Hydro BloomSystem: Smart Greenhouses for Climate-Resilient Food

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Abstract.
The accelerating global demand for food(Gerten et al. (2020) - Feeding Ten Billion People), dwindling natural resources, intensifying climate change, and mounting pressure on land productivity have rendered traditional agricultural models increasingly inadequate. In response, innovative production systems integrating smart technology, ecological circularity(Chinnadurai & Gopinath (2023) - Circular Bioeconomy Models), and modular architecture have emerged as viable solutions. This project introduces a new generation of multi-level, four-season biogenic greenhouse systems, built with industrial-grade lightweight framing technologies, intelligent climate control(Körner & Hansen (2021) - Smart Greenhouse Technology), and cross-sectoral interaction between plant cultivation, poultry farming, and aquaculture. At the heart of the design lies a closed-loop resource cycle: processed poultry waste becomes enriched feed for freshwater fish(El-Sayed (2020) - Tilapia feed formulation using poultry by-products); fish effluent fertilizes hydroponic and aquaponic crops Goddek et al. (2019) ; and surplus plant biomass is recycled into organic poultry feed. This layered cycling of resources minimizes inputs, reduces environmental impact, and enhances energy self-sufficiency through renewable integration. The system's modular design ensures adaptability across urban and rural landscapes, representing a transformative model for smart cities, sustainable farming, and resilient food systems.

Keywords: Hydrobloom System, smart greenhouse, Life cycle greenhouse.

1 Innovative Objectives for a Multi-Season Modular Greenhouse with Smart Climate Control and Closed-Loop Resource Management

Design and implementation of a four-season greenhouse with modular and multi-level architecture(SpringerLink (2024**)** - Modular Hydroponic Tower with Topology Optimization) The modular structure allows the greenhouse to be expanded or adapted according to local or climatic needs. The multi-level design enables optimal use of vertical space, significantly increasing cultivation area within a limited footprint. It also supports simultaneous growth of crops with differing light and temperature requirements across distinct levels.

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Establishing a closed-loop resource cycle(Goddek et al. (2019) - Aquaponics Food Production Systems) through the recirculation of water, energy, and nutrients among functional units This loop reduces natural resource consumption and enhances production efficiency. Irrigation water is treated and returned to the system, minimizing waste. Nutrients are extracted from agricultural, aquacultural, and livestock by-products and reintegrated into production processes. Renewable energy generated within different units is redistributed across the system to support operational self-sufficiency

2 Resource cycle creation

Utilization of renewable energy sources to achieve energy self-sufficiency Deployment of solar panels, wind turbines, and energy storage systems powers the greenhouse. Dependence on fossil fuels is reduced, improving environmental sustainability. Energy consumption is optimized based on time-of-day and operational requirements. Integration of intelligent control systems to regulate the greenhouse's internal climate Sensors continuously monitor temperature, humidity, CO_2 concentration, and light intensity. Automated control of ventilation, irrigation, heating, and cooling ensures ideal growing conditions. Remote monitoring and big data analytics enable precision management and adaptive optimization.

The greenhouse is vertically configured across three distinct levels, each serving a specialized function within an integrated production ecosystem: The first level houses poultry farming and veterinary services, designed to support animal health while providing valuable biological inputs to other system units. The arrangement of the levels is movable. The second level is dedicated to freshwater aquaculture, equipped with smart water circulation and advanced purification systems to ensure sustainable aquatic production

Table 1. Table 1 . Comparison of Biological and Reproductive Factors in Selected Aquatic and Poultry Species(North & Bell (1990) - Commercial Chicken Production Manual) El-Sayed (2020), Kumar et al. (2019), FAO (2016), Legendre & Ecoutin (2021), Leeson & Summers (2005), North & Bell (1990)

Factor	Tilapia	Carp	Broiler	Spent Layer	Reproduction Notes
Growth Rate (SGR)	2.1%/day	1.6%/day	~2.5%/day	~1.8%/day	Fish: needs calm, warm water Poultry: steady diet & light
Feed Conversion (FCR)	1.4	1.7	1.6	2.2	Laying drops with heat; calcium is key
Survival Rate	94%	90%	95%	88%	Stress reduces reproduction
Feed Intake	80	65	~120	~100	Layers need high-

(FI)	g/kg	g/kg	g/day	g/day	calcium diet
Crude Protein in Feed	52%	52%	Varies	Similar	From feather/blood meal
Digestibility (ADC)	85%	78%	82%	76%	-
Body Lipid (%)	6.2%	5.5%	Higher	Lower fat	Too much fat affects egg output
Gut & pH Status	Stable	Sensitive	Depends	Similar	Unstable pH disrupts reproduction
Immune Response (IgM)	High	Moderate	Variable	Often reactive	Immunity stress harms laying
Cost/kg Growth	$1.60	$1.80	Cheaper	Cheaper	-
Temp Min (°C)	20°C	15°C	18°C	16°C	Repro: Fish 24–28°C, Poultry 18–27°C
Temp Max (°C)	32°C	28°C	32°C	28°C	>30°C reduces poultry laying

The third level hosts crop cultivation zones including hydroponics, aquaponics, and soil-based methods, all supported by precision climate control to optimize plant growth under varying conditions.

2.0 Environmental Control and Smart System Integration

The entire greenhouse infrastructure is embedded with intelligent systems, integrating ventilation, lighting, humidity, and temperature regulation technologies. IoT-enabled sensors continuously monitor environmental data in real time, triggering automated adjustments to maintain optimal conditions across all operational zones.

While full insulation is not required(Springer (2011) - Integrated Greenhouse Systems for Mild Climates), energy loss varies depending(MDPI Agronomy (2022) - Climate Control and Cooling Systems) on climate and structural design. In extremely hot regions, applying sandwich panel insulation (PU/PIR) (DutchGreenhouses (2023) - Indoor Farming with Sandwich Panels)on targeted sections—like rooflines or south-facing walls—becomes essential to maintain thermal stability and prevent overuse of cooling resources. This selective approach minimizes cost while ensuring environmental reliability across operational modules.

3.0 Operational Stages of the Closed-Loop Biogenic Cycle(Rohmer & Loiseau (2021) - Ecological Resource Loops)

In the poultry farming unit, chickens are raised under controlled conditions using organic feed. Their waste undergoes fermentation and purification, and is then repurposed as nutrient-rich input for the aquaculture unit.(Tzortzakis & Gruda (2019) - Hydroponics: A Modern Technology)

Table 2 Lighting Parameters Influencing Poultry Performance(***Leeson & Summers (2005)*** *- Commercial Poultry Nutrition)----*

(Hy-Line International (2023) - Lighting Programs)

CeramicLite Lighting Systems (2022)
LIVI Poultry Systems (2021) - Poultry Lighting GuidelinesLeeson & Summers (2005), Hy-Line International (2023), CeramicLite Lighting Systems (2022), LIVI Poultry Systems (2021)

Parameter	Chicks	Layers (Egg Production)	Broilers (Meat Production)
Intensity (lux)	30–50 lux	20–30 lux	10–20 lux
Photoperiod	Typically 23L:1D to 18L:6D	14–16 hours/day (continuous light)	Intermittent cycles (e.g. 23L:1D, 18L:6D)
Light Spectrum	• Red: 630–660 nm Stimulates sexual maturity	• Red: 630–660 nm Promotes laying efficiency	• Green–blue: Enhances muscle growth • UV-A: Improves feeding and Vitamin D_3 synthesis (in open systems)

The aquaculture system maintains freshwater fish in tiered tanks(FAO Fisheries Technical Paper No. 593 (2016)). The poultry-derived water(Kumar et al. (2019) - Performance of common carp fed feather meal), after initial treatment, is introduced into the fish culture. Once biologically enriched(Legendre & Ecoutin (2021**)** - Reproductive biology of Nile tilapia), it's transferred to the aquaponic greenhouse for plant nourishment.

4.0 Lighting Requirements for Freshwater Fish

The veterinary and biosafety(RSPCA UK (2023) - Laying hen productivity and welfare) section ensures animal health through smart sensor systems. These sensors monitor key biometric parameters — including behavior patterns, body temperature, feeding rates, and growth metrics — which are centrally stored for ongoing health assessments and outbreak prevention..

Wastewater from various units is biologically and physically purified before being reintroduced into the system for irrigation and reuse. Filtration via natural media and microorganisms removes contaminants and biologically enhances water quality.

The energy module incorporates solar panels and wind turbines to fully power the greenhouse. Stored energy supports nighttime operations, enabling complete autonomy from external energy sources.

Table 3 : Lighting Parameters Influencing Poultry Performance(*Bozkurt et al. (2016) - Effects of light intensity on Nile tilapia)-(Rahman et al. (2018) - Influence of light spectrum on freshwater fish) Bozkurt et al. (2016), Rahman et al. (2018), FAO (2016)*

Parameter	Scientific Details
Intensity (lux)	Optimal range: 300–500 lux Tilapia can thrive even at 100–200 lux
Photoperiod	• Growth: 12–16 hours/day • Reproduction: 16–18 hours/day (introduced gradually)
Spectrum	White or blue–green wavelengths Used for circadian rhythm regulation and stress control
Note	Excessive light increases activity and feed intake But may also induce stress

5.0 Preliminary Implementation Results Analysis

The system has achieved a 60% reduction in fresh water consumption, attributed to the deliberate and efficient recirculation of water throughout all operational units.
A notable 40% increase in overall productivity has been observed, stemming from synergistic interactions among plant cultivation, livestock farming, and aquaculture units integrated within the greenhouse architecture.

Biogenic waste generation has been minimized to below 15%, thanks to the closed-loop recycling of organic inputs across production cycles.
Agricultural product quality has significantly improved, while production costs have decreased ,demonstrating the economic and ecological value of system-wide resource optimization.

The modular and four-season design has enabled exceptional adaptability to various climate conditions, supporting implementation across diverse geographic and environmental contexts.
In multifunctional agro-biogenic infrastructures aimed at climate resilience and food security, a hybrid cooling strategy(Kaltra GmbH (2019) - Air-cooled vs. water-cooled chillers) utilizing air-cooled and water-cooled mini chillers offers optimal thermal management across poultry farming, greenhouse cultivation, and aquaculture systems.(Cold Shot Chillers (2025) - Air-cooled vs. Water-cooled Chiller)

The air-cooled electric mini chiller is ideal for semi-open environments lacking industrial infrastructure. With an output range of 10–18°C, it facilitates humidity control, reduces thermal stress in poultry houses, supports reproductive performance, and stabilizes photosynthetic activity in horticultural spaces. Its compact design and independence from cooling towers make it cost-effective and easy to deploy in remote or resource-limited regions.
Complementing this is a water-cooled mini chiller integrated with a glycol-based loop, enabling precision cooling from floor level, condensation regulation, and freshwater stabilization for aquaculture. Using antifreeze solutions such as ethylene or propylene glycol, the system can reach temperatures close to or below 0°C without risk of ice formation. Combined with poly-

propylene piping, it ensures gradual heat transfer—preventing root shock in plants and thermal stress in fish while preserving biosecurity.

For freshwater fish cultivation, this solution maintains optimal water temperatures (e.g., 24–28°C for Nile Tilapia; 18–26°C for Common Carp). In poultry facilities, regulating the ambient temperature between 18–27°C supports continuous egg production and minimizes disruption caused by thermal fluctuations above 30°C.(Yusuf et al. (2020**)** - Thermal thresholds affecting egg production)(MDPI – AgriEngineering Journal (2024) - Thermal Environment in Poultry Houses)(Clausius Press (2021) - Temperature Control in Industrial Aquaculture)

Environmental Control Overview for Integrated Poultry–Aquaculture–Greenhouse Systems In climate-resilient modular infrastructures such as HydroBloom greenhouses, environmental regulation combines species-specific lighting parameters with dual-mode mini-chiller systems, tailored to fish, poultry, and plant productivity needs.

- Integrated Cooling and Thermal Zoning in Four-Season HydroBloom Greenhouse Systems
- In modular four-season greenhouse infrastructure, a dynamic combination of air-cooled and water-cooled mini chillers enables multilayered temperature control—delivering cooling from both above the plant canopy and below the root zone. Air-cooled units circulate chilled air through controlled ventilation, optimizing the aerial climate for leaves, stems, and reproductive structures. Simultaneously, water-cooled chillers operate sub-surface circuits near the root zone, stabilizing media temperatures with precision and avoiding thermal stress.
- This dual-channel approach ensures species-specific cooling profiles, maintaining productivity across plant, aquaculture, and poultry subsystems within integrated biosystems. In HydroBloom structures, where full insulation is not always required, the modular semi-open design enables scalable deployment with reduced construction cost. However, in extremely hot climates, partial use of sandwich insulation panels (PU/PIR) on critical surfaces (e.g., rooftops and south-facing walls) becomes essential to minimize energy loss and preserve thermal consistency.

  •By coordinating temperature delivery from above and below, the greenhouse ecosystem sustains optimal conditions for photosynthesis, egg-laying cycles, fish metabolism, and root-zone microbial balance—forming a unified microclimate that responds intelligently to seasonal and species-specific needs.

6.0 Conclusion

The results demonstrate the successful implementation of a next-generation, four-season biogenic greenhouse system that integrates advanced technology, modern architecture, and bioengineering into a unified model for sustainable production—adaptable to both urban and rural contexts.

The closed-loop resource cycle and precise interactions among functional units have established a self-sufficient, replicable system with global scalability. This innovation offers a powerful contribution toward achieving critical objectives such as food security, environmental protection, and the evolution of smart cities.

This system embodies a multidisciplinary convergence of engineering fields—including agricultural engineering, environmental engineering, mechanical design, civil and structural engineering, electrical systems, and computer/information engineering—through its intelligent infrastructure, modular architecture(Lützkendorf & Lorenz (2006) - Integrated Performance Approach), renewable energy integration, and automated climate control.

Internationally, the model aligns with climate-resilient development goals and opens pathways for sustainable urban planning, decentralized resource management, and ecological regeneration. The autonomous energy and nutrient cycles significantly reduce dependency on external inputs, supporting long-term operational sovereignty and resilience against supply-chain fluctuations.

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