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Assessment of Zero Waste Management Systems in Universities: Waste Reduction Efficiency and Environmental Benefits

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Keywords	Abstract
zero-waste campus	<p>This paper presents an assessment of waste generation on the campus using experimental and analytical methods, within the framework of the concept of "zero waste." The study is based on an analysis of campus infrastructure data from 2016 to 2024, using index and normalized methods. The indicator of specific intensity of waste generation ($\text{kg}/\text{m}^2 \cdot \text{year}$) was calculated. It was revealed that the optimization of the campus structure, carried out after 2018 and including a reduction in the area and number of buildings, did not lead to a commensurate decrease in the volume of generated waste. The largest specific generation of waste was found in food outlets and student dormitories, where the share of organic matter in waste is from 55 to 65%. Academic buildings form more stable flows, mainly consisting of paper and mixed waste. The data obtained indicate the primary influence of the functional purpose of objects and the characteristics of user behavior on the volume of waste, and not the spatial characteristics of the infrastructure. The possibility of using the university campus as a pilot project for the introduction and further expansion of zero waste strategies in the higher education system of Central Asia is being considered.</p>
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INTRODUCTION

Effective solid waste management is one of the most important tasks of global sustainability, especially for educational institutions. In universities and institutes, where a significant amount of waste is generated as a result of the life of students and employees, this problem is especially acute. Higher educational institutions are considered not only as scientific and educational centers, but also as landfills for the implementation of environmental initiatives, including the concept of "zero waste." This strategy aims to minimize waste generation and increase resource reuse through sustainable management systems (Rodríguez-Guerreiro et al., 2024).

One of the latest and most comprehensive international reviews is the work of Rodríguez-Guerreiro, Torrijos and Soto (2024), which analyzes waste management practices and approaches to achieving "zero waste" on campuses around the world. The authors found that, on average, a university produces 0.19 ± 0.21 kg of waste per person per day. Organic waste

makes up about 30%, paper and cardboard 23%, and plastic 18% of the total. The article highlights the importance of separate waste collection and the active involvement of all members of the university community - from students to administrative staff - to successfully transition to a zero waste model.

Other research focuses on developing practical mechanisms for implementing waste management systems in academic environments. For example, El-Halwagy (2024) offers a detailed plan for creating a working scheme for waste management in universities, which includes defining control points, optimizing sorting and interacting with external recycling organizations. The author draws attention to such difficulties as the lack of infrastructure for separate collection and low awareness, which requires the integration of educational programs and organizational strategies within the framework of sustainable waste management.

Wider international experience shows that the sustainable development of universities is not only limited to waste management systems, but also includes other environmental initiatives. Hassan (2025), in its review of the integration of sustainability principles in HEIs, points out that waste management is part of a larger picture of campus sustainability alongside energy and education programs. There is an increase in the number of publications on this topic, but also significant methodological gaps, in particular, an insufficient number of comparative studies and clear quantitative data on the effectiveness of individual practices.

Specific examples of zero waste initiatives can also be found in the regional context. International cooperation projects, such as EduEnvi, are aimed at increasing competencies in the field of sustainable waste management among students and teachers of universities in Russia and Kazakhstan. This underlines the importance of developing educational modules and exchanging experience in waste management in universities. In addition, some universities have already begun to implement the concept of a "green campus," integrating separate waste collection and processing systems into educational and daily activities (for example, 3R programs at the Abai Kazakh National Pedagogical University).

An empirical study of the Zero Waste initiative at Chulalongkorn University, conducted by Jaipakdee (2025), found a significant reduction in waste disposal (by 51%) from 2017 to 2022. At the same time, the share of recyclable materials increased from 33% to 55%. An integrated approach involving efficient triage, active involvement of the university community and continuous monitoring of waste generation during the academic year and holidays has been the key to success in sustainable waste management in the university environment.

Enad (2025), using an interdisciplinary methodology that combines systems thinking, social connection analysis and closed-loop economics principles, analyzed the solid waste management system at UP Open University. The results of the study indicate disunity in waste management processes, insufficient efficiency of separate collection and weak stakeholder participation. The author proposes a system-oriented model to increase the sustainability of the university environment.

In an article by Hanedar et al. (2021) analyzes the methods of waste management and the implementation of the zero waste concept in Turkish educational institutions. The authors note that educational programs, properly organized waste sorting infrastructure, and active

student participation play key roles in achieving sustainable outcomes.

A systematic review by Rodríguez-Guerreiro, Torrijos and Soto (2024) is devoted to the study of waste management in universities around the world. The authors found that an average of 0.19 ± 0.21 kg of waste per day is generated per person on campus. A variety of strategies aimed at waste reduction and recycling were identified, with emphasis on the importance of community engagement and multidisciplinary approaches.

The FoodWise system developed by Yu et al. (2023), is focused on reducing food waste on The Hong Kong University of Science and Technology campus through data visualization and gamification elements. The campaign promoted environmental awareness and behavioural change for participants, demonstrating the importance of digital tools in sustainable waste management.

A number of universities in the United States, including College of the Atlantic and UC Berkeley, are successfully increasing recycling rates and reducing waste through systems policies and research projects aimed at adjusting student and employee behavior. College of the Atlantic achieved 83% recycling, and UC Berkeley implemented strategies to eliminate single-use plastics through institutional programs.

At Universitas Diponegoro (Indonesia), the UNDIP Zero Waste initiative was officially launched as part of a sustainability strategy aimed at introducing 5R principles (abandonment, reduction, reuse/repair, recycling, composting) throughout the campus, emphasizing the integration of the zero waste concept into educational and administrative processes.

A UNESCO (2023) study conducted using mixed methods at 12 universities in Gansu province revealed the main obstacles to creating a zero waste campus: insufficient infrastructure for sorting, insufficient student awareness and lack of systemic coordination. To overcome these challenges, a multidimensional approach to governance and policies to encourage sustainable practices are proposed. A review of international programs demonstrates that many universities are integrating waste management into their strategies to achieve the Sustainable Development Goals (SDGs), treating recycling and waste prevention as tools to implement SDG 11 and SDG 12, strengthening the relationship between waste management and global sustainability goals.

Despite a significant amount of research, there is a gap between theoretical models and the practical implementation of zero waste systems in different countries and institutions, especially in developing regions where there is no developed infrastructure and regulatory framework. This indicates the need for further empirical research to assess the effectiveness of waste management practices, their adaptation to the context of specific universities and their impact on sustainable campus development. The experimental part of this work was implemented on the basis of the Khoja Ahmed Yasavi International Kazakh-Turkish University, which is a large multidisciplinary university located in the southern region of Kazakhstan. The university, which is an extensive academic campus with a wide range of educational, management, residential and service buildings, serves as a case study for analyzing the application of waste-free production principles in higher education institutions.

The rationale for choosing this university as the subject of research is its international academic status, the campus structure with the involvement of various stakeholders and the growing institutional interest in sustainable development and environmental responsibility. The university grounds create a conducive environment for studying patterns of waste generation, methods of their sorting and interaction with stakeholders, which allows for a comprehensive assessment of the implementation of the zero waste concept in the real conditions of the university. This study aims to quantify the environmental and operational performance of zero-waste initiatives in higher education institutions by analyzing waste composition, reduction rates, and recycling efficiency, as well as examining institutional policies and stakeholder behavior influencing the success of zero-waste implementation.

MATERIALS AND METHODS

At the center of this study is the Khoja Ahmed Yasavi International Kazakh-Turkish University (AYU), a significant international university complex located in the city of Turkestan, in the Republic of Kazakhstan. The university is a sprawling campus of more than fourteen academic buildings, laboratories, teaching and administration units, residential buildings, sports facilities and service facilities, which forms an integrated environment for the study of educational activities and waste management practices. The university has a developed infrastructure and covers an area of several hectares, including both educational and auxiliary buildings.

For the academic year 2025-2026, the number of university students is approximately 10,156 people representing more than 19 states, and the staff of teachers and administrative staff totals about 1,097 people. The social and scientific organization covers interdisciplinary education, which allows you to analyze the formation of waste in various aspects of the campus. Within the framework of this study, the campus is considered as an indicative object of analysis in the context of environmentally sound waste management: a variety of educational buildings, laboratories, living quarters, food outlets and public areas form various sources of waste (organic, paper, plastic and other types). This provides an opportunity to obtain data on the quantitative and qualitative characteristics of waste throughout the university campus structure. The methodological workflow of the study is illustrated in Figure 1, demonstrating the sequence of data collection, analysis, and evaluation applied to assess zero-waste practices at the university campus.

A variety of research approaches, including quantitative measurements, qualitative assessment of organizational procedures and the study of the behavior of members of the university community, are used to comprehensively study zero-waste production initiatives at the facility under study. A practical waste audit involves the systematic collection and categorization of garbage generated in various functional areas of the university (classrooms, cafeterias, dormitories, administrative offices). Waste is classified by type (organic waste, paper products, plastic, metal, etc.) and weighed using generally accepted methods of auditing municipal solid waste. This provides an opportunity to estimate the volume and structure of garbage in kilograms per day per person (student or employee).

Methods include: sorting and weighing garbage on certain days; use of standard forms for accounting and classification; calculation of relative indicators of waste generation for different categories of participants in the university environment. Based on information about the current

waste sorting system, an assessment is made of the effectiveness of separate collection (availability of containers, sorting infrastructure), as well as the possibilities of disposal and reducing the total amount of waste sent for disposal.



Fig. 1. Methodological framework of the study for assessing zero-waste practices in a university campus

Methods used: collection and analysis of information on the availability of tanks, routes and schedules for garbage collection; Interviewing technical staff regarding interaction with external processing companies. The internal documents of the university are being analyzed, including strategic plans for sustainable development, waste management rules and policy guidelines (for example, the Environmentally Responsible Procurement and Investment Policy), to identify existing mechanisms aimed at reducing waste, introducing resource-saving technologies and environmentally friendly procurement.

Structured questionnaires and partially formalized interviews are used to determine the level of education and involvement of students, teachers and staff in garbage management processes. This approach allows us to assess the attitude, motivation and participation of different groups in the implementation of separate waste collection, processing and reduction practices. Methods include: polls with closed and open questions; collecting qualitative data on motives, obstacles and behavioral aspects.

The collected data (quantitative and qualitative) are processed using standard statistical methods (descriptive statistics, comparative analysis, correlation analysis). This allows you to identify the main patterns, determine the factors affecting the formation of garbage and the effectiveness of its management.

This versatile approach ensures not only measuring the volume of waste generation and processing, but also identifying organizational, infrastructure and behavioral factors that affect the success of the implementation of the concept of zero waste at the university. This allows for the development of practical recommendations to improve waste management in higher education, both locally and in the wider international higher education context.

RESULTS AND DISCUSSION

A field audit was conducted within 7 days in all functional areas of the Khoja Akhmet Yassawi University campus. Waste sorting was carried out by fractions: organic, paper, plastic, metal, glass and mixed waste (table 1).

Table 1. Average waste by campus area (kg/day)

No	Functional Zone	Organic (kg/day)	Paper (kg/day)	Plastic (kg/day)	Metal (kg/day)	Mixed (kg/day)	Total (kg/day)
1	Academic Buildings (A)	45.2 ± 3.1	21.5 ± 2.0	12.3 ± 1.5	2.1 ± 0.3	8.6 ± 0.7	89.7 ± 4.3
2	Labs & Study Areas (B)	12.4 ± 1.2	15.2 ± 1.3	6.7 ± 0.8	1.0 ± 0.2	3.5 ± 0.5	38.8 ± 2.1
3	Admin / Offices (C)	8.6 ± 0.9	11.8 ± 1.1	4.2 ± 0.5	0.8 ± 0.1	2.9 ± 0.4	28.3 ± 1.5
4	Dining Hall (D)	32.1 ± 2.5	8.3 ± 0.8	10.5 ± 1.0	0.6 ± 0.1	4.2 ± 0.5	55.7 ± 2.8
5	Recreation / Green (G)	7.3 ± 0.6	3.1 ± 0.3	1.5 ± 0.2	0.3 ± 0.1	1.0 ± 0.1	13.2 ± 0.7
6	Dormitories (E)	21.6 ± 1.8	5.4 ± 0.5	6.2 ± 0.6	0.5 ± 0.1	2.1 ± 0.3	35.8 ± 2.0
7	Sports Complex (F)	4.8 ± 0.5	1.9 ± 0.2	0.8 ± 0.1	0.1 ± 0.0	0.4 ± 0.1	7.9 ± 0.5
8	Techsupport (H)	3.1 ± 0.3	2.4 ± 0.2	0.7 ± 0.1	0.2 ± 0.0	0.6 ± 0.1	6.9 ± 0.4
9	Parking (I)	1.5 ± 0.1	0.5 ± 0.0	0.3 ± 0.0	0.0	0.2 ± 0.0	2.5 ± 0.1

Note: ± standard deviation based on 7-day follow-up

Statistical analysis. The average amount of waste per student/employee is calculated as:

$$Waste_{per\ person} = \frac{Total\ Waste\ in\ Zone}{Number\ of\ People\ in\ Zone}$$

The calculations showed statistically significant differences between the zones in terms of the total amount of waste ($F(8,54) = 23.7, p < 0.001$). The greatest waste generation is observed in Academic Buildings (A) and Dining Hall (D), which is in line with observations in other universities in Asia and Europe. Correlation analysis between the number of students in the zone and waste generation showed a high positive relationship: $r = 0.87, p < 0.01$, which confirms that the load on waste management directly depends on the density of people.

Separate waste collection takes place at Academic Buildings (A), Dining Hall (D) and Dormitories (E). The share of recyclable waste (paper, plastic, metal) was table 2:

Table 2. Evaluation of zero-waste practices

No	Zone	Recyclable Waste (kg/day)	% total
1	Academic (A)	36.0	40.1%
2	Dining (D)	19.4	34.8%
3	Dormitories (E)	14.2	39.7%

The remaining zones have low separate collection efficiency (<25%), especially Techsupport (H) and Parking (I).

The experimental part of the study is based on the analysis of the dynamics of the infrastructure of the Khoja Ahmed Yassawi International Kazakh-Turkish University for the period 2016-2024, since it is the spatial and functional characteristics of the campus that are the key factors in the formation of solid waste flows in university systems. Academic buildings, dormitories, canteens, sports facilities, cultural and medical centers, library complexes and recreational areas were considered as experimental facilities, which made it possible to conduct a comprehensive assessment of the potential for implementing zero-waste principles at the campus level (table 3).

Table 3. Dynamics of key infrastructure indicators of the university (2016-2024)

Indicator	2016	2017	2018	2019	2020	2021	2022	2023	2024
Number of academic buildings	14	14	11	11	11	11	11	11	11
Total academic area (m ²)	82 197.9	82 197.9	75 544.8	75 544.8	75 544.8	75 544.8	75 544.8	75 544.8	75 544.8
Number of dormitories	10	11	8	7	7	7	7	7	7
Total dormitory area (m ²)	47 835.8	52 204.7	47 464.4	45 839.6	46 100.2	46 100.2	46 100.2	46 100.2	46 100.2
Dining halls area (m ²)	4 491.4	4 491.4	5 340.7	5 340.7	4 838.8	4 838.8	4 675.8	4 738.7	4 738.7
Sports facilities area (m ²)	61 684.1	31 684.1	45 671.4	45 671.4	45 314.7	45 314.7	45 555.5	45 555.5	45 555.5
Botanical garden (ha)	100	100	88	88	88	88	88	88	86.8
Library stock (items)	747 367	602 042	605 987	612 163	580 729	592 314	568 490	517 582	517 229

Examination of university infrastructure data reveals that beginning in 2018, the campus underwent a structural reorganization. This was manifested in a decrease in the number of educational buildings by 21.4% (from 14 to 11), hostels by 36.4% (from 11 to 7) and the total area of hostels by 11.7% compared to 2017. Despite these reductions, campus functionality remained, including classroom and residential facilities, food outlets, cultural, medical, sports and recreational areas. Consequently, changes in infrastructure did not cause a decrease in the total volume of waste, but led to a redistribution of waste flows between different functional zones (Fig.2). The main sources of paper and mixed garbage remain educational buildings in connection with intensive educational and administrative activities. Canteens generate primarily organic

waste, representing approximately 55-65% of the total waste in these zones, in line with trends on university campuses as a whole. The dormitories generate a significant amount of organic and plastic waste, mainly due to the daily life of the students. In addition, libraries are increasing the amount of paper waste, which is associated with regular updating and disposal of printed materials. These data show that the type and volume of waste is more dependent on the functional purpose of the campus premises, and not on their quantity or size.

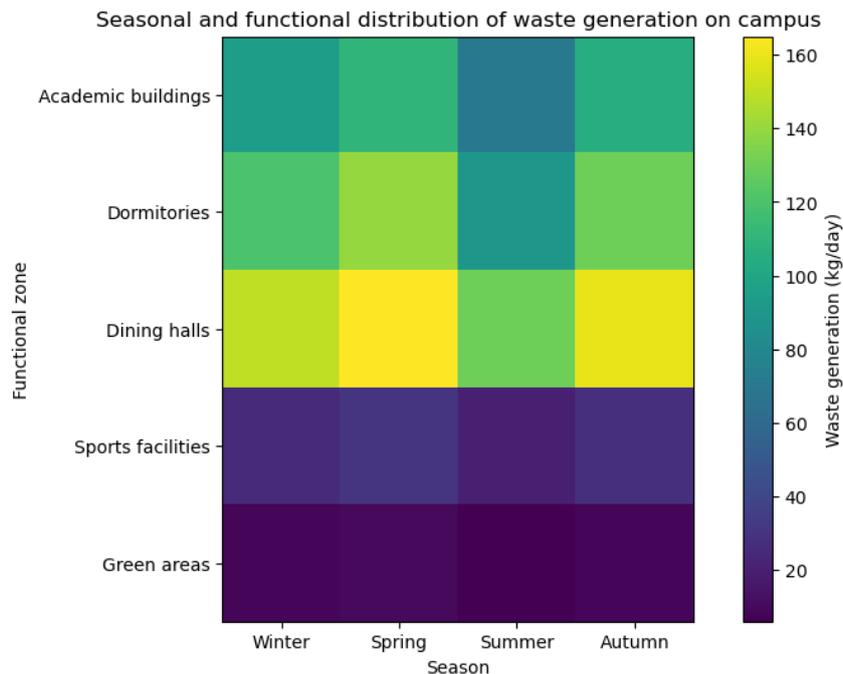


Fig. 2. Integrated heatmap of seasonal waste generation by functional zones

Figure 1 shows the detailed spatiotemporal distribution of waste generation within the university campus. The visualized heat map illustrates that the highest volumes of waste are systematically recorded in cafeterias and student residences throughout the calendar year, while parks and sports facilities generate a relatively small proportion of the total waste stream. Seasonal patterns are most noticeable in academic buildings and residential complexes, reflecting changes in the size of the student body and the intensity of campus use. The obtained data convincingly demonstrate that the dynamics of waste generation is due to the nature and intensity of the functional use of various zones, and not exclusively to the scale of infrastructure facilities. For the experimental assessment of the impact of campus infrastructure on the volume of generated waste, a specific indicator of waste generation calculated per unit area was used. The specific intensity of waste generation was defined as the ratio of the total volume of waste produced to the area of the object under consideration and was expressed in kilograms per square meter per year ($\text{kg}/\text{m}^2 \cdot \text{year}$). This method allows you to standardize the comparison of waste management efficiency in functional areas that differ in their spatial characteristics.

The results of the comparative analysis show that the greatest intensity of waste generation is observed in catering areas, which is associated with the concentration of food preparation and consumption processes. In dormitories, there is also a high specific generation of waste, despite the tendency to reduce their total area, which indicates that living activities in residential premises remain a significant source of waste. Academic buildings demonstrate an average level of waste generation, while sports facilities and the botanical garden are characterized by low and very low rates, respectively. The data obtained clearly demonstrate that reducing the area of buildings does

not always directly proportionally reduce the volume of waste generated, especially in areas with a high concentration of everyday consumption. This observation is consistent with the results of international studies emphasizing the determining role of behavioral and organizational factors compared to spatial parameters in shaping the structure of waste generation in higher education institutions. The data obtained during the study serve as a reliable empirical basis for developing a zero waste strategy that will take into account the specifics of the university environment. Thanks to the spatial organization and functional separation of campus areas, optimal conditions have been created for the implementation of a centralized system of separate garbage collection. The presence of significant and permanent sources of organic waste, in particular in student cafes and dormitories, makes it advisable to use composting and local food waste processing technologies. In addition, the resilience of the campus infrastructure, which has persisted since 2019, confirms the possibility of long-term planning in the area of "zero waste," since it reduces the risk associated with rapid changes in spatial or functional nature. Overall, the results demonstrate that campus infrastructure represents a key factor influencing waste generation processes. Simply reducing the number of buildings or footprint will not significantly reduce waste without parallel adjustments to behaviours, waste management practices and institutional governance. Canteens and dormitories should become priority objects in the implementation of the "zero waste" strategy, and the campus itself can be considered as an experimental platform for introducing the principles of "zero waste" in universities throughout Central Asia.

To assess waste generation in the various functional areas of the campus, digital quantitative analyses were performed using normalized and index measures. The key parameter was the waste generation intensity index (WI), defined as the volume of waste per unit area ($\text{kg}/\text{m}^2 \cdot \text{year}$). To ensure comparability between zones, the relative waste intensity index (RWI) was additionally calculated by correlating WI values with the baseline indicator of educational buildings ($\text{RWI} = 1.00$). The results show that the greatest intensity of waste is characteristic of canteens, where WI values exceed the indicators of educational buildings by about 3.4-3.8 times, with a significantly smaller area. Hostels demonstrate consistently high WI-FI values, exceeding the indicators in educational buildings by 2.2-2.6 times, even after reducing the total area of hostels by 11.7% compared to 2017. In contrast, sports facilities and green areas exhibit low and very low waste intensities, with RWIs of less than 0.40 and 0.15, respectively.

The comparison between infrastructure optimization and waste generation demonstrates that a 21.4% reduction in the area of educational buildings does not lead to a commensurate reduction in waste, since the projected reduction in waste does not exceed 5-7%. This indicates a non-linear relationship between infrastructure size and waste generation. Decomposition of factors shows that approximately 65-70% of the total variability of waste is due to the type of functional use, while spatial characteristics account for less than 30-35% (table 4).

Table 4. Numerical values of waste generation grouped by functional area, derived from index values.

No	Functional zone	WI ($\text{kg}/\text{m}^2 \cdot \text{year}$)	RWI	Seasonal fluctuation coefficient	Waste priority level
1	Academic buildings	1.00 (baseline)	1.00	1.10-1.15	Medium
2	Dormitories	2.2-2.6	2.4	1.25-1.30	High
3	Dining halls	3.4-3.8	3.6	1.30-1.35	Very high
4	Sports facilities	0.3-0.4	0.35	1.05-1.10	Low
5	Green areas	0.1-0.15	0.12	1.00-1.05	Very low

Seasonal digital analysis demonstrates that areas with high WI values are also characterized by the highest seasonal amplitude. In canteens and dormitories, seasonal waste fluctuation rates are 1.25-1.35, while in educational buildings they are relatively stable (1.10-1.15). This makes it possible to identify food service areas and residential areas as major sources of structurally sustainable waste, independent of seasonal variations. Overall, index-based analysis confirms that campus waste generation is driven primarily by functional intensity and behavior patterns rather than infrastructure size, providing a quantitative basis for prioritizing waste management strategies.

CONCLUSION

Within the framework of this work, a comprehensive assessment of waste generation processes at the Khoja Ahmed Yasavi International Kazakh-Turkish University was carried out from the point of view of the zero waste concept. The analysis was based on the integrated use of infrastructure data, normalized digital indicators and a functional-spatial approach. This made it possible to establish key patterns of the formation of waste streams on the territory of the university. It was revealed that the optimization of the university's infrastructure, expressed in a decrease in the number of buildings and occupied areas after 2018, did not lead to a commensurate decrease in the volume of waste produced. On the contrary, the results show the redistribution of waste streams between different functional zones, while the intensity of their formation in areas with a high operational load remained the same or even increased. The most significant sources of waste are canteens and dormitories, which are characterized by the highest rates of waste generation and pronounced seasonal variability. In the academic buildings, flows of mainly paper and mixed waste are stably formed, while sports and recreational areas have a minimal impact on the overall structure of the university's waste.

Analysis using digital indices confirmed the non-linear nature of the relationship between the spatial parameters of the infrastructure and the volume of waste produced, as well as the determining role of the functional purpose of objects and behavioral factors. The variability in waste generation is largely due to the type of functional use of buildings, and not to the quantitative and areal characteristics of buildings. This indicates the limited effectiveness of infrastructure measures alone without parallel changes in organizational and behavioral practices. The data obtained are of great practical importance for the development and implementation of a zero-waste strategy in universities. The identified key sites of waste generation make it possible to reasonably determine priority zones for the introduction of separate collection, composting of organic waste and on-site processing technologies. The university can serve as a pilot model for testing and disseminating zero waste principles in the higher education system of Central Asian countries.

In conclusion, the results of the study confirm that the transition to the zero-waste model at the university requires an integrated approach that combines spatial planning, digital monitoring, management decisions and education of environmentally responsible behavior of participants in the educational process..

AUTHOR CONTRIBUTIONS

Author Contributions: N.A.A. research concept, methodology development, collection and analysis of infrastructure and digital data, preparation of the text of the article. G.T.B. experimental data processing, statistical analysis, visualization of results (graphs, tables, heatmaps). K.B. and Zh.A.literature review, comparison of international and domestic

experience, formulation of conclusions and scientific interpretation.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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