UNIVERSITY CAMPUSES AS POSITIVE ENERGY DISTRICTS: EDUCATIONAL RESEARCH SUPPORTING STU'S GREEN TRANSITION

Andrea Šeligová*,1, Peter Morgenstein[1], Daniela Hrabovská[2], Milan Husár[2], Martin Šalkovič[2]

*andrea.seligova@stuba.sk
[1]Faculty of Architecture and Design STU, Námestie slobody 2911/19, 812 45, Staré Mesto, Bratislava
[2]Institute of Management STU, Block B2, Vazovova 2757/5, 812 43 Staré Mesto

Abstract

This article presents findings from the Green STU university research project, conducted on an elective course Positive Energy Districts. Using GIS modelling and spatial analysis tools, students assessed the existing university buildings and campuses through energy consumption patterns. Scenarios were developed to reduce energy consumption. The results provide an insight into the potential transformation of campuses and serve as a foundation for STU's strategic approach to institutional sustainability.

Keywords

Positive energy districts, sustainability in higher education, sustainability transition

1 INTRODUCTION

Facing contemporary environmental challenges and the urgent need for sustainable solutions, universities play an increasingly significant role as agents of change. In recent decades, the body of scholarly literature focusing on the integration of sustainability and related topics into university curricula has expanded substantially. Authors, such as Sterling and Thomas [1], highlight the growing importance attributed to universities' contributions across various dimensions. In addition to education and research, emphasized by Ralph and Stubbs [2], attention is also directed towards the so-called third mission, encompassing scientific, technological and cultural transfer activities, together with the productive transformation of knowledge through interactions between universities, civil society and entrepreneurial actors [3].

An equally relevant dimension is campus operations, focusing on managing the university's building stock and infrastructure. This aspect has gained critical importance in light of the widely acknowledged impact of the built environment on carbon emissions. This impact has led to the emergence of international standards and evaluation systems, such as UI GreenMetric [4], which annually reports on performance of universities in managing their facilities and infrastructure. As a result, a new conceptualization seems to be emerging, one that transcends the third mission by integrating three pillars: campus operations, education and research. These pillars are reinforced by the third mission's approach to transition, shaping how universities address their relationships with the external environment [5].

The aim of this research is twofold. On the one hand, the goal is to deliver a comprehensive visualisation of the energy use data and compare energy consumption between STU’s campuses as a basis for identification of further steps towards increasing sustainability and energy efficiency. On the other hand, the research focuses on evaluation of students’ group work and their ability to implement the PED assessment tool according to methodological instructions for sustainability evaluation and improvement of the university campuses as positive energy districts.

This article begins with an introduction presenting the context of university sustainability initiatives. The methodology chapter describes the Green STU project and students’ research conducted within the elective course Positive Energy Districts, including the analytical tools and data used. The results chapter presents findings from the energy consumption analysis and proposed scenarios for achieving energy positivity across the different university campuses. Also, it briefly evaluates the quality of results achieved by student groups. The discussion examines limitations of the applied methodology and opportunities for future research. The paper concludes with recommendations for university campus transformation towards sustainability.

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Literary overview

Many universities worldwide have set goals to decarbonize their campuses, simultaneously fostering a transition to more sustainable energy systems through expertise provision and technology development. For example, while district heating (DH) systems are less common in North America than in Europe, universities have been in the vanguard of developing DH systems on their campuses. According to Han et al [6], university campuses are well-suited for developing and testing such systems, which could help cities transition to more sustainable energy systems. However, despite these efforts, obstacles, such as a lack of regulation and investment support hinder the broader adoption of these systems in surrounding urban areas.

Eriksson et al [7] studied the modernization of three Nordic university campuses, emphasizing economic, environmental and social sustainability. Their findings reveal that universities offer favourable environments for innovation, entrepreneurship and facilitating collaboration between academia and industry. Similarly, Murray et al [8] demonstrated that energy efficiency measures at district levels in urban areas are more advantageous than measures implemented at individual building levels.

The transformation of urban building stocks, mobility systems, industries, and infrastructure necessitates an integrated and multidisciplinary approach. A significant focus within this domain is the concept of Positive Energy Districts (PEDs) which are increasingly recognized as crucial components in the decarbonization process of urban environments [9]. PEDs extend the principles of nearly-zero, net-zero, or positive-energy buildings to encompass entire districts, thereby fostering energy collaboration among buildings and contributing to broader urban decarbonization efforts [10], [11], [12], [13].

To ensure their success, PEDs must achieve environmental, economic and social sustainability for present and future generations. In 2018, the European Commission defined PEDs as energy-efficient urban areas or interconnected groups of buildings which not only achieve net-zero greenhouse gas emissions but also actively manage local or regional surplus renewable energy production [14]. These districts encompass energy-efficient, flexible urban areas or interconnected building clusters which produce net-zero greenhouse gas emissions and actively manage local or regional renewable energy surpluses. Proper implementation of PEDs requires integrating various systems, ensuring interaction among buildings, users and energy systems, and achieving sustainable energy supply and quality of life for all.

2 METHODOLOGY

The research was conducted as part of the Green STU university research project which aims to create a comprehensive sustainability assessment using GIS and BIM models for selected university campuses and structures. This specific study was carried out within the elective course Positive Energy Districtsat the Faculty of Architecture and Design of the Slovak University of Technology, open to students from their third year of study onwards.

At the beginning, based on geographical proximity and structural and spatial connections or building use, the university premises were clustered into five micro-campuses to be considered PEDs (thus resulting in different sizes and volumes of the micro-campuses). Together with the corresponding energy consumption data, they were assigned to five teams (Fig. 1) of mixed-year students to be analysed andevaluated and to suggest sustainability improvement solutions:

- Group 1: Trnava Campus – Faculty of Materials Science and Technology (MTF) and Miloš Uher Dormitory.
- Group 2: Bratislava Central Campus – Faculty of Architecture and Design (FAD), Faculty of Civil Engineering (SvF), Faculty of Chemical and Food Technology (FCHPT), Faculty of Mechanical Engineering (SjF).
- Group 3: Bratislava Uphill Campus Mlynská Dolina – Faculty of Electrical Engineering and Information Technology (FEI), Faculty of Informatics and Information Technologies (FIIT)
- Group 4: Bratislava Central Dormitories – Juro Hronec and Nikos Belojanis dormitories, including facilities.
- Group 5: Bratislava Rectorate – Administrative buildings and University hotel.

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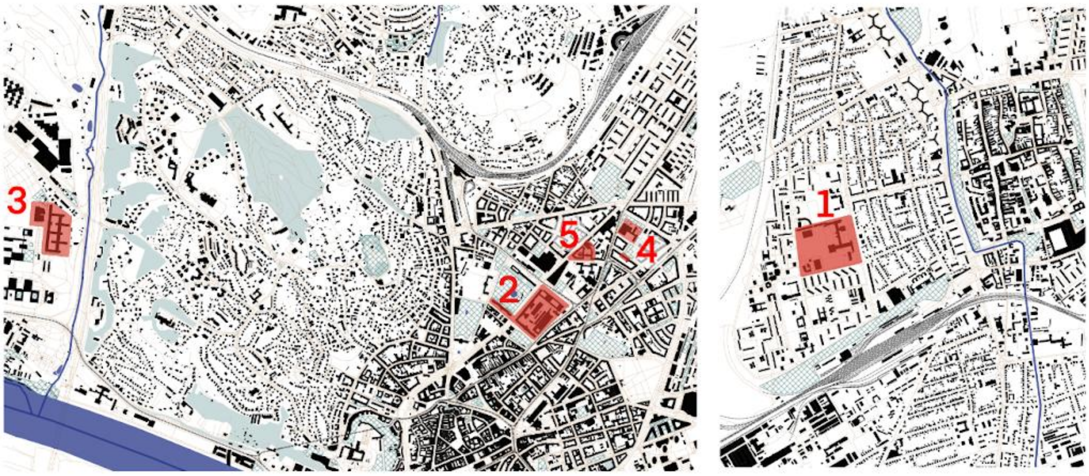

Fig. 1 Schematic map of STU premises divided into 5 micro-campuses as assigned to student research groups, the city of Bratislava on the left, the city of Trnava on the right; Trnava Campus (1), Bratislava Central Campus (2), Bratislava Uphill Campus (3), Bratislava Central Dorms (4), Bratislava Rectorate (5).

Methodologically, the research was divided into two main phases. The initial phase focused on a retrospective analysis and visualisation of resources consumption using GIS. During the analytical part, following resources were considered for each of the micro-campuses individually: electricity, district heating, natural gas and water consumption. The data provided by the STU covered a 20-year span from 2003 until 2023 with annual consumption values of individual building structures. Moreover, during this phase, students analysed architectural features, particularly focusing on internal building layouts, mapping floor areas and specific usage mix, composition of building envelopes, identifying percentage of glazed surfaces of facades and gaining other relevant data needed for the second research phase.

In the second phase, students calculated the district energy balance using the PED assessment tool developed by Simon Schneider et al. [15]. The MS Excel based tool was designed to calculate energy balance by analysing multiple parameters, allowing for comprehensive assessment toward achieving positive energy districts. The tool considers multiple features such as:

- **Urban features** (Buildable plot size, Usage mix with detailed floor areas).
- **Function specific energy demands** (User plug loads, Hot water demand, Lighting, Buildings in general, such as elevators, controls etc.).
- **Architecture and Construction** (Building envelope areas, Building geometry and orientation, Percentage of glazed surfaces, Construction methods and materials).
- **Energy systems** (Heat sources, Heat pump specifications, Photovoltaic configurations, Battery capacity).

During the second phase, students used the 2024 status quo of university buildings to deliver an assessment of the assigned micro-campuses and their energy consumption. Further, students developed various scenarios of possible improvements aimed at achieving positive energy clusters. These interventions included installation of photovoltaics on roofs or facades, implementation of green roofs and facades, introduction of heat pumps and battery storage systems, and addition of new supporting structures to optimize energy consumption patterns.

During both phases, the student groups could benefit from consultations of their work progress, addressing usage of the tools (GIS, PED assessment tool), gathering and understanding data etc. The groups presented their work-in-progress in mid-term. The project lasted for the whole winter term, i. e. approximately 12 weeks, with 2 ECTS allocated for the elective course.

Students were encouraged to visit the buildings to create a personal experience and improve their understanding of the places. Also, they had to find out relevant information for the evaluation tool. They used photography, online street view tools and, where available, drawings to establish the glazing percentage of facades and to create 3D models in the GIS environment.

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3 RESULTS

Assessing status quo

The energy consumption assessment of the status quo relied onthe pre-set building usage profiles since the simplified approach at this point did not reflect the real consumption data measured. Apart from inserting correct data on building envelopes (roof and facades surfaces) and window ratio on each facade orientation, students had to analyse the building usage mix and feed the building usage profiles in the tool with corresponding data. Correctly, distinct patterns of energy consumption with peaks during workdays and minimal consumption during weekends were revealed in micro-campuses of Uphill Campus (Fig. 4) and Rectorate (Fig. 6) consisting almost entirely of administrative and educational usages. Although the pattern of the graph of Central Campus (Fig. 3) corresponds, the usage profiles were not fed entirely correctly. Irregularities occurring are due to activation of the energy consumption flexibility feature in the tool, which would not be realistically possible in the current statuseither. In case of Campus Trnava (Fig. 2) and even more in case of Dormitories (Fig. 5), the resulting graphs of energy consumption are more balanced each day due to the significant extent of residential use. However, significant fluctuations between peak and low consumption periods were observed across all micro-campuses.

It can be stated that for assessing status quo, the resulting graphs were delivered correctly only in case of groups 2 and 3. Graphs delivered by groups 1, 4 and 5 included substantial solar energy yields, although no solar systems were added at this point. Only some of the groups were aware of this mistake during presentations and reported issues getting the correct graph out of the PED assessment tool.

Overall, the analysis of the micro-campuses has shown a low level of implementation of sustainability principles and renewable energy sources, with a small solar appliance present only in case of Rectorate (group 5). Most structures are constructed from reinforced concrete and bricks with the predominance of district heating systems. Very few or even no outdoor areas or solutions to improve the microclimate of the campuses, such as shaded areas, vegetation roofs or facades, were found. The orientation of facades was more or less uniform (around 25 % in each group), with glass facades and openings, such as windows from 10 % up to 40 % of each facade, depending on the architecture of the selected building.

Potential of the integration of sustainable energy sources

In the second stage of their projects, students proposed solutions and approaches to improve sustainability of the micro-campuses and where possible, to reach energy neutrality or positive energy balance of the PEDs (micro-campuses). Most of the groups decided to present more than one proposal, usually one optimized and one maximized approach. Three main strategies were identified in the students' projects:

Introduction of sustainable renewable energy sources - mainly integration or addition of photovoltaics into the building envelopes - based on the possibilities offered by the PED assessment tool.

Peak consumption management through combination of adding an energy storage such as electric battery, groundwater heat pump, applying flexible consumption from and feeding of the energy grid or considering electric mobility - also possibilities which could be reflected in the PED assessment tool.

Focusing on additional measures and approaches improving sustainability and resilience of the micro-campuses - features identified individually by the student groups and presented via mood boards, examples and sketches.

Integration of renewable energy sources

All groups proposed the addition of extensive PV systems on suitable roof and facade surfaces. Three out of five micro-campuses described (2, 4, and 5) are located in the Old Town urban conservation area, where installing photovoltaic systems on rooftops and facades is restricted; however, alternative solar energy solutions are available for these zones. With the exception of group 4, they also implemented new photovoltaic roof structures and shading over parking lots or courtyards, addressing the need to improve the public areas of the campuses and their microclimate, while also harnessing solar energy.

In the case of Campus Trnava, group 1 proposed a combination of flat mounted PV panels with green roofs to improve the PV efficiency on 16,424 m^2, which represents 70 % of all roof surfaces, and added 3,070 m^2 of facade mounted PV systems. In the maximal approach, the group extended active solar surfaces by another

5,500 m^2 integrated in the structures proposed for shading of walkways and parking lots. In both simulations, a positive energy balance of the district could be achieved when district heating or heat pumps were considered.

For Bratislava Central Campus, group 2 applied 4,264 m^2 of flat roof horizontal PV and nearly 20,000 m^2 of southwards facing PV tilted at 30 degrees covering roughly 8 5 % of roof areas and over 22,800 m^2 of south facade 30 degree tilted which represents 90 % of south facing facades. In the maximalistic variant, the total area of PV covering south-facing facades exceeds the available surfaces unrealistically by 140 %. In both simulated variants, the PV yields surpass energy consumption within each month of the year.

Group 3 delivered 4 variants of the Bratislava Uphill Campus, ranging from around 15% PV roof coverage up to a combination of 50 % of roof surfaces covered by horizontal, east and south tilted PV panels and 20 % of south-facing facade used for PV. The group provided a very realistic approach to refurbishment by adding new buildings to the campus to increase density and proposing photovoltaic shading of parking lots. In the most elaborated variant, the energy district reached neutrality or slightly positive energy balance.

Group 4, which focused on the Bratislava Central Dorms micro-campus, designed almost 4,000 m^2 of roof mounted 30 degree tilted PV panels covering 60 % of the roof surface. In their first variant, they combined the system with nearly 1,000 m^2 vertical photovoltaics (covering 28 % south-facing facade. In their second variant, they introduced new residential units, increasing the overall volume by 25 % while not changing the area of the roof and adding another 400 m^2 of south-facing facade-mounted PV (altogether 32 % of south-facing facades). In both variants, a positive energy balance of the micro-campus was achieved.

In the case of the Rectorate micro-campus examined by group 5, four intervention variants were explored (adding roof PV, roof PV and a new volume in the inner yard, roof PV and a PV roof above the courtyard, roof PV, new volume in courtyard and facade PV). Due to turning off (deleting) the heat pump option in the PED assessment tool for the first two variants, the calculations got corrupted and the results included neither energy consumption nor energy gains. Apparently unaware of this problem, the group performed the two other calculations with the heat pump option activated and got to correct outputs of the PED assessment tool, rendering the Rectorate micro-campus energy neutral (with 60 % of roofs or approximately 3,000 m^2 covered by PV) or energy positive (45 % of roofs and unrealistic 122 % of the south-facing facades). The group probably got confused by the quantity of variants as some of the values inserted in the PED assessment tool did not match the presented interventions. The most realistic variant with correct values and calculations (building to courtyard and approximately 60 % of roof covered by PV) resulted in nearly energy neutral or slightly energy positive Rectorate micro-campus.

Peak consumption management

Each group also attempted to manage the peaks in the energy consumption of the given micro-campus. Groups 1 (Fig. 2) and 3 (Fig. 4), which were the only ones with significant open space in the vicinity, proposed construction of new supporting buildings, including new administrative buildings as well as, additional shopping and leisure time facilities for students. Groups 2 (Fig. 3) and 4 (Fig. 5) focused on vertical extensions of existing structures, while group 5 (Fig. 6) proposed a more conservative approach, adding onlya pavilion from recycled materials in the courtyard.

In their calculations, all groups opted for installation of matching electric batteries to support the PV systems of the micro-campuses. In some of their variants, they also selected the flexible grid use option, which often made a difference and shifted the energy balance from slightly negative to slightly positive. This option, together with the batteries as well as considering e-mobility in the district, helped to decrease grid load from PV and the possibility of supporting the grid stability in case of its overload, thus contributing to peak shaving.

Additional sustainable features

Each student group later worked with a series of additional features which did not necessarily influence the energy balance calculations through the PED assessment tool however, they demonstrated a holistic approach to campus sustainability and showed students' understanding of the broader context of sustainable development in university environments. These interventions included:

- Implementation of green roofs and facades affecting the microclimate of the campus, reducing heat island effect, improving water management, reducing pollution, increasing biodiversity and contributing to subjective perception of wellbeing on the premises.

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- Installation of PV-powered street lighting, outdoor PV-shaded shelters, charging stations for electronics and e-bikes.
- Development of cycling infrastructure including bike storage.
- Installation of energy generating paving systems in high traffic areas.
- Implementation of window shading to tackle overheating of interiors.
- Introduction of soft measures targeted at building awareness of students and employees, reducing energy consumption and generally achieving more sustainable behaviour of building users.

Students were asked to design at least two different scenarios for their assigned campus areas. Several groups exceeded this requirement, submitting multiple progressive steps with detailed calculations showing incremental improvements in energy balance. Through continual design development and careful consideration of various interventions, each group successfully achieved either a positive or a near-neutral energy balance in the final solutions of their micro-campuses. The step-by-step approach allowed for clear demonstration of how different measures contributed to the overall improvement in energy performance, ranging from basic interventions to more complex solutions. This methodical progression not only showed the potential for transformation but also helped to identify the most effective combinations of interventions for each specific campus.

General evaluation of the delivered solutions

The Trnava Campus group (Fig. 2) demonstrated basic understanding of the sustainability principles and their implementation. They increased the density of the loose campus, introducing new building elements to support overall sustainability of the campus – vegetation roofs, window shading, shaded outdoor areas and parking lots with integrated PV panels. Their presentation clearly showed that they did not understand and manage the tool itself well: they presented analyses and graphs where impacts of the changes were not reflected, displayed PV yields with no PV installed and neither did they try to compare variants using different periods of the year.

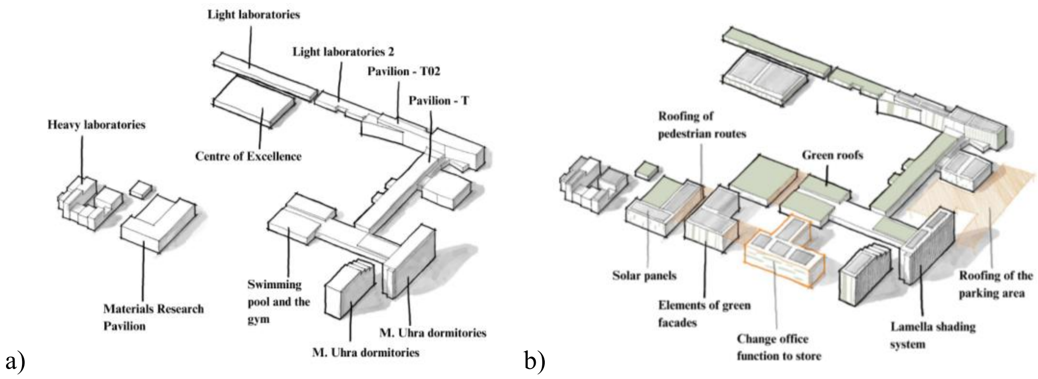

Fig. 2 Group 1 – 3D visualization of Status Quo (a) Proposed interventions (b).

Group 2 (Fig. 3), which wasdealing with the Bratislava Central Campus, showed good connection of the abstract PED assessment tool input data and the architectural mood boards - confirming their understanding of the proposed solutions, delivering additional calculations, adding technical values and presenting creative solutions, such as creation of spaces with controlled microclimate. On the other hand, the group defined usages in the tool which did not correspond to the actual usage (however, they had to deal with a complicated campus composition and with limited possibilities in the tool). They also overestimated the available south-facing facade area when using PV on more than 100 % of the surface.

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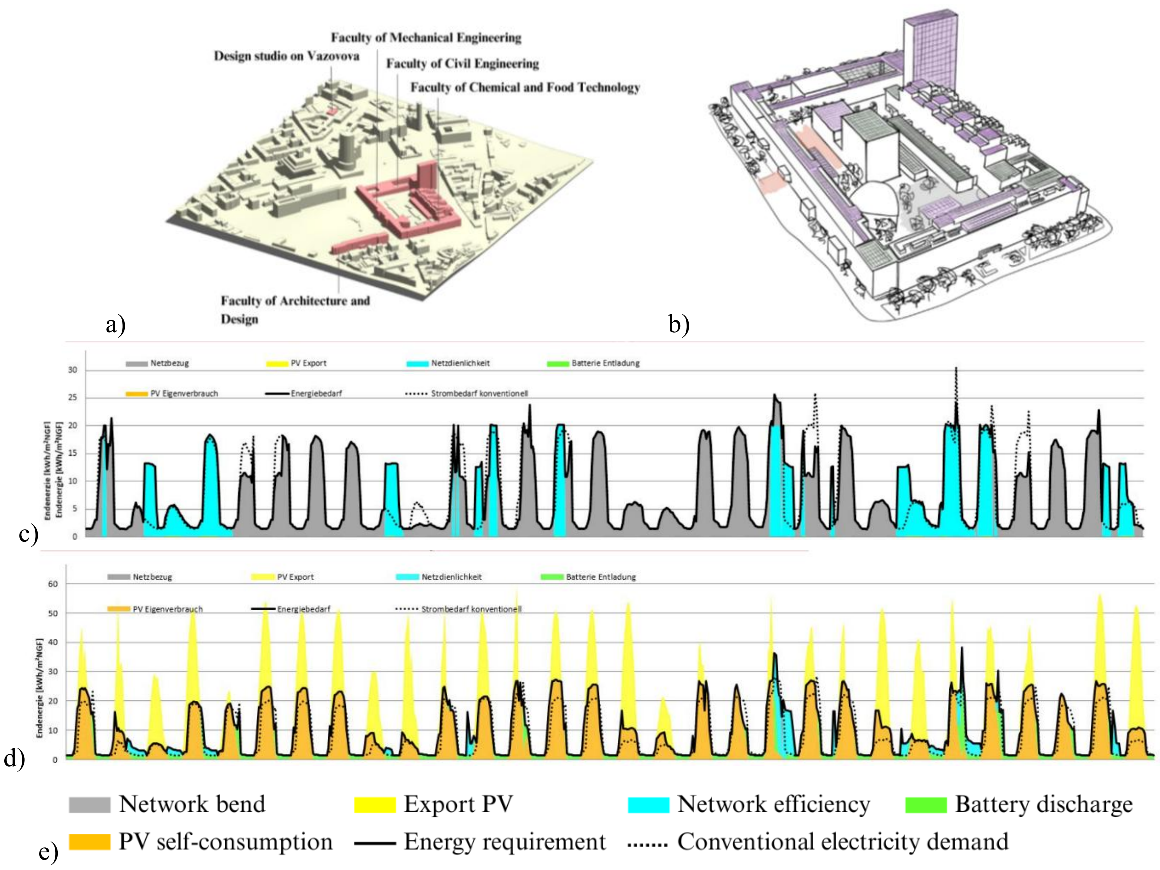
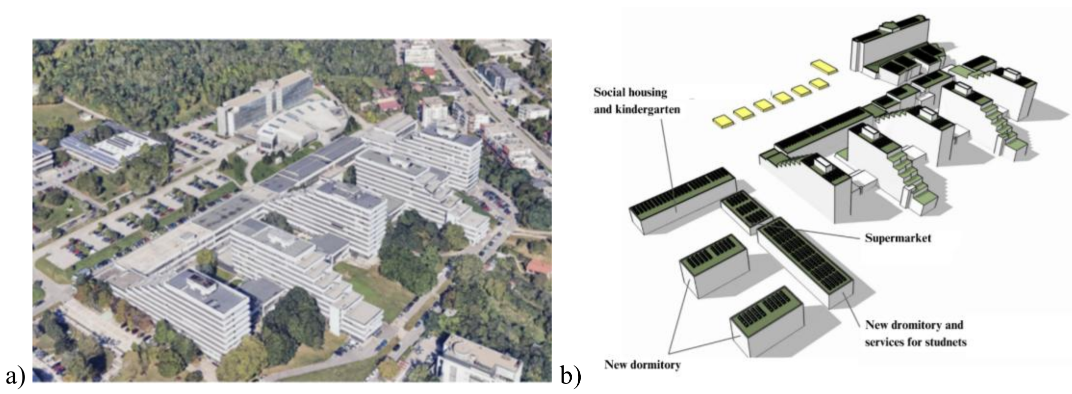


Fig. 3 Group 2 - 3D visualization of Status Quo (a) Proposed interventions (b) Chart showing daily energy consumption patterns for one-month Status Quo (c) Chart showing daily energy consumption patterns for one month after implementing the proposed interventions (d) Legend (e).

In case of the Bratislava Uphill Campus (Fig. 4), a good understanding of the PED assessment tool was shown, verifiable connection between the architectural mood board examples and their implementation in the proposed variants was made, showing understanding of the proposed solutions in architectural contexts. This group also delivered 4 solution variants, creatively extended the campus and improved attractivity of the premises. The PV placement and designated surface attribution was realistic. Proposed variants were presented comprehensively and compared correctly. During their calculations, they disregarded the energy needed for cooling (turning it off in the tool) which resulted in an unrealistically positive balance.



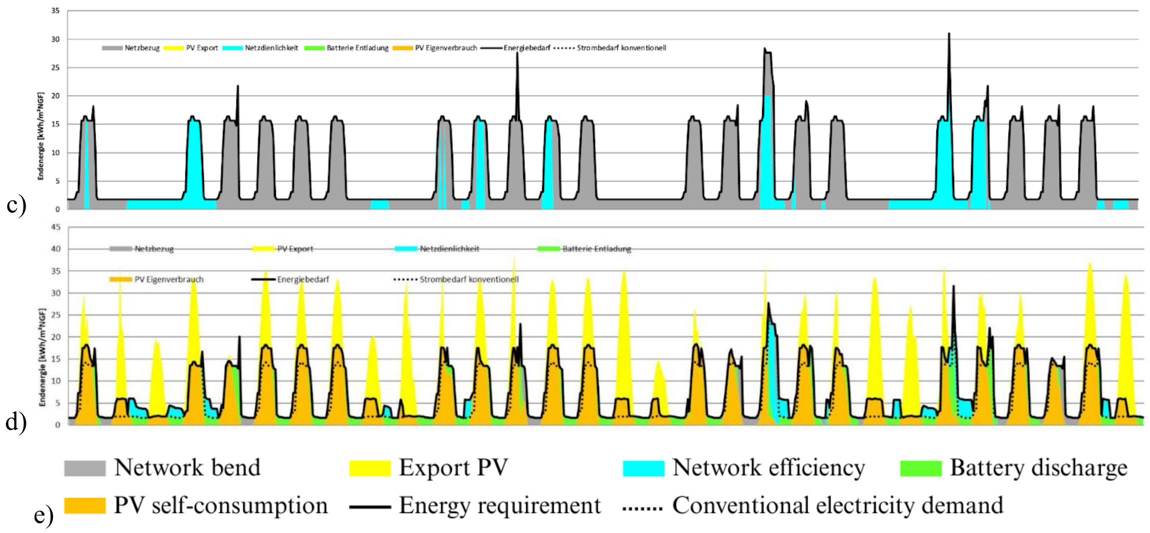


Fig. 4 Group 3 – 3D visualization of Status Quo (a) Proposed interventions (b) Chart showing daily energy consumption patterns for one-month Status Quo (c) Chart showing daily energy consumption patterns for one month after implementing the proposed interventions (d) Legend (e).

Group 4 (Fig. 5), dealing with the Bratislava Central Dorms, demonstrated a fair understanding of the tool as they, were able to define additional measures logically. Moreover, they addressed the principles of improving the environment and minimizing cooling energy consumption by proposing window shading. Additionally, they focused on motivation of users through common activities and showed understanding of the key role of user behaviour in saving energy. Nevertheless, the group did not identify the solar energy potential of full south-facing facades and struggled with selecting correct usages of building parts as well as verifying simulation results showing PV gains without installed panels.

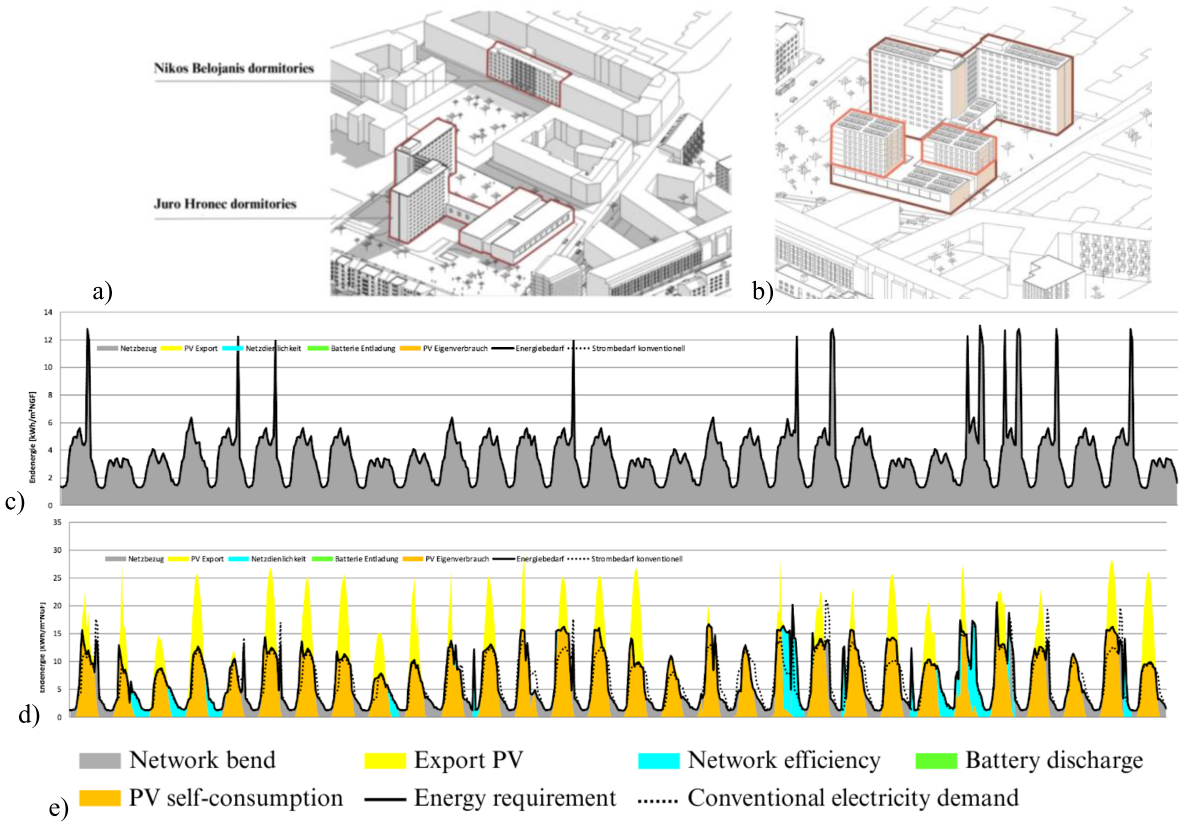


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Fig. 5 Group 4 – 3D visualization of Status Quo (a) Proposed interventions (b) Chart showing daily energy consumption patterns for one-month Status Quo (c) Chart showing daily energy consumption patterns for one month after implementing the proposed interventions (d) Legend (e).

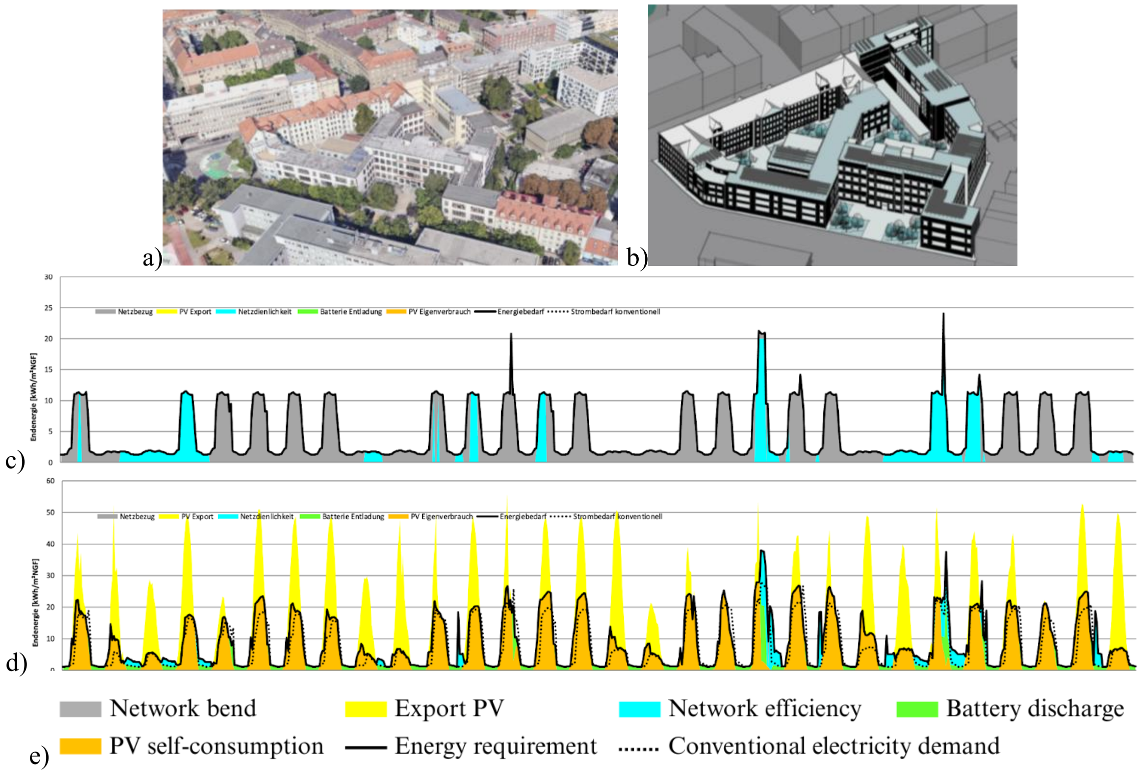

Fig. 6 Group 5 – 3D visualization of Status Quo (a) Proposed interventions (b) Chart showing daily energy consumption patterns for one-month Status Quo (c) Chart showing daily energy consumption patterns for one month after implementing the proposed interventions (d) Legend (e).

In case of the Rectorate micro-campus, group 5 (Fig. 6) presented a very complex approach, delivered a good analysis of the setting within the district, including surrounding building usages, greenery, walking distances and identification of problems. They provided a deep analysis of the micro-campus buildings usage, including detailed storey height, and showed, good understanding of the assessment tool. However, the group did not seem to be aware of problematic resulting values, not interpreting the results of the assessment tool critically enough when the tool provided clearly incorrect results. Overall, this group provided very valuable proposals to improve the environment, microclimate, complex solutions and maintaining good architectural quality.

4 DISCUSSION

The above-mentioned research methods revealed several significant limitations. The primary constraint was the PED assessment tool itself, which was originally designed for new development projects, rather than existing buildings. For the scope of the elective course, students used a simplified, pre-populated version which showed two significant challenges:

- The inability to reflect real energy consumption data from SUT buildings, creating a discrepancy between initial energy consumption mapping and subsequent campus evaluation.
- The mandatory inclusion of heat pumps in calculations, even for buildings without such systems, leading to potential calculation errors as demonstrated in the Rectorate group's case.

These technical constraints, combined with students' limited experience with complex assessment tools, sometimes resulted in difficulty identifying incorrect results or generating accurate consumption graphs. The simplified approach was necessary due to the course timeframe, yet it affected the precision of the analysis.

The study could be enhanced by incorporating additional factors, such as the economic feasibility analysis, including implementation costs and return on investment calculations, life cycle assessment of proposed materials and systems, and phasing strategies for gradual implementation.

Nevertheless, the student proposals successfully demonstrated viable pathways towards energy positivity for the SUT micro-campuses, showing good technical understanding of sustainability principles in architecture and urban design.

5 CONCLUSION

The research conducted within the elective course Positive Energy Districts demonstrates the potential for transforming university campuses into energy-positive districts by implementing strategic interventions and comprehensive planning. Student teams successfully analysed different parts of the Slovak University of Technology campus network, developing scenarios which achieved or nearly achieved energy neutrality while incorporating broader sustainability features.

Despite the limitations of the calculation tools and methodological constraints, the research provides valuable insights into the possibilities of university campus transformation. The students' work showed that achieving energy positivity is feasible through a combination of renewable energy integration, peak consumption management, and additional sustainable features. The varied approaches taken by different teams, influenced by their site-specific constraints and opportunities, highlight the importance of contextual solutions in sustainability transformations. While the primary focus was on energy balance, the students' inclusion of additional sustainability features demonstrates an understanding of the holistic nature of campus sustainability.

This study serves as a foundation for future university sustainability initiatives. It provides not only practical scenarios for campus transformation, but it also demonstrates the educational value of engaging students in real-world sustainability challenges. The findings contribute to the broader discourse on institutional sustainability and offer insights for other universities pursuing similar transformations toward carbon neutrality.

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