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INTEGRATION OF ELECTROCHEMICAL WATER REGENERATION INTO SMART HOME INFRASTRUCTURE: CONCEPT, CALCULATIONS, AND EFFICIENCY

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Abstract

This paper proposes the concept of integrating electrochemical water regeneration into smart home infrastructure. It examines the principles of electrochemical processes enabling disinfection, aeration, and chemical restoration of water without reagents. The integration of regeneration modules into the digital home ecosystem is described, including the use of sensor systems and AI-based control algorithms. Engineering calculations of energy efficiency and economic impact are provided for a residential complex of 100 apartments. The results show that implementing electrochemical modules can reduce fresh water consumption by up to 70%, decrease wastewater discharge, and increase household system autonomy.

Keywords: *electrochemical water regeneration, smart home, sustainable water use, reagent-free purification, energy-efficient systems, water cycle*

Introduction

Modern residential complexes and smart homes are characterized by increasing demands for resource autonomy and environmental efficiency. Water is one of the most critical yet limited resources, which necessitates a transition from linear water consumption models to **closed or semi-closed water cycles**.

Traditional purification and disinfection methods – such as mechanical filtration, ion exchange, and chlorination – are not fully compatible with the concept of intelligent domestic systems due to the need for reagent storage and high maintenance costs.

Electrochemical water regeneration solves this issue by allowing **disinfection and chemical correction of water using only electrical energy**, without adding chemical substances.

Methodology

1. Electrochemical Principle

Electrochemical water regeneration is based on controlled electrolysis, in which active oxygen species (O_2, O_3, $\bullet OH$) are formed in the anode zone, providing disinfection, while the cathode zone generates reducing agents that adjust the acid-base balance.

As a result, the system can **automatically correct the water's pH** and remove organic and biological contaminants without reagents.

2. Integration into Smart Home Infrastructure

Electrochemical regeneration modules can be integrated into three levels of water management:

- Local level – compact modules installed under sinks or in utility cabinets within each apartment;
- Centralized level – shared building installations connected to a monitoring system driven by artificial intelligence;
- Digital control – real-time monitoring using sensors for pH, conductivity, and temperature, with data transmitted to a home server or cloud system for optimization of operation modes.

Electronic controllers automatically regulate current intensity, treatment duration, and aeration depending on the water's composition.

3. Engineering Calculations

For a residential complex of 100 apartments (150 residents):

- Baseline water consumption: 150 L/person·day = 22,500 L/day;
- Greywater reuse rate: 60%;
- Fresh water savings: 13,500 L/day (≈ 5 million L/year);
- Specific energy consumption: 0.4 kWh/m³;
- Annual energy consumption: 3,000 kWh ≈ 20,000 RUB/year (at 6.6 RUB/kWh);
- Payback period: 3–5 years, considering average water and sewage tariffs of 100–150 RUB/m³.

Results

Integrating electrochemical modules into a smart home provides the following benefits:

1. Significant reduction in water consumption. Up to 70% of household water can be regenerated and reused for non-potable needs such as flushing, irrigation, and laundry.

2. Reagent-free operation. The system eliminates the need for storing or disposing of hazardous chemicals.

3. Energy efficiency. Power consumption is only 10–15% of that required by membrane-based reverse osmosis systems.

4. Environmental safety. Wastewater volume and the load on municipal treatment facilities are reduced.

5. Intelligent management. AI algorithms adapt operation modes to seasonal changes and individual consumption patterns.

6. Compatibility with renewable energy. Electrochemical modules can operate using solar energy, ensuring complete autonomy.

From a sustainability perspective, implementing such systems contributes directly to **UN Sustainable Development Goals (SDGs) 6 – Clean Water and Sanitation** and **11 – Sustainable Cities and Communities**, while reducing the household carbon footprint.

Discussion

The analysis demonstrates that **electrochemical water regeneration** is a technologically mature and economically viable solution for smart home infrastructure. It enables a reduction in water consumption, enhances ecological and operational autonomy, and lays the foundation for integration into broader intelligent building ecosystems.

Future developments in this area should focus on:

- optimizing module design and control algorithms;
- implementing energy storage components (e.g., capacitor banks);
- developing adaptive water-quality diagnostic systems based on neural networks.

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