Whitepaper

Food Safety in Vertical Farms

Integrating design, standards, and practicality for maintaining a safe food production environment in vertical farms.

Food from vertical farms

Vertical farming is an innovative agricultural method that involves growing crops indoors, in totally controlled environments.

This approach maximizes space efficiency and enables year-round cultivation, regardless of weather conditions. Although the concept originated in the early 20th century, it gained significant momentum around 2015, when it emerged as a promising solution to urban food security and sustainability challenges. Since then, vertical farming has transformed from a futuristic idea into a rapidly growing sector within the agri-tech industry. Initially driven by hype and high expectations, the field has matured through technological advancements in LED lighting, hydroponics, and climate control systems. Today, vertical farms primarily produce leafy greens, herbs, and microgreens due to their short growth cycles and compact size.

Looking ahead, vertical farming is poised to play a crucial role in creating resilient food systems, particularly in urban areas and regions with challenging climate conditions. Its potential to reduce land use, water consumption, and food miles positions it as a key component of sustainable agriculture.

Food Safety in Vertical Farming

Vertical farming presents a unique opportunity to enhance food safety through tightly controlled growing environments. With reduced exposure to soil-borne pathogens, pests, and pollutants, these systems inherently lower the risk of contamination. However, this same controlled setting demands strict attention to hygiene, air and water quality, and equipment sanitation. Due to the dense and interconnected nature of vertical farms, any lapse in protocol can lead to rapid contamination (see image 1). Proactive monitoring, traceability tools, and standardized sanitation procedures are vital to safeguard both product quality and consumer health.

Beyond operational controls, vertical farms must navigate an evolving regulatory landscape and increasing public scrutiny. Compliance with food safety regulations is not only a legal requirement but also a business imperative, failures can lead to recalls, diminished consumer confidence, and lasting reputational damage. As the industry expands, so too does its visibility and responsibility. Integrating food safety into the operational DNA, from design to distribution, ensures that vertical farming can scale responsibly and sustainably while maintaining the trust of regulators, retailers, and the public.

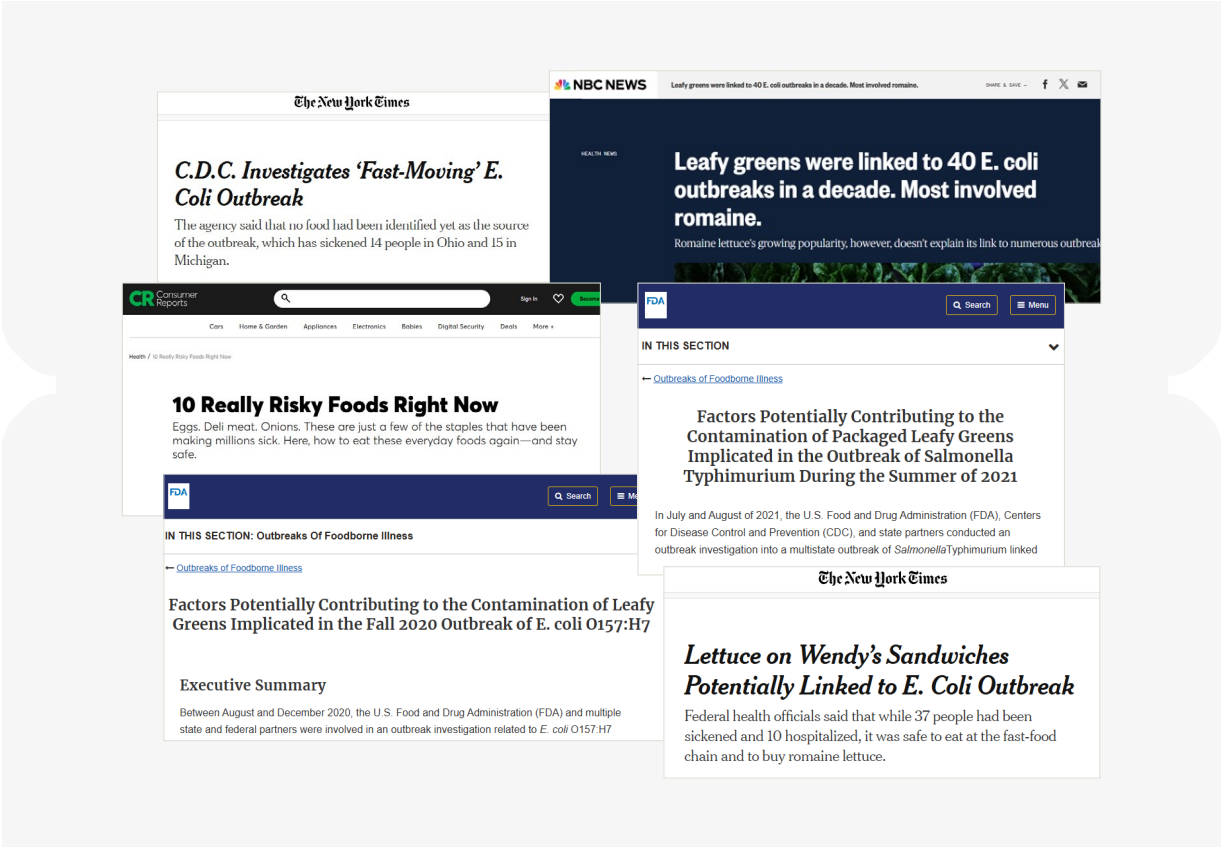


Image 1: Headlines food safety

Types and Pathways of Contaminants in Vertical Farming

Despite the controlled nature of vertical farming, various contaminants can still pose a threat to crop safety. These include **biological contaminants** such as bacteria (e.g., Salmonella, E. coli), viruses, and fungi; **chemical contaminants** like pesticide residues, cleaning agents, or heavy metals; and physical contaminants such as plastic fragments or metal shavings. Contaminants can enter the system through multiple pathways, including **incoming water sources**, **nutrient solutions**, **seeds or planting materials**, **airborne particles**, or **human handling** during planting, harvesting, or maintenance. Additionally, **equipment surfaces**, **tools**, and **packaging materials** can serve as vectors for cross-contamination. Once introduced, the closed-loop and high-density nature of vertical farms can facilitate rapid distribution of contaminants throughout the system. This makes proactive risk assessment, sanitation protocols, and environmental monitoring essential components of a robust food safety strategy.

Food Risks and Regulations for Hygienic Design

Regulations and Standards Relevant to Vertical Farming.

Vertical farms must comply with various global food safety regulations and standards, many of which were initially established for conventional agriculture but are entirely applicable to controlled-environment systems. Key frameworks include the Codex Alimentarius, a collection of internationally recognized standards developed by the Food and Agriculture Organization and World Health Organization, as well as region-specific regulations such as the FDA's Food Safety Modernization Act (FSMA) in the United States and the General Food Law Regulation (EC) No 178/2002 in the European Union. In 2025, updates to the EU's Novel Food Guidelines and China's food labeling standards now reflect a growing emphasis on transparency and traceability.

Additionally, certifications such as GlobalG.A.P., ISO 22000, and HACCP are widely adopted to demonstrate compliance with best practices in food safety management. In Japan, a specific certification system, called JAS 0012 (Japanese Agricultural Standards) was formulated as the first certification system in the world that focused exclusively on vertical farms. For vertical farms, aligning with these standards is not only a legal requirement but also a strategic necessity to ensure market access, build consumer trust, and prevent costly disruptions due to non-compliance or contamination events.

GLOBALG.A.P.

International Organization for Standardization ISO 22000

CERTIFIED HACCP FOOD SAFETY Hazard Analysis Critical Control Point

Minimizing the risks in vertical farms

To ensure food safety in vertical farming, a comprehensive approach is required that addresses potential hazards at every stage of production. The following measures are essential components of an effective risk management strategy:

Zoning: Dividing the facility into designated zones helps prevent cross-contamination between areas with different hygiene levels or activities, more about effective zoning in the next chapters.

Airflow: Proper ventilation and filtration systems reduce the spread of airborne pathogens, spores, and particulates that could compromise crop safety. More information about airflow in combination with zoning will be provided in the following chapters.

Cleaning Protocols: Regular and validated cleaning and sanitation procedures for equipment, surfaces, and tools are critical to maintaining a hygienic environment.

Personnel Hygiene & Training: Staff must follow strict hygiene practices and receive ongoing training to recognize and mitigate contamination risks.

Seed and Input Sanitation: Seeds and other inputs should be sourced from reputable suppliers and treated or tested to eliminate pathogens before use.

Water Quality Management: Water used for irrigation and nutrient delivery must be monitored and treated to prevent microbial or chemical contamination.

Pest Control: Integrated pest management strategies help prevent infestations without compromising food safety through excessive pesticide use.

Environmental Control: Maintaining optimal temperature, humidity, and light conditions not only supports plant health but also limits the growth of microorganisms.

Traceability & Recordkeeping: Detailed records of inputs, processes, and outputs enable a rapid response in the event of contamination and support regulatory compliance.

Hazard Analysis & Risk-Based Controls: Systematic identification of potential hazards and implementation of targeted controls (e.g., HACCP) ensure proactive risk management.

Airflow and hygienic zoning in vertical farms

Hygienic zoning sets up barriers to protect different areas in food factories and products from cross-contamination. Some standards describe two zones in a vertical farm: a clean area and others. The consequence is that the most significant part of the farm must be designed and operated like a clean area. A division into “clean” and “not clean” may be sufficient for small businesses.

In larger facilities, it makes sense to divide them into further zones, such as low-risk hygiene zones (often referred to as green zones), medium-risk zones (often referred to as orange zones), and high-risk zones (often referred to as red zones). Implementing zoning requires structural measures (e.g., separation, ventilation) and clear rules for employees. The zones should be organized logically to facilitate the movement of goods and people. To prevent airborne contamination, there will be different air pressures per zone, with the most critical space having the highest air pressure. This ensures a controlled air pressure.”

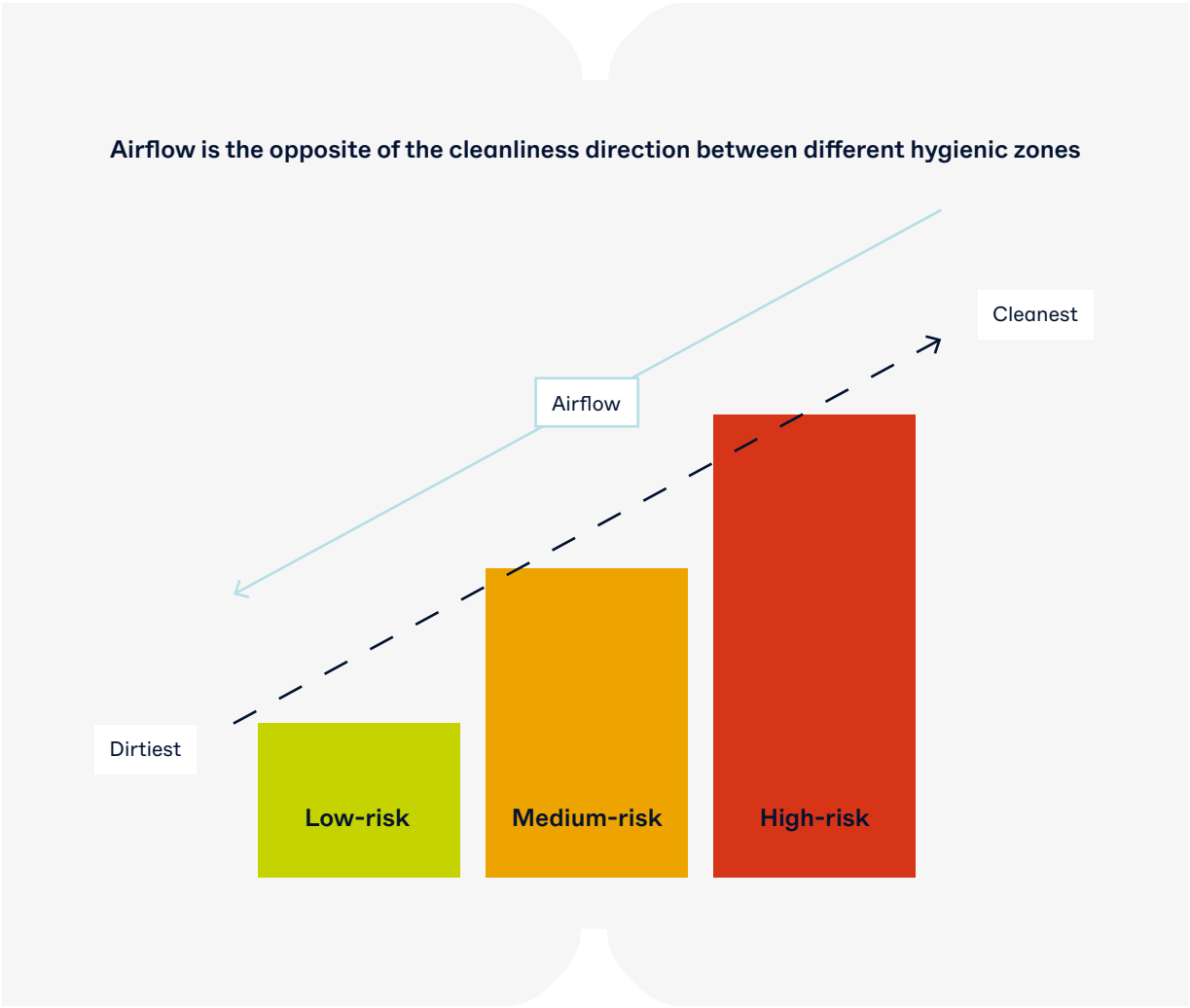


Figure 1: Ranking of hygienic zones with airflow between zones

Figure 2 applies the commonly used hygienic zones in food factories to vertical farming. Transfer zones are barriers between the different zones used to move staff and goods.

While this zoning concept aids in the vertical farm design, several questions still need to be addressed, such as “What functions must be performed in each zone?” or “How should machines operate in each zone?” Various literature sources have been reviewed, and numerous experts have been interviewed to formulate characteristics for each hygiene zone.

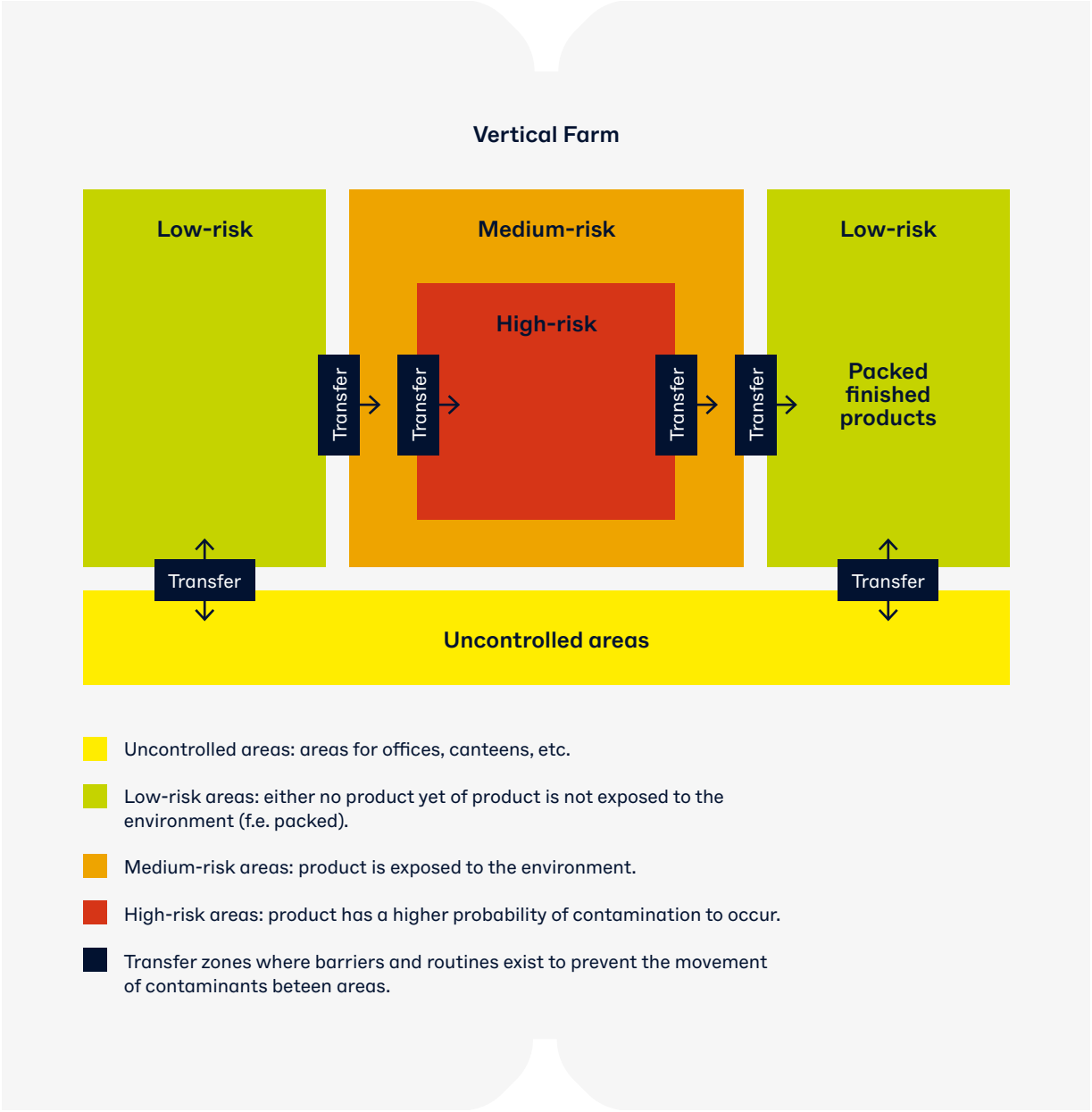


Figure 2: Hygienic zoning for Vertical Farms (inspired by Grassmann, 2019)

Table 1 Lists these characteristics for several functions per zone, as well as building-related details such as ventilation, air movement, and temperature per zone. Furthermore, staff-related protective measures and cleaning methods are assigned to the different zones. Typical equipment characteristics were derived from guidelines for designing hygienic machines and mapped to the various zones.

	Basic-risk area	Medium-risk area	High-risk area
Functions	Sowing & germination Transplanting Buffering trays Temporary storage packed products	Growing Pre & Post-harvest handling Grow tray emptying Tray washing	Harvesting Packing
Product	No product yet/product is packed	Product is growing	Ready-to-eat
Measures to prevent product contamination	-	Frequent cleaning As little as possible above product	Daily cleaning & disinfection Food grade materials
Cleaning/disinfection (Freight Farms, 2024)	Vacuuming Dry cleaning	Wet vacuuming Daily wipe-down Sanitize with a plant-safe sanitizer Tray washer: high-pressure & disinfection (daily)	Washable machines Rinsing with water Disinfection
Ventilation (Brunner, 2018)	Natural ventilation	Natural ventilation	Air filtration
Positive air movement from higher to lower zone (EHEDG, 2006)	-	Optional	Essential
Temperature (based on recent projects)	approx. 20°C approx. 68°F	approx. 15°C approx. 59°F	4°C 39,2°F
People (Meritech, 2021)	Safety shoes Hearing protection Hand washing	Footwear donning & sanitation Donning Frocks & Smocks PPE[1]: hearing protection, beard net, mask, hair net, eye protection Hand washing Hand drying	
Equipment characteristics	Steel Aluminium No food grade materials Wooden pallets	Coated steel / stainless steel Aluminium Food-grade plastics and belts above product Plastic pallets	Only stainless steel Anodized aluminium Food-grade plastics and belts Food grade lubricants Plastic pallets

Table 1: Characteristics per hygiene zone for vertical farms according to Pennisi, G.

By combining the details from Table 1 with Figure 2, a more detailed hygienic zoning representation for a vertical farm can be derived, as presented in Figure 3.

Explanation of Figure 3

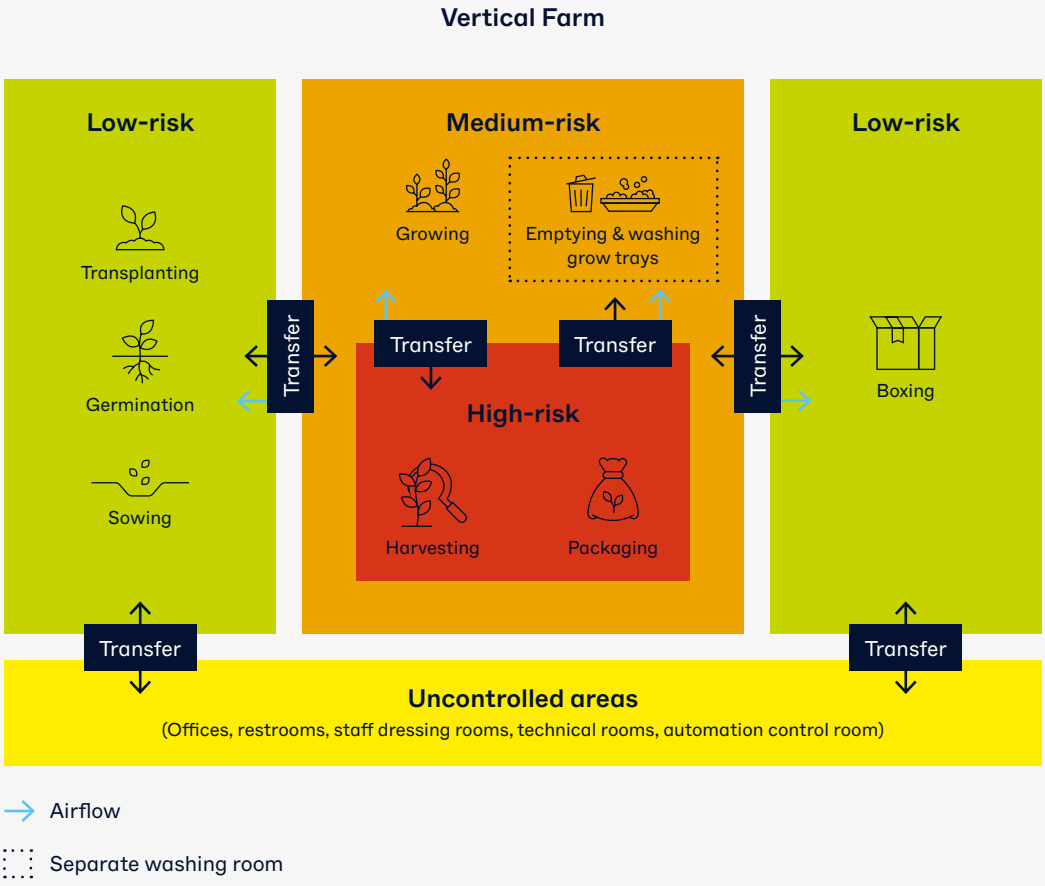
In the low-risk zone, grow trays filled with a growing medium are sown, and after germination, they are brought to the grow rooms, which are in the medium-risk zone. Eventual transplanting is done in the same medium risk zone. When the products are ready for harvest, the grow trays are brought to the high-risk zone, where they are harvested and packaged. Because the product is generally not washed (ready-to-eat), harvesting and packaging occur in the high-risk zone.

After harvesting, the grow trays are emptied and cleaned, and the packaged products are boxed and stored in a low-risk zone. The tray-washing and tray-emptying machines must be located in a separate room. This room requires high-pressure cleaning, which causes uncontrolled air movement and heavy air contamination. A separate air extraction is required to prevent further pollution of other areas.

Airflow

By creating overpressure in the higher-risk zones compared to the lower-risk zones, air can only flow from the high-risk zone to the lower-risk zone, and not the other way around. This is shown in the figure 3 below.

Figure 3: Hygienic zoning concept with details for vertical farms



Feasibility of 100% food safety

100% food safety should be the goal of every CEA facility. However, a guarantee of this remains challenging because biological systems are highly complex, human errors can still occur, environmental variability persists, and there is no unlimited budget for food safety. A more realistic approach would be to minimize risks to acceptable levels, prevent known hazards, and continuously improve the operation. This can be achieved through monitoring, conducting audits, and providing training to personnel.

100% Food safety is not a fixed destination – it's a mindset of continuous vigilance, improvement, and responsibility.

Take away

Controlled ≠ Risk Free
Even in highly controlled environments, such as vertical farms, food safety risks persist. Proactive design, monitoring, and discipline are crucial in preventing contamination.

Food Safety Is a System, Not a Step
From seed to harvest to packaging, food safety must be embedded in every layer of the operation, through zoning, airflow, hygiene, and traceability.

Strive for Excellence, Not Perfection
100% food safety is aspirational. The goal is to minimize risk through continuous improvement, rather than eliminating it at any cost.

Role of TTA-ISO

TTA-ISO offers automation solutions tailored to the specific requirements of vertical farms and other CEA facilities. We are accustomed to considering food safety in farm designs, discussing this with your food safety consultant, and implementing our automation solutions with these requirements in mind. Contact us for assistance with layout and design, or advice on automation in CEA facilities.

References

Brunner, J.C., (2018). Zoning im Lebensmittelbetrieb, https://www.gmp-support-company.com/resources/1_Zoning.pdf

European Hygienic Engineering & Design Group (EHEDG), (2006). Guidelines on air handling in the food industry, https://food-info.net/uk/eng/docs/doc30.pdf

Freight Farms, (2024). How to Keep your Freight Farm Clean and Productive: Essential Tips for Success, https://www.freightfarms.com/blog/keeping-your-freight-farm-clean

Grassmann, D. (2019). Hygienic Zoning in Food Manufacturing Factories, https://www.food-safety.com/articles/6361-hygienic-zoning-in-food-manufacturing-factories

Meritech, (2021). Hygienic Zoning eBook, https://www.meritech.com/downloadable-resources/hygiene-zone-ebook

Pennisi, G., et al., (2019). Resource use efficiency of indoor lettuce (Lactuca sativa L.) cultivation as affected by red: Blue ratio provided by LED lighting, https://doi.org/10.1038/ s41598-019-50783-z

Curious about how our cutting-edge automation solutions make a difference in your vertical or indoor farm?

Don’t hesitate to contact us; we’re eager to advise you.

tta-iso.com

sales@tta-iso.com