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Short communication

Energy efficiency in pharmaceutical laboratories: key concepts, sustainable strategies and future trends

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Introduction

All laboratories in the pharmaceutical sector require substantial energy to operate specialized equipment and maintain controlled environments (Blasco et al., 2024; Freese et al., 2024; Niu et al., 2025). A single fume hood consumes 3.5 times, and a single ultra-low temperature (ULT) freezer 2.7 times (20–25 kWh per day), the energy of an average household (Freese et al., 2024). The heating, ventilation and air-conditioning (HVAC) systems of laboratories operate at airflow rates two to ten times higher than those of office buildings, and ventilation constitutes the single most energy-intensive service in laboratory buildings (Kitzberger et al., 2022; Murray et al., 2008).

Energy efficiency is the practice of minimizing energy consumption in the laboratory without compromising safety, experimental integrity or performance. However, laboratory energy consumption is significant and complex to predict and manage due to the diverse and sometimes unpredictable nature of laboratory workflows (Niu et al., 2025). The implementation of energy-efficient practices yields both cost reductions and environmental benefits. This review provides a concise overview of energy efficiency measures as part of the strategy for sustainable laboratories of the future.

Energy efficiency measures

Energy saving equipment

Energy-saving equipment is designed to improve one or more of the following parameters: operational efficiency, i.e. lower consumption during routine use; standby efficiency, i.e. reduced energy waste while equipment is idle; process efficiency, i.e. improved overall efficiency of laboratory workflows; and lifecycle efficiency, which considers energy use over the entire service life of the instrument (Steiner, 2025). Although investment in energy-saving equipment is a cornerstone of any sustainability initiative, it is not the only approach to reducing energy consumption within a facility. Optimization of HVAC systems offers particularly high savings potential, given that heating, cooling and ventilation account for 60–70% of total building energy use (Steiner, 2025). Because laboratories tend to over-ventilate as a safety precaution, calibrating ventilation rates to the actual risk profile of the space can yield considerable savings. Demand-controlled ventilation adjusts airflow dynamically according to room occupancy and chemical activity, while retrofitting fume hoods with variable air volume (VAV) technology reduces airflow when the sash is closed,

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lowering energy waste without compromising safety (Steiner, 2025).

In refrigeration and cold storage, upgrading to energy-efficient models should be accompanied by routine maintenance: regular cleaning of condenser coils, optimization of temperature set-points and consolidation of samples to reduce the number of operating units can substantially decrease consumption. Freezer management programs, such as the elimination of redundant samples and freezer sharing among research groups (e.g., the International Laboratory Freezer Challenge), further minimize energy use (Steiner, 2025). In addition, replacement of fluorescent and incandescent luminaires with light-emitting diode (LED) lighting provides immediate reductions in energy consumption with minimal capital investment.

Architectural design of sustainable labs

Programmatic Shifting: In the northern hemisphere, offices, writing spaces and corridors are positioned along the south façade to capture passive solar warmth in winter and abundant natural light, whereas the highly regulated, heat-sensitive laboratory zones (housing analytical equipment such as HPLC systems, spectrometers and stability chambers) are oriented toward the north side of the building, where the thermal load from direct sunlight is minimal and predictable.

Digital technologies and energy savings

Some studies find that digitalization reduces energy consumption and enhances efficiency by enabling optimized processes, smart resource allocation and technological innovation, whereas others report that it may initially increase consumption owing to rising electricity demand and data traffic, while still improving energy efficiency over time through technological upgrades, real-time monitoring and improved energy management (Tufail et al., 2026). Looking ahead, artificial intelligence-driven predictive energy management, smart sensor networks and digital twins of laboratory facilities are expected to enable real-time optimization of HVAC and equipment loads. In parallel, green laboratory certification schemes such as My Green Lab and LEED are increasingly being integrated into the quality and sustainability strategies of pharmaceutical laboratories.

Conclusion

Energy efficiency in pharmaceutical laboratories requires an integrated approach that combines equipment-level interventions, optimization of ventilation and cold storage, climate-responsive architectural design and digital monitoring technologies. Given that ventilation accounts for the largest share of laboratory energy demand, demand-controlled HVAC systems and variable air volume fume hoods offer the greatest savings potential without compromising safety or data integrity. Embedding these measures into laboratory quality and management systems, supported by emerging digital tools and green laboratory certification frameworks, will be essential for the pharmaceutical sector to meet its sustainability commitments while maintaining regulatory compliance.

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