ENERGY AND HVAC ECONOMICS IN CONTROLLED-ENVIRONMENT AGRICULTURE

The hidden operating cost of climate control

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ABSTRACT

Climate-controlled environments require sustained heating, ventilation, and air conditioning (HVAC) and lighting input to maintain the temperature, humidity, and airflow conditions that biological production depends on. In poorly designed installations, maintaining this environment can consume up to 60 percent of total operating cost, a figure consistent with academic literature reporting that climate control accounts for 30 to 80 percent of operating expenditure in controlled-environment agriculture (CEA) facilities (Vakhnovskyi, 2026). Rising utility rates are amplifying the problem: the United States Energy Information Administration (EIA) forecasts continued electricity price growth through 2026, driven largely by surging demand from data centers and industrial load growth outpacing new generation capacity (Utility Dive, 2025; Huffman, 2025). This article examines why climate control is so energy-intensive, quantifies the share of operating budgets it typically consumes, reviews the utility rate trends compounding the problem in 2026, and outlines the design and engineering factors, particularly building envelope quality and HVAC system efficiency, that determine whether a facility operates near the low end or the high end of that cost range.

EXECUTIVE SUMMARY

ENERGY & HVAC OPERATING COSTS

The hidden operating cost of climate control in controlled-environment agriculture

Climate-controlled environments require sustained HVAC and lighting input to hold the temperature, humidity, and airflow tolerances that biological production depends on. In poorly designed installations, maintaining that environment can consume up to 60 percent of total operating cost, a figure consistent with academic literature reporting a range of 30 to 80 percent across controlled-environment agriculture facilities. Rising utility rates through 2026 are amplifying the problem, converting an engineering inefficiency into a direct and growing threat to margin.

30%-80%	***$51/MWH***	***66%***	***38%***
OF OPEX IS CLIMATE CONTROL	EIA 2026 WHOLESALE FORECAST	ENERGY CUT, LOW- TO HIGH-COP HVAC	HVAC SAVINGS, INTEGRATED CONTROL

KEY FINDINGS

- HVAC equipment alone typically accounts for 30 to 40 percent of total energy use in controlled-environment facilities; combined with lighting, climate control can exceed 80 percent of demand in poorly engineered buildings.
- The dominant heat and moisture loads come from inside the building, supplemental lighting and biological activity, not from outdoor weather, making this a fundamentally different engineering problem than conventional commercial HVAC.
- U.S. wholesale electricity prices are forecast to rise from roughly $47/MWh in 2025 to $51/MWh in 2026, with retail rates climbing faster than general inflation, driven by demand growth from data centers outpacing new generation capacity.
- Facility design, not climate alone, explains most of the gap between low-cost and high-cost operations: building envelope quality, right-sized equipment, high-COP HVAC, and integrated temperature-humidity control together determine where a facility lands in the cost range.

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INTRODUCTION

Any facility that grows, houses, or processes living material indoors, whether a vertical farm, a greenhouse, a hydroponic fodder installation, or a livestock barn retrofitted for climate control, faces a fundamental economic reality: the equipment that maintains the internal environment is often the single largest ongoing operating expense. Unlike a conventional commercial building, where HVAC exists primarily for human comfort, a controlled-environment agriculture facility uses HVAC to manage the heat and humidity loads generated by biological processes, supplemental lighting, and equipment, all while holding narrow temperature and humidity tolerances that plants or animals require for consistent output (Danfoss, n.d.). This distinction matters because it changes both the scale of the load and the consequences of getting the system design wrong.

The stakes have grown sharper in the past two years. Electricity demand growth in the United States, driven substantially by data center expansion, has begun to outpace the addition of new generating capacity in several regions, pushing wholesale and retail power prices upward faster than general inflation (Utility Dive, 2025). For any operator whose cost structure already leans heavily on electricity for climate control, that trend converts an engineering inefficiency into a direct and growing threat to profitability.

HOW LARGE IS THE CLIMATE CONTROL COST BURDEN

The proportion of operating cost attributable to HVAC and lighting varies enormously depending on facility design, climate zone, and crop or livestock type, but the published range is consistently wide and consistently high. A 2026 review of energy-efficient climate control in vertical farms found that HVAC equipment alone typically accounts for 30 to 40 percent of a facility's total energy usage, independent of lighting (Danfoss, n.d.). A more recent peer-reviewed analysis of climate management strategies in controlled-environment agriculture placed the combined share of operating costs attributable to climate control between 30 and 80 percent, reflecting the substantial variation between well-engineered and poorly engineered facilities (Vakhnovskyi, 2026). Separately, research on indoor farming energy loads found that HVAC and supplementary lighting together account for over 80 percent of total energy demand in some indoor growing operations, and that indoor climate-controlled production can consume 15 to 20 times more energy than outdoor cultivation of the same crop ("Optimal Energy Management in Indoor Farming," 2025).

These figures are not simply academic. Financial modeling of commercial indoor farming operations projects that energy for lighting and climate control alone can consume approximately half of total revenue under a 2026 cost structure, a proportion sensitive to even modest fluctuations in wholesale utility rates (Financial Models Lab, 2025). Where a facility falls within this range depends heavily on whether the underlying building and system were engineered specifically to minimize climate control load, or whether HVAC capacity was added as an afterthought to a structure not designed for the purpose.

WHY CLIMATE CONTROL IS SO ENERGY-INTENSIVE

The physics behind this cost burden are straightforward. In most controlled-environment agriculture settings, the dominant heat loads come not from the outside climate but from within the building itself: supplemental lighting and the metabolic activity of the crop or livestock generate continuous heat and moisture that must be actively removed to hold temperature and humidity within tolerance (Danfoss, n.d.). This is a materially different engineering problem than conditioning a conventional building against outdoor weather, and it means that even a facility in a mild climate can face a substantial, near-constant cooling and dehumidification load.

Humidity management compounds the difficulty. Heating a space tends to reduce relative humidity, while cooling and the moisture generated by plants or animals tend to increase it, and dehumidification itself generates heat, creating a coupled control problem that is difficult to optimize with simple, independently operating thermostats and humidistats (Vakhnovskyi, 2026). Facilities that manage temperature and humidity as separate, uncoordinated systems, rather than as an integrated control problem, tend to run less efficiently and consume more energy to hold the same setpoints.

Equipment efficiency, commonly measured by coefficient of performance (COP), also has an outsized effect. Peer-reviewed benchmarking research found that improving HVAC system COP from 2 to 6, a realistic range between low-efficiency and high-efficiency commercial equipment, can reduce climate control energy consumption by roughly 66 percent, corresponding to a 28 to 30 percent reduction in total facility energy use ("Benchmarking Energy Efficiency in Vertical Farming," 2024). This single variable, equipment selection at the time of installation, is one of the most significant determinants of whether a facility operates near the low or high end of the operating cost range described above.

UTILITY RATE TRENDS AMPLIFYING THE PROBLEM IN 2026

Rising electricity prices are compounding the underlying inefficiency problem rather than simply adding a fixed surcharge on top of it. The EIA's Short-Term Energy Outlook projects that the load-weighted average of wholesale electricity prices across the eleven regional markets it tracks will reach approximately 47 dollars per megawatt-hour (MWh) in 2025, a 23 percent increase over the 2024 average, and will climb further to roughly 51 dollars per MWh in 2026 (Utility Dive, 2025). On the retail side, the EIA forecasts residential electricity prices to average approximately 18.02 cents per kilowatt-hour in 2026, up from 17.29 cents in 2025, with regional prices in high-cost areas such as New England and the Pacific climbing well above the national average (Huffman, 2025).

The EIA attributes much of this growth to demand outpacing new generation capacity, particularly from data centers and other large industrial loads concentrated in regions such as Texas (ERCOT) and the mid-Atlantic (PJM), which is tightening regional power markets and pushing prices higher even where fuel costs have been relatively stable (Utility Dive, 2025). Separate analysis places the average annual growth rate of nominal U.S. electricity prices at approximately 4.5 percent between 2022 and 2026, a rate that has consistently outpaced general inflation over the same period (American Action Forum, 2025).

For any facility where climate control already represents 30 to 60 percent or more of operating cost, this rate of increase does not simply raise a line item. It compresses margins directly and disproportionately, because the electricity-intensive share of the cost structure grows faster than revenue or other, more stable input costs. Operators evaluating new installations or retrofits in 2025 and 2026 face a materially different economic calculation than they would have five years earlier, one in which energy efficiency at the design stage carries a larger and more durable financial return than it did when utility rates were flatter.

DESIGN FACTORS THAT DETERMINE WHERE A FACILITY FALLS IN THE COST RANGE

The gap between a facility with climate control at 30 percent of operating cost and one at 60 percent or higher is rarely explained by climate alone. It is explained by design choices made before a system is ever switched on.

Building envelope quality. The building envelope, meaning walls, roof, doors, and any points of air infiltration, forms the first line of defense against unwanted heat gain or loss, and it is widely regarded in the energy efficiency literature as the appropriate starting point for any retrofit. Federal guidance on deep energy retrofits recommends addressing envelope upgrades before HVAC replacement, because even highly efficient mechanical equipment cannot fully compensate for a poorly insulated or leaky structure (U.S. Department of Energy, 2025). Industry analysis of the energy retrofit market similarly found that envelope-related improvements, including insulation, roofing, and air sealing, represented the largest single revenue category in the energy retrofit sector in 2024 (Climate Change Academy, 2026), reflecting how central this factor is to overall system performance.

Retrofit versus new construction. Facilities retrofitted into existing barns, warehouses, or other agricultural structures can achieve strong efficiency outcomes, but only when the retrofit explicitly accounts for the building's existing thermal performance rather than treating HVAC capacity as a simple substitute for a well-sealed envelope. A structure with inadequate insulation and significant air leakage imposes an energy and cost penalty that cannot be fully offset by oversizing mechanical equipment (Continuous Insulation, n.d.).

Equipment selection and right-sizing. As noted above, the difference between low-COP and high-COP mechanical equipment can account for a large share of total facility energy consumption on its own ("Benchmarking Energy Efficiency in Vertical Farming," 2024). Right-sizing equipment to the actual heat and moisture load, rather than over-specifying capacity as a margin of safety, avoids the efficiency losses associated with oversized systems that cycle inefficiently at partial load.

Control strategy. Facilities that manage temperature and humidity through integrated, coordinated control, rather than independent thermostats and humidistats acting without reference to one another, consistently show measurable energy savings. Field data drawn from more than thirty controlled-environment agriculture facilities over a seven-year period found that coordinated climate control strategies reduced HVAC energy consumption by 30 to 38 percent relative to conventional independent control (Vakhnovskyi, 2026).

Taken together, these four factors, envelope quality, retrofit discipline, equipment efficiency, and control strategy, explain most of the variance between facilities operating near the low end of the climate control cost range and those absorbing the 60 percent burden described in this article's opening. None of them require exotic technology. They require deliberate engineering decisions made at the design and procurement stage, when the cost of correcting them is lowest.

CONCLUSION

Climate control is not a peripheral cost in controlled-environment agriculture; for a meaningful share of installations, it is the dominant one, consuming anywhere from roughly 30 percent to as much as 60 to 80 percent of total operating expenditure depending on how the facility was designed and equipped (Vakhnovskyi, 2026; "Optimal Energy Management in Indoor Farming," 2025). That burden is no longer static. Electricity prices are forecast to keep rising through 2026, driven by demand growth that is outpacing new generation capacity across major U.S. markets (Utility Dive, 2025; Huffman, 2025), which means that an inefficient facility built today will carry a growing cost disadvantage for the life of its equipment, not a fixed one. The organizations best positioned to weather this trend are those that treat building envelope quality, equipment efficiency, and integrated climate control as foundational design decisions rather than afterthoughts, because the return on that discipline compounds every year utility rates continue to climb.

FREQUENTLY ASKED QUESTIONS

What percentage of operating costs does HVAC typically represent in controlled-environment agriculture?

Published estimates range from about 30 percent in well-designed facilities to as much as 60 to 80 percent in poorly designed ones, depending on building envelope quality, equipment efficiency, and control strategy (Vakhnovskyi, 2026).

Why does climate control consume so much energy indoors compared to outdoor production?

Indoor facilities must actively remove heat and moisture generated by lighting and biological activity rather than relying on ambient conditions, which can require 15 to 20 times more energy than outdoor cultivation of comparable output ("Optimal Energy Management in Indoor Farming," 2025).

Are electricity prices actually rising in 2026?

Yes. The U.S. Energy Information Administration forecasts wholesale electricity prices rising from about 47 dollars per MWh in 2025 to about 51 dollars per MWh in 2026, with retail prices also climbing faster than general inflation (Utility Dive, 2025; Huffman, 2025).

What is the single most effective way to reduce HVAC operating costs?

Addressing the building envelope, insulation, air sealing, and infiltration control, before or alongside HVAC equipment upgrades typically produces the largest and most durable reduction in energy demand, since no mechanical system can fully compensate for a leaky structure (U.S. Department of Energy, 2025).

Does upgrading to higher-efficiency HVAC equipment make a measurable difference?

Yes. Peer-reviewed benchmarking found that raising HVAC coefficient of performance from 2 to 6 can cut climate control energy consumption by roughly 66 percent, equivalent to a 28 to 30 percent reduction in total facility energy use ("Benchmarking Energy Efficiency in Vertical Farming," 2024).

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