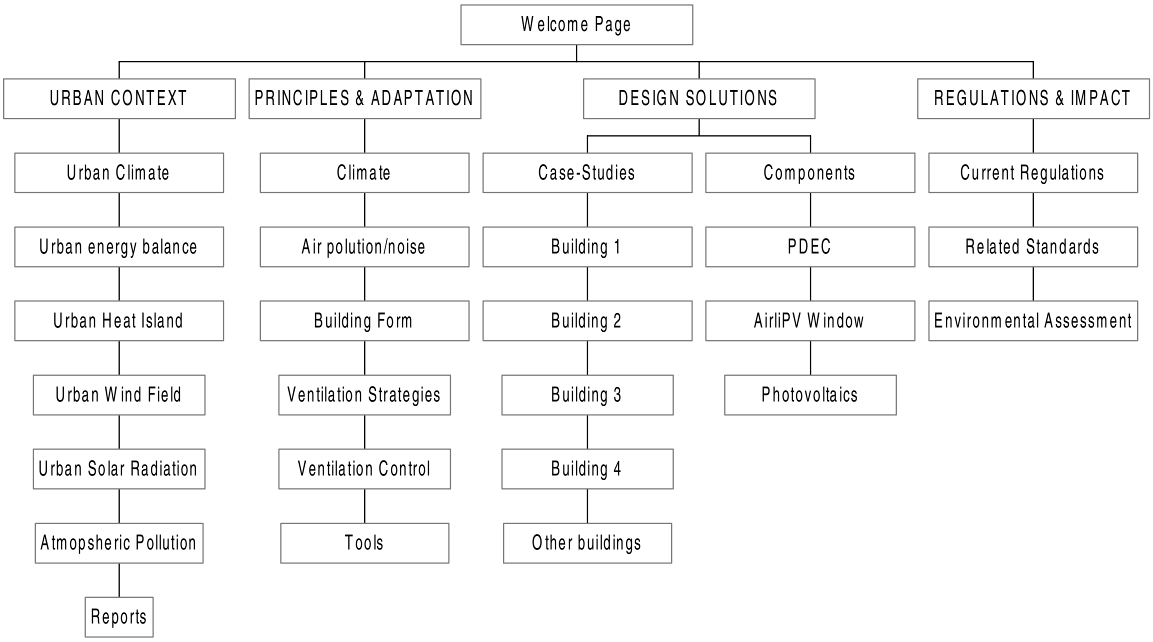
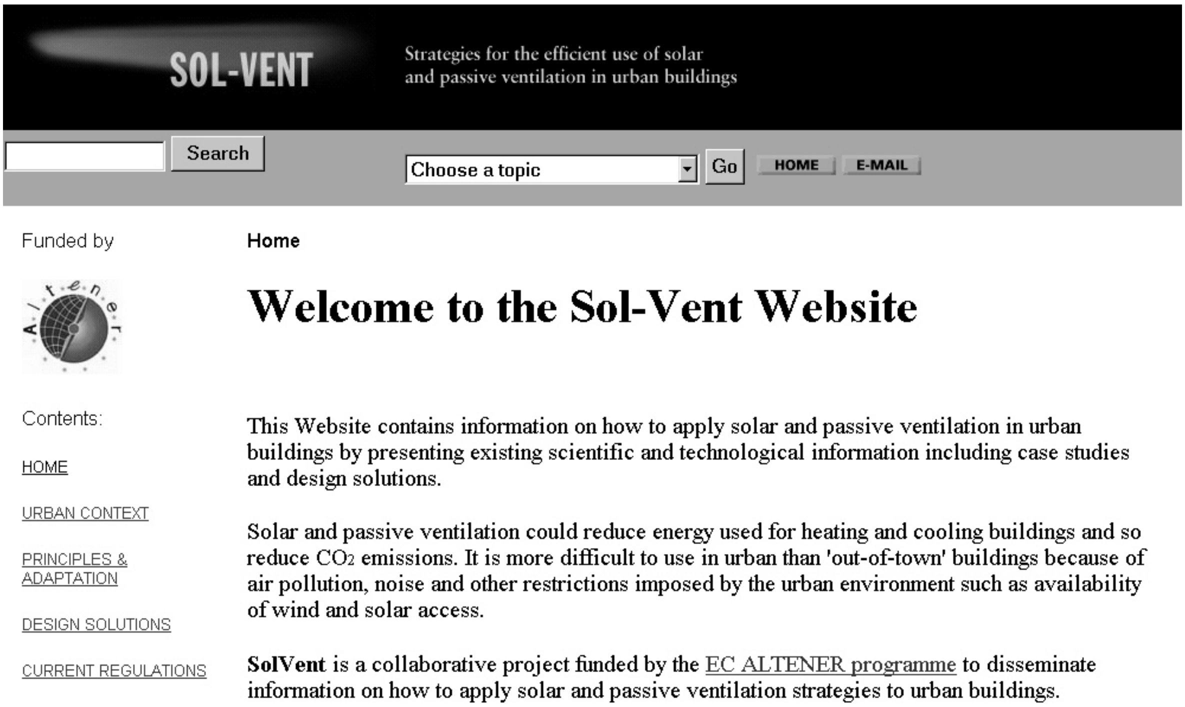


Figure 2: The structure of the website



Welcome to the Sol-Vent Website

This Website contains information on how to apply solar and passive ventilation in urban buildings by presenting existing scientific and technological information including case studies and design solutions.

Solar and passive ventilation could reduce energy used for heating and cooling buildings and so reduce CO_2 emissions. It is more difficult to use in urban than 'out-of-town' buildings because of air pollution, noise and other restrictions imposed by the urban environment such as availability of wind and solar access.

SolVent is a collaborative project funded by the EC ALTENER programme to disseminate information on how to apply solar and passive ventilation strategies to urban buildings.

Figure 3: The home page of the website

3 MAIN RESULTS AND SUMMARY OF INFORMATION INCLUDED IN THE WEBSITE

3.1 Urban context

The first section presents basic concepts of urban climate. The impact of environmental factors on building energy and environment is explained. Statistics, design data, sources of data and methods for adapting available data to suit site conditions are included in order to quantify major design challenges for natural ventilation options for a site. The following areas are covered: urban climate, urban heat island, urban wind field, urban solar radiation, and atmospheric pollution.

3.1.1 Urban climate

Urban planning is mainly concerned with distance scales characteristic for atmospheric boundary and turbulent layers. Building design is mainly concerned with distance scales characteristic for turbulent, roughness and laminar layers. Only a few parameters are regularly measured in the atmosphere. The most common are temperature, humidity, pressure, and the speed and direction of the wind. These few pieces of information taken at any point in the atmosphere basically provide a snapshot of the atmosphere at that point. From these snapshots taken simultaneously at predetermined locations in the countryside and at various heights in the atmosphere, we can infer nearly every other parameter of the atmosphere we need in order to model the atmosphere motion. Modelling atmospheric motion is essential for both weather forecasting and predicting the transport and dispersion of pollutants.

In general, weather data measured at airports or by national weather services are not representative for urban climate. It is, however, possible to obtain a statistical correlation between airport and urban conditions by comparing short series, but this approach depends on measured element; it works for temperature and dew point but it is unsatisfactory for wind speed, visibility and precipitation.

The inherent microclimatic differences of an area occupied by a metropolis are augmented by human activity. The differences in microclimate are higher when the topography is more complex. Elevation differences introduce wind disturbances and temperature changes, especially when nocturnal inversions are present. The wind is changed also by thermal conditions and buildings. This is covered in a section below on urban wind field.

Comparisons of urban impact may be achieved only if data collected before urbanisation can be compared with data obtained after urbanisation, which is a rare opportunity. Three main approaches can be used to assess the urban influence:

- statistical tests of measured parameters,
- physical modelling in wind tunnels, and
- comparison of data gathered before and after urbanisation of the same area.

3.1.2 Urban Heat Island

In general, urban climate is warmer and less windy than in rural areas. However, the variability of urban climate is high, and depends on the particular topography, regional wind speed, urban morphology, and many other factors. The change in temperature highly depends on variation and urban-rural temperature.

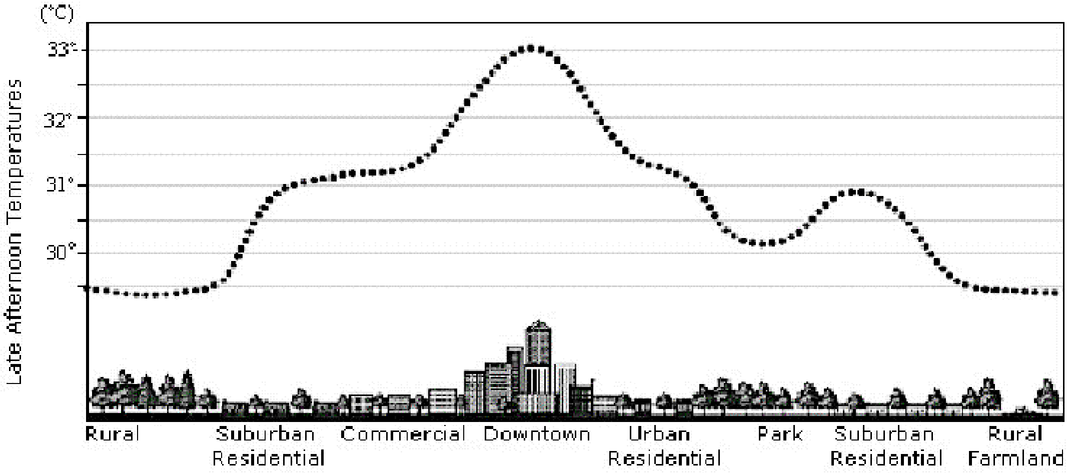


Figure 4: The changes in air temperature due to urbanisation in simplified form.

The difference between urban and rural temperatures is highly dependent on the time of the day. Urban environment is usually warmer before sunrise than rural ones, because they have cooled down overnight at a slower rate (primarily because clusters of buildings increase the heat capacity of the area and reduce its radiative cooling efficiency). As the sun rises, solar energy evaporates dew in rural areas (i.e. energy is absorbed as latent heat, with no temperature rise), but starts heating up urban fabric immediately. When the dew has evaporated, the rural surfaces start to warm up more rapidly than the urban ones, because of their lower heat capacity. As the day progresses, the urban and rural temperatures converge and it cools more slowly and the urban to rural temperature difference starts to rise. The time of maximum heat island "intensity" varies, but it is usually a few hours after sunset, i.e. the nocturnal intensity is greater than the daytime intensity.

In the summertime, the urban heat island has an impact on both air-conditioned and passively cooled buildings:

- increased external temperature results in an increased energy demand for cooling.
- night-time cooling potential is reduced.
- exceptionally hot periods can lead to a dramatic rise in the demand for air conditioning, increasing the peak electricity demand.

The urban heat island effect exacerbates this:

- air conditioning systems are less efficient when operating under large temperature differences.
- the profile of temperature and wind in an urban environment is modified and this affects the efficacy of passive cooling designs.

There are two recognised ways of reducing the intensity of an urban heat island:

- by increasing the albedo of the urban fabric, and
- by increasing the amount of vegetation, particularly trees

3.1.3 Urban Wind Field

Urban wind is one of the major unknowns of the urban environment and directly affects the potential for passive ventilation in urban buildings. In most building engineering applications, a correction is applied to meteorological wind speed usually available. However, local wind effects in the urban environment can result in large pressure fluctuations. In general, local thermal winds can develop in an urban environment. Similarly to sea breeze, a city can generate country breeze. When wind speed is low, a city is usually warmer than its surroundings. This produces breezes across the perimeter of the city, which converge to the centre. In addition, local wind patterns called thermal circulations are created by thermal gradient of different surface covers; for example asphalt and grass, allowing locally cold air to sink and locally warm air to rise.

Airflow around buildings is very complex and it directly affects the passive ventilation potential of a building. For example, the potential of natural ventilation in urban canyons is seriously reduced because of the dramatic decrease of the wind speed inside the canyon, the increased pollution levels and possible acoustic problems. A methodology is proposed as an aid to select wind speed within canyons with various characteristics (Table 1).

Table 1: A proposed methodology to aid selection of wind speeds within canyons [Santamouris, 2000].

Flow along the Canyon: Perpendicular flow
Wind Speed above the canyon < 4 m/sec
For H/W > 0.7 / Type of Flow : Chaotic. There is no coupling between the undisturbed and the wind speed inside the canyon. Thermal as well as mechanical influences play an important role in the canyon circulation. The maximum expected wind speed should not exceed 0.4 m/sec. This value (0.4 m/sec), may be used in ventilation models especially when the ambient speed exceeds 3 m/sec. For lower speeds a value close to 0.2 m/sec may be used. There is no predominant wind direction inside the canyon.
<u>For Canyons with H/W <2 and L/W >20.</u> Type of Flow **: A stable circulatory vortex is established in the canyon.** Prediction of the cross canyon *u* and vertical, *w*, air speeds : $u=u_o(1-\beta)^{-1}\,[\gamma(1+k\gamma)-\beta(1-k\gamma)/\gamma]\sin(kx)$ **and** $w=-\,u_o(1-\beta)^{-1}\,ky\,[\gamma-\beta/\gamma]\cos(kx)$ <u>For Canyons with H/W >2 and L/W >20.</u> Type of Flow **: Two vortices are developed, an upper one driven by ambient airflow and a lower one driven in the opposite direction by the circulation above.** Prediction of the cross canyon u and vertical, w, air speeds : **For the lower part of the canyon use a mean wind speed close to 0.3 m/sec.** **For the upper parts use the following expressions :** $u=u_o(1-\beta)^{-1}\,[\gamma(1+k\gamma)-\beta(1-k\gamma)/\gamma]\sin(kx)$ **and** $w=-\,u_o(1-\beta)^{-1}\,ky\,[\gamma-\beta/\gamma]\cos(kx)$ <u>For Canyons with L/W < 20.</u> Type of Flow **: Intermittent vortices are shed on the building corners. These vortices are responsible for the mechanism of advection from the building corners to mid -**

block creating a convergence zone in the mid block region of the canyon.

Prediction of the wind speed : **Use mean wind speed close to 0.4 m/sec. Prevailing direction : Parallel to the axis of the axis with a downward direction.**

3.1.4 Urban Solar Radiation

There are numerous interactions, which might affect the amount of solar radiation availability in the urban environment. In general, urban areas have less sunshine than their surroundings. In industrial cities, the loss in sunshine duration may be between 10 and 20%. The energy reduction is more important at low solar elevations and less important at high solar elevations. Some values are shown below; Table 2 presents the percent loss of solar radiation at urban sites compared to surrounding, less polluted countryside for central European cities.

Table2: percent loss of solar radiation at urban sites compared to surrounding less polluted countryside for central European cities.

Solar Elevation degC	**Winter**	**Spring**	**Summer**	**Autumn**
10	36	29	29	34
20	26	20	21	23
30	21	15	18	19
40	-	15	14	16

Apart from the general reduction of sunshine in cities, **overshadowing** by other buildings can spoil a passive solar design. This is because a solar-collecting facade needs access to low-angle sun in winter. There might be cases when, with large obstruction to the south, a glazed area may be in shadow all winter. However, it might receive solar heat gain in summer, which will be beneficial for solar chimneys.

3.1.5 Atmospheric Pollution

- Outdoor air pollution comes from many different sources: stationary sources such as factories, power plants, and smelters and smaller sources such as dry cleaners and degreasing operations; mobile sources such as cars, buses, planes, trucks, and trains; and naturally occurring sources such as windblown dust, and volcanic eruptions, all contribute to air pollution. Air Quality can be affected in many ways by the pollution emitted from these sources. These pollution sources can also emit a wide variety of pollutants.

Pollution has feedback effects on weather (e.g. on radiation transmission, visibility, fog). Traditionally, urban dispersion models are applied to predict the pollution effects in urban areas due to the large number of individual sources. Some of the models are described briefly in a report included in the website.

4 PRINCIPLES AND ADAPTATION

This section outlines how principles of solar and passive ventilation traditionally applied to out-of- town buildings could be adapted to effectively be applied to urban buildings.

4.1 Climate

Whilst the climate is often the major cause of design problems in urban environments, and solar gain and reduced airflow can lead to the urban heat island effect, it does, on occasion, offer the potential for design solutions. Local solar shading by hills and mountains and the influence of anabatic and katabatic winds can be harnessed to enable sustainable urban ventilation strategies. This section deals with how the negative effects of the climate can be reduced sufficiently for natural ventilation strategies to be adopted.

4.1.1 Reducing the urban heat island

Current knowledge would suggest that there are two main means by which the intensity of the urban heat island can be reduced - the surface albedo and the local wind flows.

4.1.1.1 Albedo

The first method is to design the external environment to ensure that excess solar heat gains to the urban environment is minimised. This can be achieved by increasing the solar reflectivity of the surfaces of the environment, both buildings and ground materials, and reducing the insolation of susceptible structures. High albedo materials reduce the amount of solar radiation absorbed through building envelopes and urban structures and keep their surfaces cooler. Materials with high emissivities are good emitters of long wave energy and readily release the energy that has been absorbed as short wave radiation. The typical white walls of southern Europe have a high albedo and are a key to solar heat-gains reduction by reflecting unwanted heat. n summer, the surface temperature, heat storage and its subsequent emission to the atmosphere are significantly greater for asphalt than for concrete and bare soil. At most, asphalt pavement can emit an additional 150 W/m^2 in infrared radiation and 200 W/m^2 in overall heat flow compared to a bare soil surface. The rate of infrared absorption by the lower atmosphere over an asphalt pavement is up to 60 W/m^2 greater than that over the soil surface or concrete pavement. Other research studies have found an influence of road construction on road surface temperature. A test road with a bed of blast furnace slag had a night time temperature up to 1.5 ^oC higher than another road based on gravel.

4.1.1.2 Local wind patterns

The local airflow in urban areas can be complex and its understanding is required to fully consider its impact on ventilation. However, there are some basic rules and guidelines that can be explored before a more rigorous investigation by means of either physical or mathematical modelling. The urban wind speed is lower than that found in rural areas because of the roughness of the urban terrain. Therefore, wind driven ventilation strategies require more detailed study of the local wind and micro-climate.

4.1.1.3 Pollution

In city centres, air and noise pollution from the outside, particularly from traffic, is perceived as a major barrier to the use of natural ventilation. However, this is not generally so. This section outlines current thinking in this area.

Air pollution

In city centres, air and noise pollution from the outside, particularly from traffic, is perceived as a major barrier to the use of natural ventilation. However, this is not generally so. A building - what ever its ventilation strategy - can (by itself) significantly moderate the general pollution outside to an acceptable level inside. This is because pollution from the major polluter, i.e. from traffic, is only significantly high during rush-hour periods rather than being continuously so during the day; the amount of pollutants coming inside is constrained to that entering by the smaller areas of openings (compared to the total surface of the building envelope); and once the pollutant has entered, it is usually diluted by the reservoir of air held within the building. Night ventilation can also help by flushing out the building from pollution from the previous day.

Noise Pollution

To be suitable for naturally ventilating buildings, air inlet devices should achieve three purposes:

1. Large capacity to provide adequate ventilation in summer months
2. Reduce the penetration of external noise
3. Reduce the amount of outdoor particles entering the building.

Such devices are now commercially available.

A recent publication on Ventilation and Acoustics which includes information on acoustics and natural ventilation as well as standards and tools for building performance, is Ling (2000).

4.1.1.4 Building Form

This section describes urban typology and building forms that could be particularly suitable for applying solar and passive ventilation strategies. It develops two concepts in built form design. First, buildings need to harmonise with their surroundings climatically as well as visually. For example tall slabs clad in reflective glass can cause turbulent gusts of wind at ground level, as well as unwanted solar glare and reflected heat. Secondly, some building forms can themselves generate a beneficial site microclimate: courtyards, colonnades and earth sheltering can all give outdoor areas protected from the extremes of the weather.

It follows a brief description of four building forms that may create beneficial site microclimate and/or enhance the effectiveness of solar ventilation.

- *Courtyards.* These can be beneficial in both heating and cooling dominated countries.
- *Colonnades.* Colonnades are usually used in cooling dominated countries and can serve a number of purposes, including natural solar shading in the summer.
- *Earth Sheltering.* During the summer, the ground has a lower temperature than ambient. Thus, the excess heat can be dissipated to it, providing passive cooling of the spaces.
- *Double Facade.* The double façade system is becoming increasingly common as a strategy for solar assisted ventilation. The building is provided with a façade made up of a large air flow path. This is used to remove excess solar heat gain onto the building and in doing so drive the ventilation of the occupied spaces. It can also serve to provide solar heated air in the heating season. The system will generally require some additional fan power at certain times.

4.2 Ventilation Strategies and Control Strategies

The basic principles of ventilation in urban areas are outlined in the website. Some recent reference books on Natural Ventilation Strategies are cited [BRE 1994, CIBSE 1997, CIBSE 2000, Allard 1998, HybVent 2000].

Given the provision to ensure that natural ventilation follows the design intent, it will still be necessary for the designer to provide means for modulating the ventilation rate to meet varying conditions. These will range from minimal flow rates under design winter weather to maximum performance under certain peak summer conditions or possibly during the night-time cooling cycle. The means of regulation, whether manual or mechanical, must be capable of the necessary levels of adjustment to meet these degrees of discrimination.

The designer should be beware of the different control characteristics of windows, i.e. natural ventilation and cooling, compared with the designed characteristic of HVAC dampers, coils etc. The control authority of a window is low and non-linear, hence the use of sophisticated control algorithms will not bring greater accuracy. Given the pulsing effect of the wind or natural ventilation, automatic controls which continuously try to correct should be avoided, and the controls response slowed. PID and PI controls are often inappropriate. In a heavyweight room, PI control can lead to mechanical systems defaulting to being 100% on when they do not see a 'quick' room response. Large dead-bands should be allowed to account for the normal swing of daily temperature. Beyond this, proportional control alone may be sufficient.

Available design tools with information on how to obtain them are included in the website.

5 DESIGN SOLUTIONS

Four case studies of naturally ventilated urban buildings are included in the website. Two are located in a hot climate (Athens); one residential and one office building. Two are located in a moderate climate (South-East England); one health centre building in London and one higher education building in Portsmouth. For each building, information about its design solutions, ventilation strategy, performance and design lessons are included. In addition, some other buildings are briefly described.

Description of novel design components, which could be used in urban buildings are included; namely (a) Passive Down Draught Evaporative Cooling which and is a cooling and ventilation strategy that could be effective in urban buildings, (b) AirlitPV Window which is a window system that is being developed under a JOULE funded project and combines natural ventilation, daylighting, photovoltaics and intelligent local control and (c) information about Photovoltaics that have been integrated into buildings and could be used to assist solar and passive ventilation.

6 REGULATIONS

In this part of the website the role of regulations is discussed and a summary of current regulations that encourage or prohibit the use of passive and solar ventilation is included. These are considered as an important boundary condition for the application of natural ventilation in buildings in general and thermally driven ventilation in particular a passive cooling strategy.

They can play two major roles:

- Regulations can be a support for applying a particular technique, natural ventilation concepts in this case; if appropriate regulations do not exist, their absence, just by itself, is an important barrier to implementation of natural ventilation.
- Regulations can also be an important barrier by imposing specific requirements, e.g. fire safety, outdoor air quality and acoustics.

It is be concluded that:

- Many non-residential buildings in Europe use mechanical ventilation.
- A significant part of the energy consumption of these buildings is due to fan operation for ventilation purposes.
- The pollution induced by the urban context increases the energy cost of fan operation due to the increase of pressure losses by additional filtering requirements.
- In the urban context, there are restrictions about the situation of the outdoor air intakes for ventilation.

7 CONCLUSIONS

This paper presented an overview of material included in the SOLVENT website dedicated to passive and solar ventilation for urban buildings. It highlighted the main points covered, which are of importance to designers when contemplating low energy ventilation for buildings located in urban areas. It is suggested that, although specialised knowledge is needed for the design of such buildings, information exists which is either directly applicable or could be adapted from principles developed for out-of-town buildings to urban buildings.

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