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NATURE-BASED SOLUTIONS AIMED AT MAXIMISING ENERGY SAVING AND THERMAL COMFORT IN PASSIVE BUILDINGS AND GREEN CITIES: ONLINE INFORMATIVE AND EDUCATIONAL RESOURCES[i]

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Abstract:
The paper presents documents aimed at increasing knowledge and awareness of solutions, mostly nature-based, for saving energy while maintaining thermal comfort in our homes and cities. Such documents consist of text, images, graphs and videos; they can be downloaded for free from the internet and can be used by the teacher with the method felt as the most appropriate. A correct orientation of the building, thanks to the changing solar position during the year, results in a lower exposure to solar radiation in summer, and a favourable exposure to warming solar rays in winter. A compact shape of the building results in a reduced surface area to volume ratio, which minimises both thermal transfers and amount of materials used in the construction. Compactness may also improve earthquake resistance. The thermal insulation of the building often provides important benefits in both winter and summer. An accurate selection of the materials is important, since they may differ greatly from one another in embodied energy, and capacity to be reused or recycled. Plants surrounding a building, if carefully positioned, may contribute to improving the thermal comfort of the occupants. Considering the projected climate change and the heat island effect, actions aimed at maintaining thermal comfort in the streets of our cities may appear as necessary. In this regard, trees, vegetated roofs, green façades and pergolas, especially if well maintained, may provide the necessary cooling benefits in cities affected by global warming.

Keywords: online educational resources, passive cooling, passive heating, urban heat islands, green cities

[i] TECNICHE NATURALI VOLTE A MASSIMIZZARE RISPARMIO ENERGETICO E COMFORT TERMICO IN EDIFICI PASSIVI E CITTÀ VERDI: RISORSE INFORMATIVE ED EDUCATIVE IN RETE
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Riassunto:
Questo articolo presenta documenti volti ad aumentare conoscenza e consapevolezza su tecniche naturali per risparmiare energia mantenendo il comfort termico nelle nostre case e città. Tali documenti consistono in testi, immagini, grafici e video; sono scaricabili gratuitamente da internet e possono essere utilizzati dall'insegnante con il metodo ritenuto più opportuno. Grazie al variare della posizione del sole con le stagioni, un corretto orientamento dell'edificio permette di avere sia una minore esposizione all'irraggiamento solare in estate, sia una maggiore esposizione ai raggi in inverno. Una forma compatta dell'edificio si traduce in un ridotto rapporto tra superficie e volume; grazie a ciò sono ridotti al minimo sia la quantità di materiali utilizzati nella costruzione, sia i trasferimenti termici. A proposito di questi ultimi, l'isolamento termico dell'edificio può offrire importanti benefici sia in inverno che in estate. Un'accurata selezione dei materiali è importante, poiché possono differire notevolmente tra loro per quantità di energia incorporata e possibilità di essere riutilizzati o riciclati. Le piante che circondano un edificio, se ben posizionate, possono contribuire a migliorare il comfort termico degli occupanti. Considerando il cambiamento climatico previsto e l'effetto isola urbana di calore, possono apparire necessarie azioni mirate al mantenimento del comfort termico anche nelle strade delle nostre città. A questo proposito, alberi, tetti a giardino, edifici con facciate e pergole verdi, possono raffrescare città esposte al riscaldamento globale.

Parole chiave: risorse educative in rete, raffrescamento passivo, riscaldamento passivo, isola urbana di calore, rinverdimento urbano

1. Aims of the teaching unit

The article presents informative and educational documents aimed at increasing knowledge and awareness of the large energy savings that nature-based solutions may provide in achieving thermal comfort for our buildings. The paper also deals with the role of urban greening in mitigating the heat island effect.

2. Materials and methods

The paper presents informative and educational resources that can be downloaded for free from the internet. They consist of text, images, graphs and videos and can be used by the teachers with the method felt as the most appropriate.

3. Introduction - Vernacular architecture

The vernacular architecture was developed by common people through a trial-and-error process, while making rational use of the available resources, and keeping in mind the local tradition and culture. *Vernacular architecture provides good examples of climate design* (1).

Two videos of Prof. Agrawal A. deal with vernacular architecture and highlight the benefits that certain building shapes, techniques, and renewable materials employed provide in local situations (2 / 3).

The traditional Thai houses (2) are built on stilts, which protect the occupants from floods in areas where heavy rains are common. Here, thin walls, large openings and shade maximise the beneficial effect of the breeze, which is essential in this warm humid climate. Bamboo is a very fast-growing plant, which makes environmentally and economically sustainable the use of this quickly renewable material for construction.

Another example of vernacular architecture is provided by buildings found in the hot dry climate of Rajasthan. Their circular shape results in a reduced surface area to volume ratio. The openings are small which, given the extremely intense solar radiation, limits glare while providing enough light (2). The roof extends beyond the mud walls, thus limiting their exposure to the extreme desert climate conditions, including the rain that sometimes may fall.

Such traditional buildings have survived over the centuries and, thanks to their design, most of them even survived severe earthquakes (2).

Another example of vernacular architecture is provided by the igloo. They are built with the only resource available, snow and ice. Their circular domical shape exhibits the lowest surface area to volume ratio (3).

A video explains the difference between green and sustainable buildings (4).

In the first case, the green buildings of an Indian campus use 100% renewable energy from photovoltaic and windmills. They benefit from a correct orientation that impedes the direct penetration of solar rays, while ensuring during the day a natural lighting (4). In the landscape surrounding this Indian campus there are native tree species whose requirements in water and maintenance are low. Here, 100% of the waste water is recycled, and the amount of water drawn from the ground or from the municipality is very small.

In the second case, a *sustainable primary school* for very underprivileged African children is made of compressed earth blocks; this local material has a very low incorporated energy (4). Here, natural ventilation and a double roof contribute in maintaining the thermal comfort and, thanks to the design of the windows, no artificial lighting systems are necessary. The rain that falls on the roof is harvested for the consumption of the school and no external water is consumed.

When we compare these buildings, we can observe that the Indian campus is energy intensive, but the energy is generated in the site. Whereas, the African school needs zero energy (4).

A document of the British Assessment Bureau provides further information on the difference between green and sustainable buildings (5).

4. The thermal comfort in buildings

"Human Comfort and Health Requirements" provides basic knowledge on thermal comfort. Figure 1.4 and related text (6 pages 10-11) helps to learn how radiant temperature and air temperature interact in determining our thermal comfort, and how we can achieve this latter.

According to "Standards of Human Comfort", our thermal comfort is very dependent on the combination of air temperature and radiant temperatures of the surfaces around us. *When such temperatures differ, we may feel a sense of discomfort*. This happens, for instance, when the ceiling is 5°C warmer or 14°C colder than the other surface temperatures in the room (7 fig. 03).

A document of the "American Society of Heating, Refrigerating and Air-Conditioning Engineers", provides more information and graphs on the thermal comfort (8). Figures 5.2.4.1, 5.2.4.4 and 5.2.4.3 deal with local thermal discomfort caused by respectively, radiant asymmetry, warm and cool floors, vertical temperature differences. Even atmospheric humidity and air currents play a role on the thermal comfort (9). The temperature differences of the surfaces of the room may create convective air currents; their velocity is lower where such differences are small, which happens in a well insulated home (9 figure 1). The thermal images (figures 3 and 4) show the performances of, respectively, a well-insulated and a common window, in winter conditions.

"Natural Convection in a room with a heater" (10) is a video whose content is summarised by the title.

In winter a high relative humidity can intensify the sense of cold. In hot weather, high levels of moisture in the air hinder the evaporative cooling effect of sweating (7).

A document of Prof. Minke G. describes the advantages and disadvantages of loam as a building material, which can absorb and desorb air humidity faster and in larger amounts than other materials used for construction. In a newly built house in Germany, where interior and exterior walls are made of earth, the relative humidity rate observed during 8 years was nearly constant at around 50%, which results in healthy living conditions (11). *The raw earth used in building walls and clay-based plasters can moderate the humidity fluctuations; the benefits are clear, thanks to the reduced need for dehumidifiers and mechanical ventilation* (12).

The traditional rammed earth constructions do not use additives; on the contrary, nowadays stabilisers are used in order to improve earth strength and resistance. "Reduction of rammed earth's hygroscopic performance under stabilisation: an experimental investigation" studies the influence of stabilisers on the moisture buffer capacity of rammed earth. According to the study, the stabilised rammed earth exhibits a considerably reduced moisture buffering ability that, however, is better than common building materials, such as bricks and concrete (12).

According to the authors, further investigations are necessary to find alternative stabilisation methods that, using minimum amounts of low-impact stabilisers, provide the needed mechanical and hygrothermal performances (12).

4.1 Passive heating of buildings

A video shows the upgrading of a house according to passive solar design, which results in a reduced need for mechanical heating and cooling (13). Some images of the video show the south side of the house after upgrading. Thanks to roof overhangs sized to shadow the windows, in June the high angle sun rays do not enter the home. Conversely, in December the rays of the sun can enter the building and provide heat and light, thanks to their lower angle. The insulating material covering the walls retains the warmth in winter, and contributes to repel the heat in summer.

Figure 4 (14 part 2 of 4) and a video (13) show buildings heated in a similar way. During the day the solar rays enter the building through a south-facing window. Here, the air is heated and, at the same time, heat is stored in the walls and on the floors. During the night or during cloudy days, the heat previously accumulated is re-radiated into the living space and contributes to maintaining thermal comfort.

Figure 7 (14 part 2 of 4) shows a different design, based on indirect solar gain. Here, much of the heat is stored in a wall placed just behind the south-facing glass. In the space between the glass and the wall, the air is heated and continuously flows into the living space. During the night, the heat stored in the wall is radiated into the living space, while the top and bottom vents are closed.

Figure 9 (14 part 2 of 4) shows a greenhouse constructed in front of the storage wall. Here, both this latter and the greenhouse are heated by the sun.
The document provides much information aimed at sizing correctly the diverse parts of a solar-heated building (14 part 2 of 4).

A website provides information and images on passive heating in Australia (15> Passive design> Passive heating).

Two US documents deal with windbreaks that protect the house from cold winter winds, which may reduce heating costs by up to 30% (16 / 17).

4.2 Passive cooling of buildings

Figures 1-13-14 (18) show the wind towers used in Iran. The breeze enters through the wind tower and exits through one or more windows downwind, thus providing natural ventilation inside the building as shown in figure 21. Such wind towers, also called wind catchers, in some cases, incorporate an evaporative cooling system.

Many centuries ago, the wind towers were built in Iran; subsequently, this technique spread to other countries of the Middle East, including Egypt (18 figure 2 and table 1).

The passive cooling of buildings that use night-time ventilation is a strategy aimed at providing thermal comfort, which is maintained during the daytime without spending energy on air conditioning (19). According to "Potential for passive cooling of buildings by night-time ventilation in the present and future climates in Europe", this technique seems to be generally applicable in both Northern Europe and other parts of this continent. Whereas, in the southern part of Europe, such possibilities are more limited.

Considering the climate change, further investigations are required to understand the long-term potential of this technique.

"Using Wind Catchers as a Passive Cooling System for Residential Buildings in Cyprus" studies the effect of a wind catcher applied over the staircase of a modern building (20 fig. 5).

During nighttime the wind catcher has proved beneficial, thanks to the air flow and to the reduced air temperature; the cross ventilation through the windows contributed importantly to the comfort. But, using this *wind catcher during daytime made the inside warmer* (20).

A document of the Australian Government, aimed at creating sustainable homes, inter alia, provides much information, principles and technical details regarding passive cooling for the diverse climates of this country (15> Passive design> Passive cooling).

Shading of glazing is important in passive cooling, particularly when the sunlight reaches the glass at a low angle, which happens through east- and west-facing windows, respectively in the morning and in the afternoon (15> Passive design> Passive cooling).

Figure 2 (14 part 1 of 4) shows how the *density of the energy arriving on a surface is dependent on the angle of incidence*. When the rays arrive perpendicularly, this results in the highest density of rays striking a surface. Conversely, the more the light is tilted away from the perpendicular position, the lower the ray density.

A video shows the apparent path of the sun. We can observe that in summer, the rays of the sun hit at a low angle the east and west walls of the house. Differently, the south wall is lightened by sunlight arriving at a low angle in winter (21).

A building oriented with the longest axis running east-west provides benefits all year round. In fact, this implies a maximised exposure of the south surface to the winter sunlight. In summer, this building minimises the exposure of the east and west walls during, respectively morning and afternoon (14 part 2 of 4 / 21).

According to a 2018 article, in Florida, this exposure (22 figure 1) may lower $75-100 the annual cooling cost for an average house.

The 4th and 5th graphs show the intensity of the solar exposures on the east and west sides of a house in summer; they are more intense than that observed on the equator-facing surface shown in the 3rd graph (23> Thermal Comfort> Buildings> Building Configuration> Building Orientation).

In the 4th image, the thickness of the arrows represents the amount of solar radiation arriving on the diverse sides of a house in summer and in winter, in this country of the southern hemisphere (15> Passive design> orientation).

Dark-coloured materials absorb solar radiation and make a house cheaper to heat in winter but, summer cooling is more expensive. The contrary applies to light-coloured buildings that reflect sunlight (22 / 14 part 3 of 4).

In Florida the cooling season is longer than the heating season; here, light-coloured homes prove more energy efficient (22).

A simple experiment shows the importance of colour on the absorption of thermal radiation (24 video).

An animation shows large deciduous trees that, in summer, provide shade and reduce air conditioning cost by 35% (16> Summer Shade). Interestingly, in winter the same deciduous trees, planted on the east and west sides, allow the sun to provide warmth and light to the house, as shown in the animation (16> Winter Warmth).

Careful attention should be paid in positioning the vegetation so that it does not interfere with the cooling breezes, and with an efficient functioning of both solar water heater and air conditioner (22 / 16> Summer Shade).

In areas where cool breezes are common, maximising their flow may contribute importantly to passive cooling. An image shows how trees and shrubs may funnel breezes (15> Passive design> Passive cooling).

In areas where cool breezes are limited and temperature difference between day and night exceeds 6-8°C, the hot internal air is replaced with night's cool air thanks to temperature-pressure-differential. In this situation, full-height opening windows provide the best performances (15> Passive design> Passive cooling).

Each degree of temperature reduction implies a 10 percent increase in energy consumption of the air-conditioner (15> Passive design> Passive cooling). The use of ceiling fans may reduce by up to 75% air-conditioner use.

An image shows how a solar chimney, combined with an underground pipe system, may provide ventilation and cooling (15> Passive design> Passive cooling).

A document from the Arizona Solar Center provides information on passive cooling. Fig. 21 (14 part 3 of 4) shows an overhang that shades a window from early May to mid-August while allowing the winter sun to enter (13 Video). As an alternative, deciduous trees or a trellis supporting the growth of *deciduous vines* can be used to shadow the south part of the house.

According to "Enviroscaping to Conserve Energy: a Guide to Microclimate Modification" (22), in areas close to vegetation the evaporative cooling may lower air temperature by as much as 5°C. On the contrary, surfaces such as asphalt and concrete reflect large amounts of heat.

When east and west walls are hit by the sun, vertical shading structures, such as vegetation may protect the house (25 first photo / 14 part 3 of 4). Care must be taken to avoid that vegetation blocks the night cool breeze, which plays an important role in the cooling strategy.

Figure 23 (14 part 3 of 4) shows cool night air entering the house through vents placed in a low position, which replaces the hot air that rises and exits through openings located at high points. This air change can be intensified by a predominant cool night breeze, provided that the low vents are located on the windward side and the high vents on the leeward side. Figures 24 - 25 – 26 show other techniques aimed at improving ventilation and cooling. The document also deals with evaporative cooling methods.

4.3 Thermal insulation

Three websites (26 / 27 / 28 video) provide information on the heat losses, which occur mainly through outside walls, ground floors, doors, windows and roof.

A document of the Passive House Institute deals with thermal insulation which, interestingly, in Austria and Germany are economically supported by the governments (29). *In a passive building, thanks to insulation, the heat lost through the external walls can be reduced by a factor of 10*.

According to the paper, the insulation will last at least 40 years (29).

4.4 Importance of building shape from the energy point of view

According to a document of the London Metropolitan University, a compact shape tending toward a cube minimises both losses and gains of heat in buildings, thanks to a low surface area to volume ratio (23> Thermal Comfort> Buildings> Building Configuration> Building Shape / 23> interactive> Design Matrix> Surface Area to Volume Ratio).

Minimising the surface area of a building envelope for a given interior volume, results in a reduction of both thermal transfers, and embodied energy of the materials used in the construction (30).

Other factors may suggest a different shape for a building. For instance, in warm-humid climates an elongated shape may favour daylighting and ventilation; here, in order to satisfy the primary need of air movement, even the streets should be oriented to utilise the natural wind patterns (23> interactive> Design Matrix> Street Widths).

4.5 Mitigation of the impact related to the materials used in building houses

A document deals with the *embodied energy* of materials. This is the sum of all the energy required to produce such materials or products, and includes mining, manufacture and transport. When building or renovating a house with sustainability in mind, this embodied energy is to be taken into consideration (15> Materials> Embodied energy).

The materials may differ greatly from one another in their embodied energy, as shown in the tables, and in the capacity to be reused or recycled (15> Materials> Embodied energy). A circle graph shows the proportion of operational and embodied energy over the 50-year life of a typical brick veneer house.

As much as 40-44% of Australia's waste is generated by the building industry; reduced size of homes, and design aimed at reducing wastage may help to minimise the impact. Much of that waste, however, can be recycled (15> Materials> Waste minimisation).

A correct construction system may result in durable buildings (15> Materials> Construction system).

Figures 7 and 8 (30) compare buildings of different compactness and size. In fig. 7 we can observe that moving from left to right their shape is more and more distant from optimality. The authors of the article suggest considering the importance of an optimal shape in the design of a building, which may result in greater sustainability (30).

The longevity of a building can be increased thanks to the adoption of inner partitions, that are not load-bearing, and can be easily rearranged to accommodate the changing needs of the people, while the structural carcass is maintained (31).

Office partition systems are also easily moved from a place to another (32). The materials should be no toxic and not outgassing; their recycled content is also important. Urban planning plays an important role in saving materials and energy. For instance, urban sprawl can be avoided by encouraging the reuse of old buildings. According to this US document, existing buildings can be adapted to new uses, often at a lower cost than brand-new construction (32).

The roofs of the buildings may work as rainwater collecting devices, combined with cisterns that hold this water. This latter can be used, e.g. for toilet-flushing. For the same purpose, well planned plumbing systems may facilitate the reuse of graywater resulting from handwashing or from cooking (32).

Energy-conscious developments are planned around pedestrian walkways and public transportation, and not around automobiles (32).

4.6 Thermal mass in buildings

The thermal mass is a property of the materials that can absorb, store and then release large amounts of heat, *which is very important in moderating the fluctuations of indoor temperature*. The images and the graph may provide a deeper knowledge on the subject (33).

A graph shows the daily temperature fluctuations for different construction methods and varying levels of thermal mass (15> Passive design> Thermal mass).

In winter, materials like bricks and concrete absorb the heat of the sun and, during the night they re-radiate the warmth back, as shown in the first drawing. Conversely, during the summer days, bricks and concrete absorb the heat from the home, the heat is then transported outside by the cool night breeze (15> Passive design> Thermal mass). Lightweight construction materials, such as wood have a low thermal mass. This document also deals with the thermal lag.

Thermal mass combined with external insulation of the building may improve the comfort in summer and winter. During the summer nights, a special care should be taken in providing a natural ventilation aimed at dissipating the heat, thus reducing the maximum day temperature by 1 to 2 degrees (23> About> Site Map> Thermal Mass).

Where diurnal temperature ranges are high, thermal mass combined with a high level of insulation and airtightness may provide important benefits.

The heating and the cooling potential provided by the thermal mass of the floor is maximised when there are no carpets. The thermal mass may prove useful, in certain climates and on certain conditions. In hot-humid climates low-mass constructions are preferred, unless the house is air-conditioned.

The thermal mass may slow the response time when used in a room that is heated or cooled intermittently (15> Passive design> Thermal mass).

The materials that provide thermal mass, when used in the required amounts, have a high *embodied energy*; for this reason, they should be used only in situations where they provide significant benefits. In some cases, the use of phase changing materials is suggested for lightweight buildings (15> Passive design> Thermal mass).

According to the table, water has the highest specific heat capacity among the materials that provide thermal mass. Interestingly, the water can provide thermal mass in an otherwise lightweight home, as shown in the last photo (15> Passive design> Thermal mass).

Figure 8 (14 part 2 of 4) shows a water wall that collects and stores the heat during the day. The heat is then radiated into the living space at night.
"How passive solar design and thermal mass can cut your energy bills" is a video on life in a passive house (34).

5. Resistance of buildings to natural disasters

Of course, while renovating or building a house (15> Buy, build, renovate), the safety of the occupants must be accounted for. The *resistance to natural disasters implies the further benefit of a more extended useful life of buildings, which results in a greater sustainability*.

Some documents provide technical information and images that deal with a safe shape of buildings: "Guide book for building earthquake-resistant houses in confined masonry" (35 pages from 21 to 28), "Seismic design guide for low-rise confined masonry buildings" (36 from page 29 to 32), "A Tutorial: Improving the Seismic Performance of Stone Masonry Buildings" (37), and "Construction manual for earthquake-resistant houses built of earth" (38 from page 9). The construction of an earthquake-resistant building implies, inter alia, a regular and compact shape, and continuity of the walls between storeys.

"Construction and maintenance of masonry houses – For masons and craftsmen" also provides information on earthquake resistant houses (39). According to this Peruvian booklet, for instance, the walls of a building should not be weakened breaking them to place electrical conduit or accessories.

In an earthquake resistant building, soft-storey ground floors should be avoided (40 text and images from page 15).

Several images show roofs and verandas that, thanks to their design, are best suited for areas where strong winds and cyclones may occur (35 from page 125).

An animation shows the effect of soil type on earthquake damage (41> Buildings & Bedrock: Effects of amplification & liquefaction).

According to "Homeowner's Guide to Landslides - Recognition, Prevention, Control, and Mitigation", a landslide may occur in a matter of seconds, or over the course of much longer times (42). The guide explains which factors increase the driving forces that contribute to causing a landslide, and what can be done to increase the resisting forces that stabilise the slope.

A recognition may allow us to discover the signs of landslide potential or activity. The areas where landslides occurred in the past are at risk. Text and images may help to learn (42).

Pages 30-31-32 (35) deal with a site selection aimed at mitigating landslide and flood risks.

5.1 Green Façades

"Effects of a Vertical Green Façade on the Thermal Performance and Cooling Demand" has found a reduction of up to 1°C in indoor temperature, and energy saving up to 35% for cooling a building where a green façade has been applied (43). The benefit is more significant at higher temperatures and in locations where the solar radiation is stronger. The plant of the experiment is a Bougainvillea, a climbing tree that exhibits fast growth and requires low maintenance. In winter, this plant sheds its leaves, which allows the walls to be warmed by the sun (43). The images in figure 3 show the building of the experiment; table 1 summarises previous experiments on this subject.

In urban areas, a lot of houses with green façades may reduce outdoor temperatures and contribute to cleaning the air and creating a silent relaxing atmosphere (43). According to the paper, however, not all the scientists agree on the benefits that green solutions provide.

A UK study has found that *Hedera helix* covering brick walls exhibits insulation properties against heat loss in winter (44). The study has found that this insulation reduced by 37% energy used in maintaining a constant temperature of the water tank encased in the small brick construction. Again, according to "A Hedera Green Façade – Energy Performance and Saving Under Different Maritime-Temperate, Winter Weather Conditions" (44), even larger savings have been observed under extreme weather conditions.

In Germany, incentive programs supported greening initiatives in about 35 cities. Table 1 (45) compares benefits and costs of green façades and extensive green roof structures; table 2 compares several climbing plants and provides some comments. Table 3 provides the results of interviews with citizens living in greened and non-greened houses. For instance, the questions were about: "damages at the façades", "thermal insulation in winter", "better urban climate" and "more insects".

According to the document, in temperate climates, there are 30-50 woody climber species suitable for creating vegetated façades, whereas in the tropics, there are as many as 300-500 useable plant species (45).

According to "Green wall systems: A review of their characteristics", the installation of green façades (46 fig. 2) is cheap because they have low maintenance needs and no materials are necessary. But some climbing plants can damage the building surface.

The sustainability of a living wall system (46 figure 4) depends on, e.g. type of materials used, durability, recycling potential and water consumption. However, an evolution towards the sustainability is necessary.

Table 1 (46) compares advantages and disadvantages of green wall systems. Figure 9 shows a modular living wall with edible plants.

5.2 Green roofs

Among the environmental benefits of green roofs, there are both temperature regulation and reduction of the heat island effect; they may prove particularly useful in dense urban environments (47). "Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West" provides images of green roofs, and information on their basic elements, also including: cost, maintenance, and typical reasons for their failure.

"Structural Implications of Green Roofs, Terraces, and Walls - Seaoc 2008 Convention Proceedings" is a document whose title summarises the content (48).

A website provides information and images on green roofs; the document also provides an image of an earth-covered house (15> Materials > Green roofs and walls). This kind of construction can provide substantial thermal and acoustic insulation, to an extent that depends on the thickness of the soil and other variables.

5.3 Green cities

An educational website deals with the urban heat islands, shown in satellite images (49). Asphalt and concrete absorb the heat of the sun, which results in temperatures higher by several degrees than in vegetated areas. This temperature difference is stronger at night than during daytime.

An increasing urban population, projected to reach 70% by 2050 on a global scale, and growing cities may compound the problem (49). Tall buildings reduce air flow, while human activities add warmth, thus exacerbating the heat island effect.

For instance, a study has found that the waste heat, that results from air conditioners, increased air temperature by 1°-2°C or more in a Tokyo office district on weekdays (50). This waste heat results from both the energy that the air conditioners consume, and the heat that they remove from the interiors. According to the Japanese study, during holidays, thanks to the low working activity in the office district, this waste heat did not influence the outdoor temperature.

"Climate Change - Urban Heat Islands Mean Warming Will Be Worse in Cities" (51) and "Climate Change and Heat Islands" (52) suggest the adoption of cool roofs and green spaces in urban areas as warming mitigation measures.

Not every solution is appropriate for every city. For instance, reflective roofs provide cooling benefits in summer; but this effect is maintained in winter, which in colder climates is not desirable. Another aspect of the problem is that, in water-scarce areas, maintaining green spaces might be a challenge (52).

"Heat Island Cooling Strategies" provides images and information on the subject (53).

A Slovak study reports the thermal benefits that vegetation provides in several cities. In the Nitra city park, the temperature was 2.3-2.5°C lower than in other parts of the city. Here, a higher humidity rate compared to the street space was observed, respectively 72.27% and 64.02% (54).

According to the abstract of a conference paper, entitled "Influence of Height and Thermal Characteristics of Green Facades in Pedestrian Thermal Comfort", the reduction in air temperature at 1.5 m – 0.5 m distance from the façade was 1.1°C (55). During this experiment carried out in Singapore, however, a reduction of about 11°C in the radiant temperature was observed.

A document (56) provides guidance aimed at optimising tree placement for getting cooler and more comfortable cities, while considering design and orientation of the streets and, the cost of the investment for planting and maintaining the trees. For instance, in areas where the buildings are low, the broad streets east-west oriented are particularly exposed to large amounts of solar radiation. Here, the shade of the trees provides the largest benefit (56 tables pages 10-11-12).

Two images in page 10 (56) show respectively a healthy and an unhealthy tree. The trees need to be well watered, which may result in canopies providing a large shade and an intense transpiration.

The vaporisation of the water, that takes place in the leaf, absorbs a large part of energy received, and allows the continuous cooling of the leaves (57). In plants whose transpiration is abundant, the temperature of the leaves is lower than that of the air. Conversely, in a plant suffering drought the transpiration is limited, and the temperature of the leaves is likely to be up to 10°C higher than that of the air.

Preferably, the irrigation should be provided from a *water sensitive urban design*, which implies, for instance, the infiltration of stormwater into the soil surrounding the tree. This results in watered trees and, at the same time, a reduced runoff volume (56 fig. 7).

According to the *water sensitive urban design*, the rainwater falling on the roofs, or on the porous asphalt, is directed into the soil where the trees have their roots. Many links and images help to learn how the rainwater is stored in the soil, thus providing water for the plants during the dry periods (57> Take a self guided tour> Central city WSUD tour). A website, and the video that it contains, help us to learn how the water may contribute in creating a livable city (57> lessons from the drought - City of Melbourne).

Another video helps to learn how the city is adapting to the climate change (58> Adapting to a Changing Climate – Melbourne's Story). Here, a few critical risks have been identified: *water shortages, flash floods and increase in extreme heat waves; these latter are associated with the heat island effect.* In this city, as many as 3,000 trees per year are being planted; this action is aimed at cooling the climate.

According to "The Impact of Small-Scale Greening on the Local Microclimate—A Case Study at Two School Buildings in Vienna", small scale greening measures, especially in shaded positions, are not very effective. The temperature decrease observed at 0.1 m from the green façade was not higher than 0.1°C. Conversely, thanks to the shading provided by a green pergola, a reduction up to 4°C in the perceived temperature has been observed. According to the authors, only large-scale urban greening may improve thermal comfort for pedestrians, while also shading buildings (59).

In Phoenix, extreme temperatures exacerbated by the heat island effect may negatively impact pedestrian activity. Here, the so called "Connected Oasis" is an important part of the Downtown Plan. It consists of a *network of streets with shaded sidewalks connecting the centre of the city with adjacent neighborhoods*, which is aimed at making the pedestrian traffic thermally comfortable (60).

5.4 An overview on the health effects of urban greening

A Chinese research has studied the influence of the tree cover in streets on both blood pressure and pulse rate of six students (61 fig. 4). According to the study, such physiological indices were more favourable where the tree cover was more intense.

The authors discuss the limitations of the study; according to them, however, there are good reasons for urban planners to plant trees along the streets with the aim of improving comfort and sustainability (61).

Two papers deal with the health effects that may result from incorporating vegetation in the design of a city (62 / 63).

A video provides interesting lectures, such as "Urban Greening – Biodiversity benefits and health risks" and "The role of urban greenspace connectivity on the emergence of tick-borne diseases". Parasites and pathogens are an integral part of biodiversity, and increasing this latter we may expect increased diversity of parasites and pathogens. In certain situations, however, we may hypothesise the opposite. Urban green spaces have been relatively little studied and many open questions remain on this subject (62).

However, urban greening may provide health benefits that likely outweigh such potential health risks (62 / 63). Green environments, for instance, may motivate physical activity, reduce noise and stress exposure. Vegetable gardens may provide fresh food while also motivating physical activity (63).

5.5 Interactions between buildings and plants

The plants may provide widely recognised benefits for people, climate and environment. However, there are mutual interactions between plants and built environment, sometimes negative, that need to be accounted for in advance. Two websites provide information on how to prevent tree damage to people and properties (64 / 65> Tree Dangers).

According to "Preventing Construction Damage to Trees", after the end of construction works, sooner or later, some trees may decline and die. This may depend on physical wounds caused by careless working or from excavation. Soil compaction resulting from construction activities may decrease both oxygen and moisture availability, which is very harmful for trees (66). The document provides tips aimed at protecting the trees from this kind of injuries.

"Firewise Landscaping - A Guide to Protecting Your Home from Wildfire" provides tips aimed at minimising the risk of wildfire damage if, for instance, the home is located in the middle of a woodlot or in the Wildland-Urban interface (67). In this regard, several images suggest solutions that enhance the beauty and the diversity of the property. The document provides guidelines that combine energy saving with wildfire protection (67).

5.6 Ventilation corridors

A smart urban planning may take advantage of sea breezes or prevailing winds to maintain a natural ventilation (56).

Stuttgart is known for the low wind speeds; nevertheless, especially in the slopes and in the valleys, local winds may develop that play a significant role for the ventilation in some parts of the city (68).

According to "Towards a Liveable Urban Climate: Lessons from Stuttgart", climatological observations revealed some natural flows of fresh air existing in this city (69). *In Stuttgart, there are guidelines that promote an optimal arrangement of buildings and the alignment of parks and streets that maximise the airflows, thus creating green corridors for the ventilation*. Figure 8 (69) shows a protected fresh air corridor.

Figure 4 (70) shows the scheme of the nocturnal cold air flow in Stuttgart.

The maintenance of such ventilation corridors is an important part of the planning policy in Stuttgart. Here and in other German cities, the *urban climate is recognised as a public good*. Interestingly, here is a *high degree of public acceptance regarding the limitations on private property aimed at improving the urban climate* (69).

Figures 13 and 14 (71) of a Chinese study show respectively, the influence of plant arrangement on the ventilation, and three kinds of urban wind corridor.

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Conflict of Interest Statement

The author declares no conflicts of interest.

About the Author

The author is a former middle school teacher, and wrote about 65 educational papers starting 35 years ago. Areas of interest: Health Education, Environmental Education and Prevention of Natural Disasters. The author has a University Degree in Biology.

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