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Role of biomass in urban energy management

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Abstract. When making decisions on the use of energy, both on building and on city level, biomass plays certainly a role in looking for sustainable solutions. This study starts with highlighting some key points regarding urban energy management, including world urbanization trends, heat island effect of big cities and energy hierarchy in energy management. With these in mind, it is worth considering, how the shading effect of surrounding biomass can mitigate the heating needs as a wind barrier in the winter or decrease the cooling load as shadowing element in the summer, both for buildings and whole cities. These can be further enhanced by biomass integrated in the buildings' envelope: green roofs and green walls can have significant energy conservation effects, according the characteristics of their different types. Lastly, urban disposal of biomass can lead to renewable energy generation, both in case of biogas production and waste incineration. These shading, covering and fuel possibilities all underline the importance of biomass in urban energy management.

Introduction – Aims and methodology

Recent global trends of urbanization, as well as world-wide concerns about sustainable development and, particularly, energy management, have led to various considerations. One aspect of the possible solutions is the increased and reasoned use of biomass in urban environment. This study aims at pointing out some key aspects of possible uses of biomass for urban energy management purposes.

Methodolgy used was a review of the literature of primary and secondary sources on the broad context of urban energy management (importance of urban climate and hierarchy of energy management solutions), and three important aspects of biomass use in urban context. First, the role of surrounding biomass around buildings. Second, role of covering biomass on the roofs and walls of buildings was analysed. Third, the role of dry and wet biomass wastes was added as energy sources for urban energy needs. A Conclusion then summarizes the main findings of literature research. Sources are listed in the last section, whereas photo and image credits are given via footnotes.

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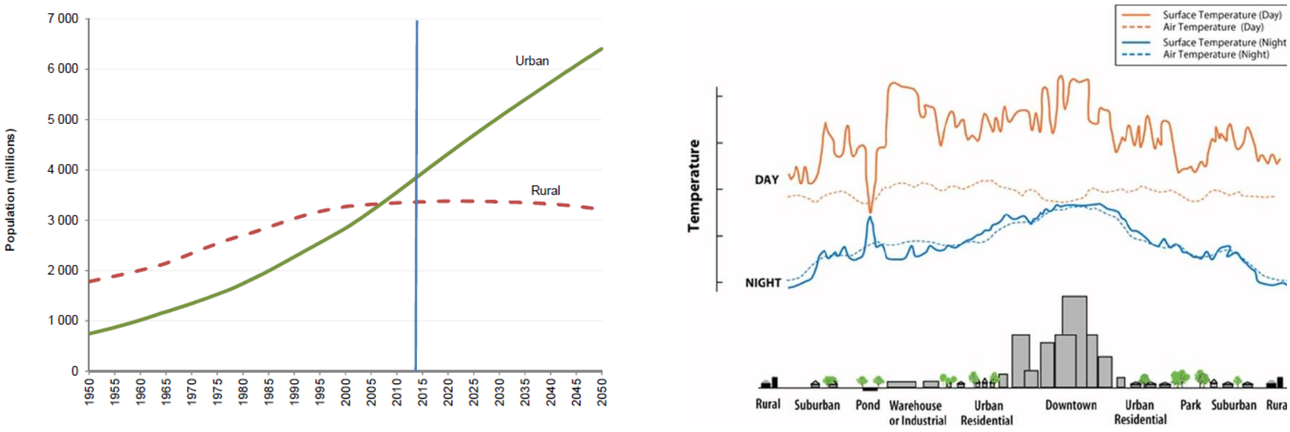
1. Urban energy management

1.1. The growing importance of urban climate

As key findings of the urbanization trends in the world, the 2014 United Nation's report [28] highlights that more people live in urban areas than in rural areas, 54%. In 1950, 30 % was urban, and by 2050, 66 % of the world's population is projected to be urban (Figure 1.a). The most urbanized regions include Northern America (82 %), Latin America and the Caribbean (80 %), and Europe (73 %). All regions are expected to urbanize further over the coming decades. Asia, despite its lower level of urbanization, is home to 53 per cent of the world's urban population, followed by Europe (14 %) and Latin America and the Caribbean (13 %). Continuing population growth and urbanization are projected to add 2.5 billion people to the world's urban population by 2050, with nearly 90 per cent of the increase concentrated in Asia and Africa, and these are projected to become 64 and 56 % urban, respectively, by 2050. Close to half of the world's urban dwellers reside in relatively small settlements of less than 500,000 inhabitants, while only around one in eight live in the 28 mega-cities with more than 10 million inhabitants like Tokyo (38 million), Delhi (25 million), Shanghai (23 million), and Mexico City, Mumbai and São Paulo, each with around 21 million inhabitants. By 2030, the world is projected to have 41 mega-cities. The fastest-growing urban agglomerations are medium-sized cities and cities with less than 1 million inhabitants located in Asia and Africa. As the world continues to urbanize, sustainable development challenges will be increasingly concentrated in cities. Integrated policies to improve the lives of both urban and rural dwellers are needed.



a

b

Figure 1. The world's urban and rural population, 1950-2050 (a)[28] and the urban heat island effect (b)[23]

As regards urban mesoclimate, one of these challenges is the urban heat island phenomenon (Figure 1.b) that can be observed in big cities. As compared to the surrounding rural and suburban areas, cities are often referred to as urban heat islands, with the central city having the highest temperatures. This is primarily due to the low amount of vegetation in central cities: buildings, asphalt, and concrete absorb solar radiation, and emit longwave radiation that heats the atmosphere. Cities also use large amounts of energy and emit this energy as waste heat, further warming the urban heat islands.

1.2. Hierarchy of energy management solutions

From the point of view of sustainable development, it is vital that the energy demand of buildings shall be reduced, especially to meet carbon emissions targets. It has been estimated that the energy demand of both existing and new buildings can be reduced by 70–80 percent, with the potential for reducing the demand of new buildings being greater than that of existing buildings [10]. Importance of these savings derives from the fact that both globally and within the European Union, residential, commercial and industrial buildings' energy consumption take up a significant part of the primary energy demand. Most of the technologies and design strategies for this reduction already exist and are considered 'mature' [14][16], meaning the technology or design strategy is one that is now relatively stable and well understood, and that has been in use for a period of time, though not necessarily in widespread use.

To achieve low energy demand, and to minimise carbon emissions, a basic guiding framework is required. Based on the widely used waste hierarchy, which in its simplest form is to reduce, reuse and recycle, the energy hierarchy has been developed to provide a clear, practical framework that has been widely adopted (e.g. Greater London Authorities Energy Plan, 2014). This energy hierarchy can be defined as having a sequence of five priorities based on the principle of reducing energy demand first before addressing issues of decarbonisation and the availability of the energy supply (Figure 2.)

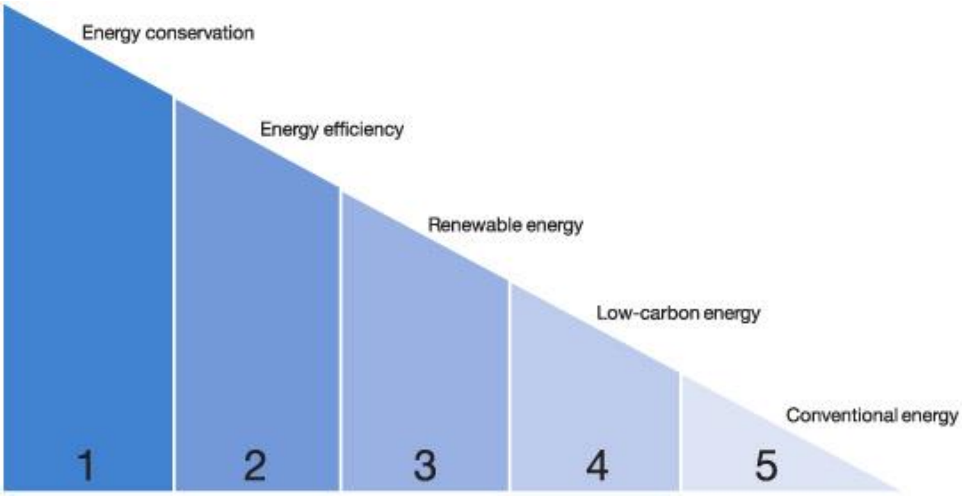


Figure 2: A graphical representation of the energy hierarchy, showing relative importance of priorities from left to right [22].

The first two priorities of the energy hierarchy are concerned with managing (i.e. reducing) the demand for energy, or eliminating wasted energy. The first priority, energy conservation, is the reduction or elimination of consumer's unnecessary energy demand. The second priority is energy efficiency. There are two main aspects to energy efficiency: the efficient conversion of energy (such as the generation of electricity in power stations) and the efficient use of energy. In the built environment context, the efficient use of energy is concerned.

Energy conservation and energy efficiency are often confused, but they are not the same. Energy conservation involves using less or going without a service to save energy, whereas energy efficiency is concerned with using less energy without reducing the level of service. Energy conservation and energy efficiency are linked but neither automatically guarantees energy reduction, due to the rebound effect.

The remaining priorities are concerned with energy supply. The third priority refers to the substitution of conventional energy with renewable energy resources such as wind, geothermal, solar thermal, photovoltaics and biomass. Biomass is regarded in this paper not only because this is the simplest way to store solar energy for cold seasons, but also because greening measures – city greens, green roofs, green walls - provide organic matters for biomass fuels periodically, after the lifetime of their living components.

The final two priorities in the energy hierarchy involve conventional low-carbon energy systems and fuels (e. g. nuclear energy), plus improving the efficiency of energy production and fuel switching. An example for building-sized application can be the more efficient energy generation such as combined heat and power (CHP) via a natural gas engine.

Technology and management focused measures and decisions to improve the energy performance of buildings can be realized on various levels, from macro levels of country and region to the meso-level of city-scale and district-level arrangements, and to the micro level of an individual building. Below, some of the meso- and micro-level solutions are briefly described and evaluated.

2. Surrounding biomass as improvement of buildings' energy performance

2.1. Shading of a building

Starting with the immediate environment of a building, Passive Solar Design (PSD) principles consider the particular aspects of a site that contribute to a site's micro climate. These include the sun's path over the year, the prevailing wind direction and the surrounding landscape (trees, buildings, slopes, etc.). This context is used to suggest potential design strategies that can best exploit the available solar energy in that environment for providing heating, cooling, daylighting and ventilation (or humidity control), without the need for energy-hungry mechanical systems such as mechanical ventilation [4].

Besides fulfilling social needs and values of urban society regarding trees and parks, functional uses (and design) of urban vegetation could include economic, environmental and engineering uses as well [15]. As an environmental and economic benefit, trees and other vegetation exert significant impacts on building energy budgets. Heating and cooling costs can be reduced by appropriate use of vegetation or increased by careless placement. Overall home energy conservation can be realized through proper landscaping.

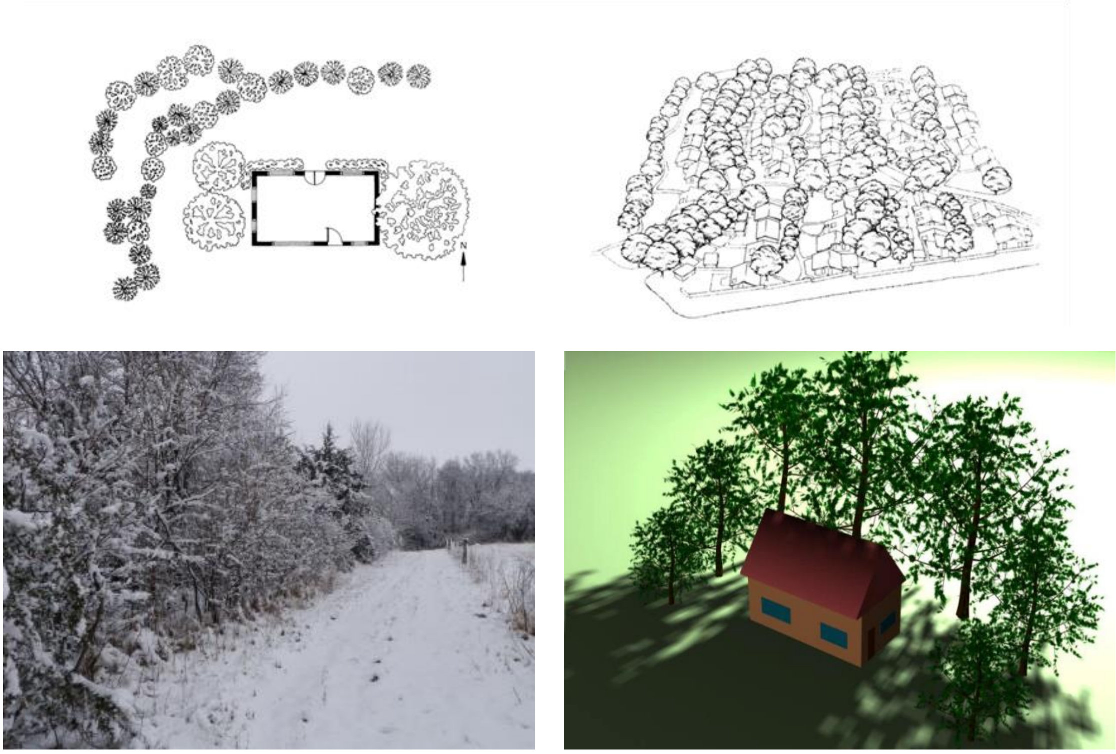
In the summer, trees on the north side of a building increased electricity use by 1.5% and trees on the west and south sides reduced electricity use by 5.2% in the quite hot climate of Sacramento, California [7]. Trees planted on the west side of residential homes provided the best net effect with savings from reduced cooling costs. As estimated, a 31% reduction in carbon emissions can result from strategic tree placement on properties surrounding homes. Another study [9] likewise found home energy savings from solar irradiance and wind speed reductions by shade trees in the north-eastern United States.

In hot, sunny climates summer shade is the most effective for energy savings, while in cold climates reducing wind speed and passive solar gain provide the greatest savings. Scattered trees throughout a residential neighbourhood have the effect of one large windbreak in reducing wind speeds. Solar irradiance interception of medium-sized deciduous trees can be 80% interception in summer and 40% interception in winter. For maximum energy savings in cold climates of the Northern Hemisphere, it is recommended [21] to plant deciduous trees on the west and east sides of homes, no trees on the south side, windbreaks on the north and west, plantings to shade air conditioners, and an overall increase in tree canopy over communities.

2.2. Planning for neighbourhood

In combination with renewable energy sources, however, the fact can be pointed out that solar access or blockage is important considering that even minor shading of photovoltaic (PV) systems will cause a significant reduction in producing electrical energy. Building construction and insulation levels are also important determinants of energy use; better insulation techniques and products decrease energy use [12]. Trees have not always been found as the most successful strategy to reduce energy use. Well-insulated homes, conservation measures, and energy efficiency are also important and in some situations the most successful strategy to reduce energy use [16]. Based on these considerations, some authors suggest even an optimum landscape concept for a temperate climate in the Northern Hemisphere (with winter wind predominantly from the west and northwest) (Figure 3a) [8].

Solar access laws are generally concerned with two problems: shading of property by structures, and shading by trees [15]. In line with examinations that even deciduous trees in winter can intercept 25 to 60% of solar radiation [30], some authors have used computer modelling [26], with the result that rows of deciduous trees to the south of houses with solar collectors constituted an energy penalty in all but the hottest climates, and recommend that communities with widespread or increasing use of solar collectors reexamine their tree-planting policies. They also proposed a mature tree canopy plan for a solar access neighborhood, as depicted in Figure 3b.



a b

Figure 3: Wind shading (a)[1] [8] and insolation control (b)[2] [26].

2.3. Mitigating the heat island effect

An optimum planting strategy for a city to arrange tree canopy in a proper way can help to reduce also the heat island effect seen in urban areas (Figure 1.b). Computer simulations predicted [1] that increasing the tree cover by 25% in the cities of Sacramento, California, and Phoenix, Arizona, will decrease the 2 pm air temperature in July by 3.3 to 5.6°C. Comparing several studies the average values were found [5] that urban areas are 0.5 to 1.5°C warmer in temperate latitudes and 3°C warmer in tropical climates compared to the surrounding countryside.

Field data on urban trees and land cover maps, through modelling of tree effects on building energy use and pollutant emissions [17], led to the results that energy and pollutant costs in the continental United States can be spared in the scales of a yearly $4.7 billion from electricity use reduction, $3.1 billion from savings of heating use, and $3.9 billion from avoided pollutant emissions. The calculated average reduction in residential energy use due to trees is 7.2 percent, which can be further increased by specific designs.

Beyond the design of buildings' surroundings on city-wide and individual buildings' scale, there are possibilities to green the buildings themselves, considering the below solutions and technologies.

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[1] Photo: https://plantsandpests.files.wordpress.com/2013/12/windbreakwinter-jan-hygnstrom.jpg?w=560
[2] Photo: http://www.greenandpractical.com/shade2.jpg

3. Biomass covering buildings

3.1. Greening of buildings

The use of horizontal and vertical greening has an important impact on the thermal performance of buildings and on the effect of the urban environment as well, both in summer and winter. Plants are functioning as a solar filter and prevent the adsorption of heat radiation of building materials extensively, among various other benefits: e.g., green roofs offer rainwater retention and detention as well as improvements in microclimates, urban habitats, and the performance of the host buildings.

Horizontal greening solutions of buildings (green roofs) are easier to understand, since these have many similarities with normal, horizontal green spaces and gardens. Green roofs provide many benefits regarding energy savings and energy efficiency. These roofs reduce cooling loads, by reducing the temperature of the roof surface by shading it and by evapotranspiration. The surface of a green roof, and thus the air directly above the green roof, will be significantly cooler than the surface of a traditional roof and the air above the traditional roof. This reduces the heat island effect of urban areas. A green roof protects the roof membrane from damage caused by sun and storms, and a green roof can create a park-like environment for people to use directly or use by looking onto the greenery. In winter or in cooler climate, an additional soil layer acts as an insulation against cold temperatures. Historically, examples of grass growing soil layers can be found even on top of prehistoric cave homes as well as on the roof of ancient Norwegian houses.

Applying green façades is not a new concept either; however, it has not been thoroughly examined as an energy saving method for the built environment. Vertical greening can provide a cooling potential on the wall surfaces of a building, which is very important during summer periods in warmer climates. In colder climates, evergreen species create an external insulation layer and contribute to energy savings, decreasing heat loss.

3.2. Green roofs

Green roofs have at least threefold benefits as regards energy management, air quality improvement and rain water control [3].

Green roofs reduce energy use in buildings. The thermal mass of the green roof provides a slight reduction in the heating load through the roof, but the reduction in cooling load through the roof is more prominent in a hot summer, especially when the growing medium is wet. This can approach a 75 percent reduction.

Green roofs take in carbon dioxide and give off oxygen, and can make modest reductions in air pollutants like particulate matter, NOx, SOx, CO, and ground level ozone. A ~100 square meter green roof can absorb the particulate matter produced by 15 cars over a year's time.

Green roofs absorb rain water and hold on to it for a while. More water is contained in a deeper intensive green roof than in a thin extensive green roof. Evapotranspiration puts some of the water back into the atmosphere, providing additional cooling effect on the roof.

Figure 4. The California Academy of Sciences building[3]

The California Academy of Sciences building in Golden Gate Park in San Francisco, has a ~ 1 ha green roof (Figure 4). This is covered by a mix of native annual and perennial plants [29]. Rainwater is used for irrigation. There are 60,000 photovoltaic cells mounted on an overhang that surrounds the building and 90 percent of the occupied areas are naturally illuminated.

As regards green roof types, their three main types - extensive, intensive and productive green roofs - differ in their concept, as well as the vegetation used, investments and gains, operation and maintenance, and building energy conservation effects. As regards their structure and layers, the main difference is in the depth of the fertile soil top layer (Figure 5). Extensive green roofs have plants that are drought tolerant and can live on rain water only, and their roots can live even in a shallow soil layer. Intensive green roofs are built to produce more vegetation, but their plants need increased soil depth and, depending on local climate conditions, even regular irrigation. Productive green roofs need even more soil, more irrigation and more human labour as well, since these are intended to produce food.

As the illustration below depicts, plants are grown in the substrate (soil) layer of the green roof, which covers the roof continuously. The substrate layer retains water and anchors the plants of the vegetation layer, while a drainage layer evacuates or stores excess water. A waterproofing membrane and root barrier separate these water-carrying layers from the actual roof structure, which consists of an insulation layer and the roof slab or structural support.

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[3] Photo: http://www.calacademy.org

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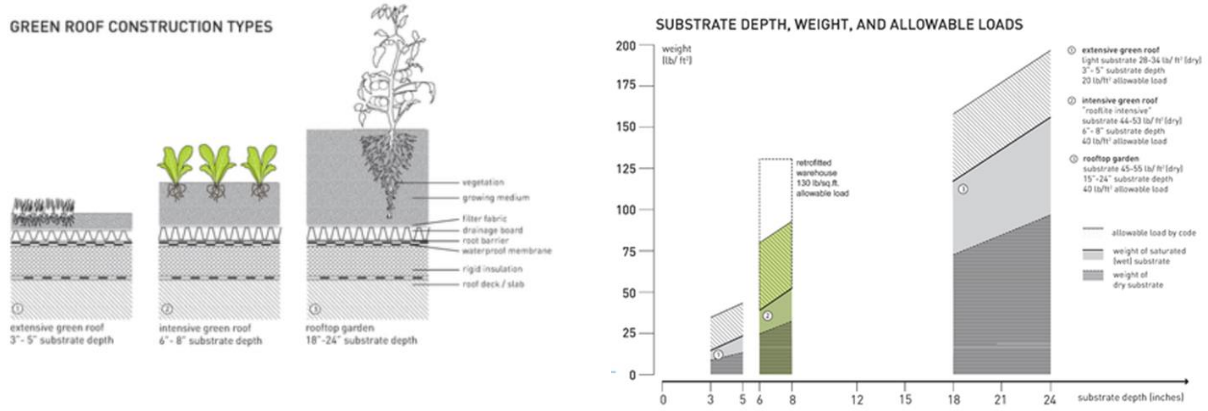

a b

Figure 5. Construction (a) and roof load (b) of the three main green roof types [20]

Rooftop gardening transforms underused urban roofs into new vegetated areas. They especially benefit dense urban areas and warehouse districts that lack adequate space and infrastructure for ground-based urban agriculture and green spaces, adding the benefits of food cultivation in the city, to the other environmental benefits that green roofs offer.

Besides rain water utilization and eventual irrigation of green roofs, several urban agricultural projects have developed closed-loop systems that circulate water through different stages of plant irrigation, purification, and fertilization. These self-sustaining, water-efficient growing systems can be integrated into building systems to maximize resource efficiency, further expanding their benefits and synergies with the built environment.

3.3. Green walls

The sides of a building can be as green as its roof or surroundings. However, the names of the different vertical greening concepts may need some clarification. Concepts and designs of building-integrated Living Walls, Green Façades, Vertical Gardens or Vertical Farms differ from each other [2]. Green walls as "vegetated building envelope systems," can be divided into green facades, and living walls (Figure 6). In case of green facades, historical direct facades consist of a bare wall covered with some climbing plants, whereas indirect façade systems include a structure fastened to the wall that provides a trellis for vines and climbers planted in the ground or in containers. The newer living walls are basically a modular grid of wall panels attached to the building – consisting of modules complete with live plants and a conventional soil or layered-felt growing medium, an irrigation and nutrient-delivery system, and a support structure.

Figure 6. Direct (a) and indirect green façades (b), and a living wall ('vertical garden') system (c) [18]

Given that gardens serve either ornamental, decorative purposes (Figure 7a) or food production, a living wall can look like a beautiful collection of wildflowers, ferns and ground covers, as well as a likewise interesting, but edible composition of lettuce, onion, radish, or other vegetables (or fruits like strawberry). These can be called vertical farms (Figure 7b,c). Although this is not to be confused with the concept of the hypermodern equipment growing food plants several stories high within the inner part of a building, using only artificial light, the same term applies to both the building-enclosed system and the facade-mounted one.

Figure 7. 'Vertical gardens': ornamental and cultivated living walls: Le Mur Végétal, or plant wall, at Quai Branley Museum, Paris (a) [2], and the vertical farm of the USA pavilion at Expo Milano 2015 (b[13], (c)[11])

The environmental and economic sustainability of vertical gardens enclosed in dark building interiors is debated. Facade-integrated living walls look more natural. At Expo Milano 2015, the proof that vertical farming is feasible was seen in the USA pavilion, where an entire wall was used to install a green surface of vertically-grown crops in modules that rotate through 90 degrees. The "fully-farmed frontage" was designed to cover nearly seven hundred square metres, not just for its great visual impact, but to present to visitors a concrete solution for the future to the problem of food production, remembering also that plants are particularly good at considerably lowering the quantity of pollutants in the air.

The benefits of vertical greening concepts of green facades, be as productive as a living wall, are due to their thermal behaviour [18], due their shading, wind barrier and thermal mass features.

Vertical greening systems are effective natural sunscreens that reduce the surface temperatures behind the green layer compared to the bare façades.

These systems act also as a wind barrier: inside the foliage of the direct and indirect systems and inside the air cavity of the LWS a low (respectively 0.08 m/s and 0.1 m/s) wind velocity can be measured, and the reduction of the wind velocity affects the thermal resistance of the building envelope and thus its efficiency. However, a higher wind velocity found inside an air cavity of 20 cm thickness of the indirect greening system demonstrates that it is also possible to speak about an optimal air cavity thickness for greening systems (around 40–60 mm), which can ensure a stagnant air layer.

In case of living walls, even the soil (substrate), the material (HDPE) of the modules containing plants and substrate, and the supporting structure, adds an additional thermal mass and insulation in front of the original wall. An “extra” created air cavity can be added as well to the benefit of the wind velocity reduction due to the foliage.

Cost-Benefit Analysis of the economic sustainability over the life cycle of two combined greening systems, vertical greening and green roof, installed on an Italian office building, revealed [19] that the tax incentives and the combination of green systems can make the installation and the maintenance costs economically sustainable during the life span of a greening system.

These benefits have to be added to the multi-functionality of vegetation for the urban environment, with respect to the increase in biodiversity, mitigation of urban heat island effect, reduction of air pollution, production of biomass and the social and psychological wellbeing of city dwellers.

On building scale, computational research has evaluated the integration of solar systems and vertical farming systems into tropical buildings’ envelope, using five performance indicators like solar energy (electricity) and farming potential as well as façade design’s impact on indoor daylighting, shading and thermal conditions [24], with multi-criteria decision analysis (MCDA) method, final optimal façade design being selected for four types of facades integrating PV and farming systems for north and south orientations.

As regards the city-scale possibilities of vertical farming, another study has explored the potential self-sufficiency in terms of food and energy in Singapore, based on sunlight availability, computations showing that plot ratio and building height had the highest impact (site coverage had less), while all facade orientations have food and energy harvesting potential in low-latitude regions [25], also adding that the available farming and PV area in relation to the total population had more influence on self-sufficiency than the reduction of sunlight availability due to building typology and morphology.

4. Biomass as an energy source for urban energy management

The more energy efficient is the building envelope, or a city in a whole, the more efficient is the use of energy sources, like biomass fuels. After all the above energy conservation and energy efficiency measures are taken, the same size of a biomass fuel conversion equipment can supply a greater share of the building’s or a city’s energy demand. Alternatively, a smaller size of the biomass fuel conversion equipment, and a smaller amount of the related investment, is needed to cover all the (remaining) energy needs.

Biomass from urban spaces consists mainly of municipal and industrial wastes and wastewater, and to a smaller extent, of biomass residues from maintenance of – horizontal and vertical -green areas. The two main groups of urban biomass waste are dry and wet biomass.

Wastewaters and easily biodegradable food residues as well as green plant material (e. g. grass clippings) can be used as substrate for anaerobe digestion (Figure 8a). When converted into biogas production, these can serve even as vehicle fuel. A former study investigating the local possibilities of biogas as fuel for public transport has evaluated the local sources of biogas, the sewage treatment plant and the landfill gas from the waste disposal site with the result that both are principally good for vehicle fuel (although used for other purposes). Solid remainders of the digestion can be used as fertilizer, or, if no other uses are available, these can be pressed, dried and used for generating heat as other types of solid biomass.

a b

Figure 8. Urban biomass energy examples: sewage sludge digesters [4] and waste incineration plant[5]

As regards the energy use of the constantly re-generated municipal solid waste and its considerable biomass (carbon) share, waste incineration plants (Figure 8b) can provide solution. As a study highlights, waste utilization and waste prevention should not contradict each other [27]. Countries that have high waste incineration rates also achieve the highest recycling rates, e.g. the Netherlands, Switzerland, Austria, Germany and the Scandinavian countries. Common base feature of their policies is that they have sharply restricted or even banned landfill as a cheap disposal route, for example by taxes, or prohibiting legislation. Whereas waste reduction is a matter of material efficiency of manufacturing and of altering of consumer behaviour favouring products including less waste within their life cycle, waste incineration remains an important tool for disposal security and energy recovery in a recycling economy based on material and resource efficiency.

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[4] Photo: https://www.flickr.com/photos/brianhayes/313512627

[5] Photo: http://www.staedte-fotos.de/1024/muellheizkraftwerk-wuerzburg-28042012--34771.jpg

Conclusion

Regarding massive global urbanization trends and the heat island phenomenon in a larger urban environment, the conclusion can be made that urban energy management is and will be more and more important. To handle the energy problems in urban settings as sustainable as possible, energy management measures and improvements should follow the energy hierarchy, starting with demand-side energy conservation and then energy efficiency, followed by the supply-side renewables, low-carbon technologies and more efficient conventional energy generation.

Greening the environment of buildings, that is, implementing a proper design of surrounding biomass can have considerable energy conservation effects, as improvement of individual building's envelope's thermal performance as a wind barrier and a solar filter, as well as effective tool against the heat island effect of cities, also decreasing the thermal performance needs of individual buildings.

Biomass in building envelopes can significantly add to its energy efficiency. On one side, green roofs reduce cooling loads, by reducing the temperature of the roof surface by shading it and by evapotranspiration. The more intensive the type, from an extensive to a productive green roof, the thicker the additional insulation layer it represents on the roof. Productive green roofs are pioneers of urban farming. On the other side, vertical greening can provide an effective natural sunscreen, and insulating air layer, that reduce the surface temperatures behind the green layer in summer in warmer climates. In colder climates, evergreen species create an external insulation layer to decrease heat loss. Green façades also act as wind barriers. However, indirect greening system have an optimal sizing of their air cavity in order to prevent higher wind velocity between the bare wall and the green layer. More than direct and indirect green facades, living walls add additional thermal mass and insulation layers to the buildings' envelope.

The last step in the order of the energy hierarchy is renewable energy. Biomass energy is regarded in this paper not only because this is the simplest way to store solar energy for cold seasons, but also because greening measures – city greens, green roofs, green walls - provide organic matters for biomass fuels periodically, after the lifetime of their living components. Wet and dry biomass can be processed through biochemical and thermochemical conversion technologies, in urban context, anaerobic digestion processes of sewage sludge treatment and municipal waste incineration of dry organic waste.

Considering these possibilities, the conclusion can be drawn that biomass can and should play an important role when designing energy management measures for urban buildings and settlements.

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