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UTILIZATION OF RENEWABLE NATURAL RESOURCES WITHIN THE FRAMEWORK OF THE GREEN BUILDING CONCEPT

Annotation *In modern times, urbanization process plays a significant role in the evolution of humanity. The increasing urban population results in the explosive expansion of cities. The majority of world population is expected to be represented by urban dwellers. In accordance with the provisions of the United Nations Commission on Sustainable Development nature-friendly technologies of solar and wind energy, water supply and vertical greening systems may be regarded as considerable components of sustainable development whose high-priority objective is satisfying the needs of the modern society and future generations without exposing them to danger. Management of sustainable development is, certainly, the prior task in planning smart cities. The paper studies prospective of utilization of the major sources of renewable natural resources (water, sun and wind energy, accompanied with bio walls) integrated within green building concept.*

Key words: *wind turbines, water management, solar windows, vertical greening systems, green buildings, smart city, power utilization.*

Анотація. *Сьогодні процес урбанізації відіграє значну роль в еволюції людства. Зростання кількості міського населення призводить до швидкого розширення міст. Очікується, що більшість населення світу буде представлено міськими мешканцями. Відповідно до положень Комісії зі сталого розвитку ООН, екологічно чисті технології сонячної та вітрової енергетики, систем водопостачання та вертикального озеленення можуть*

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розглядатися як вагомі компоненти сталого розвитку, чиїм першочерговим завданням є задоволення потреб сучасної суспільства та майбутніх поколінь. Управління сталим розвитком, безумовно, є першочерговим завданням у плануванні «розумних міст». У роботі розглядаються перспективи використання основних джерел відновлюваних природних ресурсів (води, сонця, енергії вітру, та біостинами) інтегровані у концепт зеленої будівлі.

Ключові слова: *вітрові турбіни, управління водними ресурсами, сонячні вікна, системи вертикального озеленення, зелені будівлі, розумне місто, використання енергії.*

Аннотация. *Сегодня процесс урбанизации играет значительную роль в эволюции человечества. Рост городского населения приводит к быстрому расширению городов. Ожидается, что большинство населения мира будет представлено городскими жителями. Согласно положениям Комиссии по устойчивому развитию ООН, экологически чистые технологии солнечной и ветровой энергетики, систем водоснабжения и вертикального озеленения могут рассматриваться как веские компоненты устойчивого развития, чьей первоочередной задачей является удовлетворение потребностей современного общества и будущих поколений. Управление устойчивым развитием, безусловно, является первоочередной задачей в планировании «умных городов». В работе рассматриваются перспективы использования основных источников возобновляемых природных ресурсов (воды, солнца, энергии ветра, и вертикального озеленения) интегрированные в концепт зеленого здания.*

Ключевые слова: *ветряные турбины, управление водными ресурсами, солнечные окна, системы вертикального озеленения, зеленые здания, умный город, утилизация энергии.*

The Problem The expansion of cities creates a lot of problems and challenges for contemporary city planners and architects around the world. Such changes in modern demographic processes require corresponding modifications in approaches to construction. All these challenges are aimed at achieving better standards of living, making people's lives better and easier. Such challenges should be the prior task for modern society, national and international organizations.

Green building concept is a component of the eco-friendly structure of environmentally favourable construction aimed at improving health and life standards of Smart cities. Green skyscrapers are crucial in the development of new intellectual systems regulating the activities of citizens and combining various communication technologies with reasonable utilization of natural resources which, as a result, form integrated sustainable networks.

The purpose of the present paper is to investigate the prospective of utilization of the major sources of renewable natural resources (water, sun and wind energy, accompanied with bio walls) within green building concept.

Review of Publications Modern urbanization processes play a significant role in the evolution of humanity. The increasing urban population results in the explosive expansion of cities. The majority of world population is expected to be represented by urban dwellers (i.e. the urban population will be increasing faster than world population in general). According to forecasts by 2050, 66 per cent of the world's population will live in cities. Compared to the current year this rate is about 55 per cent. To manage city's assets the new forms of urban development visions and concepts should be provided.

Most metropolises and utilities want to get smarter. They consider the smart cities movement as providing more than some significant improvement. The concept of smart cities became very popular during the latest decades and now it is widespread all over the world. Today Smart City also has a special focus on energy and mobility in conjunction with the use of modern ICT for climate protection (low carbon) and quality of life. Challenges of climate change and demographic development also play an important role.

Management of sustainable development and efficient energy utilization are, certainly, the prior tasks in planning smart cities. It is urgent to find not only new theoretical approaches, but also a new methodology while planning the purposes of sustainable development. Technological advancement of the latest decades in the establishment of new materials, resource management, and information and communication field served as the foundation of sustainable development and gradually have become more and more popular. Nevertheless, such innovations and initiatives still do not have enough consistency, complexity, justification in setting priorities in the development strategies and so on.

Problem Setting We propose to combine major sources of renewable natural resources: water, sun and wind energy, accompanied with bio walls. Then consider in detail the elements of the system of utilization of renewable natural resources under the green building concept (Fig. 1; Fig. 2):

1. *Solar windows as potential solar power generators:* the technology of transparent photovoltaic cells permits visible light to enter the interior of a building, thus producing electricity and providing other benefits;

2. *Wind energy utilization:* prosperous source of renewable energy ensures high-level performance, eco-friendliness and zero operational costs;

3. *Water management* as a key solution to the water scarcity problem: water recycling – the reuse of water that cannot be potable anymore; water harvesting – capturing rain when it falls or seizing the run off in villages or towns;

4. *Vertical greening systems:* modern architecture is focusing on systems as a way to restore the environmental urban integrity, biodiversity, and sustainable development.

The Main Results of the Research

The first element of the green building concept is solar windows. To begin with, we would like to emphasize that those windows will be transparent due to the successful efforts of scientists and alternative energy companies, so they will not affect the general view or the amount of light absorbed by the inner space of the skyscraper. Secondly, utilization of solar windows can help increase energy production significantly with less space being exploited compared with solar panels that need a lot of room and sometimes are difficult to be taken care of. Furthermore, buildings will generate electricity that eventually can be used not only to satisfy the needs of this particular edifice, but also in other buildings of the city as well. Solar power windows will reduce bills for heating the building, because they act as a thermoshield, which protects the building from being cooled, especially during cold periods. In addition, such solar panels are not difficult to install, which will reduce installation costs. That is very crucial taking into account the fact that most skyscrapers do not have a lot of roof space for regular solar panels.

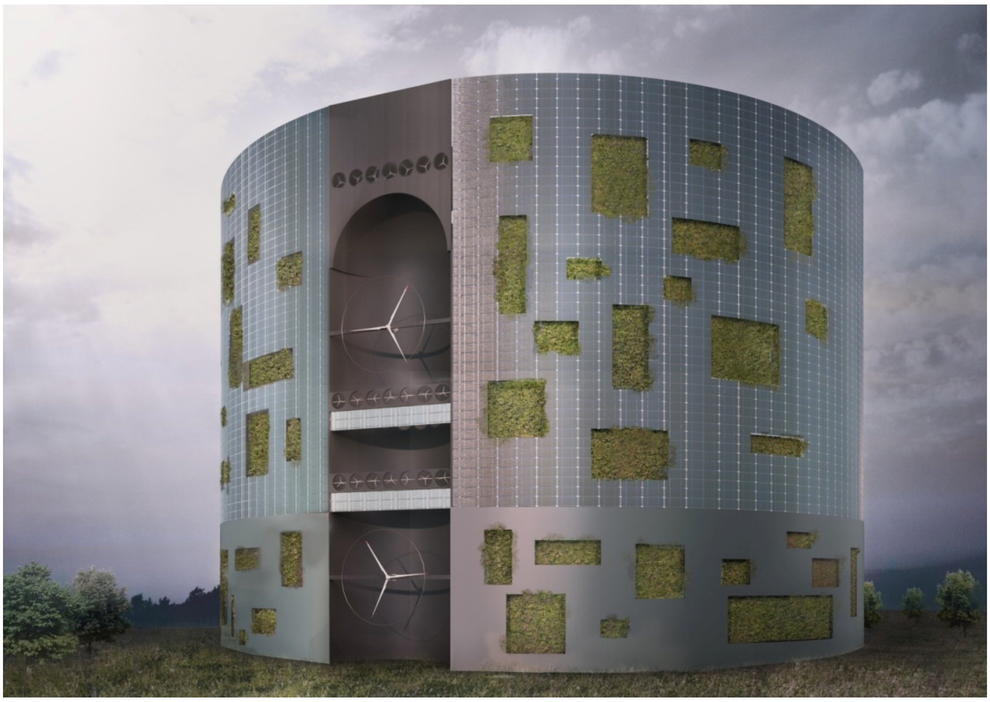

Figure 1 The front of the building

Source: Concept created by the authors.

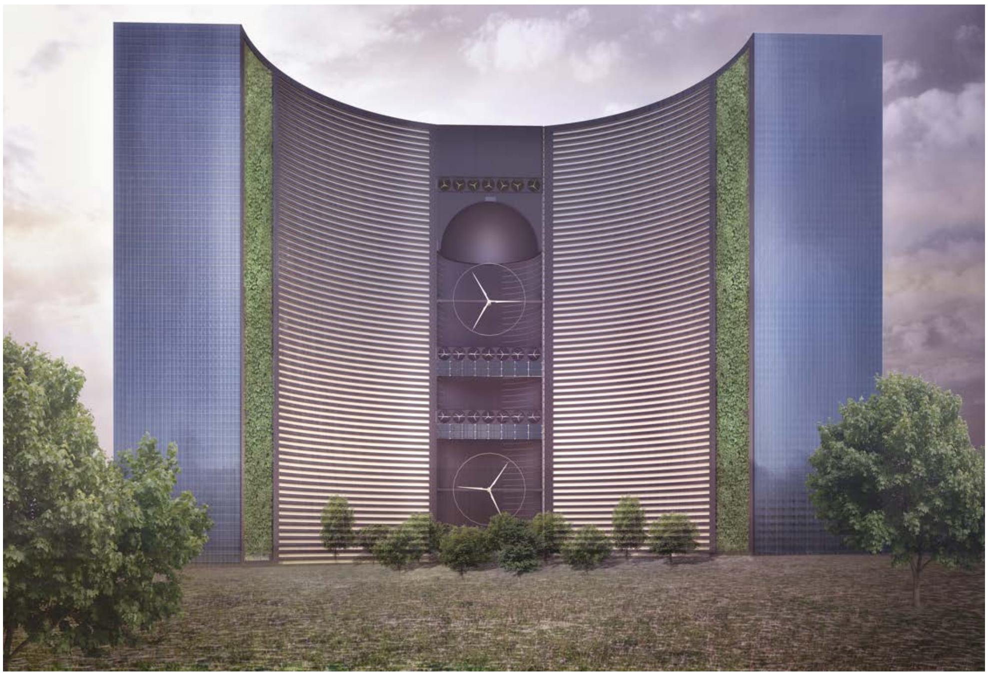

Figure 2 The rear of the building

Source: Concept created by the authors

Solar Windows as Potential Solar Power Generators: Technology Overview

Considering the great amount of solar energy that penetrates the Earth's surface every day, we think it is of the greatest importance to ensure the utilization of this power source. The benefits of solar energy are obvious: it is renewable, clean, abundant, free and eternal. A lot of countries have been using this source of energy successfully. Countries with the most solar power capacity include Belgium, South Korea, Australia, USA, Spain, France, Italy, Japan, China and Germany (the last three are reported to produce the largest amounts of solar power in the entire world).

Conventional solar panels are not efficient enough because they suck up only 37.5% of sunlight (Hantula, 2010). That is why the idea of installing solar generating windows is gaining popularity now due to the growing importance of the Smart City concept.

Recalling the fact that the number of skyscrapers is growing exponentially, we consider them a great place for windows that are solar energy generators. A lot of research has already been done in the sphere of this alternative energy source.

In one of them, a start-up 'Ubiquitous Energy' from Massachusetts states that commercial buildings have more space to be used comparing with roofs. Richard Lunt, Vladimir Bulovic and Miles Barr (2013) discuss new transparent photovoltaic cells that can be placed on any surface. The scientists also claim that about 50 % of solar energy is represented in infrared light, while 10 % is in the form of ultraviolet. Their technology permits visible light to enter the interior of a building, thus less artificial light is needed. Special solar cells in such windows selectively transmit light that is visible to human beings while soaking up the infrared and ultraviolet kinds of light. The structure of such windows is quite simple: the thickest layer is the glass, plastic or other transparent material, then there are several layers of PV coating: two of them absorb sunlight, interact and create energy to flow to special electrodes that are connected with circuits which help the current go out of the device. In addition, anti-reflective coatings can be utilized on both surfaces of such a window to decrease the probability of reflection because reflected light does not travel through this device.

Advantages of using the solar cells are astounding: windows in skyscrapers, for instance, provide a huge vertical area that is exposed to light during morning and early evening. In one experiment carried out by the aforementioned professors the team calculated that if all these windows had special transparent solar cells – even with 5% efficiency – the power generated by them would cover about 25% of the electricity needs of one skyscraper. Furthermore, such solar cells could block a lot of infrared light thus reducing costs for air conditioning. All these benefits can be acquired without destroying the design of the building.

Merck, the German company, is to cooperate with Polysolar, a huge building-integrated photovoltaics producer for the Power Generating and Energy Saving Windows Project (Andrews, 2016). The project will operate in terms of the concept of zero carbon buildings by developing transparent solar windows that can generate power and regulate temperature. It will be based on the trials by partners to develop viable power-generating windows using photovoltaic technology. Also, the company sees lisicon (lithium super ionic conductor) as a key photovoltaic element, because it is flexible and robust. Merck also emphasizes the idea of Building Integrated Photovoltaic (BIPV). The company is currently working on innovative materials to ensure creating facades and solar-activated windows.

Polysolar (England) has invented solar power window coating that allows letting in visible light while absorbing sun rays for creating electricity. They use a special active material, a colorless absorbent layer, which can be printed. This method has a definite advantage: it can be printed in any shape, size, using different types of glass. At the same time, it can work even with lower levels of sunlight, which augments its efficiency. In addition, such panels can be placed on vertical surfaces of skyscrapers and all light (ambient and reflected) is absorbed, so the position of such solar panels is not as significant as for original solar panels that have to absorb a lot of direct sunlight.

The commercialization of the Power Generating and Energy Saving Windows Project will decrease energy costs of skyscrapers while giving architects a lot of freedom in pursuing their own ideas. Transparent solar panels are not difficult to install on windows and roofs; at the same time, they are lightweight, low-cost and quite durable.

Solar Window Technologies in the USA has recently announced that the usage of its technologies would cover all the costs concerning the development and installation of special solar energy windows (Mearian, 2015). Consequently, they will pay for themselves in a year, while generally solar panels need 5 to 11 years in order to pay off. Another advantage is that they can be installed on existing glass surfaces thus decreasing adjustment costs as well as they can produce electricity even in shaded places comparing with conventional solar energy systems. The coating developed by this company applies only non-toxic materials, such as hydrogen and carbon and it can be attached even to flexible foundation, for example, made of plastic. In general, Solar Window Technologies utilize a new form of transparent photovoltaic cells that facilitates construction, replacement and repair of existing windows.

Another American company Next Energy Technologies claims that it can produce viable solar windows that combine aesthetics and high level of performance (Hayden, 2016). Those windows will use abundant materials and low-cost production methods. In addition, their solar windows will be transparent enough and can be incorporated in dual-pane windows, which eliminates costs concerning encapsulation costs. In designing such innovative solar power systems, Next Energy evaluates the site of the building, its orientation, utility rate of a particular area and weather conditions. According to representatives of Next Energy, the product will pay for itself in a year and can work for 30 years. The transparent solar window coating is printed onto glass while the panels are being produced and it consists of photovoltaic organic compounds.

Recent studies have discovered that by incorporating subatomic particles we can increase their performance. For example, some solar power batteries use super small components called nanowires. They concentrate sunlight and send it to photovoltaic cells augmenting efficiency 15 times. In addition, now researchers are capable of turning photovoltaic cells into thermophotovoltaic cells (Lombardo, 2014).

The team of scientists at Berkeley has discovered a special material that can capture both light and heat. That is very important because traditional solar systems lose about 90 per cent of heat. The main advantage of these cells – quantum dots – is that they are very small, there can be 50 atoms of such dots across regular double-paned windows, and you cannot even see them due to their transparency (Zheng, Ji, Yu and Wang, 2016).

In conclusion, despite some disadvantages concerning the exploitation of solar windows on skyscrapers, they have definite advantages: adaptability, low-cost and growing efficiency which promotes the success of their employment for practical purposes in the nearest future while creating Smart cities.

Perspectives of Wind Energy Utilization

Wind has long served as a power source to humans. From the Netherlands to farms in the United States, people have utilized windmills for pumping water or grinding grain. Today, windmills have a modern equivalent – a wind turbine – it can generate electricity from the wind energy.

Wind turbines, like aircraft propeller blades, convert the moving air into power for an electric generator that provides electricity. In brief, a wind turbine is completely different from a fan. While the latter utilizes electricity to make wind, wind turbines use wind to produce electricity. The wind turns the blades, which spin a shaft, which is connected to a generator and makes electricity.

The wind energy installed in the world grew 12.4% in 2016 up to 486.749 MW according to Global Wind Energy Council (GWEC) data. China, the USA, Germany, India and Spain are the main world producers of wind energy. Industry experts predict that if this pace of growth continues, by 2050 one third of the world's electricity needs will be covered by wind power.

The most powerful wind turbines generate enough electricity annually (about 12 megawatt-hours) to supply about 600 homes (Nelson, 2013). Wind farms have a lot of turbines grouped in specifically windy spots. Smaller turbines constructed in a backyard can generate enough electric supply to serve the needs of a particular family or small enterprise.

Wind is an alternative source of energy that causes no air or water pollution. And since the wind is free, expenses concerning its maintenance are nearly zero as soon as a turbine is built. That is why this source of energy is considered a promising one in the development of the Smart City concept.

Wind energy technologies can be divided into two categories – macro and micro wind turbines. The first type is used for huge power production such as wind farms, and the second type is utilized for household electricity production. Micro wind turbines are appropriate for application at the construction scale and are called ‘building-integrated wind turbines’ (Nelson, 2013).

Disadvantages involve complaints from locals that wind turbines are perilous and loud. The slowly rotating blades can also damage birds and bats, but not as many as cars, electricity cables and tall buildings do. The wind is also changeable: if it is not blowing, no electricity is being produced.

To be more adaptable for integrating into buildings, micro wind turbines are also being designed to be more visually attractive, without compromising their performance. One more purpose is to diminish noise arising from blade rotation and generator noise. This can be attained by using low-noise blade designs, vibration isolators, and sound absorbing and reducing materials around the gearbox and generator (Heier, 2014).

Modern improvements in creating integrated wind turbine technologies involve higher reliability, increasing performance at low wind speeds and lowering capital cost. Wind turbine blades are now designed with lightweight materials and aerodynamic principles, therefore they are sensitive to small air movement.

These technologies involve the following pattern: a wind turbine should be settled in the middle of the roof above the turbulence layer (to be efficient enough a wind turbine has to be exposed to wind at speeds above 5 miles per hour). The closer a turbine is placed to the roof’s edge toward the prevailing wind the lower the turbine can be situated. A lower height mast is beneficial in terms of expenses and height limitations. This is true if the period of time when the wind blows from other directions than the prevailing one can be neglected. The location of the turbine also depends on the direction of wind streams, their volume and variability (Nelson, 2013).

There are a few examples of successful wind energy projects integrated into the design of commercial buildings, especially skyscrapers.

For instance, Strata SE1, nicknamed ‘Razor’, is a 43-storey building in London. Strata SE1 is one of the first skyscrapers in the world to make wind turbines a part of its construction. The three 9-metre wind turbines on the roof are rated at 19 kW each and are expected to generate a combined 50MWh of electric power annually. They are supposed to produce sufficient energy to provide power for the common areas (8% of the energy needs of the building). It shows productive wind energy application in such a densely populated space as London. The architects strived for developing a building to meet the sustainability goals and promote the Smart City concept. Simultaneously, wind turbines do not interfere with the image of the building and do not create noise for its occupants (Chino, 2010).

The Bahrain World Trade Centre serves as an appropriate example of building-integrated wind turbines in a large-scale business construction application. This tall building incorporate three horizontal-axis wind turbines, each with a 29m rotor diameter, into sky-bridges connecting two 50-storey towers. The total costs for the wind turbines were estimated to be nearly 3.5% of the total project cost. The three wind turbines generate between 1,100MWh to 1,300MWh annually, meeting about 11% to 15% of the building’s electricity demands (Chapa, 2007). The special shape of the towers would direct the airflow through the turbines. Square buildings interrupt the continuous flow of air and create turbulence which reduces wind turbines performance and lead to their premature failure. Thus, structures that comprise turbines need curved surfaces to keep the wind flowing directly towards the blades. A wind turbine incorporated into the area between the two towers brings about a 25 % more efficient performance than a free standing device. The footprint of each tower creates an airfoil form that speeds up air flows over the turbine and stops turbulence. By centralizing the wind, constructions can improve the performance of wind turbines (Chapa, 2007).

Researchers at Hong Kong University and Lucien Gambarota of Motorwave Ltd. proposed Motorwind, a mix of micro wind turbines connected along a horizontal axis. Motorwave's micro wind turbines are not heavy, compact of 25 cm rotor diameter, and can produce energy with wind speeds as low as 2 meters per second. According to tests, turbines aligned within a surface space of one square meter and a wind speed of 5 m/sec generate 131 kWh/yr. Plans for the Hong Kong Sea School are to place 360 micro turbines encircle an area of 20 m^2. Consequently, such turbines may be added in those places where there are no strong winds or they tend to change their direction quite often (Heier, 2014).

To sum it up, the whole idea of using wind energy seems to be very promising. We assume this is a great source of renewable energy with profound advantages, such as high-level performance, infinity, compatibility with the overall design, eco-friendliness and zero operational costs connected with installation. Furthermore, its adaptability, simple integration with buildings and availability make wind a reliable alternative to conventional energy sources.

In general, we propose to locate wind turbines in the central row of the structure starting from the 20^{th} floor because wind streams are not strong enough below this line and installing wind generators there will be insufficient. On the other hand, beginning from the 20^{th} floor wind turbines will be able to generate a lot of energy because the main wind flows will be directed towards the central part of our semicircular edifice (towards the windy side which should be determined based on the wind rose for a particular region). Regarding the efficiency and compatibility with a general system, we think it is better to use wind turbines with 5 blades:

- 5-blade wind turbines will increasingly refine annual energy production in low wind conditions, especially for areas with average wind speeds of 5 m/s. Consequently, there will be a 60-per cent increase in the annual energy production.
- 5-blade wind turbines can dramatically improve the safety and reliability of such wind power producing systems. These turbines will also eliminate the chance of over-speed control malfunction. In the long run, it will diminish the costs concerning the depreciation of wind turbines.

- the lower blade rotation speed of 5-blade turbines will reduce the noise level in such buildings. As a result, they will be friendly to occupants and will not hamper usual operations taking place in residential areas.

The next location of wind turbines could be the last storey of the skyscraper. We assume it would be reasonable enough to commit the whole floor to wind energy production, in particular due to the fact that atmospheric turbulence augments with altitude. Therefore, constant wind power production would be provided. In addition, we consider the location of special micro wind turbines on the top of the building because they are accessible, low-cost and do not need special maintenance.

Water Management as a Key Solution to the Water Scarcity Problem

Considering the feasibility of depletion of water resources in the nearest future, humanity is currently working on some projects to save this priceless resource. We strongly believe that water recycling systems and water harvesting used in green buildings are key solutions to this problem. In fact, water and power are closely related: it means that by saving water we save energy. Water usage is reported to be the biggest energy consumer. Nowadays, we find greywater recycling systems quite productive, especially taking into account their lower energy exhibition and maintenance costs. However, we need to ensure that inhabitants are not exposed to any hygienic risks.

In most cases, commercial buildings utilize drinking water for different purposes, while some applications (fountains, toilet flushing and irrigation) do not need that. Water recycling is about the reuse of water that cannot be potable anymore. It can significantly decrease use of potable water without austerity. In general, water wastes can be divided into blackwater (sewage water) and greywater (it is clean and can be used for washing). Greywater use is an effective tool in terms of improving the performance of water utilization in buildings and other urban environments. Some greywater systems deliver the water without any additional processing. Others filter and purify it before delivery, thus disposing of solids, pathogens and chemicals). Their systems of purification can be either chemical or physical.

There are three components to ensure greywater usage in buildings:

- *Diversion and filtration devices* They can include special filters and pumps in order to divert water to shower vertical plant systems.
- *Manual bucketing* It involves huge reservoirs and other facilities for gathering water from showers, washing machines, toilets and so on.
- *Treatment and re-use systems* These systems process water to make it appropriate for household use. This water can be employed for toilet flushing, washing and above-ground irrigation.

Greywater can be utilized in different ways. Firstly, it can be used for irrigation outside the building (for vertical gardening). In this case, it cannot harm plants, so wastewater from processing equipment, sinks and showers should not contain dangerous chemicals. It can be attained by making occupants use only non-toxic biodegradable soaps and by purifying the greywater before it is utilized. Simultaneously, a garden greywater system can divert water from showers, baths as well as washing machines so that certain components are filtered out. After this, water is to flow to a storage tank or directly through an irrigation system to water the plants.

Secondly, greywater can be utilized for flushing the toilet. If we want to create a green construction subject to the Smart City concept, we need to bear in mind that tons of drinking water are turned into waste while we take a shower or use toilets. For instance, Environmental Planning and Design, the Californian LLC (2015), emphasizes in its project the employment of dual-flush toilets than can use 0.6-1.2 gallons per flush while conventional toilets use 1.6 gallons per flush. In addition, waterless urinals can enhance the building’s perfomance and are more hygienic than standard examples. Low-flow plumbing can also improve the water performance: by installing sinks and showers that are equipped with low-flow mechanisms which reduce water consumption.

Of course, greywater cannot be utilized for drinking, cooking or for other kitchen uses, showering, bathing, filling swimming pools and so on. We also have to remember that while we can utilize water from baths, washing machines, laundry tubs, we cannot apply water from kitchens and toilets because of some harmful and insoluble elements in it.

One more way of saving water resources is water harvesting. It is about capturing rain when it falls or seizing the run off in villages or towns. In general, we can capture runoff from rooftops, local catchments, seasonal floodwaters from local streams and so on. Scientists and architects consider water-harvesting systems in buildings a very promising source in respect of achieving goals of sustainable development.

The total amount of water that is received in the form of rainfall falling over an area is called the rainwater endowment of the area (Malloy, Brock, Floyd, Livingston, Webb, 2013). The collection efficiency explains the fact why all the precipitation dropping over an area cannot be harvested (due to spillage, evaporation, etc.). These two indices comprise the water harvesting potential of the area (we multiply rainfall (millimeters) by collection efficiency).

Nowadays there are many examples that support water harvesting systems in buildings, especially skyscrapers ("Rainwater Harvesting and Utilization", n.d.). For instance, Singapore, which has limited water supply, is seeking to develop new methods of water harvesting. They place light roofing atop of the buildings to act as catchment. Harvested roof water is kept in specialized cisterns for non-potable uses. A recent survey demonstrated effective saving of 4% of the water used in such a way. As a result of such savings, the cost of collected water was estimated to be $0.96 against the previous cost of $1.17 per m^3. The Changi Airport also effectively uses harvesting: they have built two impounding reservoirs. One of them is designed to balance water flows during coincident high runoff (it rains every day in Singapore due to its equatorial climate) and incoming tides and the other reservoir is employed to collect the runoff itself. This water is used for toilet-flushing and non-potable functions, such as fire-fighting. This water harvesting system is estimated to save nearly $390,000 per annum.

At the same time, there are some plans of building skyscrapers using water harvesting systems. In one of them, designers Barttomiej Gowin and Tomasz Janus

(2013) decided to create a huge tower *Hydro Aero Device* to be placed somewhere in deserts. It operates to harvest a reliable source of water from the environment around it. The building works by condensing moisture on cold tubes. Then collected water travels through canals to a central tank. Water from the tank can be distributed to residents of the tower or to the surrounding community. In another project, the Polish firm H3AR (2011) decided to use underwater lakes of the Sahara Desert in Darfur, Sudan. H3AR's Watertower aims at tapping this resource through good design and effective water management. The skyscraper resembles a baobab, 'the upside down tree' of deserts and dry regions. The building will have water pumps and a treatment plant. These pumps will take the water from the aquifer, force it to move to the building and store it within the skyscraper itself. In addition, such towers (the firm plans to build 3 towers) will be constructed from dry clay to be mined on the site. The project can successfully solve the issue of water shortages not only in Sudan, but also in other dry regions all over the world. The Durst Organization (2007) decided to create a completely green building for the Bank of America. A living roof used to retain water during huge rainfalls eliminates the need for stormwater defense. Furthermore, rainwater is to be collected in four places and to be applied for the cooling system and toilet flushing. In the basement, architects want to place 44 ice-tanks filled with treated greywater that is frozen at night. These ice-cubes will be a low-cost solution to the problem of air conditioning systems in skyscrapers: as they melt, they, in fact, cool the building. In addition, a significant share of the ground for the basement having been excavated, pockets of water in fissures of the rock were found. This groundwater was connected with steam condensation and air-conditioning condensation and is to be used with toilets and the cooling system. The system is estimated to reduce water-fees of the building by 25 per cent.

Another perspective involves using fog harvesting technologies (yet it is under-researched). This type of water harvesting relies on such factors as air moisture, directed wind flow and density. This technique has been tested in different coastal highlands around the world. Such a passive technology is reported to yield 200 L/day across the year (Cho, 2011).

The main advantage about water harvesting is that rainwater has no pollutants, such as minerals, salts and other man-made contaminants. At the same time, it does not need sophisticated collecting facilities and can be successfully used in the regions of excessive rainfalls. On the contrary, we have to realize that such things as acid rains may happen, and it will definitely decrease the utility rate of rainwater and expose people who are going to use if for practical purposes to danger.

In terms of water harvesting and recycling, we believe that installing a special catchment area on the roof of the building to collect rainfall in any forms would be beneficial. Thus, all water from the roof may be used through special sprinklers for watering the vertical gardening system, in the case the climate of the region is dry or does not provide enough precipitation. Moreover, all water collected from bathrooms, toilets, washing machines (greywater) is to be contained in the special reservoir in the basement of the skyscraper. Then this water will be recycled with the help of special organic elements and can be used for toilet flushing, irrigation and washing. There will be the system of particular pipes and tubes to connect the reservoir with the whole building. So as to facilitate the process of water recycling we have to ensure that inhabitants of the building use special organic household chemicals that are easy to dissolve. In addition, the edifice will be equipped with special dual-flush toilets, sinks and showers with low-flow mechanisms to reduce the amount of water being wasted. In conclusion, it will create a special cycle that will help us use water resources rationally and at minimum cost. Moreover, the basement of the skyscraper will place the underground parking for electric cars which are an indispensable part of the sustainable development concept.

Vertical Greening Systems

One of the significant parts of the green building concept is a greening system. Nowadays the urbanization process plays a significant role in human evolution. Rural populations are declining while urban populations are continuously increasing, leading to rapid expansion of cities. Such global urban development leads to a range of consequences, such as alterations in local urban climate, urban ecology and hydrology as well as concentrating materials that effectively retain heat and create impervious surfaces. It is worth noting in particular that skyscrapers and other tall buildings serve as multiple surfaces for the absorption of solar radiation that is therefore reradiated as heat, i.e. intensifying the efficiency of urban areas’ warming up. This fact, linked to the waste heat produced by energy use, leads to increasing temperature in cities known as urban heat island (UHI) effect, according to Environmental Protection Agency, also it leads to the further emergence of other problems ranging from human health issues to higher energy consumption due to the overuse of air conditioning systems.

As we know, urban areas are the major concentrators and emitters of multiple contaminants resulting from human activities within the built environment. In consequence, carbon dioxide (CO2) and harmful toxins such as Volatile Organic Compounds (VOCs) frequently reach damaging atmospheric levels in some metropolitan areas.

To solve such arising problems new development strategies should be implemented for the purpose of minimizing the deleterious environmental effects of urban infrastructure while improving their social and economic value.

The extension of urban areas also leads to such a significant alteration as the decreasing green areas. As a result, an insufficient volume of plants results in an insufficient level of absorbed carbon dioxide and produced oxygen. One of the most efficient alternative ways of extraction the maximum benefit from plants without harming the urbanization process is creating vertical greening systems (VGSs). It turns out to be an innovative and swiftly developing field towards sustainable and environmental construction.

Vertical greening systems are also known as bio walls, green-wall technologies or vertical gardens. It is the construction of vertical structures that spread vegetation which may or may not be attached to a building facade or to an interior wall. There are many basic systems of vertical gardening, which can be used both alone and combined, creating a variety of options for green screen. Generally, they are divided into two main structural groups: green facades and living walls. Green facades, also known as green screens, are formed by climbing plants or cascading groundcovers and owing to the lower diversity and density of plants; they usually require less intensive maintenance and safety than living walls. In contrast, living walls are normally more complex systems that include a supporting structure with various attachment methods. A waterproof backing is required to isolate the living wall from the building in to avoid problems with dampness (Pérez-Urrestarazu, Fernández-Cañero, Franco-Salas & Egea, 2016).

Vertical gardening is a classic way of design using climbing and clinging plants. By using this technique, people decorate facades, disguise unsightly buildings, create a shadow zone and create a very favourable microclimate. Typically, different supporting structures that are used allow plants to cling to them and grow in the right direction. Modern architecture is dramatically focusing on vertical greening systems as a way to restore the urban integrity, biodiversity and sustainable development of the environment (Perini, Ottelé, Raiteri, 2013).

Research shows that vertical greening systems have many advantages. They can be interesting as not only an eco-friendly project, but also as a beneficial method of saving space and providing more comfortable standards of living. Benefits of vertical greening systems can be considered in the context of ecological, environmental, and social implications.

Firstly, vertical gardening in large cities or Smart Cities is one of the best ways of preserving the Earth's biodiversity. Nowadays this issue is in the range of the most incremental for the contemporary society as it concerns everybody. Such systems may be utilized to grow species that can address specific functions that are missing in the urban environment, mostly oriented to plants' ability to remove air pollutants.

Secondly, we should take into consideration that in contemporary building and construction development the use of plants to enhance the quality of the surrounding environment is becoming a key point in consideration, because VGSs serve not only as esthetic means but also as a means of rendering environmental services, for example natural cooling of air, water filtration, and mitigation of several environmental problems. In this aspect, vertical greening also plays an vital role in creating the appropriate microclimate in the urban territories, as plants absorb a significant portion of solar radiation for their growth and biological activities, such as respiration, transpiration, and photosynthesis. In addition, plants in the living walls may serve as effective noise isolators or noise barriers which is a very important factor of maintaining people’s comfort (Pérez-Urrestarazu, Fernández-Cañero, Franco-Salas & Egea, 2016).

Thirdly, vertical gardening systems are indispensable in the context of reevaluating and transforming the landscape of urban territories. Innovative architectural solutions that implement greenery elements either for the restoration of old buildings or in the design of new ones would certainly upgrade the appearance of the Smart city and other cities in general.

The wide use of vertical gardening has a great impact on the thermal efficiency of buildings and on the environment of the urban areas. Plants serve as a solar filter and prevent heat radiation adsorption of building materials extensively. Provision of vertical greening systems is not a new conception; however, it has not been considered as an energy saving method for the environment. Vertical greening can be functioning as a cooling factor on the building surface, especially during summer in arid climates. In cooler climates such systems operate as external insulation stratum, thereby ensuring energy savings and reducing of heat being lost.

Vertical greening systems are already widely used all over the world, but not on a large scale. In many countries there are many single eco-friendly ‘green’ skyscrapers, for example *Urban Cactus* in the Netherlands, *Bosco Verticale* in Italy, *MaHouse* in France and so on. China is known to be creating vertical forests that will generate 60 kg of oxygen a day. Moreover, these buildings will be home to more than 1,100 trees and 2,500 plants and will absorb 25 tons of CO2 every year. Such forests can to solve the issue of polluted air and smog. It has considerable impact on the environment protection and biodiversity of the world.

To summarize, vertical gardening systems provide many ecological, environmental, and social benefits, such as preserving the Earth’s biodiversity, providing environmental services, such as natural air cooling, water filtration, several environmental problems’ mitigation, transforming the landscape of urban territories and so on. Modern architecture is intensely concentrated on vertical greening systems as a method to keep the ecological integrity of urban areas, biodiversity and sustainability.

Vertical gardening system in our concept will be presented as green insertions covering the surface of the building. Those plants should be selected according to prevailing climate patterns in a particular region. Furthermore, accumulated water and abundant sunlight will ensure proper handling of the vertical gardening.

It should be mentioned that it is very crucial to consider the location of green skyscrapers in particular. It is affected by the proportion of the solar and wind energy capacity, with vertical gardening and water management systems being possible in different sites. That is why if a building is constructed at the seaside (Miami, Shanghai, Barcelona) where huge wind currents exist, we will have a correlation between these two types of renewable energy in favour of the wind power. So, if this building is to be situated in a place with enormous solar radiation, such as desert cities (Casablanca, Las Vegas, Ordos) we will have more solar energy produced.

Finally, our Smart City will consist of smart homes and energy buildings that utilize the wireless communication, modern security systems and privacy protection, as well as efficient and attractive design that is complementary to the surrounding environment. These components will operate thanks to intelligent energy management systems and smart grids facilitating urban transportation, life of ordinary people and critical infrastructure protection. The holistic approach to enhance management and coordination of the services to be provided include the following views: smart people, governance, economy, mobility, environment, and living as a whole.

References

1. Boschee, P. (2014). Produced and flowback water recycling and reuse: economics, limitations, and technology. Oil and Gas Facilities, 3(01), 16-21.

2. Bowerman, B., Braverman, J., Taylor, J., Todosow, H., & Von Wimmersperg, U. (2000, September). The vision of a smart city. In 2nd International Life Extension Technology Workshop, Paris (Vol. 28).

3. Chapa, J. (2007, March 28). BAHRAIN WORLD TRADE CENTER Has Giant Wind Turbines. Retrieved from http://inhabitat.com/bahrain-world-trade-center-has-wind-turbines/

4. Chino, M. (2010, March 15). The Strata: World's First Skyscraper With Built-In Wind Turbines. Retrieved from http://inhabitat.com/the-strata-worlds-first-skyscraper-with-built-in-wind-turbines/

5. Dempsey, N., Bramley, G., Power, S., & Brown, C. (2011). The social dimension of sustainable development: Defining urban social sustainability. Sustainable development, 19(5), 289-300.

6. Edwards, B. W., & Naboni, E. (2013). Green buildings pay: Design, productivity and ecology. Routledge.

7. Fahrenbruch, A., & Bube, R. (2012). Fundamentals of solar cells: photovoltaic solar energy conversion. Elsevier.

8. Hantula, R. (2010). How Do Solar Panels Work?. Infobase Publishing.

9. Heier, S. (2014). Grid integration of wind energy: onshore and offshore conversion systems. John Wiley & Sons.

10. Hopwood, B., Mellor, M., & O'Brien, G. (2005). Sustainable development: mapping different approaches. Sustainable development, 13(1), 38-52.

11. Hui, S. C. (2015). Critical Evaluation of Zero Carbon Buildings in High Density Urban Cities. Zero Carbon Building Journal.

12. Mearin, L. (2015, September 4). Solar windows can power buildings. Retrieved from http://www.computerworld.com/article/2980236/sustainable-it/solar-windows-poised-to-change-the-way-we-power-buildings.html

13. Nelson, V. (2013). Wind energy: renewable energy and the environment. CRC press.

14. Lendino, J. (2015, April 20). This fully transparent solar cell could make every window and screen a power source. Retrieved from

https://www.extremetech.com/extreme/188667-a-fully-transparent-solar-cell-that-could-make-every-window-and-screen-a-power-source

15. Pérez-Urrestarazu, L., Fernández-Cañero, R., Franco-Salas, A., & Egea, G. (2015). Vertical greening systems and sustainable cities. Journal of Urban Technology, 22(4), 65-85.

16. Perini, K., Ottelé, M., Haas, E. M., & Raiteri, R. (2013). Vertical greening systems, a process tree for green façades and living walls. Urban Ecosystems, 16(2), 265-277.

17. Redweik, P., Catita, C., & Brito, M. (2013). Solar energy potential on roofs and facades in an urban landscape. Solar Energy, 97, 332-341.

18. Sahu, K. K., & Sahu, M. (2014). Vertical gardening: For present age environmental protection. Recent Research in Science and Technology, 6(1).

19. Wang, L. (2015, August 23). Revolutionary new solar windows could generate 50 times more power than conventional photovoltaics. Retrieved from http://inhabitat.com/revolutionary-transparent-solar-cells-could-produce-50-times-more-energy-than-conventional-solar/