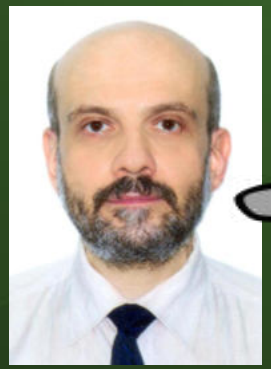
THEORETICAL AND EXPERIMENTAL RESEARCH OF GREEN STRUCTURES ADVANTAGES FOR ENGINEERING CALCULATIONS

Tetiana TKACHENKO, PI of the work, Dr Hab., professor, senior researcher, Head of the Department of Environmental Protection Technology and Labour Safety, Kyiv National University of COnstruction and Architecture, a member of the Technical committee for standardization TC 82 "Environmental Protection", member of workgroups for Ukrainian standards including standardisation of green structures, academician of the Academy of Technical Sciences of Ukraine and the Academy of Construction of Ukraine, member of the International Association of University Ecologists and the International Society for Geometry and Graphics, known in Ukraine and far beyond its borders expert in the fields of green construction, green structures, green standards etc. She constantly participates in international projects and grant programs, teaches in training courses under the UN support



Viktor MILEIKOVSKYI, Responsive Executor of the work, Dr Hab., professor, senior researcher, Professor of the Heat-Gas Supply and Ventilation Department, Kyiv National University of COnstruction and Architecture, academician of the Academy of Technical Sciences of Ukraine and the Academy of Construction of Ukraine, member of American Society of Heating, Refregiration and Air-Conditioning Engineers and the International Society for Geometry and Graphics, teaches in training courses under the UN support, among the scientific directions – theoretical and experimental research of heat-mass exchange in green structures and turbulence simulation

IN UKRAINE, UP TO 90 % OF BUILDINGS WERE DESTROYED BY COMBAT ACTIONS

Irpin, new buildings

RC Flaminho

RC «Na Haidara»

Pictures from the „Monitoring Map by LUN Misto" https://misto.lun.ua/

RC «Irpinski Lypky»

The film "Destroyed Houses" Vyshgorod district, Kyiv region. 23.06.2022" https://www.youtube.com/watch?v=xhGl9rR4NF0

Bucha

Picture from the article "Tragedy in Bucha: Broken Houses in the City Began to Be Demolished". https://www.dsnews.ua/ukr/politics/tragediya-v-buchi-u-misti-pochali-znositi-zruynovani-budinki-25072022-463209

On October 26, 2022, at 03:00 a.m., a missile destroyed the building of the Druzhkovka Dwelling and Communal Professional College of the DonNACEA (Kramatorsk), which was renovated with EU funds in 2021.

BROKEN INFRESTRUCTURE

Due to the war, the road infrastructure was significantly damaged. On 6 May 2022, losses exceeded UAH 900 billion.

Photo and data from the article "Due to the war, the road infrastructure was damaged for more than UAH 900 billion - "Ukravtodor".
https://www.radiosvoboda.org/a/news-ukravtodor-pro-zbytky/31837340.html

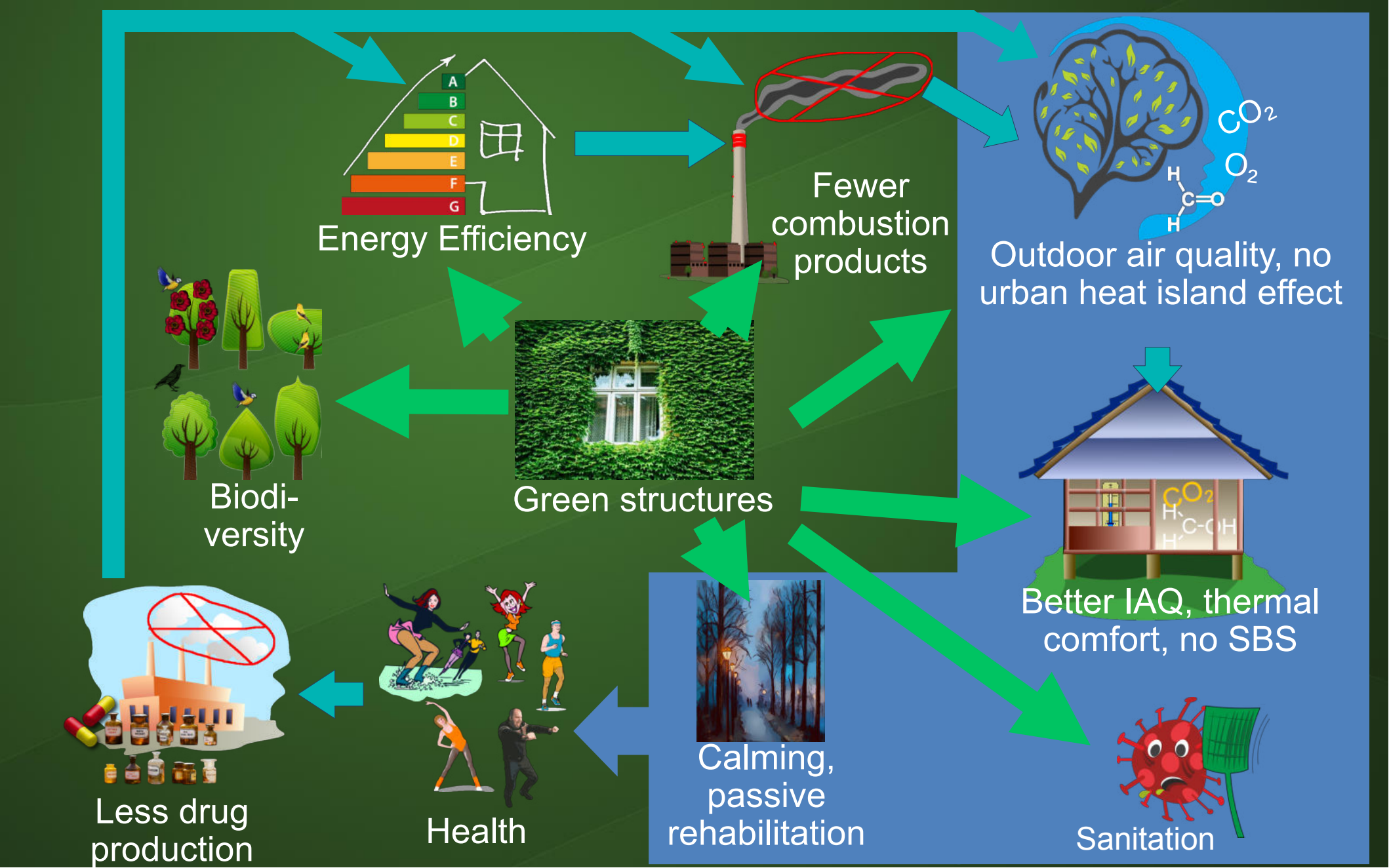
Restoration of rainwater drainage on highways requires a lot of money.

DEVELOPMENT IS ON TIME

Main problems:

- high requirements for energy efficiency and environmental friendliness;
- lack of funds

A solution that satisfies both conflicting requirements is "green structures" - a combination of structures and living plants


A
B
C
D
E
F
G
Energy Efficiency
Fewer combustion products
Outdoor air quality, no urban heat island effect
Biodi-versity
Green structures
Better IAQ, thermal comfort, no SBS
Less drug production
Health
Calming, passive rehabilitation
Sanitation

This direction of construction is well-known for thousands of years – the Hanging Gardens of Semiramis, the Sennacherib's Palace of Nineveh or sod roofs in Scandinavia

Sod roofs of Faroe islands

Hanging gardens of Babylon
Reconstruction by F. Kriskhen

Today, most well-developed countries have building standards for green roofs

Germany
FLL-2018
Green Roof Guidelines

United Kingdom
BREEAM
The standard of environmental estimation of building objects. Brings additional points for “green” structures

Switzerland
SIA-312

Italy
UNI 11235:2015

The United States of America
LEED
The standard of environmental estimation of building objects. Additional points for “green” structures

International society ASTM D5602/D5602M-18(2022), D5635/D5635M-18(2022), D7851-17, D8014-17, E2777-20, E2396/E2396M-19, E2397/E2397M-19, E2398/E2398M-19, E2399/E2399M-19, E2400/E2400M-19, E2788/E2788M-18

UKRAINE

DBN B.2.2-12:2018 only mentions „green” structures as a kind of city greening

DBN V.2.6-220:2017 has an obsolete drawing of a “green” roof from an article of the lecturer from 90th of XX century.

FLL-2018

ADVANTAGES

- The technical aspects are written very detailed, which allows for reliable and efficient construction
- A large amount of positive effects of the implementation are mentioned

DISADVANTAGES

- Focused on green roofs only;
- Not all positive effects are mentioned, such as:
  - cooling effect by evapotranspiration;
  - organization of ways of migration of biota in depth built-up areas
- There are no methods for calculating positive effects except water retension, which means that there are no methods for calculating vegetation layers from the point of view of thermal physics for maximum effect

UNI 11235:2015

ADVANTAGES

- Very detailed classification;
- Very detailed description of conditions for vegetation;
- Rainwater storage is regulated;
- There are data for calculating the reduction of rainwater runoff;
- A lot of attention is paid to technical and economic aspects;
- Ecological compensation is shown.

DISADVANTAGES

The same as previous

SIA 312

sia ADVANTAGES

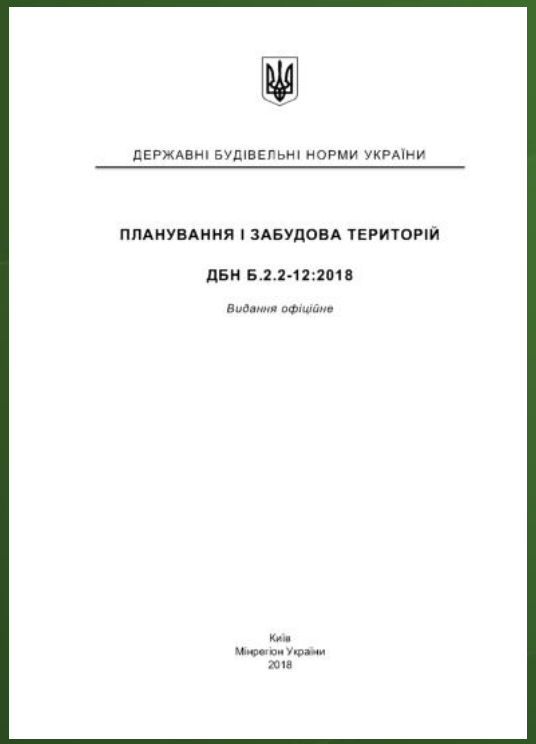
In old versions, the main idea was ecological compensation – a generalized term for measures to maintain and restore the function of habitats and their interaction, especially in intensively used or densely populated areas. One of the main goals of old versions was to promote local biodiversity. Current version contains more technical aspects including water retention effects.

DISADVANTAGES

The standard is very brief. Other disadvantages are the same as previous.

Ukrainian standards

Today, Ukraine has very weak standards .
DBN B.2.2-12:2018. Planning and development of territories



ДЕРЖАВНІ БУДІВЕЛЬНІ НОРМИ УКРАЇНИ

ПЛАНУВАННЯ І ЗАБУДОВА ТЕРИТОРІЙ

ДБН Б.2.2-12:2018

Видання офіційне

Київ
Мінрегіон України
2018

8.2.6 На територіях житлової, громадської, курортної та рекреаційної забудови слід передбачати засоби:

– загального озеленення ділянок (дерева, чагарники, газони, квітники),
– площинного озеленення (дахів, міжрейкових трамвайних полотен, гольф-полів);
– вертикального озеленення будинків і споруд (фасадів, балконів, шумозахисних стінок);
– відновлюваного озеленення (порушених ділянок, ярів, схилів).

At the territories of residental, civil, resort and recreational development should be:
– general greening (trees, shrubs, lawns, flower-gardens)
– plannar greening (roofs, inter-rail tram tracks, gols courses)
– vertical greening of houses and structures (facades, balconies, noise-protective grids)

Ukrainian standards

DBN B.2.2-5:2011. Improvement of territories

ДЕРЖАВНІ БУДІВЕЛЬНІ НОРМИ УКРАЇНИ

Планування та забудова міст, селищ і функціональних територій

БЛАГОУСТРІЙ ТЕРИТОРІЙ

ДБН Б.2.2-5:2011

Видання офіційне

Київ
Міністерство регіонального розвитку, будівництва та житлово-комунального господарства України
2012

9.9.15 Об'єм, характер і місце проведення робіт з компенсаційного озеленення треба визначати у кожному конкретному випадку окремо. Проект компенсаційного озеленення включають як самостійний розділ проекту реконструкції або будівництва.

Компенсаційне озеленення треба проводити в найближчий сезон, придатний для висаджування зелених насаджень, за можливості на тій же ділянці, де була знищена деревно-чагарникова рослинність, при цьому кількість одиниць рослин і займану ними площу не можна зменшувати.

В умовах ущільненої забудови допускається застосовувати вертикальне озеленення, а також облаштування садів на покриттях будівель.

9.9.15 Volume, nature and location of works for compensation greening should be determined in each specific case separately. Project of the compensatory greening should be included as an independent section of the project reconstruction or construction.

Compensatory greening should be carried out in the next suitable season for planting, if possible, on the same site where tree and shrub vegetation was destroyed, while the number of plant units and the area occupied by them cannot be reduced.

In the conditions of compacted buildings, it is allowed (but not recommended) to use vertical landscaping, as well as arrangement of gardens on the roofs of buildings.

Ukrainian standards

Today, Ukraine has very weak standards for greening of buildings.
DBN V.2.6-220:2017

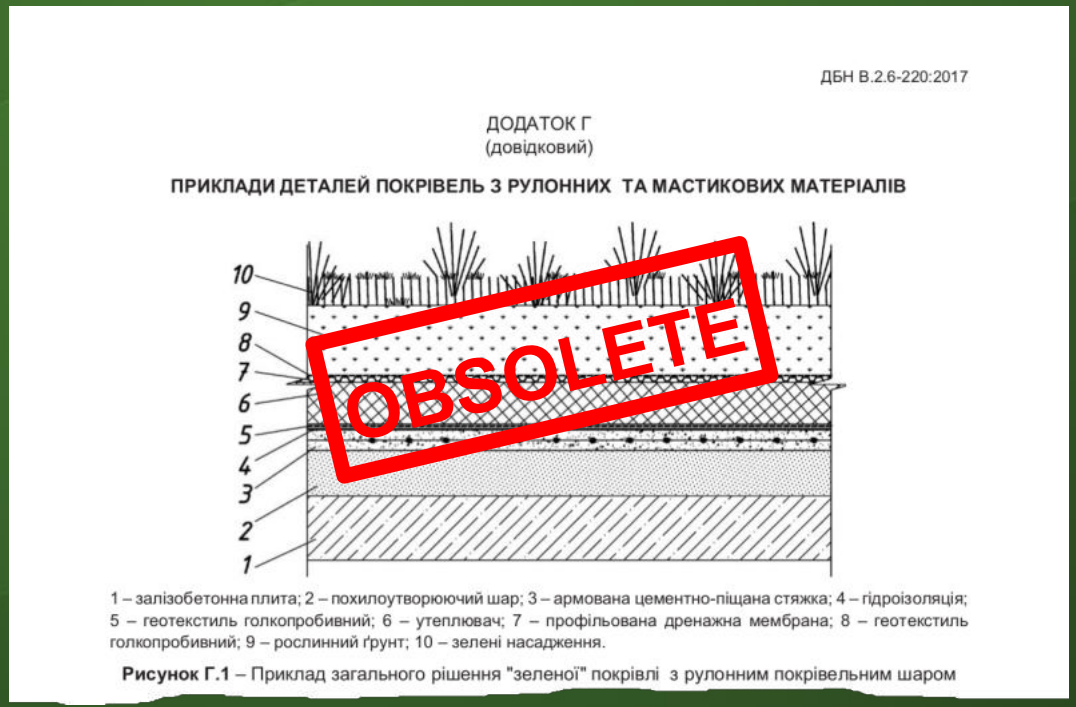
ДЕРЖАВНІ БУДІВЕЛЬНІ НОРМИ УКРАЇНИ

ПОКРИТТЯ БУДІВЕЛЬ І СПОРУД

ДБН В.2.6-220:2017

Видання офіційне

Київ
Міністерство регіонального розвитку, будівництва
та житлово-комунального господарства України
2017



ДБН В.2.6-220:2017

ДОДАТОК Г
(довідковий)

ПРИКЛАДИ ДЕТАЛЕЙ ПОКРІВЕЛЬ З РУЛОННИХ ТА МАСТИКОВИХ МАТЕРІАЛІВ

1 – залізобетонна плита; 2 – похилоутворюючий шар; 3 – армована цементно-піщана стяжка; 4 – гідроізоляція; 5 – геотекстиль голкопробивний; 6 – утеплювач; 7 – профільована дренажна мембрана; 8 – геотекстиль голкопробивний; 9 – рослинний ґрунт; 10 – зелені насадження.

Рисунок Г.1 – Приклад загального рішення "зеленої" покрівлі з рулонним покрівельним шаром

This drawing was borrowed from an article from 90-th of XX centiry.

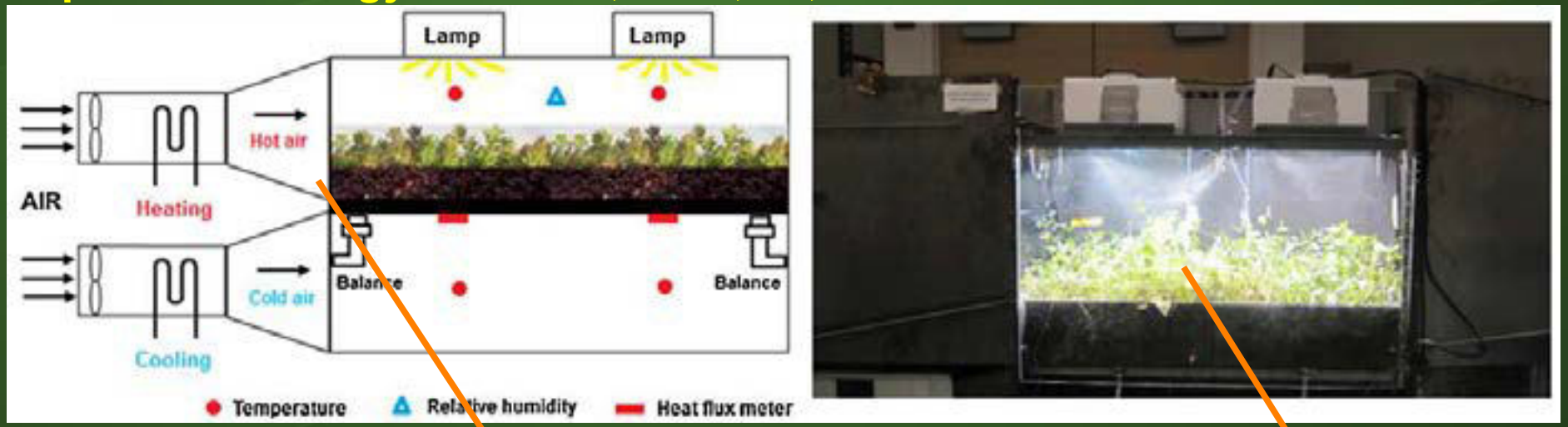
The author - Tetiana Tkachenko

Why the standards aren't perfect

The main problem is the lack of engineering calculation methods of positive effects except for rainwater because there are too few systematic quantitative researches on them.

A wind tunnel, Lassie, France.

Ouldboukhitine S.-E, R. Belarbi. Experimental characterization of green roof components. *Energy Procedia*, 2015, 78, 1183-1188.



Flow separation

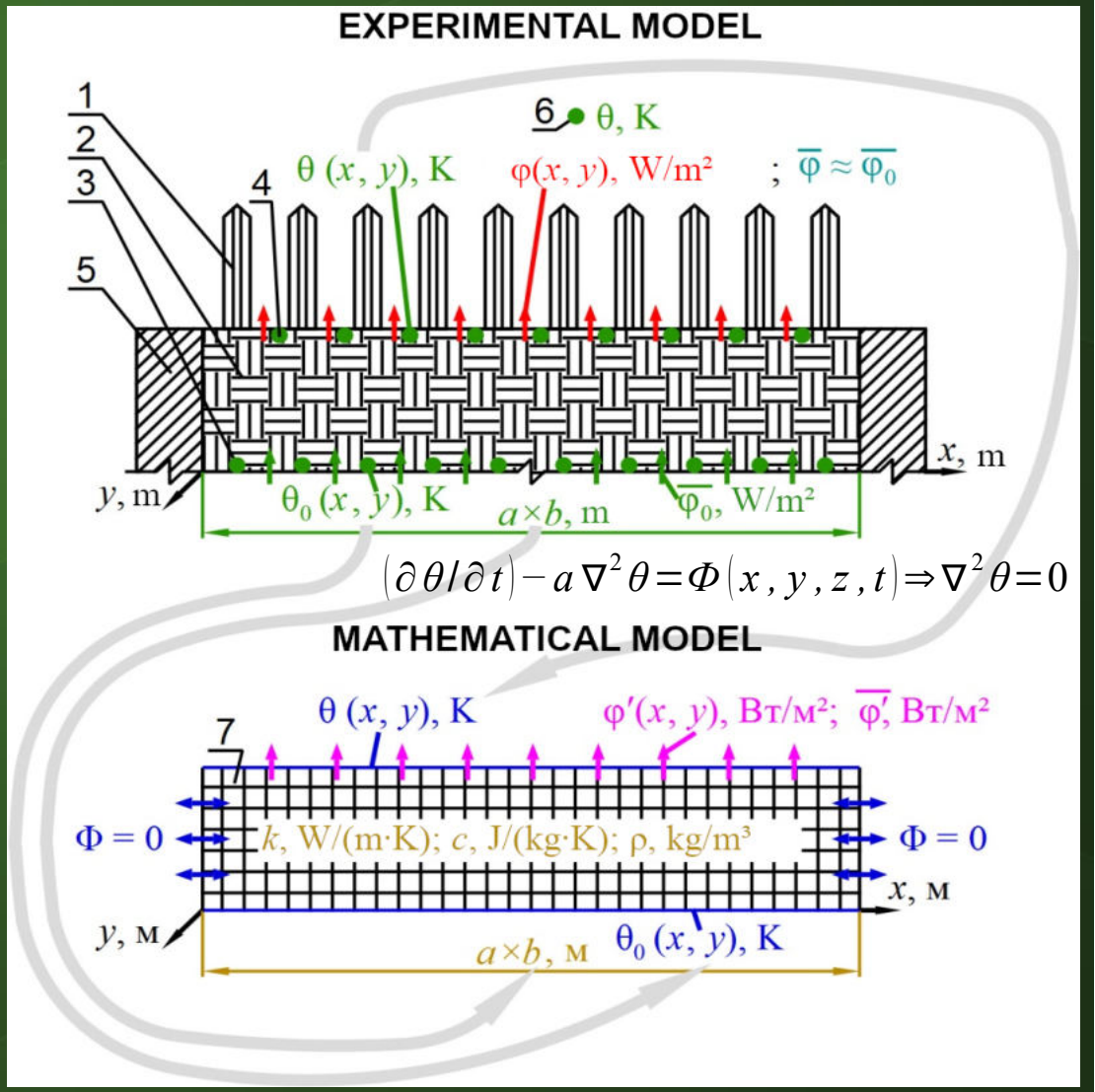
More than 10 % of the occupied cross-section

THE RESULTS OF RESEARCH AT KYIV NATIONAL UNIVERSITY OF CONSTRUCTION AND ARCHITECTURE, WHICH BRING THE REGULATORY BASE TO A PRINCIPALLY NEW WORLD LEVEL

ADDITIONAL HEAT INSULATION

For the first time, a method was created and the heat transfer resistance of the vegetation layer of green roofs.

1 – plant layer; 2 – soil; 3 – temperature sensors; 4 – position of the free temperature sensor in the soil; 5 – insulation; 6 – position of the free temperature sensor in the air; 7 – a source of even heat flux; 8 – parallelepiped for mathematical modeling of temperature distribution and heat flows:
black color – models; green color – measurement results; blue color is an assumption that is valid with sufficient heat insulation of the stand; blue color – boundary conditions of the mathematical model; brown color – parameters of the mathematical model; pink color – results of mathematical modeling; red color is



ADDITIONAL HEAT INSULATION

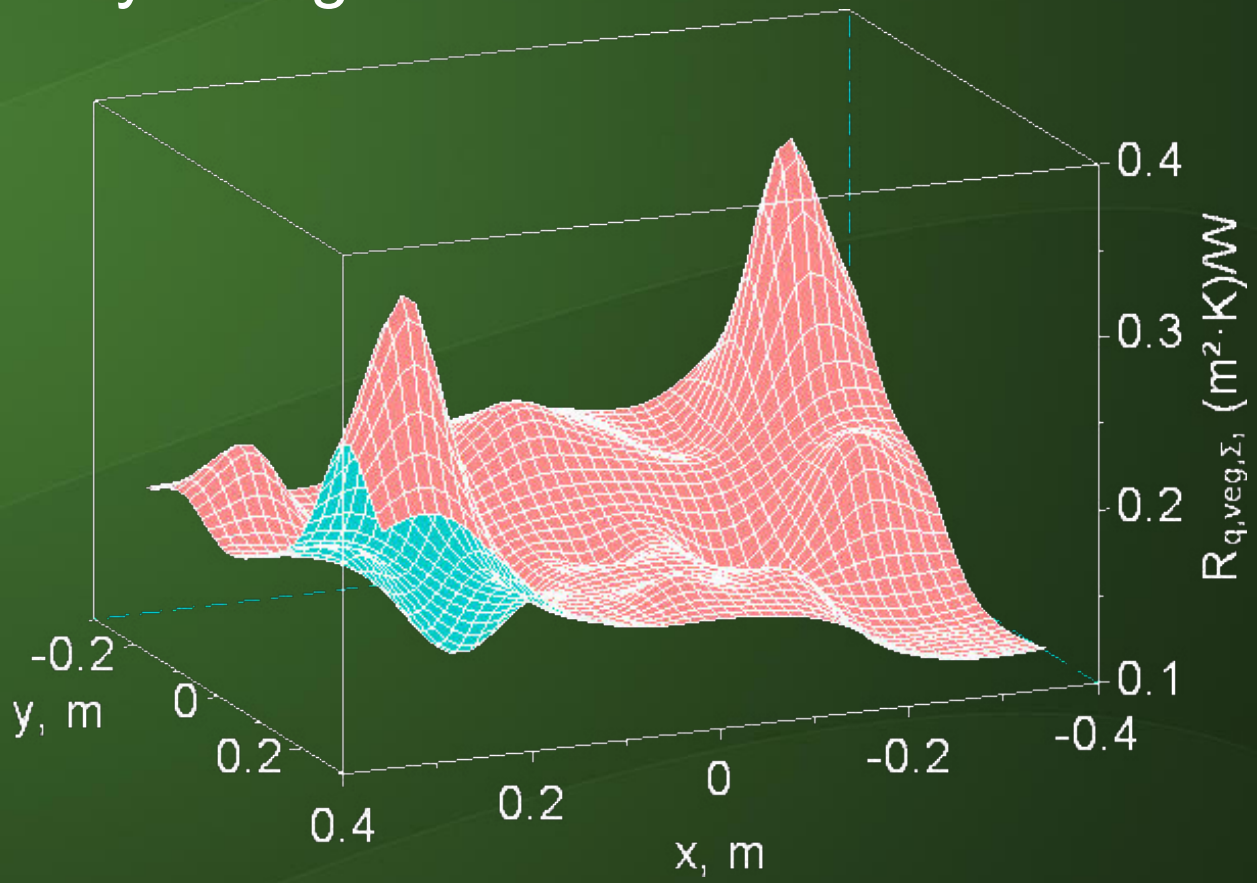
$$\frac{\varphi}{\overline{\varphi}} = \frac{k\frac{\partial\theta}{\partial n}}{k\frac{\partial\theta}{\partial n}} = \frac{k\frac{\partial\theta}{\partial n}}{k\frac{\partial\theta}{\partial n}} = \frac{\frac{\partial\theta}{\partial n}}{\frac{\partial\theta}{\partial n}} \propto \frac{\partial\theta}{\partial n} \Rightarrow \varphi = \overline{\varphi}\frac{\frac{d\theta}{dn}}{\frac{d\acute{}\theta}{dn}}$$

$$\varphi = \frac{\varphi'\overline{\varphi}}{\overline{\varphi'}} \approx \varphi'\frac{\varphi_0}{\overline{\varphi'}}$$

Overline is the averaging by the area, prime is the simulation data; φ_0 – heat flux from the heat source under the experimental model

ADDITIONAL HEAT INSULATION

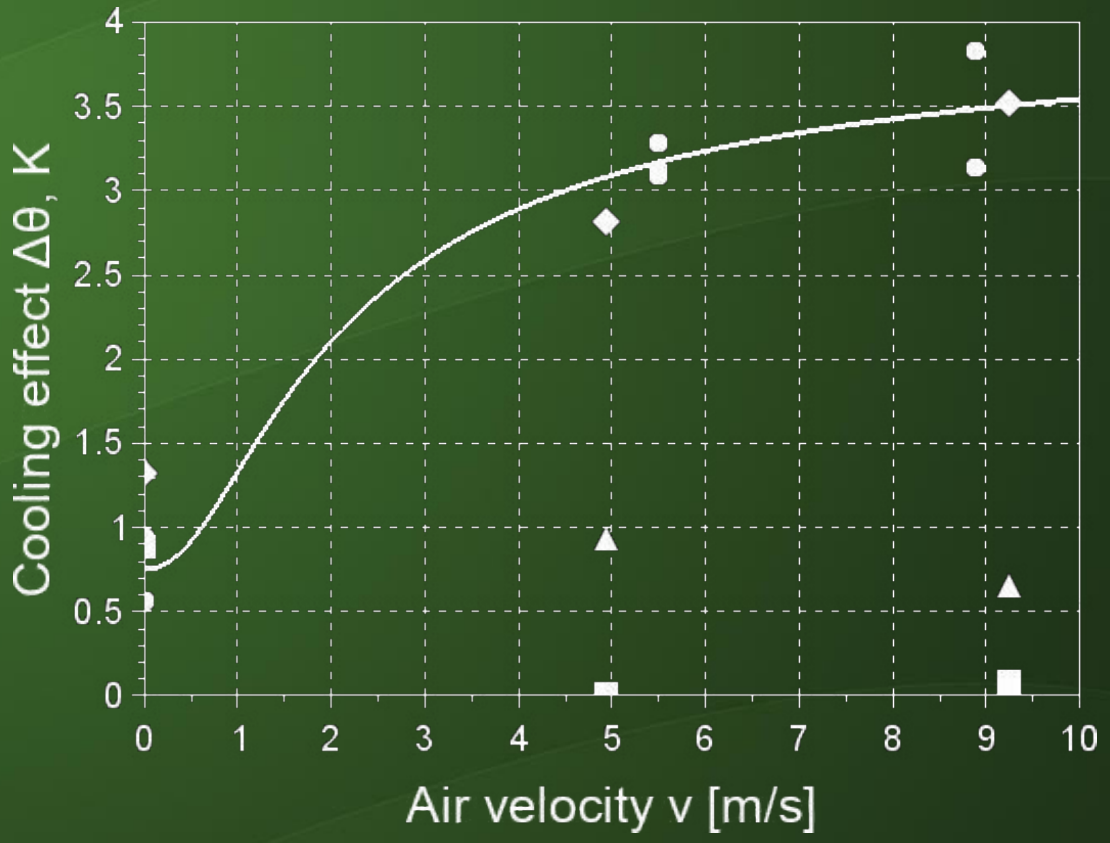
For the first time, a method was created and the heat transfer resistance of the vegetation layer of green roofs.



This allows to calculate energy savings for air conditioning, as well as heating in the spring-autumn period

COOLING EFFECT

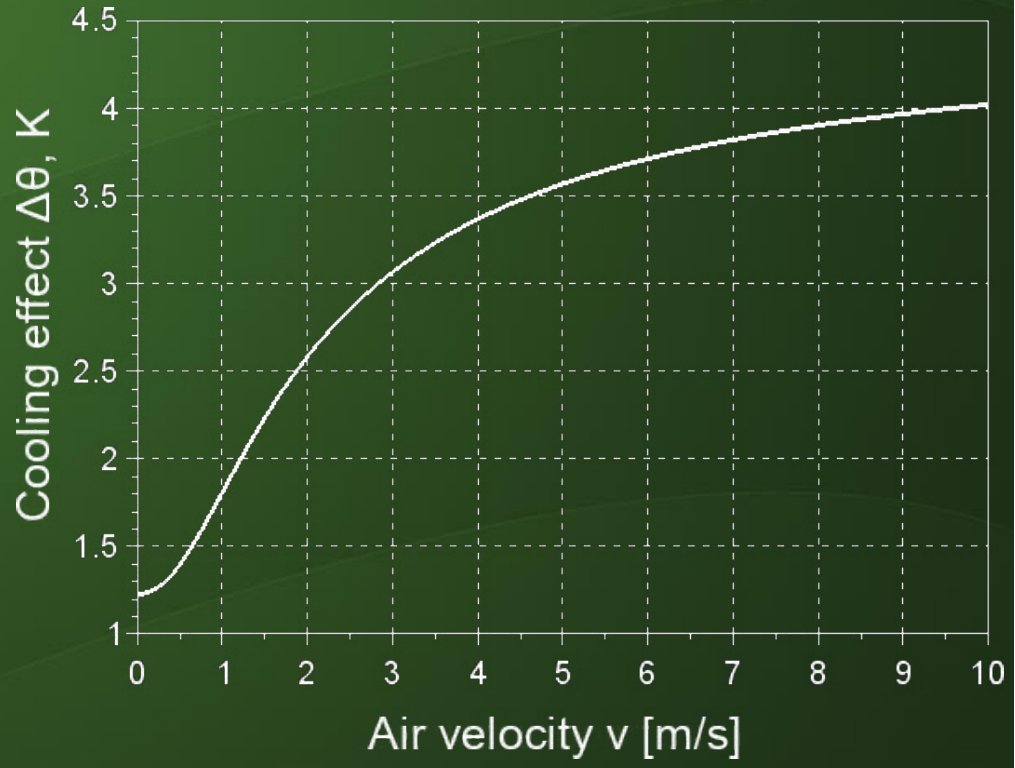
For the first time, a clear definition was introduced – temperature difference around and under the vegetation layer



This allows you to determine energy savings for air conditioning or the effect of passive air conditioning

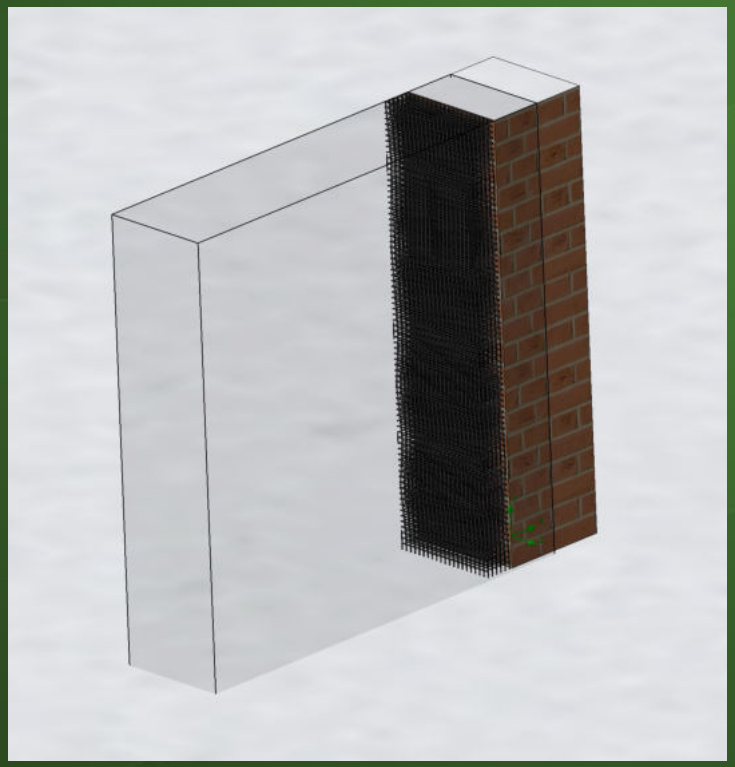
COOLING EFFECT

Greening with Parthenicissus quinquefolia is more effective than with grass (*Lolium perenne*). Such greening requires minimal costs and can be carried out at any time during the operation of the building



THERMAL INSULATION IN WINTER

Computational Fluid Dynamics Simulation. Standard k-ε model



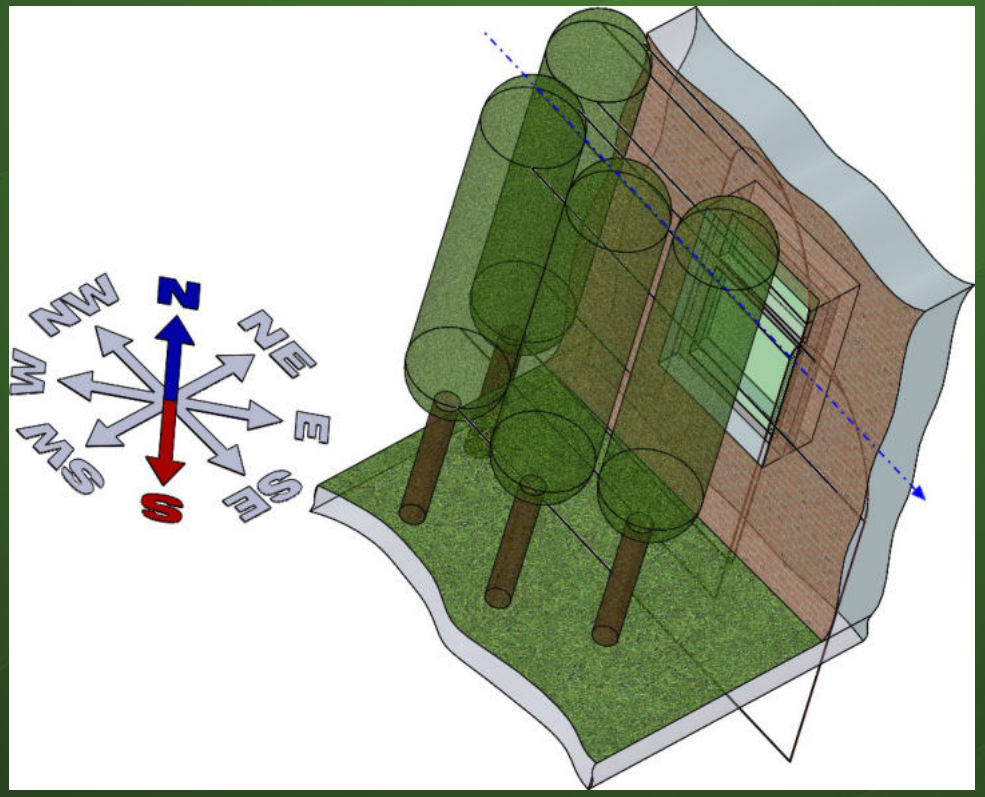
Computational Fluid Dynamics Simulation. Standard k-ε model

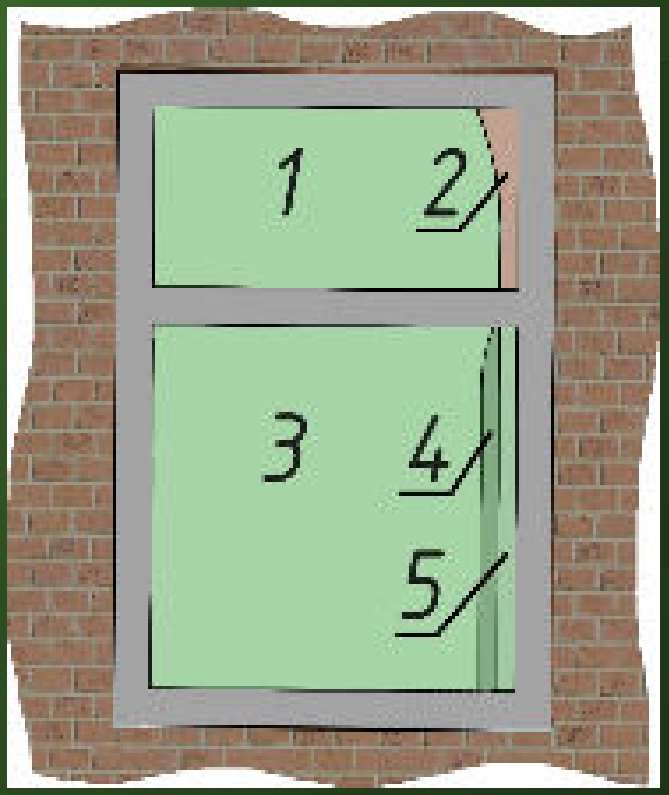
Wind direction	Wind spped [m/s]	Thermal resistance [m²·K/W]
Calm	Calm	0,71
To the façade	2	0,12
To the façade	5	0,09
At a 45° angle	2	0,077
At a 45° angle	5	0,035
Estimated external heat transfer	—	1/23 = 0,043

We have a calibrated heat flux meter and
we'll perform field studies next heating period

AUTOMATIC SUN PROTECTION

can be performed by decidous plants, which shadow glazing at summer and allow solar radiation in winter with the most natural view from the glazing

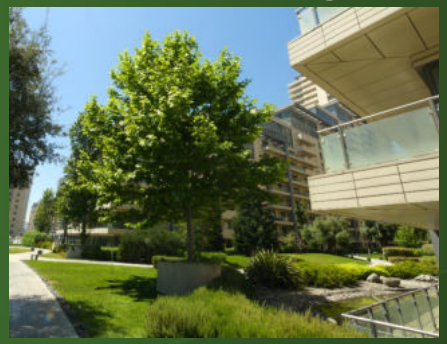




AUTOMATIC SUN PROTECTION

To estimate the light transmission properties, it's possible to use a camera and to avoid special measuring devices

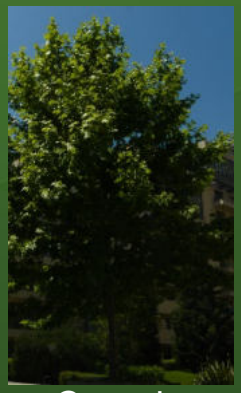
The object – Port Baku Residence.
A model in Heydar Aliyev Centre



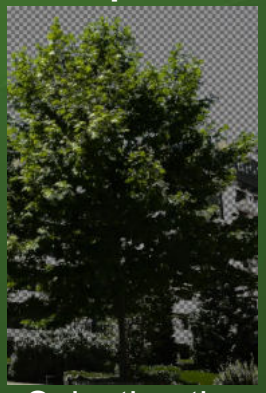
The original image

Image processing by RawTherapee 5.8 and GIMP 2.10.18 Open Source software (chessboard pattern – transparency)

Correction of the exposition



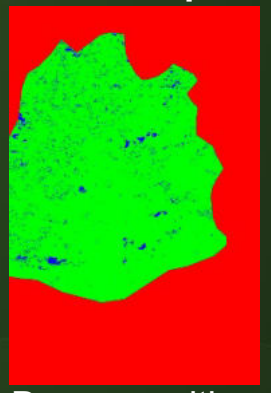
Cropping



Selecting the background "By colour" without antialiasing and deleting it

Isolation of the crown by "Lasso", inverting the selection and deleting

Discolouration of the crown to totally black by "Monomixer" with all zero values

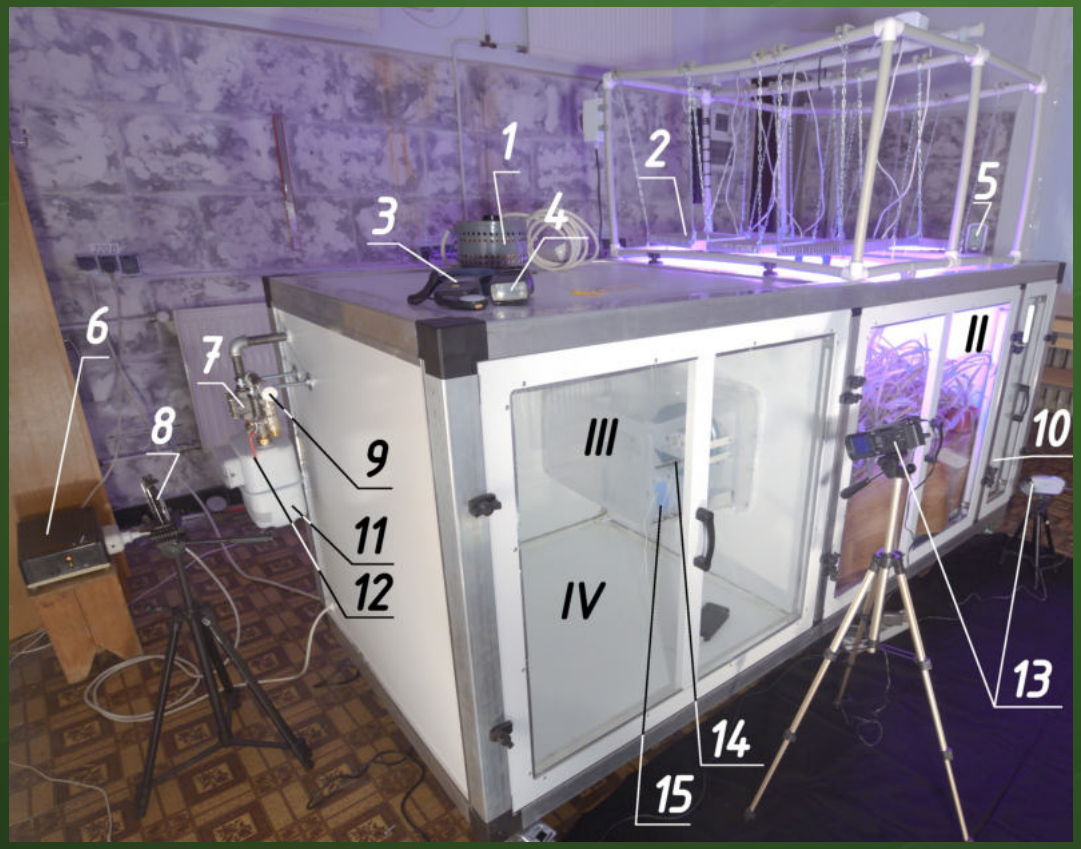


Decomposition by colour channels using"Select by colour" tool and "Bucket" tool

The "Histogram" panel gives number of pixels:
green – C = 1506670; blue – B = 62476.
Optical transmission
T = 62476 / (62476 + 1506670) = 4 %

LABORATORY TESTS OF CO_2

Gas Echange Chamber
In the laboratory of Heat-Mass Exchange in Green Structures



I – inlet section;
II – gas exchange section;
III – outlet measuring volume;
IV – outlet section
1 – light dimmer;
2 – LED phytolamps;
3 – lux-meter;
4 – synchronising flash;
5 – gas analyser in the room;
6 – ferroresonance voltage stabiliser;
7 – filter;
8 – gas meter shotting camera
9 – control valve for airflow
10 – gas analyser on inlet
11 – gas meter G1.6
12 – shut-off valve
13 – adjustable filled bottom
13 – camcorders for gas analysers
14 – mixer-fan
15 – gas analyser on outlet

ORGANIZATION OF BIOTA MIGRATION ROUTES

Solomianskyi district, Kyiv

Plot No. 1 – an industrial area with a nine-story building. "Orlyatko" park and the territories of educational institutions are nearby.

Plot No. 2 has two parks - "Sputnyk" and "Youth" - gathering places for birds that will be able to find new homes on "green roofs".

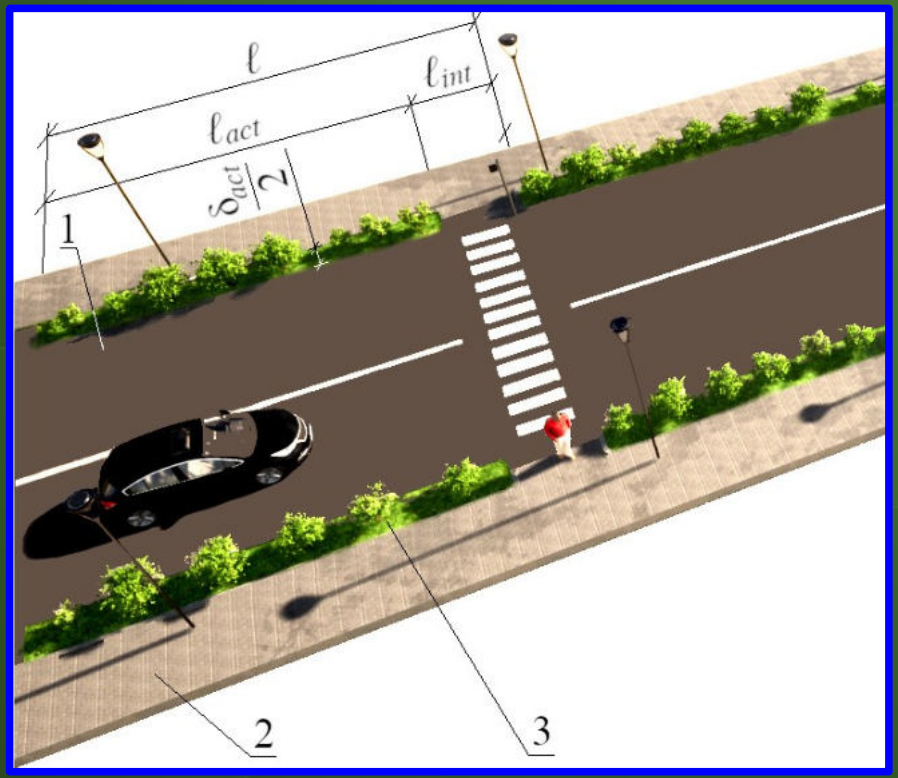
Plot No. 3 near the private sector, two parks (Solomyansky Landscape Forest Park and Protasiv Yar Park).

Plot No. 4 is very densely built-up.

Plot No. 5 borders the private residential sector and has the park "Vidradny", the park of the "Prestige" lyceum and the green area of the Medmistechka. The building is 5-storey, rather compacted in the area of Novokaravaev Dachy.

The condition for the creation of bird migration routes is the limiting of the distance between "green" structures.

RAIN-GARDEN BANDS INSTEAD OF EXPENSIVE RAIN-WATER SEWERAGE



1 – carriageway; 2 – pavement; 3 – rain-garden band.

For Kyiv, the width δ_{act} is no more than 11 % of the road width

RAIN-GARDEN BANDS INSTEAD OF EXPENSIVE RAIN-WATER SEWERAGE

Experimental Research

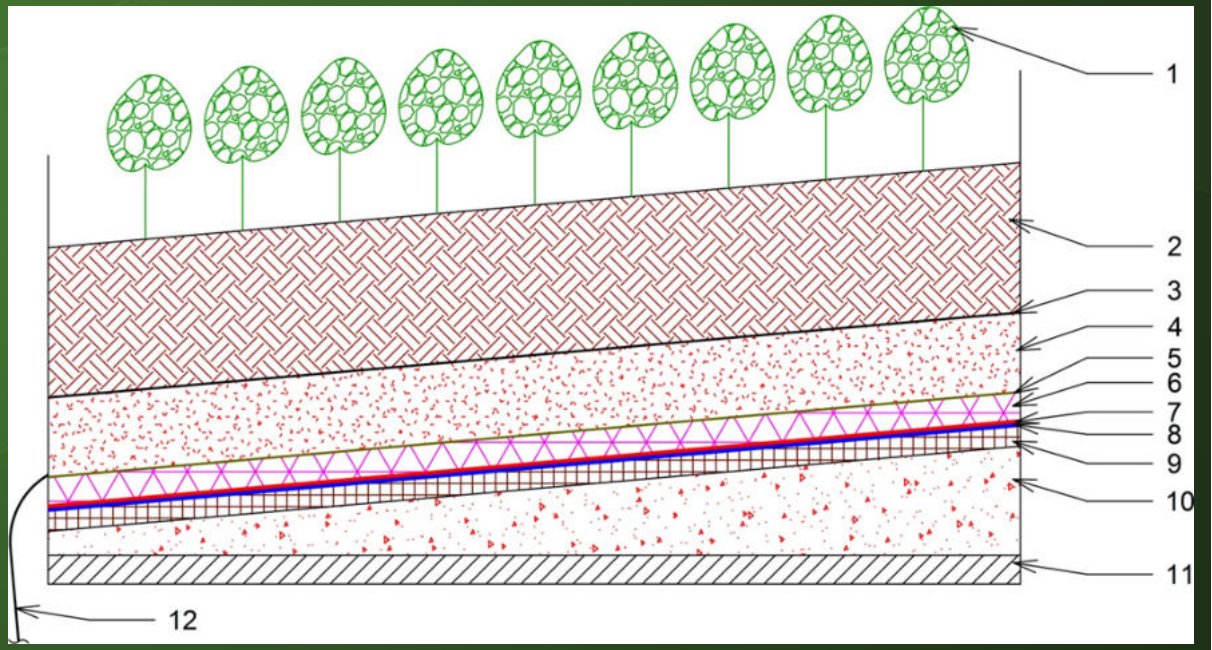
In the Laboratory of the Environment Parameters

The model of a rain-garden band, which is tested without and with plants

Filtration column for laboratory tests

GREEN ROOF OF DOMESTIC MATERIALS by Tetiana TKACHENKO

More than 16 years of success



1 – рослини; 2 – субстрат; 3 – фільтрувальний шар з термоскріпленого геотекстилю; 4 – дренаж з керамзиту; 5 – бар'єр для коренів зі склополотна; 6 – утеплювач з екструзійного пінополістиролу; 7 – пароізоляція (пароізоляційна плівка УкрСпан); 8 – гідроізоляція євроруберoїд; 9 – армована цементно-піщана стяжка; 10 – похилоутворювальний шар з керамзиту; 11 – несуча основа – залізобетонна плита перекриття; 12 – водозлив

GREEN ROOF OF DOMESTIC MATERIALS by Tetiana TKACHENKO

Mathematical model of development (Tumanov's scale)

Group 1 – Armeria, Aster alpinus, Diánthus deltoídes, Iris, Centaurea;

$$\Phi T_1 = 4{,}28 + 0{,}69\,\tilde{\varphi} + 0{,}75\,\tilde{n}_{sun} + 0{,}63\,\tilde{\theta} - 0{,}78\,\tilde{V} \pm 0{,}090$$

Group 2 – Stipa, Aster, Alyssum, Gypsóphila, Saponaria, Tanacetum, Lysimáchia, Deschampsia cespitosa, Léymus, Helictochloa, Filipéndula, Euphórbia;

$$\Phi T_2 = 4{,}46 + 0{,}33\,\tilde{\varphi} + 0{,}40\,\tilde{n}_{sun} + 0{,}34\,\tilde{\theta} - 0{,}39\,\tilde{V} \pm 0{,}067$$

Group 3 – Festúca valesiáca, Salvia L., Phlomoídes, Polýgonum, Hypericum L., Iberis L., Iris sibirica L., Artemisia, Thymus serpyllum L, Melica, Carex, Scutellaria.

$$\Phi T_3 = 4{,}49 + 0{,}39\,\tilde{\varphi} + 0{,}43\,\tilde{n}_{sun} + 0{,}39\,\tilde{\theta} - 0{,}39\,\tilde{V} \pm 0{,}089$$

Relative humidity

$$\tilde{\varphi} = \frac{\varphi - 58{,}55}{7{,}55}$$

Sunny days Number

$$\tilde{n}_{sun} = \frac{n_{sun} - 39{,}3}{9{,}6}$$

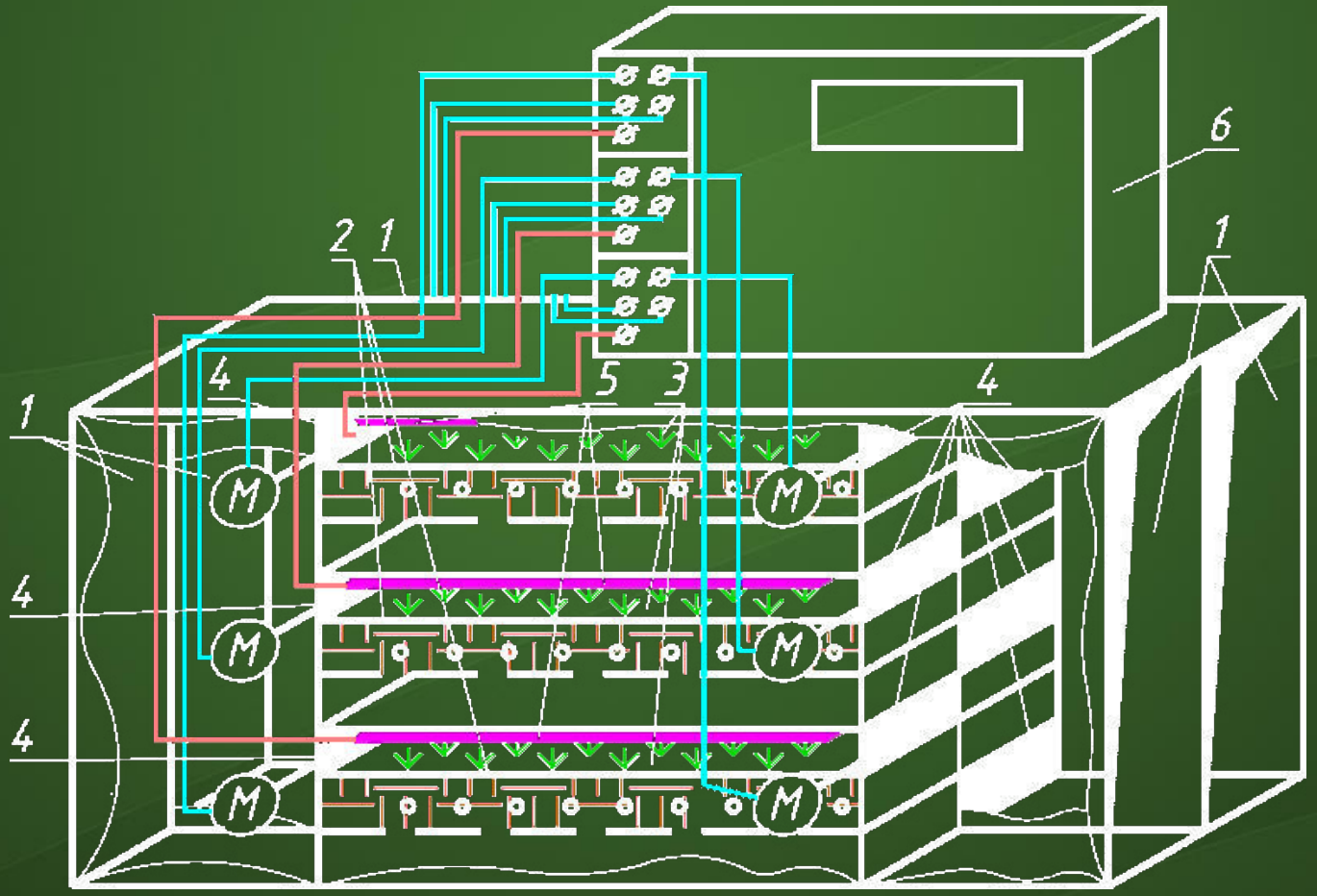
Temperature

$$\tilde{\theta} = \frac{\theta - 9{,}6}{0{,}9}$$

Air velocity

$$\tilde{V} = \frac{V - 4{,}7}{0{,}5}$$

VENTILATION PHYTOFILTER – 24/7 OXYGENATION



1 – duct;

2 – tray with plants, automatic irrigation and drainage;

3 – space for ventilation air with plants;

4 – valve with motor M;

5 – illumination (LED phytolamps for growing recommended);

6 – controller

- **The inlet air is always directed to a space(s) with O_2 release;**
- **the exhaust one is always directed to spaces with breathing only**

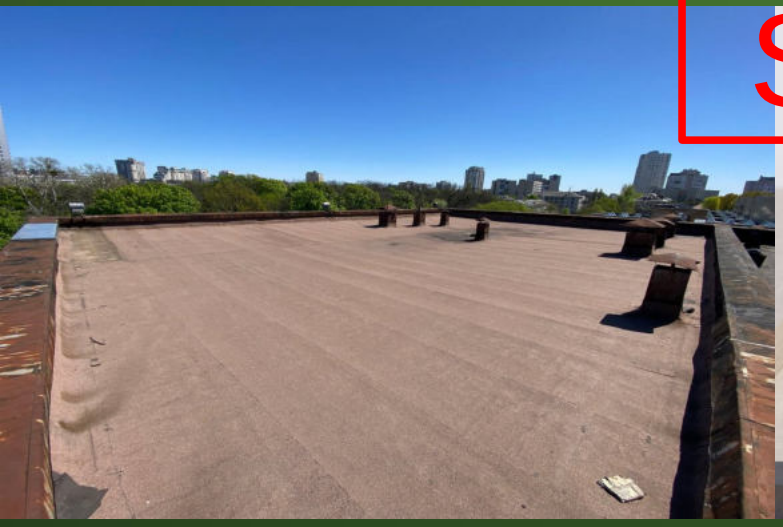
MASKING BY GREEN STRUCTURES

Hitler's headquarters in Poland

Kyiv

GREEN ROOF PROJECT, KNUCA

Needs Sponsorship



The first research and teaching green roof biolaboratory in Kyiv

Authors: Prof. Tetiana TKACHENKO & post-grad. Roman HLUSHCHENKO

CONCLUSIONS

Green structures are a promising biotechnology for sustainable development to overcome energy poverty, improve health, achieve energy independence, compensate for the negative impact of combat actions and ecocide on the environment and passive post-war rehabilitation;

The spread of green structures requires a well-systematised regulatory framework, which, taking into account the original research presented, can become the leading one in the world;

THANK YOU FOR YOUR ATTENTION

Tetiana TKACHENKO, PI of the work, Dr Hab., professor, senior researcher, Head of the Department of Environmental Protection Technology and Labour Safety, Kyiv National University of Construction and Architecture, a member of the Technical committee for standardization TC 82 "Environmental Protection", member of workgroups for Ukrainian standards including standardisation of green structures, academician of the Academy of Technical Sciences of Ukraine and the Academy of Construction of Ukraine, member of the International Association of University Ecologists and the International Society for Geometry and Graphics, known in Ukraine and far beyond its borders expert in the fields of green construction, green structures, green standards etc. She constantly participates in international projects and grant programs, teaches in training courses under the UN support

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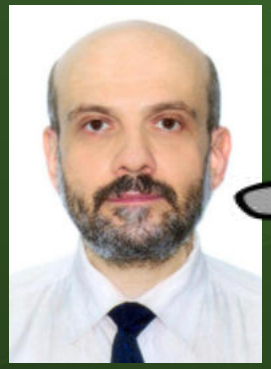

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