Passive cooling and summer friendly design and engineering
Guidelines for building owners

Prepared by Sofia Energy Centre
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1. Introduction

- **Ambition of guideline**
These guidelines are oriented towards final consumer of energy for cooling and the main purpose of the document is to provide a tool for choosing most sustainable and ecological solution for cooling needs of buildings.

Emphasis is put of building design and orientation and use of passive cooling solutions.

Therefore the guidelines are mostly suitable for consultation during planning and design stages of new and major renovated buildings.

- **Sustainability**
Sustainable summer comfort can be defined as achieving good summer comfort conditions with no or limited use of conventional energy and through the use of environmentally non-harmful materials.

The studies and interviews with experts revealed that cooling in Bulgaria is still not a major issue as compared to heating energy consumption. Still its importance is expected to grow with the economic development of the country, rising the living standards and global warming. Sustainable cooling solutions refer mainly to application of passive cooling principles both for new and renovation buildings.

- **Techniques:**
A broad spectrum of techniques has been developed in different parts of the world reaching high maturity such as: dwellings cut in the rock (earth cooling), wind-captures in Iran (convective cooling), sprinkling water by fountains (evaporation cooling) and painting facades in white – in South Europe and North Africa (protection from sun radiation).

All these cooling techniques are based on solutions that:
- reflect or minimize solar radiation penetration in dwelling premises;
- facilitate heat transfer from inside to outside without usage of any additional mechanical energy.

The above are completely passive cooling techniques that can be grouped in the following chapters:

1) Architectural and building techniques;
   - Form and orientation;
   - Building envelope, glazing;
   - Shading;
   - Thermal mass;
   - Wind-captures;
   - Natural ventilation;

2) Natural techniques for cooling (passive cooling techniques)
   - Earth cooling;
   - Evaporation cooling;
   - Radiation cooling
2. Architectural and Building techniques

2.1. Form and orientation

Orientation and form of the building, as well as the structure, character and colour of surrounding surfaces, influence on the values of absorbed solar radiation.

The reflection characteristics of one or another façade material or covering are directly connected with the colour and texture of these surfaces, i.e. depends on their optical characteristics (coefficient of reflection, absorption and transmission).

The surface temperature of the wall can be reduced by about 10-15°C depending on the choice of appropriate colour directing to the lighter ones.

The orientation towards the four cardinal points has high influence on surfaces of a given volume. At a given volume of the building its geometry also has an influence.

The right choice of orientation and geometry can protect the building from excessive heating.

A certain zone depending on its position on the building envelope and on its orientation towards the four points of the world, realizes different percentage of heat losses. Apparently mostly cooled are angle spaces in a building.
Investigating the form, volume and orientation of a building and the number and size of openings, it can be concluded that:

- At a given volume, a form with maximum surrounding surface has maximum cooling;
- Depending on orientation towards the four points of the world, the surrounding surfaces have different percentage of cooling (the biggest is the percentage for surfaces oriented towards North);
- biggest are the heat losses from glazed openings (for one-family houses they are around 33 %);
- When increasing the number and sizes of glazed openings cooling increases;

2.2. Building envelope, glazing
The cooling process can be increased with the application of a number of architectural and construction solutions. The building envelope is the barrier that controls the level of heat transfer.
A significant share of cooling is done through both transmission and infiltration processes.
Cooling due to natural infiltration can be quite significant if systems for its easy control are not applied.

When applying respective technical means it is necessary the architectural and building solution to be in compliance also with:

- Topography of the terrain; orientation and location;
- Building forms, ratio between surrounding surface and built area;
- Zoning and planning;
- Coefficient of heat transmission of surrounding elements (transparent and opaque);
- Type and characteristics of vegetation;
- Direction, frequency and speed of wind;
- Infiltration and natural ventilation, convective heat exchange

### 2.3. Shading

Traditional systems for solar radiation reflection are internal and external shading devices: curtains, blinds, sun canopies, etc. They reduce the brightness of the received sunlight, limit the ability of solar radiation penetration in the living space and improve its thermal and visual comfort.

<table>
<thead>
<tr>
<th>Варианти на елементите на създаването на защита от слънчевата радиация</th>
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<tr>
<td><strong>Архитектура-строителна формативи</strong></td>
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<tr>
<td>архитектурно строителни форми - кутия, структури, декоративна решетка и т.н.</td>
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<tr>
<td>балкони, долинки</td>
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<td>декоративни решетки</td>
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<td>ефект от разполагането на охлаждащо подвижно устройство от вътре или от вън</td>
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<td><strong>Източници на прозорци</strong></td>
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<tr>
<td>призматични стъкла</td>
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<td>откривани стъкла</td>
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<td>оцветени стъкла</td>
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<td>прозрачна изолация</td>
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The cumulative solar radiation is formed from direct solar radiation, diffuse radiation from the sky and reflected radiation from surrounding surfaces of buildings around.

The outside shading devices can stop direct radiation, reduce the impact of diffuse and reflected radiation, but also can influence the illumination, brightness, view and natural ventilation. Natural lighting, natural ventilation and overheating protection are the three factors which should be always taken into account in order to avoid use of artificial lighting, forced ventilation or air-conditioning.

Thus in order to avoid overheating in summer months it is necessary to use sun canopies but at the same time it is necessary to ensure three-hour sunshine on the day of the vernal equinox (on 21 March from 7 to 18 hours and sunrays to fall in the middle of window opening at a height 1 m from the floor at a horizontal angle not less than 20°). Apparently the problem is complex and its solving requires multidisciplinary knowledge.

When building environment with appropriate comfort it is necessary not only to guarantee maximum heat gains and illumination from solar radiation all year round but also to guarantee protection against overheat and over-lighting in the summer time and heat losses during winter time.

Often the architectural and building solutions necessary to keep thermal and lighting comfort are contradictory and the skill is to find the balance by compromising between them.

2.4. Wind capture

Wind captures are traditional building element for passive cooling of buildings.

Fig.1 Wind capture from the town of Yazd (1- general view; 2. Plan of five typical wind-captures; a) one-way; b) two-way; c) four-way; d) eight-wall with two openings on each side; e) four-way with two fake openings on each opposite sides; 3.characteristic section of the wind-capturing tower a) main summer room; b) ground floor; c) inner yard with water pool.)
This device captures the wind from different directions. Cool air entering the openings falls down and cools the neighboring premises. If there is no wind the air in wind-capturing tower is getting warm and goes up. In this way the cool air is taken from the garden and cools the house.

Wind capture has been known in Egypt since the New Kingdom Age in 1500 BC. In the Middle East from Pakistan to North Africa the wind capture has also been known long ago. In Iran it has been applied in the regions with hot and dry climate. In the Persian Gulf the wind capture was a tower with square section mounted on the roof and with openings on one side open to the sea breeze.

The wind captures usually have been built with bricks and have had a height from 30 cm to 5 meters. The highest is 33,35 meters and is built on the roof of a garden pavilion in the town of Jazd in Iran. They have been built also on the roofs of dwelling buildings, caravanserais, mosques and water reservoirs.

Wind towers in Hajderbad, Pakistan, demonstrate passive use of wind for building ventilation. In this hot steppe climate the cooling afternoon wind coming always from the same direction, allows for situating the wind captures perpendicularly to wind direction. This system, a model for passive energy efficient ventilation, works only if there are great temperature differences.

Based on the same working principle we have today a lot of varieties in the forms of this building element. It has been widely applied also in the modern traditional and contemporary architecture.
Interesting is the solution at hotel village Madina Jumerajh built in the traditional Dubai architecture with the wind captures next to the modern and famous hotel Burge Al Arab.

Fig. 7. A view to the roofs of town Jazd, Iran

Fig. 8. Hotel village Madina Jumerajh built in the traditional Dubai architecture with the wind captures next to the modern and famous hotel Burge Al Arab. (Aidam O’Rourke)
One of the classic examples for passive use of wind for building ventilation is De Monfort University, completed in 1993 in the town of Lester, UK. In order to ensure natural lighting and ventilation in all inner zones there are different concrete solutions on each floor from the ground floor to the third floor. Ventilation ducts in similarity to wind captures stay above the roof of the central parts of the building and create possibilities for solar light to penetrate in depth.

Fig. 9 A view to lecture rooms in De Monfort University, Lester, UK (1993)

With the development of building technologies today there are a lot of opportunities to develop modern solutions with new modern forms often combined with other technical solutions. These are: systems for effective ventilation with fresh air with exhaust heat recuperation; systems with noise-free ventilators with variable speed for directing of air flow in a specific premise. There are so called wind-catchers providing natural ventilation without
any movable parts, sun-catchers directing the captured sunlight in building inner parts and a combination of these two types

Fig 11 A view to the element composed of combination of modern wind-catcher and sun-catcher

Fig 12. Modern roof wind-catchers

Twenty four wind-catchers are installed on the roof of “Saint Anna” School in Jersey and they provide cooling to class rooms on the ground floor and on the first floor. A special system (monodraught) provides the ventilation of also of the neighbouring inner corridor. Win-capturing system is designed in the way that it provides the necessary for natural ventilation sucking and pressing regardless the wind direction. Warm air is going up air pressure in the room decreases and cool air goes in them as a result of higher air pressure outside. This invisible change in air pressure causes air draught providing natural ventilation.
Fig 13. Twenty four wind catchers installed on the roof of Saint Anna School in Jersey. A modern interpretation of working principle of wind-catcher can be seen in Solar chimneys in "Building Research Establishment" (BRE), Watford, UK.

Fig 14. Solar chimneys in Watford, UK – a view and principle working scheme.

The sun-shined side of the chimney is painted in dark colours and is opaque. Usually thin materials with high heat conductivity (as metals) or thicker is they have high thermal mass (masonry) are used. The thin materials will work immediately after the sunshine falls on them and the thick ones will start working a few hours later and will stop working also a few hours later.

At this systems called “cooling towers” in order to increase their efficiency often are put evaporating elements on the top in order to increase their density and to reach cooling effect also by evaporation. During the night the process is reverse the cooling tower acts as a chimney ventilating the room air.

In the two-storey school Tanga situated in the suburbs of Falkenberg, the use of wind catcher towers is included in the system by which two class rooms (one above the other) are
cooled. More efficient work of the tower is ensured by glazing of its upper part and by mounting of a fan. There are also sensors for CO₂ concentration in the class rooms mounted in this school.

Fig 15. View to the two-storey school Tanga in the suburbs of Falkenberg with total built area of about 1363 m²

Fig 16. View and principle working scheme

These requirements forming most of the principles of passive ventilation, cooling and climatisation systems combined with the realised necessity of control of air quality are in the basis of future development of the ideas of hybrid ventilation.

2.5. Infiltration

Infiltration (non-controlled transfer of air through surrounding walls of the building), can be a source of significant thermal losses (or gains) and thus it forms zones of thermal comfort in dwelling premises. In major parts of the buildings infiltration is inevitable. The
process that is taking place influenced by infiltration can add to some design solutions for mixed and natural ventilation.

Natural ventilation uses the natural wind power to supply fresh air to the building. Fresh air refreshes the smell, supplies oxygen and increases thermal comfort. Natural ventilation system relies on the ability of air to move around the building in order to level the pressure.

2.6. Ventilation

Building ventilation has two main goals – to control air quality and to keep thermal comfort during different seasons. The long known devices such as wind towers, solar chimneys, fountains, water pools, etc., as well as those from our Bulgarian Renaissance architecture (lowering the level of the floor around fire-place, lifting with some steps the level of sitting places on the porch, situating all auxiliary premises at the wind-faced side) are exactly the architectural and building solutions to reach these goals.

This is due to the following two main facts:
- Low almost zero air contamination level from the activities of those old civilizations and therefore the realized necessity of air control;
- Usage of one and the same natural phenomena and same fresh air sources, etc.

With the industrialization and development of technologies requiring so called “clean rooms”, with the design and building of production isolated from the outside space (hermetically closed, underground, etc.) the requirements for securing and guarantee of air quality have risen up significantly. This has lead to improvements of the systems for heating, ventilation and air-conditioning.

Today the interest towards ventilation is rising also from the point of view of energy efficiency strategy achieving the desired air quality in buildings and increase of thermal comfort. This has lead to giving a new meaning to opportunities to use to a maximum extent of the principle of natural ventilation together with mechanical ventilation at solving these issues.

In the technical literature the used term is “hybrid ventilation”. According Annex 35 of the document approved by International Energy Agency at its International Forum on 14 May 2001 "Hybrid ventilation is two-component system controlling minimum energy consumption at maintaining acceptable air quality and thermal comfort in buildings. One of the components uses natural forces for ventilation, the other one – mechanical” (see Table1)
Table 1

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<thead>
<tr>
<th>HYBRID VENTILATION</th>
<th>COMPONENTS</th>
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<tr>
<td></td>
<td>Natural</td>
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<td></td>
<td>Natural ventilation</td>
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<td></td>
<td>Mechanical</td>
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<td></td>
<td>Forced ventilation</td>
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<td>Air quality</td>
<td>Wind (infiltration)</td>
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<td>Temperature differences</td>
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<td>Thermal comfort</td>
<td>Architectural and building solutions-</td>
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<td></td>
<td>orientation, glazing, shading</td>
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<tr>
<td></td>
<td>Natural phenomena</td>
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<tr>
<td></td>
<td>(chimney effect, Thermo-siphon effect)</td>
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<tr>
<td></td>
<td>Fans</td>
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<td></td>
<td>Filters</td>
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<td></td>
<td>Air-conditioners</td>
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<td>Chillers</td>
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Basis of the philosophy of hybrid ventilation is to maintain comfort inner environment by alternative opposing and combination of these two components in order to avoid costs, energy sanctions and environmental consequences throughout its all-year-round utilization while forced systems are used only in cases when passive systems (natural forces) cannot provide the required level of ventilation.

Main working principles of hybrid ventilation are as follows:

- **Natural and forced ventilation.** This principle is based on two autonomous systems each of them solving independently from the other specific problems. Natural ventilation systems cover the needs of intermediate seasons (spring and autumn) and forced ventilation systems cover mid-summer and mid-winter. Or mechanical ventilation systems are used during day working hours and natural ventilation provides cooling in the night.

- **Natural ventilation assisted by fans** it is based on the systems of natural ventilation with separate or implanted ventilators.

- **Forced ventilation assisted by stack-effect and wind pressure** – it relies on optimum usage of factors causing natural ventilation. In this system natural ventilation covers a significant part of necessary air pressure.

### 2.6.1. Natural ventilation

Apparently in passive techniques of hybrid ventilation the main role is of natural ventilation, based on the three natural phenomena: wind pressure, chimney effect and thermo-siphon effect.
The wind causes positive pressure values in front of the building and negative behind it. (at wind direction). In order to level the pressure fresh air penetrates through the openings of wind-faced façade of the building and leaves it through the openings on the opposite side. This ensures supply of fresh air in premises in the summer and in the winter reduction of ventilation to the level to provide elimination of humidity and pollution.

Chimney effect originates from the difference between air density which in its turn depends on temperature and humidity. Cool air is heavier that worm air at the same humidity level and dry air is heavier than humid air at the same temperature level. Due to this warmth and humidity rendered by inhabitants and other sources force the air to go up and worm air goes out from selling and roof openings thus sucking fresh air from lower situated openings.

Thermo-siphon effect has the same working principles as chimney effect but it uses direct sunlight to warm-up the air in the building. This requires large glazing equator oriented facades. Dark surfaces blow the glass absorb direct sun-light, rise their temperature and again emit long-wave infrared radiation (warmth) back to closed space. If there is wind, warm air is being sucked through high situated openings and in the lower ends of space enters cool air. This is a reason for strong convection inside the building. If outer openings are closed the convection takes palce inside the building and thus it is being heated even in cloudy days.

One of the first examples for working hybrid ventilation is the one in Commerce bank Building in Frankfurt designed by Arch. Norman Foster and built in 1994-1997. This is the highest building in Europe (298,74 meters high including the antennae, with total built area about 70 000 m² and accommodating about 2500 employees), for which at design stage in 1991 there was a condition to be the first in the world sky-scrapper with natural lighting and natural ventilation. The ventilation concept of the building includes not only control of air quality but guaranteeing of thermal comfort during the whole year.
At this height of the building natural ventilation cannot always be used due to occurrence of high-speed wind around the building. At these circumstances mechanical ventilation and active cooling systems are switched on.

Significant role for natural ventilation has also the design solution to divide the central inner space into three groups of twelve-storey atriums with gaps between them forming four-storey winter gardens along the façade. The offices depending on their location into the building plan can open windows either to the inner building space or to the outside open space.

2.6.2. Natural ventilation assisted with fans

This system has been applied in the finished in 1998 three-storey office building of "Bang & Olufsen" in Denmark with 1650 m2 of total built area situated in open area outside Struer.

The used principles of hybrid ventilation are stack effect and wind pressure assisted by a system of fans. The North façade is totally grazed with narrow horizontal strips for the openings located low on the façade in front of the slab and has no sum protection elements.
The South façade is with minimum glazing without breaking the requirements for normal natural lighting in rooms and automated window systems for control of passive cooling in the summer are used.

When ventilation is necessary openings and moisturising devices are opened and if the normative values cannot be reached by natural ventilation then the forced ventilation is switched on.

Ventilation is controlled by an automated systems connected with mini air-conditioning system placed on the roof. If the outside temperature is below +0°C ventilation system is closed to be protected against freezing. It is also closed when it is raining, snowing or strong wind. There are sensors mounted in the building which control ventilation and account for CO₂ contents.

**2.6.3. Stack and Wind assisted mechanical ventilation**

This system has been applied in the building of “Media School” in Norway. The working principle is as follows: fresh air enters influenced by the wind pressure through the openings of the nearby-situated tower. There also the systems for forced ventilation are mounted. Air flow passes through underground channels with high thermal mass in order to reduce daily thermal amplitudes and to distribute through the basement corridors.
Fig 25: A view to the building of Media School
Fig 26: A section and a plan of the building of Media School through the underground channels of forced ventilation systems
3. Natural techniques for cooling (passive cooling techniques)

Passive cooling techniques include using of some well known phenomena based on basic physics laws leading to depriving of heat from bodies. These phenomena can be grouped as follows:

- Earth cooling;
- Evaporation cooling;
- Radiation cooling

3.1. Earth cooling

Earth cooling using air as a medium, is based on long-term thermal inertia of the Earth causing almost constant temperature of the Earth mass several meters below the surface. A system of stitch-free pipes on this level with forced air circulation are the basis of an active cooling system.

Same is the principle of Earth cooling using water as a medium. The natural phenomenon that water temperature is not lower than about 10°C is used as a cooling source. This system also requires forced water circulation to heat exchanger making it also an active cooling system.

3.2. Evaporation cooling

Evaporation cooling uses wet basis, pad or water sprinkles in the air. This is a process that could be direct if the incoming air pours over wet objects. Evaporation leads to significant cooling caused by increase of latent air temperature.

Evaporation cooling can be indirect process when outside air provides cooling mainly through heat-exchanger air-air. It this case cooling is present in all cases when a constant level of latent air capacity is maintained.

3.3. Radiation cooling

Radiation cooling is based on heat losses of long-wave radiation of one object to another with lower temperature. There are two types:

- Passive radiation cooling
- Hybrid radiation cooling

The structure of the two types is of three parts:

- Radiator, radiating heat energy;
- Medium, that accumulates heat energy of the building and transfers it to the radiator (transfers heat energy from certain parts of the building to the radiator)
While in passive radiation cooling the building envelope is the one to perform the three functions, in hybrid radiation cooling there are specially designed elements with specific characteristics performing separately or in combination these functions. In spite of the fact that these passive cooling techniques include using of some known natural phenomena their application requires involvement of additional equipment and energy sources providing higher efficiency of these systems. The necessity to use additional energy source make these systems active and therefore are not of interest from the point of view of passive cooling techniques.

4. Best practice example: a kindergarten in Sofia where passive solar techniques will be implemented

The pilot building to show how passive solar principles are put into practice, is a designed kindergarten in Iztok Quarter, Sofia Capital Region. The building has 2 storeys with 1200 m² area and 3840 m³ volume.

The kindergarten will be situated in a very green area located in Iztok quarter of Sofia Capital Region. Its orientation along long axis, is East/West. No active cooling foreseen, only passive cooling solutions will be implemented.

For solar protection during summer time apart from the foreseen greening there will be also shades. Also is foreseen thermal insulation on the building envelope in order to achieve normative values as follows:

Heat transfer coefficient (U W/m²K):
- For walls < 0,5;
- For roof < 0,3;
- For windows and balcony doors < 1,5 (this coefficient is smaller than normative one 2,63)

Description of cooling approach:
- Orientation of building: East/South of play-rooms (used mainly in the mornings), East/North of sleeping premises (used mainly in the afternoon)
- Maximum possible implementation of greening – for this purpose will be used the already present big trees in the area, which will be preserved during construction
process. The building is low (only two storeys) and greening will cover all its facades.

- Implementation of shading on windows.
- Implementation of high-level thermal insulation which works both ways – keeping warm in the winter and cool in the summer.

Below is given architectural drawing of the kindergarten

5. Conclusions
Utilisation of passive cooling approach when design and construction or major renovation of all types of buildings is essential for reduction of energy consumption for cooling needs. It is expected that present guidelines with make building owners aware of natural ways to avoid the need of cooling and will apply these knowledge in the process of building construction or renovation. With the active new building construction going on in Sofia Region and in Bulgaria as a whole this is expected to lead to avoidance of major increase of cooling consumption in the future expected with the economic development and increase of living standards in the country.