Survey

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Façade greening – from science to school

Fassadenbegrünung – Forschung gestaltet Unterricht

https://doi.org/10.1515/auto-2024-0022
Received January 30, 2024; accepted April 22, 2024

Abstract: The growing need for cities to adapt to anthropogenic climate change has ushered into a new paradigm where architecture synergistically meets nature. Façade greening may help to take over multifunctional ecosystem services that impact on city residents' well-being as well as on building energy budget. In recent studies on façade greenings, we demonstrated a cooling effect in summer, an insulation effect in winter and a Nitrogen dioxide absorption potential. Introducing this knowledge into school by offering project days led to longer-term changes in students' knowledge, but not in their environmental attitudes. The latter will probably require constant reminders such as a series of project days focusing on environmental issues, bioengineering solutions and personal adaptation strategies.

Keywords: façade greening; climate change; energy saving; air quality; teaching; school experiments

Zusammenfassung: Die Anpassung an den anthropogenen Klimawandel wird für Städte immer notwendiger. Dies hat zu einem neuen Paradigma geführt, bei dem Architektur und Natur synergetisch zusammenwirken. Ein Beispiel dafür sind Fassadenbegrünungen. Sie können multifunktionale Ökosystemleistungen übernehmen, die sich auf das Wohlbefinden der Stadtbewohner und den Energiehaushalt der Gebäude auswirken. In aktuellen Studien zu Fassadenbegrünungen konnten wir einen Kühleffekt im Sommer, einen Dämmeffekt im Winter und ein relevantes Stickstoffdioxid-Absorptionspotenzial nachweisen. Der Transfer dieser Erkenntnisse in die Schule erfolgte durch das Angebot eines Projekttags im universitären Schülerlabor. Dieser führte bei den Jugendlichen zu längerfristigen Veränderungen bzgl. ihres Wissens, aber nicht ihrer Umwelteinstellungen. Um Letzteres zu erreichen, wäre ein umfangreicheres Angebot wünschenswert, wie z. B. eine Reihe von Projekttagen, die sich mit verschiedenen Umweltfragen, Lösungen aus den Bioingenieurswissenschaften und persönlichen Anpassungsstrategien befassen.

Schlagwörter: Fassadenbegrünung; Klimawandel; Energieeinsparung; Luftqualität; Unterricht; Schulexperimente

1 What science tells us

1.1 Introduction

Cities contribute to climate change and are themselves severely affected by its consequences. Prolonged high temperatures with increasingly tropical nights turn densely built and heavily sealed urban neighborhoods into heat islands with negative effects on the health of city dwellers, biodiversity and urban greenery. Climate protection and adaptation to climate change are therefore necessary strategies that cities need to adopt.

Harnessing plants' refined and multifunctional ability to guarantee ecosystem services such as urban heat reduction and air phytoremediation is one example of how "nature's engineering" might help cities to adapt to the various detrimental effects of anthropogenic climate change. Incorporating plants into densely built environments presents a sustainable solution, helping to decrease urban heat [1] and gas pollutants such as Nitrogen Dioxide (NO_2) and Ozone (O_3) [2], to reduce noise and to preserve and strengthen biodiversity.

The potential for reducing the heat budget of buildings through façade greenings has been a subject of discussion for quite some time. The reason for the lack of consensus on specific values is primarily due to the dynamic nature of the topic under investigation. Different experiments conducted under varying climatic conditions have

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resulted in various degrees of cooling achieved by different façade greening systems [3]–[6]. In addition, there is limited information available regarding the air phytoremediation potential of climbing plants, as the relevance of façade greening for urban climate adaptation has only recently been recognized.

The aim of the various projects of our research group is to carry out measurements on thermal impacts of façade greening systems under real conditions. Also, data were collected from gas-flow measurements under experimentally standardized laboratory conditions, to compare the influence of green ("green architecture") and non-green ("grey architecture") façades on parameters such as temperature, Nitrogen Dioxide (NO_2) and Ozone (O_3) – both considered as harmful anthropogenic gases in cities [7].

The results of the data collection will be incorporated into an overall assessment of the thermal benefit potential of façade greening systems (to improve the urban climate) and air quality as an ultimate urban adaptation strategy to climate change.

1.2 Cooling and insulation potential of green façades

To quantify the cooling and insulation effects of ground-based ivy façade and wall-bound façade greening, wall-surface temperature profiles were collected using data loggers on south exposed façades in two different locations.

1.2.1 Ground-based ivy façade

1.2.1.1 Methods

Data loggers (iButtons) were programmed for an hourly reading and placed on the wall surfaces of two buildings adjacent to each other in the city of Bonn (Figure 1). The house under investigation has had a *Hedera helix* (ivy) façade greening for the past 25–30 years. While the adjacent house was a white-painted façade without greening. Both had concrete surfaces. Results obtained from predominantly hot and cold days were compared to each other as shown below.

1.2.1.2 Results

Wall surface temperatures (shown in Figure 2) varied up to about 25 °C on a typical summer day with peak periods between 12 and 2 pm where the temperature difference was at the highest.

During cold periods the green façade acted as an additional insulating layer, providing a warmer temperature on the surface of the wall as compared to the adjacent wall as shown in Figure 3.

1.2.2 Wall-bound façade greening

1.2.2.1 Methods

Similar to the previously described method, data loggers were fixed to the surfaces of both a greened and a white wall without greening (Figure 4).

1.2.2.2 Results

The data collected for the temperature parameter shows that the wall-mounted façade greening has a consistent cooling effect on warmer days, compared to the non-greened façade sections (see Figure 5).

The temperature profiles for colder periods also showed that the wall-bound façade greening has a continuous insulating effect compared to non-greened façade sections.

1.2.3 Discussion

Improvements in the building's energy budget can be observed in both extreme weather conditions (hot and cold days).



Figure 1: An image of the ground-based façade greening under investigation; with arrows showing locations of data loggers.

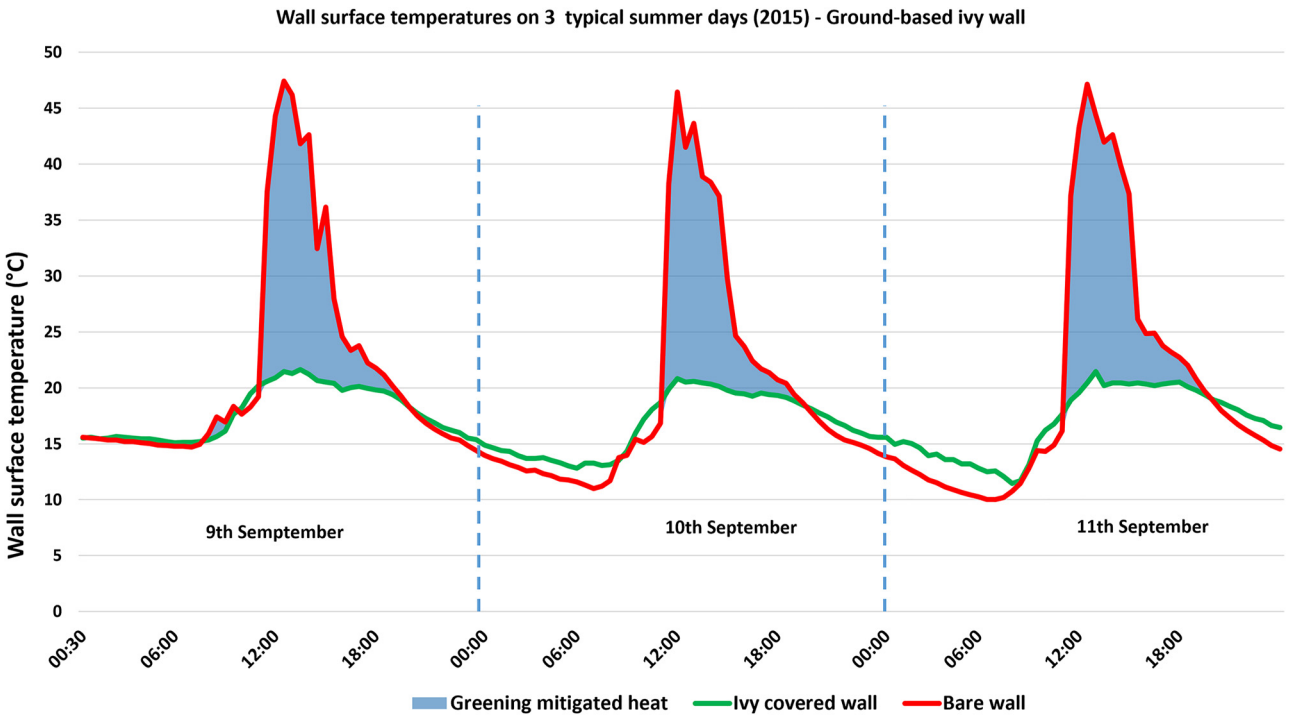


Figure 2: Temperature profiles of a greened and a white painted wall; showing surface temperature differences on summer days, and a relatively stable surface temperature of the greened wall while the white wall undergoes temperature rise and fall.

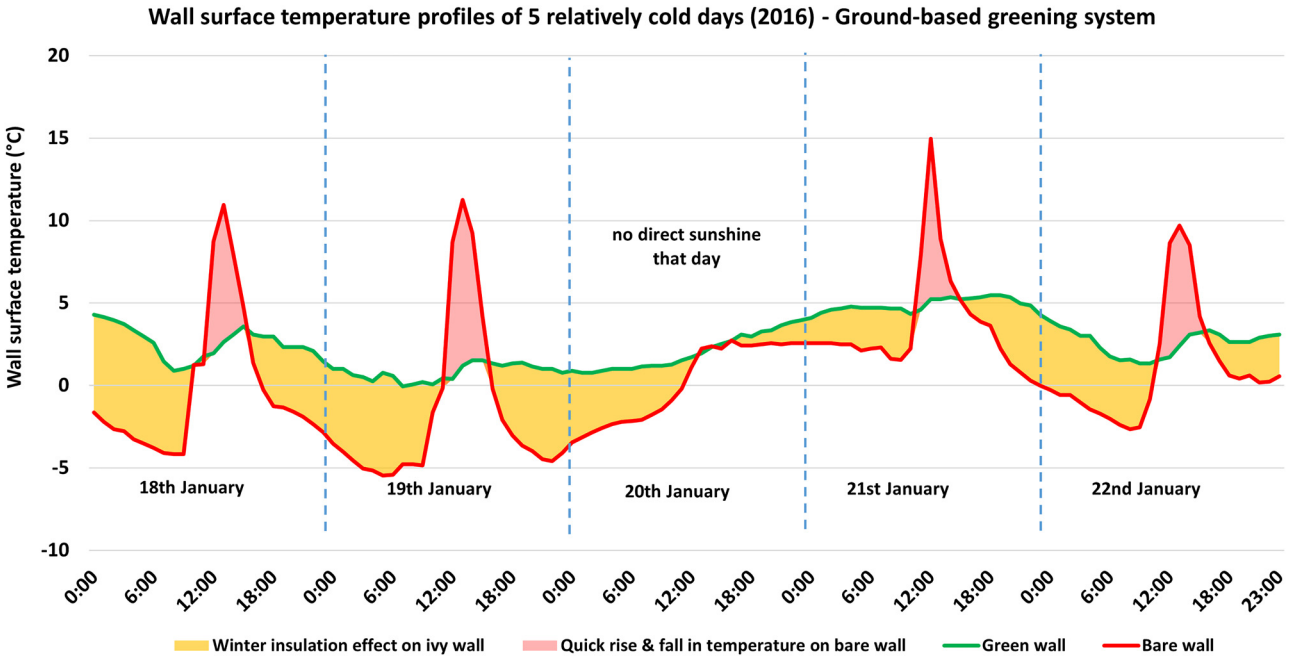


Figure 3: Surface temperature profiles of an ivy wall and white painted wall; showing insulation effect of the greened wall and its relatively stable temperature while the white wall undergoes temperature rise and fall.

During warm periods, the climbing plants offer a protective layer which prevents direct sunlight from reaching the surface of the wall it is covering, hence reducing the amount of energy incident onto the surface of the wall. This is due to the proximity of the plants to the wall with the leaves absorbing light energy and casting their



Figure 4: Image of the wall-bound façade under investigation.

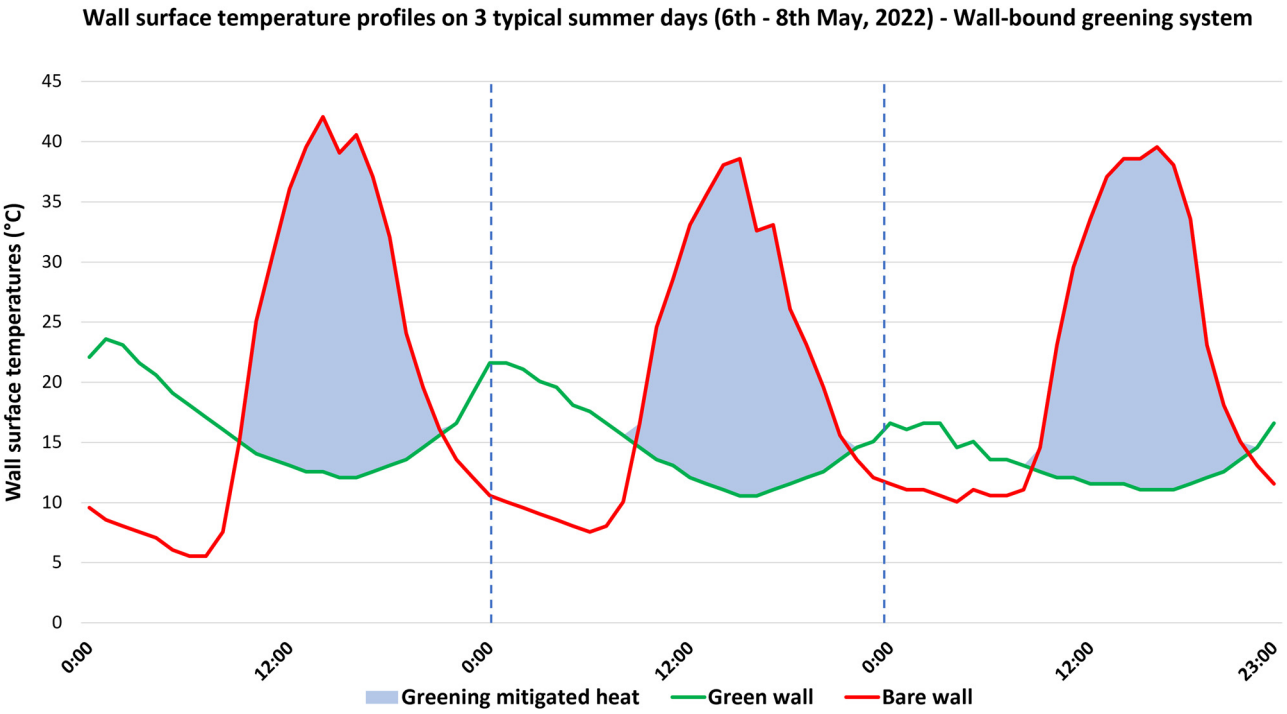


Figure 5: Temperature profiles on a south oriented façade: showing the difference in temperature on the surfaces of both greened and bare-white wall simultaneously (6th – 8th May 2022).

shadows onto the surface which contributes to temperature reduction.

In addition, the process of evapotranspiration or transpirational cooling which involves the use of energy from the leaves and its environment as temperature regulating mechanism contributes to the overall cooling effect observed on the surface of the green wall as compared to that of the white wall.

On the other hand, cold temperatures tend to produce a rather more interesting effect as an evergreen vegetation layer (like an ivy façade) assumes the role of an extra insulation layer. During cold temperatures the flow of heat

energy from buildings is usually from within the apartment to the outside environment. This is because temperatures inside are mostly between 18 and 20 °C making energy loss from inside to the outside environment the main driver of energy consumption. With the extra vegetation acting as an insulation layer, the rate of heat loss from the greened house is significantly reduced.

There are great similarities between the cooling effect of both ground-based and wall-bound systems; however, there is also a noticeable difference: the wall-bound system presents a peculiar rise in wall-surface temperatures at night. This is cooled through out the day and rises again at night. This could be explained by the possible blocking of the radiative heat energy emitted by the building at night, as it serves as an insulation layer preventing or reducing the dissipation of heat energy from the building at night.

Finally, there is an important aspect of façade greening often overlooked which is the protection of the building from extreme thermal stress which has a direct link to the longevity of the building.

1.3 Absorption of pollutant gases (NO_2 & O_3)

There is ample evidence showing different absorption potentials of greenhouse and pollutant gases in some woody plant species [8]. However, information on the air phytoremediation potentials of commonly used climbers in façade greening is limited. Given the heterogeneous distribution of air pollutants in the built environment, plants happen to be the best options for their control in our sparsely greened cities.

To methodically examine this effect, we subjected common climbing plants in a flow-through device to specified amounts of air constituents and examined how these compounds were affected by the plants by examining the compositions of the effluent air with two gas analyzers namely, a mid-infrared laser absorption spectrometer (TDL) and a cavity-ring-down spectrometer (CRDS).

The fundamental idea behind the experimental strategy was to apply brief, pulse-like feeds of gases and analyze the concentration changes that occurred right after the pulses. The quick impacts of the plants on the filtration of the applied gas components were analyzed by plotting the time-dependent lowering of the pulse-induced peaks in both illuminated and dark-phases. In this section the absorption potential of NO_2 will be presented because of its status as a pollutant gas of great concern in cities. N_2O, which is a stable tropospheric gas was used as a control, with its source being ambient air.

1.3.1 Experimental design

A graphical representation of the instrumental setup is shown below (Figure 6) with the ivy subspecies “Plattensee”

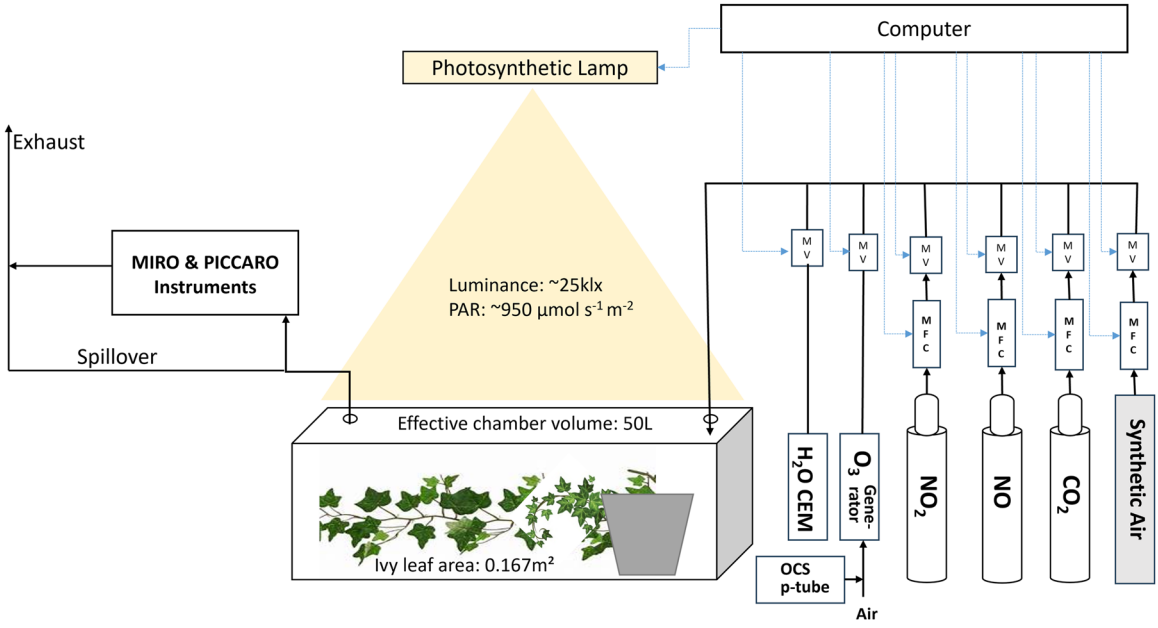


Figure 6: Experimental setup (with an ivy plant) for the greenhouse and pollutant gas absorption experiment. The reaction chamber incorporates a ventilator and a temperature sensor. The constant volume flow rate of synthetic air through the reaction chamber is 10 L/min. The term “MFC” denotes mass flow controllers and “MV” magnetic three-way-valves. The leaf area of 0.167 m^2 given in this figure relates to a specimen of the ivy variety *Hedera helix* “Plattensee” used in this experiment.

as an example. The plants were placed in a small reaction chamber and subjected to a day-night cycle using an LED lamp. The illuminated phase (day) of the experiments ranged from 9 am to 6 pm, after which the lights were switched off for the dark phase (night). The operating temperature in the chamber has been monitored using a temperature sensor called "ibutton" (Hygrochron data logger) averaging 24 °C+/−2 °C.

1.3.2 Results

It was observed that the absorption of NO_2 presented diurnal variations, with most of the absorption occurring in the illuminated phase of the experiment. The results for *H. helix* "Plattensee" are summarized and presented in Figures 7 and 8. Similar results were also obtained for other plant species used for façade greenery.

The time scale in Figure 7, collated over a 24-h period under both illuminated and dark phases of the experiment translates into an absorption rate of about 95 µg/h NO_2 for a leaf area of 0.16 m^2 at a concentration of 40 µg/m^3 NO_2 during the illuminated phase of the experiment as shown in Figure 8 below.

A more detailed explanation of how the absorption rates were calculated can be accessed through Aduse-Poku et al. [9].

1.3.3 Discussion

The permissible limits of Nitrogen Dioxide (NO_2) in the European Union have been revised to align more with the Air Quality Guidelines of the World Health Organization by 2030 because of the EU- Green Deal [10]. For NO_2 this results in a reduction of 50 % from an annual average of 40 µg/m^3 to 20 µg/m^3. What this means is that cities will have to find innovative ways to reduce these pollutants to conform with the revised limits by 2030.

This will be a constraint on the cities already exceeding the current limits. According to the results obtained, *H. helix* at a concentration of 20 ppb NO_2 (about 40 µg/m^3) has the potential to reduce 5493 µg NO_2/m^2 leaf area/day. Projecting these results onto a typical street canyon with the conditions of the laboratory experiments presents about a 17 % reduction in NO_2 pollution levels if the street is covered by an ivy plant.

2 What students should know

2.1 Introduction

It is important that the knowledge gained about the environmental effectiveness of green façades is passed on to

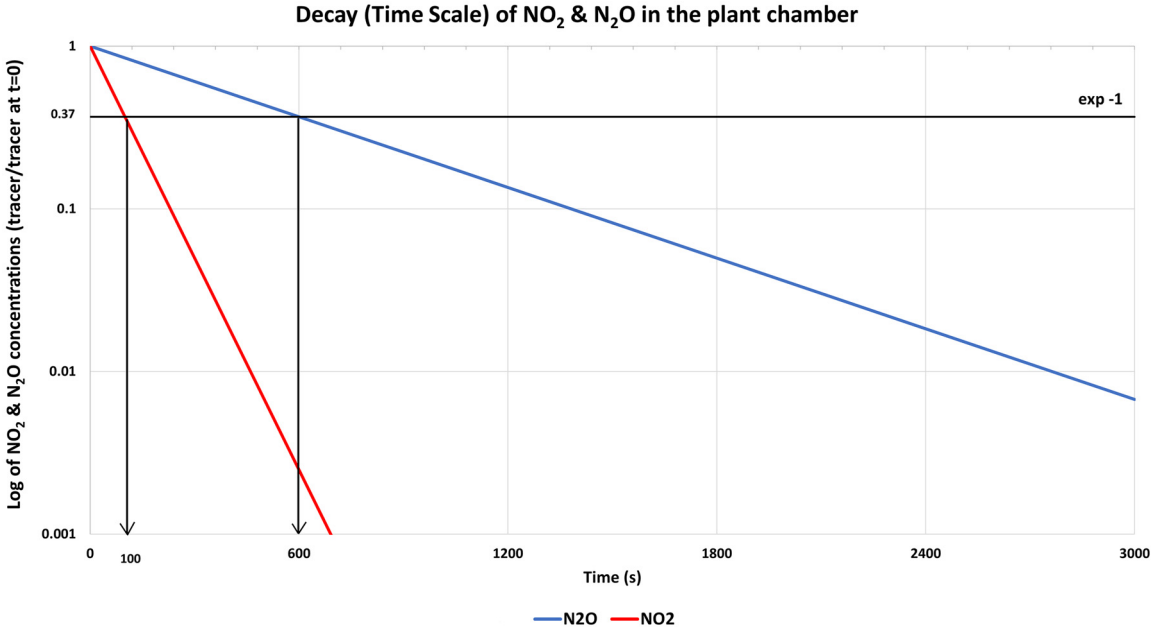


Figure 7: Timescale of decay – the time taken for N_2O (control) and NO_2 to be absorbed or eliminated from the plant chamber using the ivy variety *Hedera helix* "Plattensee". Every hourly collated point (see Figure 8) is a summary of the above-described decay trends of both NO_2 and N_2O.

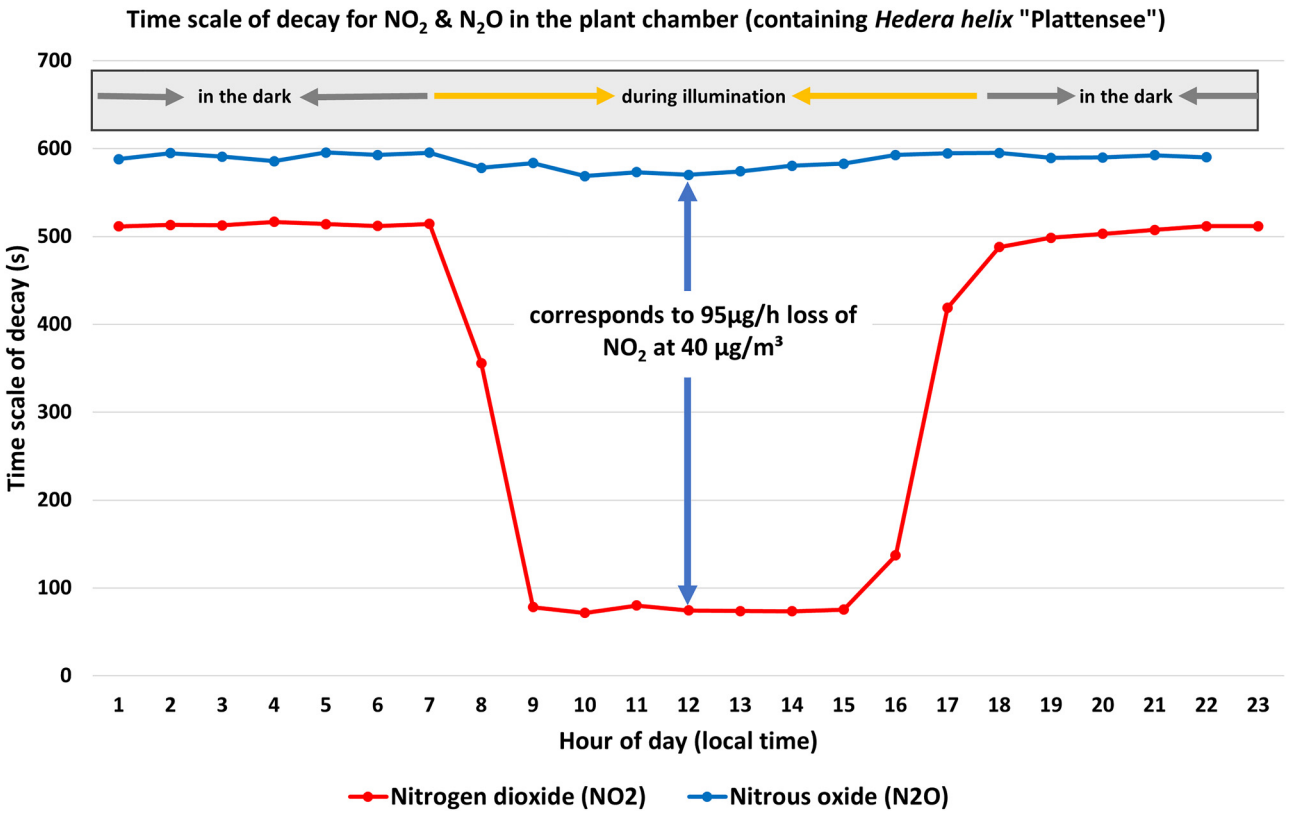


Figure 8: NO_2 uptake by *Hedera helix* "Plattensee" with a leaf surface area of 0.16 m^2.

the next generation [11]. By this, the acceptance of climate-friendly measures (in this case green façades) should be strengthened and the implementation of these measures, particularly in urban centers, should be accelerated. Schools offer themselves as a place of mediation, so that young people can transfer the newly acquired knowledge to their families and support climate-friendly initiatives.

However, the question remains as to how these current topics can be integrated into school lessons, even if the curricula do not (yet) specify them. Three strategies are briefly outlined here. (i) Linkages could be established between the new topic to be taught (in this case green façades) and existing curriculum content. The basic scientific knowledge (on photosynthesis, shading, evaporative cooling and knowledge of species) is then applied in a new context, namely that of façade greening. (ii) New topics, such as façade greening, can be integrated into pre-service-teacher training so that student teachers can bring their experience directly into their lessons when they enter the profession and act as multipliers. (iii) In order to reach in-service-teachers with their classes, teacher training programs can be developed on the one hand and school project days can be offered on the other. Such project days can be organized as extracurricular learning opportunities provided by scientific institutions, e.g. in their school laboratories.

2.2 Intervention

At the University of Cologne, we developed a project day on the topic of façade greening for students in grades seven to nine and tested it with a total of more than 130 pupils. It allows pupils to acquire new knowledge using (a) models, (b) simple experiments (taken from the literature but being newly compiled) and (c) current data from scientific research. The project day is divided into three phases, which are briefly described below. This description refers to a more comprehensive version of the project day than the one tested for effectiveness (see below).

The project day starts with a short introductory phase in which different environmental problems in urban centers are identified by asking students for their prior knowledge in a plenary discussion. The following overarching question is whether façade greening can contribute to mitigating at least some of the problems identified by the pupils.

The work phase is a station-based learning program. The aim of this phase is to familiarize students with the

different types (station 1) and effects of green façades (station 2–6). The stations address topics of biology and physics lessons, like photosynthesis (station 2), absorption and thermodynamics (station 3 and 4) or biodiversity (station 6). Three stations (2–4) refer to experiments in which individual plants (such as ivy) are used as models for an entire façade. Other stations focus on scientific activities like species identification (station 6) or interpreting scientific data (station 5).

- The aim of Station 1 is to introduce students to different types of façade greening using models (or alternatively real façades or photos). The focus here is not only on the technical construction, but also on familiarizing students with different plant species that are suitable for different types of façades. In this way, students' knowledge of species is also increased.
- At station 2, students investigate the extent to which plants reduce the level of the greenhouse gas CO_2 in the air. For this purpose, the change in the CO_2 content is measured in closed containers (e.g. aquariums), with and without plants, using a sensor over a defined period of time. If required, the effect of CO_2 as a greenhouse gas can also be demonstrated in a separate experiment by irradiating closed containers containing air with different CO_2 concentrations with a light source and measuring the temperature increase.
- Station 3 demonstrates the shading effect of a green façade, which leads to a lower temperature rise inside a building. This is also a model experiment in which a temperature sensor is located in a wooden box that is exposed to a radiation source either directly (naked) or covered with ivy.
- Station 4 demonstrates that plants transpire and that this process leads to a cooling of the environment. In total, there should be two separate model experiments. In the first experiment, a sensor is used to demonstrate an increase in humidity in a closed container when a plant is present. In a second experiment, students should experience the cooling effect caused by the evaporation of water molecules from a moistened cloth.
- Station 5 deals with the topic of particulate matter concentration in the air and the extent to which this can be reduced by green façades. As student experiments on this topic are difficult to carry out, experimental data from research is presented, which should then be interpreted by the students. Ideally, the young people would be shown a short video of the experiment at the beginning so that they have a better idea of how the results were obtained.
- At Station 6, the influence of façade greening on biodiversity is to be recorded. For this purpose, living organisms can be searched for on a bare as well as a green façade and assigned to different animal groups in order to record the diversity of species and number of individuals. Alternatively, students can work digitally with photos of different magnification levels.

In the final phase of the lesson, the collected data is summarized and it is examined to what extent the problems which students have associated with conurbations, can be reduced by green façades. Based on the modelling experiments and the recorded data, qualitative statements can be made. If the measured effects could additionally be extrapolated to an entire building façade or a whole street canyon, then the effects would be even more impressive. This could further enhance the project day and may be a task for the future.

2.3 Analysis

Ongoing research on the effectiveness of our project day has so far led to the following findings: It resulted in an increase in students' knowledge, which was still present four weeks later. This knowledge includes both general environmental knowledge relating to green façades and specialized experimental knowledge acquired by the students as a result of carrying out the experiments. However, the project day did not bring about a change in general environmental attitudes. Only the attitude towards green façades changed to a more positive one immediately after the project day, but had decreased again four weeks later. Longer-term and/or repeated interventions are necessary if major changes in environmental attitudes are to be achieved [12], [13]. This could involve a series of several project days on various environmental topics, through which the relevance of environmental measures is repeatedly reminded to the pupils. It would therefore make sense for school laboratories to expand their programs by developing several project days relating to biological engineering and its potential for environmental protection.

2.4 Conclusions

In conclusion, it can be said that the topic of façade greening is very well suited to transferring scientific findings into school education because of its concreteness, good comprehensibility and comparatively easy implementation. Wherever possible, such a relationship between science and school should be established to demonstrate the benefits of biological engineering in moving our society towards greater sustainability. School laboratories can play a major

role here when it comes to imparting solution-based knowledge relating to environmental problems.

Acknowledgments: Our thanks go to Simon Meul, who developed the first version of the project day on façade greening as part of his Master's thesis, to Marie Brüggemann, who analyzed the student data, and to Maren Flottmann for her constant support and feedback. In addition, we want to thank Dr. Franz Rohrer of the FZJ – Forschungszentrum Jülich, who made the quantification of the gas pollutants possible, and the company KREBS & CONRADS whom through their innovative window greening project BILLY-GREEN gave room for experiments for the scientific part of this paper. Finally, we are grateful for the financial support provided by the ZIM programme of the Federal Ministry for Economic Affairs and Climate Action and by the funding line GRÜN hoch 3 of the City of Cologne.

Research ethics: The present survey did not require the approval of an ethics committee, because the research did not pose any threats or risks to the respondents, and it was not associated with high physical or emotional stress.

Author contributions: The authors have accepted responsibility for the entire content of this manuscript and approved its submission.

Competing interests: The authors state no conflict of interest.

Research funding: Project: Innovative façade greening system to increase the energy efficiency of buildings: "BILLY-GREEN". Funding line: Central Innovation Programme for small and medium-sized enterprises (SMEs). Funding organization: Federal Ministry for Economic Affairs and Climate Action Application number: KK5136801AJ0. Project term: 01.02.2021 bis 31.07.2023. Project title: GrüneFassadeKöln: Optimization of building energy efficiency by means of façade greening. Funding line: GRÜN hoch 3/GREEN to the power of 3. Funding organization: City of Cologne. Project term: 01.10.2021 bis 31.05.2023.

Data availability: The data presented in this paper are available on request from: Bio-data: HE, Educational data: KS.

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