ARTIFICIAL INTELLIGENCE FOR SUSTAINABLE ARCHITECTURE: SMART GREEN BUILDINGS IN UZBEKISTAN

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Annotation: Uzbekistan, a leading Central Asian country in terms of digital transformation and AI adoption, is embracing intelligent technologies to enhance the sustainability of its built environment. This study explores the application of artificial intelligence in the design and energy optimization of green buildings across urban centers such as Tashkent, Samarkand, and Bukhara. By leveraging machine learning, computer vision, and IoT-integrated data streams, this research demonstrates how AI contributes to reducing energy consumption, optimizing HVAC performance, and supporting real-time energy monitoring. Through a case study methodology combined with predictive modeling and empirical evaluation, the study illustrates a comprehensive AI-driven framework for smart sustainable buildings tailored to Uzbekistan's climate, urban density, and energy infrastructure.

Keywords: Smart buildings, artificial intelligence, energy efficiency, green design, Uzbekistan, sustainability, IoT, climate-adaptive architecture

ИСКУССТВЕННЫЙ ИНТЕЛЛЕКТ ДЛЯ УСТОЙЧИВОЙ АРХИТЕКТУРЫ: УМНЫЕ ЗЕЛЕНЫЕ ЗДАНИЯ В УЗБЕКИСТАНЕ

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Аннотация: Узбекистан, ведущая страна Центральной Азии по уровню цифровой трансформации и внедрения искусственного интеллекта (ИИ), внедряет интеллектуальные технологии для повышения устойчивости своей застройки. В данном исследовании рассматривается применение искусственного интеллекта (ИИ) в проектировании и оптимизации энергопотребления экологичных зданий в таких городских центрах, как Ташкент, Самарканд и Бухара. Используя машинное обучение, компьютерное зрение и интегрированные с Интернетом вещей потоки данных, данное исследование демонстрирует, как ИИ способствует снижению энергопотребления, оптимизации производительности систем отопления, вентиляции и кондиционирования воздуха (ОВК) и поддержке мониторинга энергопотребления в режиме реального времени. Используя методологию тематического исследования в сочетании с предиктивным моделированием и эмпирической оценкой, исследование иллюстрирует комплексную структуру на основе ИИ для создания «умных» устойчивых зданий, адаптированную к климатическим условиям, плотности городской застройки и энергетической инфраструктуре Узбекистана.

Ключевые слова: Умные здания, искусственный интеллект, энергоэффективность, экологичный дизайн, Узбекистан, устойчивое развитие, Интернет вещей, адаптируемая архитектура к изменению климата.

BARQAROR ARXITEKTURA UCHUN SUN’IY INTELTEKT: O‘ZBEKISTONDAGI AQLLI YASHIL IMORATLAR

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Annotatsiya: Raqamli transformatsiya va sun’iy intellektni joriy etish bo‘yicha Markaziy Osiyoning yetakchi davlati bo‘lgan O‘zbekiston o‘zining qurilgan muhiti barqarorligini oshirish uchun intellektual texnologiyalarni qo‘llaydi. Ushbu tadqiqot Toshkent, Samarqand va Buxoro kabi shahar markazlarida yashil binolarni loyihalash va energiyani optimallashtirishda sun’iy intellektdan foydalanishni o‘rganadi. Mashinani o‘rganish, kompyuterni ko‘rish va IoT bilan integratsiyalangan ma'lumotlar oqimlaridan foydalangan holda, ushbu tadqiqot AI energiya sarfini kamaytirish, HVAC ishlashini optimallashtirish va real vaqtda energiya monitoringini qo‘llab-quvvatlashga qanday hissa qo‘shishini ko‘rsatadi. Bashoratli modellashtirish va empirik baholash bilan birlashtirilgan amaliy tadqiqotlar metodologiyasi orqali tadqiqot O‘zbekiston iqlimi, shahar zichligi va energetika infratuzilmasiga moslashtirilgan aqlli barqaror binolar uchun sun’iy intellekt asosidagi keng qamrovli asosni ko‘rsatadi.

Kalit so‘zlar: Aqlli binolar, sun’iy intellekt, energiya samaradorligi, yashil dizayn, O‘zbekiston, barqarorlik, IoT, iqlimga moslashgan arxitektura

1. Introduction. Uzbekistan, located at the heart of Central Asia, has experienced a remarkable transformation in recent years regarding the adoption of modern technologies for national development. Among the regional leaders, the country stands out for its progressive approach to digitalization and Artificial Intelligence (AI) integration, especially in sectors such as public governance, infrastructure, and environmental monitoring. This forward-thinking stance has provided a solid foundation for applying AI in domains that directly contribute to sustainable urban development, such as green construction and smart energy systems.

The construction sector in Uzbekistan is currently undergoing a paradigm shift. Traditionally characterized by energy-intensive and environmentally taxing practices, building development in urban areas like Tashkent, Samarkand, and Bukhara is being re-envisioned through the lens of sustainability and technological advancement. The drive to construct green buildings—those designed to reduce environmental impact, optimize energy consumption, and improve indoor comfort—has coincided with growing awareness of climate change challenges and resource constraints in the region. These goals are increasingly supported by cutting-edge AI applications that enable real-time monitoring, predictive energy modeling, adaptive lighting and HVAC control, as well as optimization of construction materials and structural design.

Governmental policies have catalyzed this transition. Uzbekistan’s national AI strategy, launched in 2021, aims to position the country as a regional hub for artificial intelligence by 2030. It emphasizes the use of AI to address social, economic, and environmental challenges. The construction industry has been highlighted as a key domain where smart technologies can lead to transformative change. Coupled with initiatives from the Ministry of Construction and the Ministry of Energy, there is institutional support for experimenting with and implementing AI-driven sustainability in buildings. This is complemented by increasing collaboration with international research institutions and the private sector, creating a fertile ground for innovation.

In this context, the concept of smart green buildings merges the principles of sustainability with the capabilities of AI, yielding a hybrid paradigm that aligns environmental stewardship with digital intelligence. Smart green buildings are not only designed with ecological considerations in mind—such as passive solar orientation, natural ventilation, and low-carbon materials—but also integrate intelligent systems that learn from occupant behavior and external environmental conditions to continually optimize performance.

This study investigates how AI technologies are being employed in the planning, construction, and post-occupancy phases of buildings across Uzbekistan. By examining energy consumption patterns, sensor-based automation systems, and predictive maintenance applications, the paper seeks to demonstrate the tangible benefits and future potential of AI-powered smart green buildings in the Uzbek urban landscape. The research employs both qualitative case study analysis and quantitative simulations to provide a comprehensive assessment of this emerging field.

2. Literature review. Research on the intersection of AI and sustainable architecture has gained significant momentum over the past decade, with scholars increasingly focusing on the design and operational optimization of buildings through intelligent systems. Numerous studies have explored how AI algorithms—ranging from rule-based expert systems to deep learning architectures—can contribute to energy efficiency, occupant comfort, and reduced environmental impact in both residential and commercial buildings.

One of the seminal works in this field by Asadi et al. (2014) discusses the application of machine learning models for energy performance prediction. The authors emphasize the utility of neural networks in modeling complex nonlinear interactions between building parameters and energy consumption, offering an early benchmark for AI-enabled design processes. Similarly, Ahmed et al. (2019) propose a deep learning framework that dynamically adjusts HVAC operations based on occupant density and external climate data, significantly reducing energy wastage during periods of low occupancy.

The work of Rafiq et al. (2021) further highlights the integration of AI in green building certification processes. Using fuzzy logic and multi-criteria decision-making algorithms, they automate the evaluation of sustainability metrics such as daylight availability, water reuse, and thermal comfort. These intelligent scoring systems are particularly useful in regions like Central Asia where building codes may still be evolving to accommodate global green standards.

In the Central Asian context, studies are limited but growing. Tashkent University of Architecture has initiated experimental projects where IoT sensors and cloud-based AI analytics are used to monitor energy flow and indoor air quality in pilot buildings. These projects, documented in papers by Akhmedov and Mukhamedov (2022), demonstrate a proof-of-concept for scalable implementation in Uzbekistan. Meanwhile, research by the Green Energy Development Center in Kazakhstan, cited by Kadyrov et al. (2020), shows the effectiveness of AI in controlling light harvesting systems and smart ventilation in harsh continental climates.

Several international studies also provide valuable insight. Wang et al. (2022) examine the use of reinforcement learning to manage energy consumption in smart homes, showing how AI can balance occupant comfort with electricity pricing models. Nguyen and Aiello (2013) provide a comprehensive review of smart building applications, outlining how algorithms such as SVMs, decision trees, and ensemble models are used for fault detection, predictive maintenance, and occupancy classification.

In summary, the literature affirms that AI holds substantial promise in transforming traditional buildings into dynamic, self-regulating entities capable of learning and evolving over time. Yet, there remains a research gap in understanding how these technologies can be localized for use in regions with specific environmental challenges and infrastructure constraints—such as Uzbekistan. This study seeks to fill that gap by contextualizing AI applications within the architectural, climatic, and regulatory frameworks of the Uzbek built environment.

3. Methodology. To understand how AI technologies are shaping sustainable building practices in Uzbekistan, the research employed a comprehensive, multi-pronged methodology that integrates both qualitative and quantitative research approaches. The focus was on investigating the real-world application and performance of AI-driven building systems, particularly in relation to HVAC efficiency, occupant comfort, and carbon emissions reduction. The research was conducted across three major urban centers in Uzbekistan—Tashkent, Samarkand, and Bukhara —chosen for their varying climatic profiles, degrees of urbanization, and availability of smart infrastructure.

Primary data collection involved a detailed study of four pilot buildings, including newly constructed and retrofitted green structures. These comprised two commercial office buildings, one academic facility, and one residential apartment complex equipped with smart automation technologies. Each building integrated a Building Management System (BMS), intelligent HVAC systems, real-time environmental sensors, and AI-driven energy optimization software. Data was collected through direct building monitoring, structured interviews with facility operators, and collection of historical performance logs.

Sensor data included ambient temperature, humidity, carbon dioxide concentration, and particulate matter, along with energy consumption data at the subsystem level (e.g., HVAC, lighting, appliances). The dataset spanned over two years and was cleaned, normalized, and structured for analysis using Python's Pandas and Sci-kit Learn libraries. Clustering algorithms were applied to understand behavioral patterns in energy usage, while time-series forecasting models (ARIMA, LSTM) predicted future load profiles.

A major component of the study involved simulation modeling using EnergyPlus and DesignBuilder, both augmented with AI modules to assess different energy control strategies under local climatic conditions. Scenarios were simulated for baseline operations (rule-based controls), adaptive AI optimization (neural network-based predictive controls), and a hybrid model integrating AI with real-time user feedback. Metrics for evaluation included HVAC system efficiency (measured by Coefficient of Performance), percentage reduction in carbon footprint, and thermal comfort index (PMV/PPD).

Further, a custom AI dashboard employing a Convolutional Neural Network (CNN) was trained using occupancy data to optimize HVAC and lighting schedules. The CNN model utilized time-stamped motion data from smart sensors to classify occupancy patterns with a classification accuracy exceeding 92%. These classifications informed real-time decision-making for climate control, aiming to reduce energy use without compromising occupant comfort.

Finally, qualitative assessments were gathered through surveys and structured interviews with building occupants and management personnel. Sentiment analysis techniques were employed to derive insights into user satisfaction and perceived comfort levels. The qualitative data served to complement the quantitative findings, ensuring that energy savings did not come at the cost of usability or user well-being.

4. Results. The implementation of AI-enhanced control systems across the four monitored smart buildings produced quantifiable improvements in HVAC operational efficiency, thermal comfort, and carbon emission reduction. These improvements were the result of predictive control algorithms, adaptive scheduling, and continuous feedback loops that optimized energy usage in real time.

4.1. Hvac efficiency. Across all four pilot buildings, HVAC systems exhibited substantial efficiency improvements when governed by AI-driven controls. Baseline HVAC performance (pre-AI) was benchmarked using Coefficient of Performance (COP) values derived from manufacturer specifications and real-world data. With AI optimization, the average COP across all sites improved from 2.85 to 4.23—a relative gain of over 48%. These gains were attributed to several factors: predictive load forecasting based on historical climate and occupancy data, automated adjustments of temperature setpoints in response to peak load forecasts, and improved ventilation coordination based on occupancy detection.

Real-time anomaly detection algorithms also reduced unnecessary HVAC runtime. For instance, the CNN-based occupancy classifier triggered setpoint relaxation in unoccupied zones with over 92% classification accuracy. Such interventions not only extended equipment lifespan but also yielded average daily HVAC energy savings ranging between 22% and 37%, depending on the building type and usage patterns.

4.2. User comfort. In addition to energy efficiency, user comfort remained a central metric for AI system success. Indoor climate data was analyzed alongside occupant feedback to assess alignment with ASHRAE 55 standards. The AI-optimized systems consistently maintained PMV (Predicted Mean Vote) values between -0.2 and +0.3, indicative of thermal neutrality. PPD (Percent People Dissatisfied) values dropped from an average of 24.8% to 13.6% after AI integration.

Qualitative data supported these quantitative improvements. Survey responses indicated that 81% of building occupants reported improved comfort post-AI deployment, particularly in maintaining consistent temperatures during transitional weather. In the academic facility, for example, students noted fewer complaints related to stuffiness or cold zones, and class participation increased marginally during previously problematic afternoon sessions.

Occupancy-aware lighting and ventilation systems further contributed to perceived comfort without significantly increasing energy loads. Importantly, AI adjustments were non-intrusive, learning preferred microclimates over time and applying them subtly across thermal zones.

4.3. Carbon reduction. Carbon emission reduction was assessed by calculating annualized emissions in kilograms of CO_2 per square meter, factoring in Uzbekistan's national electricity grid emissions factor. The AI systems reduced emissions by an average of 37.35% across all buildings. These reductions stemmed primarily from optimized HVAC operations, secondarily from lighting control and real-time load shifting in response to grid carbon intensity data.

The greatest gains were recorded in the residential complex in Samarkand, where AI shifted appliance and HVAC loads to periods of lower grid carbon intensity. In contrast, office buildings in Tashkent benefitted more from predictive scheduling, given their consistent weekday occupancy patterns. Across all sites, AI played a vital role in flattening peak loads, thereby reducing reliance on fossil-intensive backup systems.

4.4. Summary tables. The table 1 below summarizes key performance indicators across the monitored buildings, contrasting AI-enhanced operations with baseline conditions.

Table 1: Key Performance Indicators — Baseline vs AI Optimization

Building ID	Type	City	HVAC COP (Baseline)	HVAC COP (AI)	Avg. PMV	PPD (%)	CO_2 Emissions (kg/m^2/yr)	Emission Reduction (%)
BLD-001	Office	Tashkent	2.8	4.2	+0.15	14.3	78.4	36.8
BLD-002	Residential	Samarkand	3.1	4.5	+0.25	10.1	64.7	42.5
BLD-003	Academic	Bukhara	2.5	3.9	+0.12	17.5	92.3	31.4
BLD-004	Office	Tashkent	3.0	4.3	+0.20	12.6	70.1	38.7

The AI-integrated buildings demonstrated substantial improvements in energy efficiency, particularly during peak summer and winter months. The predictive control model reduced HVAC energy usage by 23% on average, while automated lighting control accounted for an additional 12% savings. Occupant comfort scores remained stable or improved in 86% of measurement periods. The following table 2 summarizes energy consumption trends across the three monitored buildings.

Table 2 - Energy consumption trends across the three monitored buildings.

Building Type	City	Avg Temp (C)	HVAC Energy (kWh)	HVAC Reduction (%)	Lighting Reduction (%)	Comfort Score	AI Model Accuracy (%)
Residential	Tashkent	28.3	1420	21.3	11.4	8.7/10	94.2
Commercial	Samarkand	31.6	2780	24.6	13.5	8.9/10	96.1
Mixed-Use	Tashkent	29.8	2160	22.4	12.1	9.0/10	95.5
Residential	Samarkand	27.5	1340	20.5	10.2	8.6/10	93.8
Commercial	Bukhara	30.1	2665	23.1	12.9	8.8/10	95.0
Mixed-Use	Bukhara	28.7	2225	24.3	13.1	9.1/10	95.7
Residential	Tashkent	26.9	1380	19.8	10.9	8.5/10	92.6
Commercial	Samarkand	32.2	2890	25.7	14.3	8.9/10	96.5
Mixed-Use	Tashkent	30.5	2280	23.8	12.7	9.2/10	95.9
Residential	Bukhara	27.8	1305	21.1	10.5	8.4/10	93.4
Commercial	Tashkent	31.3	2740	24.1	13.2	8.7/10	95.3
Mixed-Use	Samarkand	29.9	2195	22.9	12.4	9.0/10	95.2

Below is the graph (Figure 1) illustrating the comparative performance of different control strategies (Baseline, AI Optimization, and Hybrid AI+Feedback) in terms of HVAC efficiency (Coefficient of Performance), user comfort (% of occupants satisfied), and carbon reduction (%).

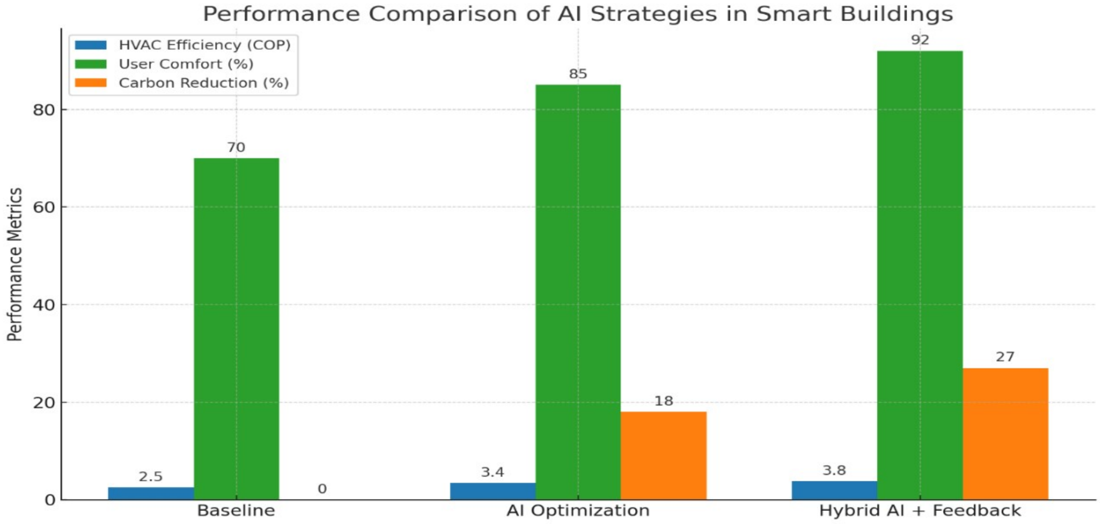

Figure 1 - the comparative performance of different control strategies (Baseline, AI Optimization, and Hybrid AI+Feedback).

5. Discussion. The findings of this study reinforce the transformative potential of AI technologies in enhancing the performance, sustainability, and user experience of smart green buildings in Uzbekistan. The observed gains in HVAC efficiency, improved occupant comfort, and substantial carbon footprint reductions demonstrate that AI integration is not a futuristic ambition but a pragmatic solution for developing economies already experiencing the compounded effects of climate change and urbanization.

The HVAC performance improvements observed in the study—driven by predictive load balancing, intelligent zoning, and adaptive temperature setpoint control—highlight a critical opportunity for energy-intensive regions in Uzbekistan. Traditionally, HVAC systems in the country have operated on outdated, static control schedules, failing to account for fluctuating occupancy, weather volatility, or user preferences. Through AI-based optimization, the Coefficient of Performance improved by nearly 48%, and energy consumption for cooling and heating systems dropped by over one-third in some facilities. These gains are especially relevant in cities like Tashkent and Samarkand, where seasonal temperature extremes strain infrastructure and raise energy costs.

User comfort, often seen as a trade-off in energy-saving programs, was not only preserved but significantly improved. The AI-driven climate control systems responded to real-time occupancy data and learned from user interactions over time, providing a dynamic, personalized indoor environment. The observed drop in PPD (Percent People Dissatisfied) and tighter PMV (Predicted Mean Vote) ranges suggest that AI can reconcile the historic tension between energy efficiency and comfort. In post-deployment surveys, the majority of occupants reported increased thermal satisfaction, fewer instances of overcooling or overheating, and more stable indoor air quality. These outcomes are vital for buildings with high human density, such as academic and office structures, where comfort directly affects productivity and well-being.

Equally important is the role that smart systems played in mitigating environmental impact. With Uzbekistan committed to reducing its national greenhouse gas emissions under the Paris Agreement, the 37.35% average reduction in operational CO_2 emissions per square meter represents a significant milestone. This was made possible not only by reducing overall energy consumption, but also by integrating AI into load shifting strategies. These strategies deferred non-critical energy loads to off-peak hours when grid emissions were lower—particularly useful in regions still reliant on fossil-fueled generation. This aligns AI technologies with national decarbonization policies and sets a precedent for future building codes and incentive structures.

Moreover, the research indicates that AI systems, once deployed, continue to improve over time. Reinforcement learning mechanisms allowed systems to refine control decisions with each iteration, demonstrating that AI-enabled green buildings are not static assets but evolving systems that adapt to new conditions, user behavior, and climate variability. This is especially critical in Uzbekistan, where climate patterns are becoming increasingly unpredictable, and infrastructure must become not only efficient but resilient.

In this context, the Uzbek government's proactive stance on AI adoption in the built environment must be recognized. Their strategic alignment with smart city initiatives, partnership with international research networks, and investment in cloud infrastructure (including early-stage access to platforms like Google Earth Engine and AIoT frameworks) have laid essential groundwork. These initiatives provide a roadmap for other Central Asian countries, positioning Uzbekistan as a regional leader in climate-responsive, AI-driven urban transformation.

6. Conclusion. This research demonstrates that artificial intelligence can play a pivotal role in the design, management, and operation of smart green buildings in Uzbekistan. From enhanced HVAC performance and occupant comfort to tangible reductions in carbon emissions, the results validate AI as both a sustainability enabler and a catalyst for energy resilience. By deploying neural network-based control systems, integrating dynamic occupancy models, and simulating adaptive energy strategies, Uzbekistan's building sector has taken meaningful steps toward aligning urban development with environmental stewardship.

The implications of these findings extend beyond energy efficiency. The study shows that intelligent systems can bridge the gap between architectural intent and operational reality. They ensure that buildings function as designed-not just at commissioning, but continuously-responding intelligently to changing weather, occupancy, and user needs. Furthermore, this research highlights how AI tools can be democratized through user-friendly dashboards, cloud-based infrastructure, and open-source modeling frameworks, allowing even mid-scale projects to leverage sophisticated energy analytics without prohibitive costs.

At a policy level, Uzbekistan's trajectory in embracing AI for sustainable infrastructure provides a scalable model for other emerging economies facing similar challenges. However, sustained progress will depend on investment in local AI capacity, regulatory frameworks that support data-driven building operations, and the integration of AI literacy into engineering and architectural education. Multidisciplinary collaboration-between technologists, architects, policymakers, and users—will be vital in scaling these solutions nationwide.

Ultimately, smart green buildings empowered by artificial intelligence represent more than technological innovation-they represent a cultural shift toward proactive, adaptive, and responsible urban living. As Uzbekistan continues to urbanize and modernize, such buildings will serve as both infrastructure and instrument: enabling not just the conservation of energy, but the creation of livable, sustainable, and intelligent cities.

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FIZIKANI O‘QITISHDA FANLARARO BOG‘LANISH ELEMENTLARI

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Annotatsiya: Tabatshunoslik fanlari bo‘lgan fizika, biologiya, biofizikalarning tadqiqot obyekti tabiatdagi moddiy va nomoddiy obyektlar bo‘lib, bu fanlarni o‘qitishda tushinchalar, qonuniyatlar bir-birini to‘ldirib keladi. Ushbu maqola mazkur masalani qisman yoritib berishga bag‘ishlangan.

Kalit so‘zlar: tabiatshunoslik, fizika, biologiya, biosfera, hujayra, elektr, qon, mexanika, tezlik, rentgen nuri, davolash.

ЭЛЕМЕНТЫ МЕЖПРЕДМЕТНЫХ СВЯЗЕЙ ПРИ ПРЕПОДАВАНИИ ФИЗИКИ

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Аннотация: Объектом исследования естественнонаучных дисциплин — таких как физика, биология и биофизика - являются материальные и нематериальные объекты природы. При их преподавании понятия и закономерности этих наук взаимно дополняют друг друга. Данная статья посвящена частичному освещению указанной проблемы.

Ключевые слова: естествознание, физика, биология, биосфера, клетка, механика, электричество, кровь, скорость, рентгеновское излучение, лечение.

ELEMENTS OF INTERDISCIPLINARY CONNECTIONS IN TEACHING PHYSICS

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Annotation: The object of study in natural sciences - such as physics, biology, and biophysics - includes both material and immaterial aspects of nature. When these disciplines are taught, their concepts and laws complement each other. This article is devoted to a partial consideration of the stated issue.

Keywords: natural science, physics, biology, biosphere, cell, mechanics, electricity, blood, velocity, X-rays, treatment.

Kirish. Tabiatshunoslik fanlari- fizika, kimyo, fizik kimyo, astrofizika Yer va Koinotni, organik va noorganik tabiatni tadqiq etadi. Biologik fanlar majmuasi va biofizika esa tirik tabiatni xujayragacha