

Digital Modules of the Green Buildings to Study Protection of Air Quality

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Abstract

The aims of this study are to simulate air flows inside and around multi-storey green building spaces together with the distribution of concentrations of harmful substances and microorganisms to increase the sustainability of design solutions for green modules. Among the objectives of the study are assessment of bioclimatic comfort, risk analysis of bioclimatic eco-safety in the framework of aeration and pollution modeling, as well as eco-optimization of building design, which corresponds to Sustainable Development Goal 11 (SDG 11), sustainable cities and communities, and is essential for promoting healthy urban communities. The methodology is based on sequential Computational fluid dynamics (CFD) of air flows around and inside buildings with the determination of aggregate stagnant air zones, after which the concentrations of harmful substances and microorganisms are simulated based on the database of air samples and concentration calculations taking into account the influence of air flow directions and green modules. The data obtained on the areas and forms of stagnant air zones with the accumulation of concentrations of harmful substances and microorganisms allow us to consider various design approaches to building facades, floor plans and to reconsider the role of green spaces depending on the technology of the cultivation green modules to improve bioclimatic comfort and bioclimatic eco-safety.

Keywords: Digital model, modular system, ecology, green buildings, air quality

INTRODUCTION

City management in the period of late urbanization and counter-urbanization must become sensitive, responsive and adaptive. Modern urbanists and architects, scientists and teachers help urban environment by the increasing density of smart building technologies and the speed of transformation [1-2].

The early period of urbanization created a model of behavior in which everything is subordinated to the desires and needs of a person. Climate change is foremost driven by the industrialization and the use of fossil fuels, whereas modern urbanization is rather a consequence of these processes. More and more adaptive models are developed under rapidly changing climate conditions [3], more building models are based on an artificial intelligence [4]. In the future, the culture of behavior will change in the direction of creating horizontal links between the city, its inhabitants, nature, technology and technology.

Green multi-storey buildings improve the city design [5]. In this regard, some re-searchers demonstrated the ability of modular green technologies to increase thermal insulation [6,7]. Thermal characteristics of green modules were

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investigated [8]. The impact of green modules in reducing building energy consumption was analyzed [9,10].

The construction sector currently accounts for 38 percent of global energy-related CO₂ emissions, in accordance with Report of the United Nations Environment Program (UNEP), green approaches are needed [11]. Therefore, there is an urgent need to actively reduce energy demand in new construction and use energy efficient materials. It should become more sensitive to nature and the environment, able to maintain and develop biodiversity, and contribute to overcoming the climate crisis.

The climate crisis forces us to consider strategies to work with existing cities to find effective solutions to mitigate the impacts of the elements, in particular, the use of roofs, the creation of a sustainable green frame of the city, which can work like a “sponge” and can naturally adapt the city to climate shocks [9]. It will also help achieve other UN Sustainable Development Goals (SDGs), for example, goal number three (“good health and well-being”), since a green roof is a quiet place for extra greenery in a busy city, where you can enjoy peace, greenery and silence in the heart of the city. To achieve goal number 6 (“clean water and sanitation”), green roofs can be used to slow down the drainage of rainwater and collect water for irrigation, reuse as “grey” water. On the other hand, the green roof is also a space for the social community, for the implementation of inclusive programs, for example, for growing vegetables for personal consumption or public spaces, for example, for sports, which implements the goal of sustainable development number 11 (“sustainable cities and communities”) [11]. The green roof is not only a space for greenery small residential houses, but in the future there will be new formats of vertical farms and using on the rooftops of multi-storey residential and public buildings, and it will have the greatest impact on the distribution and speed of air flows, heat accumulation, distribution shaded areas, which means conditions for green spaces on the ground and the bioclimatic comfort of people.

The change in air flow by multi-storey buildings causes a number of negative natural phenomena, high wind speeds formed around a multi-storey building, especially at low temperatures, adversely affect a person, in some cases green spaces both on the ground and on the surfaces of multi-storey buildings along the facades and on the roof (flat roof) are means of compensating for negative aerodynamic effects for the bioclimatic comfort of people in open spaces and at windows.

Building design features such as size, window openings, orientation, distribution and ventilation means, wall materials and different constructive elements can greatly affect air quality in and around residential areas. These design and technological features are very closely related to the local climate, for example, for a cold climate the window size will be smaller and the layers of thermal insulation will be larger [12].

Some studies have obtained results that geometry of residential areas play a decisive role in shaping the microclimate [13-15] and also, geometry of residential areas is a key factor influencing exposure to sunlight and air.

In this regard, the experience of construction and modernization of multi-storey buildings require a revision of their design approaches, taking into account the possible use of green spaces, for example, in green modules. We know that CFD method allows flexible modeling so it can be applied to solving many different problems and making accurate predictions. One of the essential disadvantages of this method is that precision incurs high computational costs [16-17].

Multi-agent task planning and resource apportionment in a smart grid is considered in study of modelling the proposed integrated solutions matrix for the case-study of São Paulo megacity using the LEAP_SP simulation model for the period 2014–2030 [18].

The measurements of green modular systems on the buildings showed that the adding only an outdoor green layer to the conventional wall is insufficient in all hot regions, and the best thermal performance against heat transfer is in the living-aired-concrete wall using outdoor perennials plants and 5 cm middle air layer [19].

In this study, computational fluid dynamics (CFD) of air flows around and inside buildings with the determination of aggregate stagnant air zones, after which the concentrations of harmful substances and microorganisms are simulated based on the database of air samples and concentration calculations taking into account the influence of air flow directions and green modules on the buildings.

MATERIALS AND METHODS

Methodological concept of the influence of green modules on the aerodynamics of a multi-storey building.

The methodology of the research work is the development of approaches to the formation of design solutions for the placement of green modules for vertical and roof greening systems, taking into account the assessment of the aerodynamic characteristics of a multi-storey building and the aerodynamic coefficients on its surfaces [12,34]. This is achieved by analyzing the aerodynamic coefficients on the surfaces of the walls and roofing of a multi-storey building, followed by their adjustment when placing green modules for vertical and roof greening systems [30,32]. The determination of the aerodynamic coefficients makes it possible to select the landscaping scheme necessary for a multi-storey building and the types of plants in the green modules. The project for placing green modules based on the determination of aerodynamic coefficients allows to select the level of wind protection necessary for a multi-storey building, taking into account individual wind effects, which allows the designer to quickly and efficiently conduct alternative design.

Methods for estimating aerodynamic coefficients on the surfaces of multi-storey buildings.

The methodology for determining aerodynamic coefficients on building surfaces uses existing test and calculation results [29], a combination of a high-rise building and a mid-rise building was combined, while in the direction of the wind flow, the mid-rise building was located behind the high-rise building [13-18].

Bioclimatic comfort is directly related with the speed and direction of wind flows at construction areas. The traditional Beaufort scale gives an idea of the mechanical effect of wind on the human body [19]. Basic wind speed values according to F.E. Weiss (1970) and A.D. Pendwarden (1973): $V = 5$ m/s - threshold value of comfortable speed; $V = 10$ m/s is definitely an uncomfortable speed value; $V = 20$ m/s - wind speed dangerous for humans. Formula for calculating effective speed wind, taking into account gusts is showed below:

$$V^e = V \left[1 + k \left(\frac{v'^{\frac{1}{2}}}{V} \right) \right], \quad (1)$$

where V is the average speed;

$v'^{\frac{1}{2}}$ - root mean square value of the longitudinal velocity component;

k is a constant value characterizing the degree of significance of the impact of pulsations (different authors have values ranging from 1 to 3).

On the basis of the above studies, the authors evaluated the design options suitable for creating a classification of the locations of multi-storey buildings in the development.

We used concentration calculations taking into account the influence of air flow directions and green modules of the multi-storey buildings (Figures 1-2).

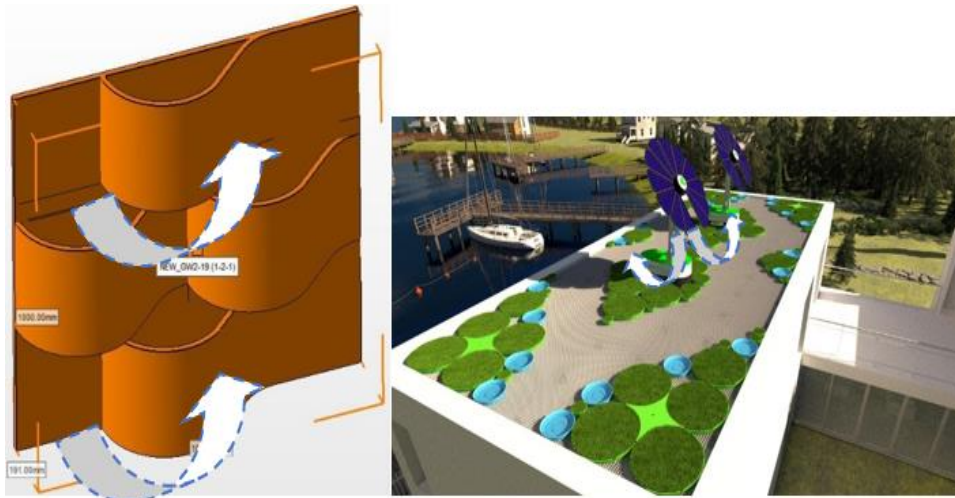


Figure 1. 3D model of green modules on the buildings, with air flow directions.



Figure 2. The green modules, using on the multi-storey buildings.

Green buildings and modern construction innovations are oriented on smart technologies, sustainable design of the buildings and their urban areas, from modern LED lighting systems to irrigation systems on green roofs and other surfaces (green walls) [20-24]. Bioclimatic comfort of residential areas is a key element for improving the quality of environment for the human health [25-31].

The predicted changes in microclimate, aeration conditions of the territory and aerodynamics of buildings are shown on the digital models (Figure 3). From meteorological data, the directions of the highest average speeds, as well as the directions of winds with the highest gusts (up to 10 m/s), were selected for the experiment: for the eastern and northeastern directions the average wind speed was chosen to be 3.2 m/s, for the northwestern and southwestern directions - 10 m/s.

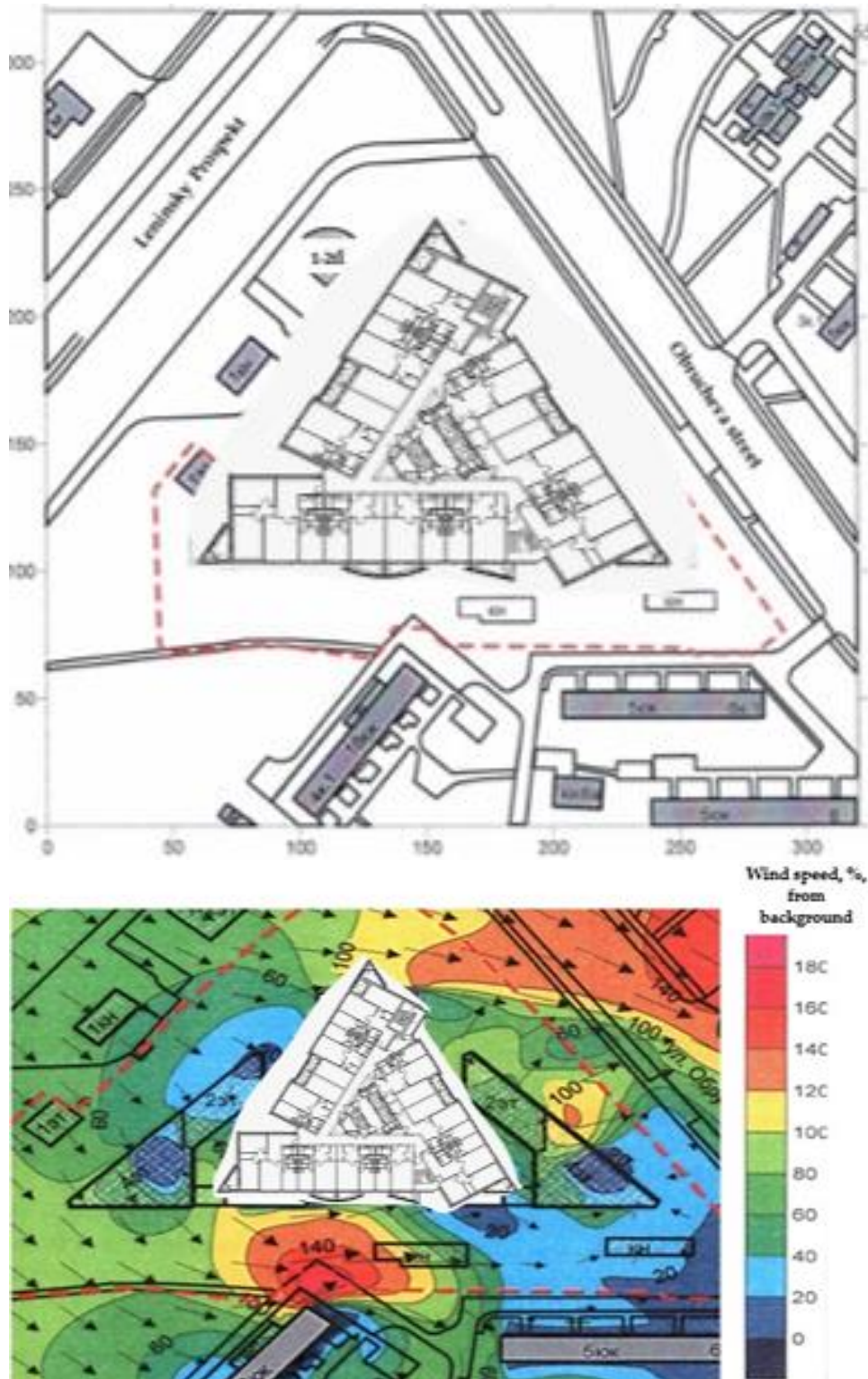


Figure 3. The input data for modeling of predicted changes in microclimate, aeration conditions of the territory and aerodynamics of buildings: (a) design plan, (b) numerical modelling schemes

Zones of increased discomfort (speed winds over 5 m/s) are highlighted in red. It is recommended for design windproof small designs architectural forms, using greening structures and increasing regulatory wind loads 2.3 times. Zones of probable discomfort (wind speed in pulsations over 5 m/s) are highlighted in black. It is recommended for design windproof greening structures and increase in

regulatory wind loads in 1.7 times. Zones of stagnant air masses (wind speed less than 1 m/s) are highlighted in blue. It is recommended ventilation due to temperature effect convection and windproof small designs architectural forms, using greening structures and increasing regulatory wind loads 2.3 times.

Based on the results of computational and experimental studies, the following results were obtained: areas with discomfort in winter are insignificant and occupy from 12 to 15% of the total squares; the areas of territories with stagnant zones in summer are insignificant and occupy 15-17% of the total area plot.

It is necessary to note the great influence of the parameters of the existing and design provisions of the building (width of the street, highway and boundaries of residential development and the area within these boundaries), as well as the influence of the relief residential area, geometric parameters of development, horizontal density indicators and multi-storey buildings, which does not allow us to give an unambiguous assessment of the location of a high-rise public residential complex. Conducting such studies at the design stage helps to significantly improve comfort presence of a person on the territory of the object under study, which is especially important for areas with dense development, as well as areas with high-rise buildings. Also, based on the results obtained, it is possible to draw conclusions about the presence of zones with low wind speeds, in where harmful substances and chemically active dust can accumulate.

RESULTS AND DISCUSSION

Based on the results of computational and experimental studies, results of assessment of bioclimatic comfort were obtained: areas with discomfort in winter are insignificant and occupy from 12 to 15% of the total squares; the areas of territories with stagnant zones in summer are insignificant and occupy 15-17% of the total area plot. Risk analysis of bioclimatic eco-safety in the framework of aeration and pollution modeling showed that it is possible to draw conclusions about the presence of zones with low wind speeds, in where harmful substances and chemically active dust can accumulate. Results of eco-optimization of building design, which corresponds to Sustainable Development Goal 11 (SDG 11), demonstrate that projects using vertical greening structures and green roofs increase bioclimatic environmental safety. In the concept of green urbanism, methods of sustainable green construction, by increasing areas with open soil cover and green spaces, increase heat consumption for evaporation, reduce the share of absorbed solar radiation, which leads to an increase in the integral albedo of urban areas. The inclusion of green modules on multi-storey buildings has a great impact to the urban ecology, the maintenance and long-term functionality of these green spaces, particularly in urban environments with varying climate conditions is determining by construction materials and technology of maintenance of green modules. Firstly, green modules are made of high-density polyethylene (HDPE), a durable plastic that provides strength and resistance to heat resistance. Recently, it has become very popular for the production of durable plastic parts, such as HDPE products. Its main advantages against wear include high strength and weight, low friction coefficient and low moisture absorption. High impact resistance, dent and scratch resistance, mold resistance, fungus resistance, rot resistance, mineral acids, alkalis, soil and weather resistance, and resistance to chemicals, water, solvents, acids, detergents and cleaning liquids. Therefore, in any weather, this plastic will be the best choice for using modules with plants on the roofs and walls of buildings. Secondly, the technology of installing modules with plants on the roofs and walls of buildings involves an integrated irrigation system, which is very convenient when used on high-rise buildings. It should be emphasized here that in this case, more powerful pumps should be used to supply water to the height, and the possibility of integrating them inside the walls should be considered.

The analysis of the accumulated scientific experience and the proposed classification of the location of multi-storey buildings in development revealed that so far there is no reasonable design approach for vertical and roof gardening, which allows taking into account the wind regime at any location of a multi-storey building in development. It is also clear that concentrations of harmful substances vary depending

on the height and configuration of buildings. In this study, we took into account wind parameters and height, as well as maximum limit concentrations of harmful substances in the air [33]. These results can be applied to densely populated urban areas with a variety of architectural solutions.

Air flow analysis and evaluation aerodynamic coefficients on the surfaces of multi-storey buildings.

The study identified the main parameters of the air flow around a multi-storey building that are important for placing green modules on walls and flat surfaces based on an assessment of aerodynamic parameters.

1. Zones of increased speeds, characterized by the following parameters:
 - The angle of change in the direction of propagation of the air flow, which has an increasing pulsating change in its speed;
 - The relative area of the zone of high speeds, covered by the distribution of the air flow, which has an increasing pulsating change (from 10 m/s to 20 m/s) in its speed (length and width of the zone along the surface of the building relative to the planes of the walls and coating).

As a result of this study of air quality for green modules using digital twins, it is proposed to create an impenetrable protective barrier 2 m high as a wind protection for buildings, using green walls located along the perimeter of the operated roof with green systems; windproof structures 3.5 - 4 m high, with a spatial grille that serves as a diffuser to dampen gusts of wind. The cell dimensions of the spatial grid are 0.15 - 0.3 m (or structures equivalent according to the theory of similarity of permeability). The distance from the fencing barrier must be at least 1.5 m. The distance between individual structures is no more than 8 meters.

In this case, it is certainly necessary to take into account the influence of external factors, such as local climate and surrounding urban structures. The proposed sustainable design solution for green modules is reliable in theory, since the structures are made taking into account streamlined shapes when applied to buildings under various weather conditions, including wind loads. However, to take into account the results in different geographical contexts and the adaptation guidelines for this, it is necessary not only to conduct experiments in different geographical regions, but also to correctly select the types of green wall plants for use in different climate conditions.

CONCLUSIONS

Green module technologies used in this study influence the air flows and help to reduce harmful substances and microorganisms within multi-storey green building spaces because of its huge surface, in previous studies our results obtained prove that modular green wall systems can improve the air quality by removing harmful pollutants from the air near the buildings [34-35].

This study is a preliminary attempt, we plan to continue it in future studies, our pre-sent results are following:

1. As a result of the research, a technique has been developed that allows the formation of facades and flat roofs of multi-storey buildings with green modules (Figures 1,2) based on aerodynamic characteristics. At the same time, comfortable conditions for human life are provided both in the surface area of building and around a multi-storey building.
2. The parameters of the change in the air flow around a multi-storey building are re-vealed. They are:
 - Angle of change in the direction of propagation of the air flow;
 - Relative area of the zone of increased speeds.

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