# The Principles of Energy Efficient Microclimate Provision in the Skyscraper “Biotecton” of 1 km Height

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## Abstract

The article deals with the formation of a healthy human living environment in superstructure buildings with the requirements of indoor air quality, environmental and constructive safety. The results of the development of "Biotecton" - an ultra-high-rise multi-functional building (the height is 1000 m) are presented. In order to effectively overcome the wind and seismic loads, the principles of the structure of the natural form (Gramineae stems, Triticale) are used. It is a multi-tiered spatial structure, in the nodes of which there are dampers for limiting oscillatory movements. For solving the problems of increasing the energy efficiency of ventilation and air conditioning, the use of air from height 1000 m with the minimum of anthropogenic pollution is investigated. Two mechanisms of the movement of air in a superstructure were investigated: natural impulses (under the action of gravitational pressure and wind) and mechanical (fans). It is shown that the natural pressure is insufficient for air movement. The mechanical impulse is necessary, but its energy requirement can be compensated by a renewable energy source - wind turbines with a total capacity of 5.3 MW. For high air quality, the use of "oxygen gardens" in green areas, which are evenly spaced along the entire height of the building, is explored. The study proposed a list of plants that effectively clean air from pollution, sequestrate excess $CO_2$, enrich the air with oxygen and release phytoncides that effectively fight against pathogenic microorganisms.

**Keywords:** superstructure building, skyscraper, indoor air quality, ventilation, oxygen gardens

## 1. Introduction

In connection with the consolidation of the development of cities-metropolises throughout the world, the active implementation of the "fabric" of the city is not only high-rise buildings but also tall buildings (above 75 m). Every year, the number of high-rise buildings in the world is growing, which is due to the demand for such types of objects and the development of the latest architectural, engineering, engineering and design solutions.

Skyscrapers bring people very high above the surface of the earth, which separates them from the natural environment. There is a need for an artificial microclimate of skyscraper premises with the requirements of temperature, humidity, gas composition of air, environmental safety of premises, intellectualizing of the building, etc. The energy component of the maintenance of a skyscraper is growing, which complicates the balance of the relations of natural and artificially created environment.

The task of creating vertical spatial structures based on natural forms capable of interacting with the environment to ensure their viability was the basis for the development of the skyscraper "Biotecton", capable of overcoming the height of 1000 m, conducted by scientists and students of the Kyiv National University of Construction and Architecture since 2015. As a basis, the stem of cereals has been taken as a shape-forming architectural and constructive element. The constructive shape of the *Gramineae* stems has the same effects of natural influences and mechanical forces as acting on the skyscraper. Stems of cereals with an average diameter of the base of 3 mm can reach a height of 1500 mm. When the coefficient of harmony is 1:500, the rye stem carries a spike, which is 1.5 times heavier than the weight of the stem itself.

2. Previous studies

Previous anatomical studies conducted by scientist Alexey Lazarev (*Lazarev A, 1985*) confirmed that the internal structure and relationships between the structural elements of stems can effectively bear the loads on the vertical spatial structure (Fig. 1).

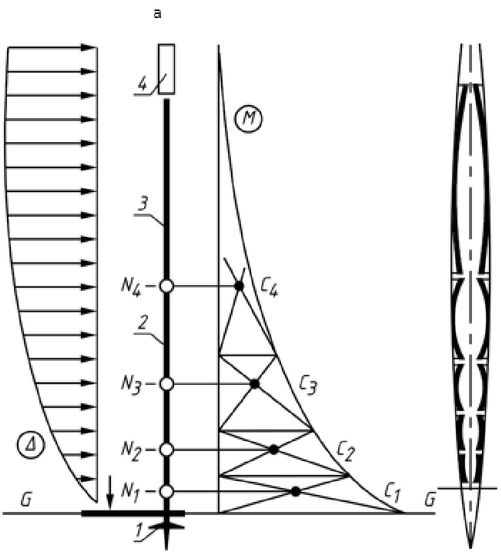


Figure 1 Features of the structure of the stem of wheat:
a – scheme of static work of the wheat stem by the architect A. Lazarev and the engineer G. Sarkisian;
b – structure of the stem of wheat:
1 – root; 2 – internode; 3 – stem; 4 – spike; $N_1$ ... $N_4$ – stem nodes; *G – G* – the ground level $C_1$...$C_4$ – centres of equal planes on the diagram *M* of bending moments; Δ – the displacement diagram

As a result of anatomical studies of *Gramineae* stems, *Triticale*, the following features of the shape of its structure were determined:

- a stem of cereals is a multi-tier structure, which is divided into a number of internodes, which reduce the force of wind pressure and the load;
- internodes of stems have a spindle-like shape, which reduces the deflection;
- at the nodes of the stem there are dampers – elastic hinges that form a dynamic damping system to limit the oscillatory movements of the stem;
- additional stability is provided by a mutual arrangement in the stem of firm and soft tissues, their ability to work both on compression, and on stretching;
- the cereal root system is a strong complex system, which consists of the main vertical root, lateral roots, more roots developing in different directions.

3. The basis of the "Biotecton" structure

The three-dimensional shape of the ultra-high-rise building "Biotecton" of height 1000 m is based on the tectonic structure of rye, which is musty-tier and multi-functional structure. The effectiveness and efficiency of the bearing system of "Biotecton" are achieved by separating the structure of the building by three dampers, spindle-like shape with minimal reliance area, the system of braces, stiffening core and root-like foundations to ensure effective mounting of the structure.

The damper is a dynamic shock absorber system, which allows fading of the amplitude of oscillation and increasing of seismic resistance. The model of the damping system (Fig. 2) of "Biotecton" is based on the results of anatomical studies and experimental tests on the vibrating bench in the laboratory of aerodynamics. The damping effect (quenching) fluctuations in the model "Biotecton" has been confirmed using devices Bruhl and Kyer (Denmark).

Multi-tiered, multifunctional structure "Biotecton" has free spaces, allowing their free use while ensuring efficiency and economy.

4. The grounding of air exchange principles

4.1. Main principles

An important principle of designing "Biotecton" was the creation of a comfortable environment for people. One of the main factors of comfort is the provision of air exchange for the organization of a healthy microclimate in premises with suitable heat-humidity conditions.

A significant part of the glazing of the facades and the impossibility of traditional ventilation of the premises through open windows leads to a significant increase in power demand for air conditioning. These and other factors cause special design of air exchange in "Biotecton" and require researches of energy-efficient solutions. At the level of 1 km, there is fresh, cool and clean air independently of artificial pollutions at the Earth's surface. Therefore, it is a good idea to take the air from the upper levels of "Biotecton". The air will move down (Fig. 3) by a duct in the inner stiffening core and after that will be distributed by premises. At the altitude of 1 km, the air temperature during the warm period of the year is lower (ICAO, 1993) than on the surface of the Earth by 6.49 °C/km (averaged value), which reduces the energy consumption for air cooling.

In this great building, there is a necessity for high air exchange amount. For energy efficiency, we need to search for ways of reducing the air demand, decreasing the energy for air movement and treatment.

4.2. The grounding of the air movement motive

Two options for air movement motive are used in ventilation and air conditioning: natural (under the action of gravitational pressure and wind) and mechanical (fans). If the temperature of the external air near to the ground level is 32 °C (305.15 K), the temperature of the intake air at the level of 1 km will be $t_{ext}$ = 32 – 6.49 = 25.51 °C or $T_{ext}$ = 298.66 K. The density of this air coerced to the standard atmospheric pressure is (Mileikovskyi & Klymenko, 2016) $\rho_{ext}$ = 353 / 298,66 = 1,1819 kg/m$^3$. Comfortable air temperature during a warm period of a year for the design of buildings and microclimate systems (EN 15251:2011 (2011) in residential buildings, office space, conference halls, classrooms, restaurants is $t_{wz}$ = 26 °C. ($T_{wz}$ = 299.15 K) The corresponding air density is $\rho_{wz}$ = 353 / 299.15 = 1.1800 kg/m$^3$. Gravitational pressure on the ground floor (height between the air intake and the premises is about $H$ = 1000 m) at gravitational acceleration $g$ = 9,80665 m/s$^2$ is $\Delta P_{gr} = (\rho_{wz} - \rho_{in})\, g\, H$ = = (1,1819 – 1,1800)·9,80665·1000 = 19 Pa, which is not enough for a kilometre network of air ducts. Another negative aspect of the use of gravitational pressure was studied by the authors in the paper (Mileikovskyi & Klymenko, 2016): natural ventilation has low energy efficiency. Energy (heat) of exhaust air (total energy) is [W]

$$E_{tot} = \Delta Q = c_p\, \rho_\ell\, L\, (T_\ell - T_{ext}), \qquad (1)$$

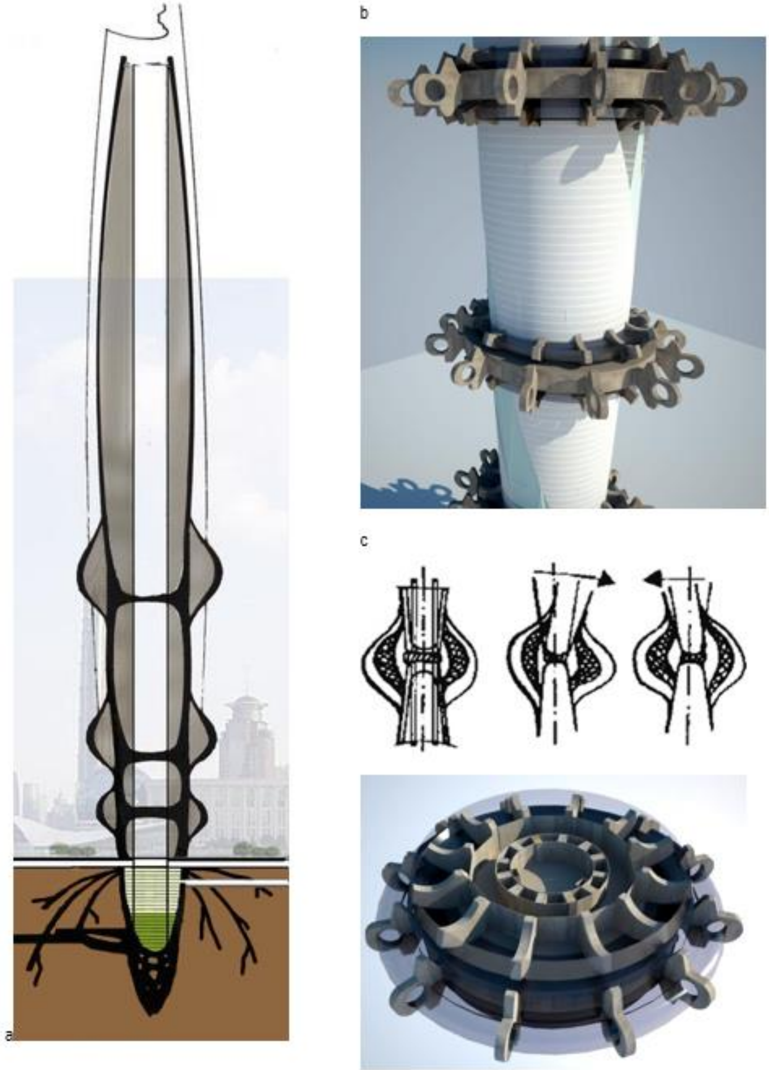


Figure 2

Demonstration system "Biotecton":
a – sketch of placement, b – general view of the damping system, c – wheat stem damper,
d – an element of the damper

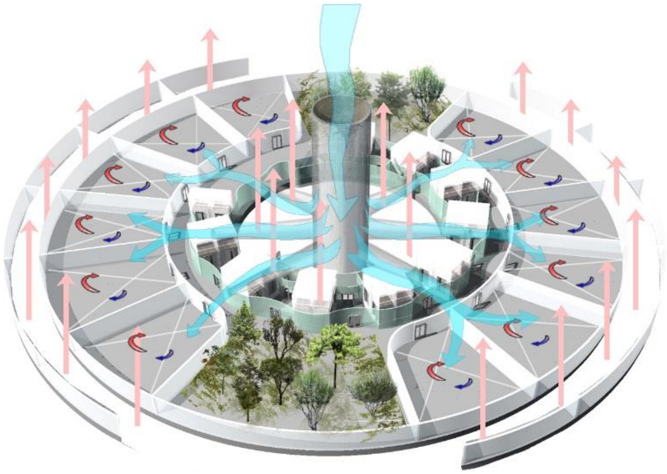

Figure 3 Spatial scheme of the ventilation system in "Bietekoton"

where $c_p$ = 1006 J/(kg·K) – isobar heat capacity of air (Mileikovskyi & Klymenko, 2016);
$L$ – volume flow rate of air, m$^3$/s. For simplicity, sensible heat is used, which leads to a certain underestimation of the heat supply and an overestimation of the efficiency of the system. Useful energy is the energy that is used for the movement of air through the air ducts (with pressure losses equal to the gravitational pressure [Pa]) [W]:

$$E_{usef} = \Delta P\, L. \quad (2)$$

The effectiveness $\eta_{v,g}$ of the natural ventilation is determined (Fig. 4) as the ratio of the useful energy $E_{usef}$ [W] to the total $E_{tot}$ [W] taking into account the formulas (1...3):

$$\eta_{v,g} = E_{usef} / E_{tot} = g\, H / (c_p\, T_{ext}) = 9{,}75 \cdot 10^{-3}\, H / T_{ext}. \quad (3)$$

By Fig. 4 the effectiveness of natural ventilation in the cold period of the year is only 3.5%. Therefore, the mechanical ventilation with the heat (cold) utilization from exhaust air should be preferred. For this purpose, it is proposed to use mechanical combined extract and input ventilation units with heat pumps located in technical spaces. They take air from the duct, located on the axis of the building. For disposing the exhaust air, other airline in the stiffening core can also be used. Air release can be carried out under the facade glazing to transport it to the top of the building. The condition of using this space is to prevent the condensation of moisture on the glass in the cold season for these climatic conditions. Condensation worsens the operating conditions of the enclosing structures and distorts the view from the windows.

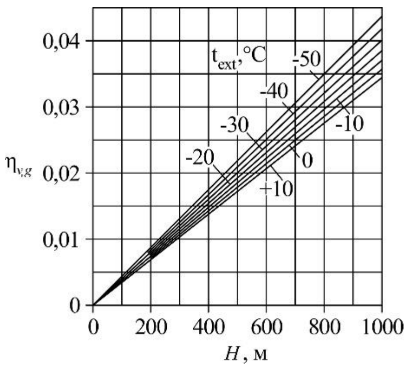


Fig. 4. Schedule of the coefficient of efficiency of natural ventilation

(Mileikovskyi & Klymenko, 2016), extended to 1 km

Typically, the pressure of embedded fans in the standard combined ventilation units is not sufficient to provide the movement of air by kilometre air ducts. Therefore, we should install an additional fan or fans that will create sufficient pressure and air flow in the air ducts. At the top of the buildings, we should use wind turbines to utilize the energy of winds, which are significant at such level. According to preliminary data of mathematical modelling, the wind turbines provide 5.3 MW of energy, which at properly designed airlines and air ducts should be sufficient for air movement.

**4.3. Biotechnical method of improving air quality**

To improve the quality of the internal air, green zones (Fig. 5) are designed in "Biotecton", which can be used for ventilation on each floor. Interior landscaping of skyscrapers provides an opportunity for improvement of ecological and psychological comfort of a person. Landscaping zones in the vertical spatial structure of "Biotecton" make it possible to give access to the natural environment. In "Biotecton", planting is the basis of the architectural and planning decision. The green interior band may spirally wrap the building. Green areas of common use in "Bietecton" are located one per five floors. The proposed solution gives an opportunity to provide 30 % landscaped volume of the skyscraper and to ensure its even placement in the height of "Biotecton". In fact, thanks to the projected planting system in Bietekoton, a person has access to the natural environment on every floor of the building.

In order to improve the air exchange in the premises of "Biotecton", it is proposed to use "oxygen gardens", which are envisaged by the project in "green zones". Most "oxygen gardens" are above the cloud level. Therefore, they are under the constant influence of solar radiation, which allows obtaining a stable photosynthesis during the year. There are two options for using "oxygen gardens":

1. The inflow air with the flow rate $G_{ext}$ [kg/s] and the concentration of $CO_2$ $q_{ext}$ [ppm] is fed to oxygen gardens, where it is further enriched with oxygen, and after that, the air will be supplied to other premises. This solution allows getting the best conditions for people to rest in the "oxygen gardens";

2. Some part of the exhaust air with flow rate $G_R$ [kg/s], and $CO_2$ concentration $q_\ell$ [ppm] from the premises without the possibility of release of harmful and odoriferous substances is recirculated to oxygen gardens, which, through sequestration of $CO_2$ will be enriched with oxygen and becomes re-usable. Due to the increased concentration of $CO_2$ in the exhaust air, plant growth improves.


Figure 5 A three-dimensional planning solution of the biotecton planting system:
a – general view of "Biotecton", b – floors with greening; c – section of greening;
d – general view of "green zones"; e – turn of greening zones on different floors

For the accepted assortment of plants, it is possible to calculate the total sequestration of $CO_2$ $\Delta S$ [mg/s]. Then the decrease in the concentration of $CO_2$ [ppm] in the air passing through an "oxygen garden" with the flow rate $G$ [kg/s] is [ppm]

$$\Delta q = 1000\,\Delta S / G. \quad (4)$$

Air and $CO_2$ balance in the "oxygen garden" [kg/s, mg/s]

$$G_{ext} + G_R = G_{in}. \quad (5)$$

$$G_{ext}\, q_{ext} + G_R\, q_\ell - \Delta S = G_{in}\, q_{in}. \quad (6)$$

Required flow rate by of external and recirculated air in the "oxygen garden" using equations (5) and (6)

$$G_{ext} = G_{in}\,(q_\ell - q_{in}) / (q_\ell - q_{ext}); \quad (7)$$

$$G_R = G_{in}\,(q_{in} - q_{ext}) / (q_\ell - q_{ext}). \quad (8)$$

If recirculation is not used, the reducing of the standard sanitary norm $G_{norm}$ [kg/s] of external air can be achieved up to [kg/s]:

$G_{ext} = G_{norm} (q_{ext} – \Delta q) / q_{ext}$.        (9)

Thus, "oxygen gardens" reduce the need for outdoor air, and thus increase the energy efficiency of ventilation and air conditioning. They are a biotechnical method for energy-efficient indoor air quality achievement.

**4.4. Plant assortment for air quality control**

Although plants have no specialized respiratory organs, they are actively taking part in gas exchange. This phenomenon is based on two of the most important physiological processes: photosynthesis and breathing. For photosynthesis, plants absorb $CO_2$ from the ambient air. One of the final products of photosynthesis is oxygen, without which the existence of all living things on our planet would be impossible. The process of respiration of plants in many respects is the opposite to photosynthesis.

Unlike many animals, plants do not have adaptations that would provide an active flow of gases. They penetrate into plants solely by osmosis, that is through passive diffusion along the formed gradients of concentration. The gases contained in the tissues of a leaf, in a cortex, in a stalk and in a root, are also passively moved by the special intercellular moves. These "gas pipelines" are combined with ambient air with the help of stomata that are located on the surface of leaf plates. Plant cells can be considered as tiny water containers. Many gases are well soluble in the aqueous phase. Thanks to this, the absorption of gases by plants is very fast. It is known that many harmful substances cause plants to intensify the processes of respiration. Consequently, plants react actively to them. It is logical to assume that in the process of the long evolution in plants, they implemented protective mechanisms that allow neutralizing harmful substances and gases entering the tissue together with carbon dioxide. This assumption is confirmed in (*Yan Van der Neer (2005)*. Specialists of NASA have derived a generalized coefficient of air purification efficiency of plants (Table 1). It was calculated taking into account the degree of danger of absorbed gases, the breadth of their spectrum, and the rate of their absorption. This coefficient is expressed in terms of units and is located on a numerical axis in the range from 0 to 10.

For qualitative air, it is also recommended to use phytoncide plants, through which the air of the premises is restored. For "oxygen gardens" it is recommended to additionally use plants with CAM-metabolism, which contributes to limiting the loss of moisture during nights. As a result, in these plants, stomata are opened at night to absorb $CO_2$ and store it in the form of organic acid in vacuoles of cells. At day, the stomata are closed. The organic acid decarboxylates again to $CO_2$. Such plants include, for example, species of the genus *Sedum*, which may be promising for the "green vertical" walls in the rooms.

Thus, "oxygen gardens" reduce the need for outdoor air, and increase the energy efficiency of ventilation and air conditioning.

**Conclusions**

For the provision of a stable and healthy operation of skyscrapers, it is possible to use natural shapes. "Biotecton" - a building with high of 1 km – is stable and can provide high indoor air environment quality due to use of the shape of rye. The calculations presented have shown that natural ventilation is not able to provide normative air exchange in the premises of "Biotecton" during the warm period of the year due to low natural pressure – less than 20 Pa.

Table 1.

Absorption by plants of poisonous substances

| Appointment | Absorbed substance | Cleaning quality | Recommended use for premises |
|---|---|---|---|
| Aglaonema | Benzene, toluene | 6,8 P | with artificial carpeting |
| Azalea | Formaldehyde | 6,3 | in rooms of any type |
| Aloe | Formaldehyde, tobacco smoke | 6,5 | in recently built or renovated |
| Anturium | Formaldehyde, ammonia, toluene | 7,2 | of any type |
| Araucaria | Various impurities | 7,0 P | offices and halls |
| Musa | Formaldehyde | 6,8 | greenhouses and winter gardens |
| Begonia | Volatile chemical compounds | 6,9 | of any type |
| Guzmania | Formaldehyde, toluene | 6,0 | of any type |
| Dendrobium | Methanol, acetone, formaldehyde, ammonia, toluene | 6,0 | offices |
| Dieffenbachia | Formaldehyde | 7,3 | of any type, except children's |
| Dracaena | Formaldehyde, benzene, trichlorethylene | 7,8 | of any type |
| Kalanchoe | Formaldehyde | 6,2 P | of any type |
| Calathea | Formaldehyde | 7,1 | selectively in offices and rooms |
| Codiaeum | Volatile chemical compounds | 7,0 | selectively in offices and rooms |
| Maranta | Various impurities | 6,6 | in the winter gardens; in largely backlit aquariums |
| Neoregelia | Toluene, various impurities | 6,4 | of any type |
| Nephrolepis | Formaldehyde | 7,5 | in the dark with high air humidity |
| Peperomia | Formaldehyde | 6,2 | of any type |
| Hedera | Formaldehyde, trichlorethylene, benzene | 7,8 | of any type |
| Sansevieria | Formaldehyde, trichlorethylene, benzene | 6,8 | of any type |
| Syngonium | Formaldehyde | 7,0 | of any type |
| Spathiphyllum | Formaldehyde, acetone, trichlorethylene, benzene | 7,5 | of any type |
| Scindapsus | Formaldehyde, benzene | 7,5 | of any type |
| Tradescantia | Formaldehyde | 7,8 | of any type |
| Phalaenopsis | Formaldehyde, toluene | 6,3 | of any type |
| Ficus | Formaldehyde, trichlorethylene, benzene | 8,0 P | of any type |
| Philodendron | Formaldehyde | 7,0 | of any type |
| Phoenix | Toluene | 7,8 | of any type |
| Chlorophytum | Formaldehyde, carbon monoxide, tobacco smoke | 7,8 P | of any type |
| Chrysalidocarpus | Formaldehyde, trichlorethylene, benzene | 8,5 | with high air humidity |
| Cyclamen | Летючі органічні сполуки | 6,0 | with high air humidity |
| Cissus | Volatile Organic Compounds | 7,5 | in semi-oiled spaces of any type |
| Schefflera | Formaldehyde, benzene, toluene | 8,0 | in rooms of any type |
| Schlumbergera | Volatile chemical compounds | 5,6 | in well-lit rooms any type |
| Aechmea | Formaldehyde, volatile organic compounds | 6,8 | in rooms of any type |

Remark. P - phytoncides emissive plant

In the cold season, natural ventilation has a low efficiency of 3.5%. Therefore, the advantage must be given to mechanical ventilation with the utilization of heat (cold) of exhaust air. At the same time, it is recommended to use a renewable energy source – wind turbines with a total capacity of 5.3 MW. It is expedient to remove air from the upper part of the building through clean air and more moderate parameters than in the surface layer. It is a good idea to use "oxygen gardens" with plants that clean air from pollution, to sequester excess $CO_2$, enrich the air with oxygen, and release phytoncides that effectively fight against pathogenic microorganisms, in order to decrease the necessary airflow.

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