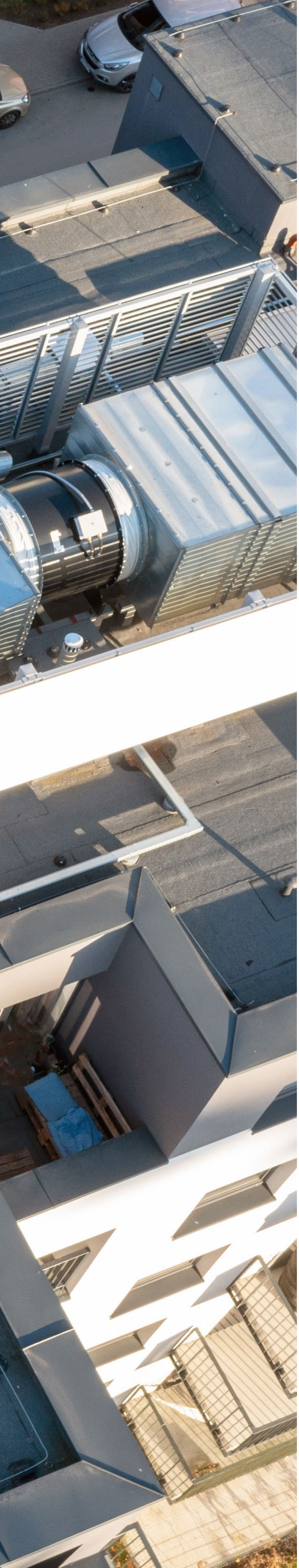
Variable speed control for fans

The design guide for reliable and sustainable air movement systems



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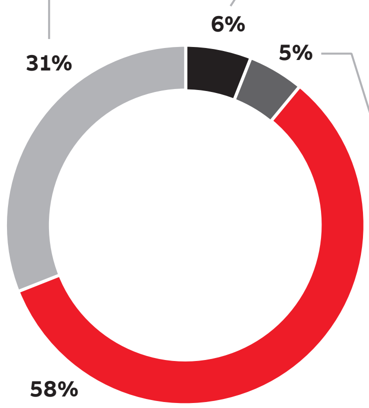
Introduction

Fans are important, and the most common components of any HVACR system. They move air into a building and return it back outside, often through multiple stages of air treatment, to maintain a comfortable and safe indoor environment.

To make the process reliable, efficient, and future-proof, solutions for an air movement system should be selected wisely. Fans can come as a package with motors and control electronics, meaning not only mechanical but also electrical aspects should be considered when making a choice.

This paper will guide consultants, system integrators, facility managers, and building owners in selecting the most optimal fan speed control solution, taking into account multiple considerations that are not always obvious but have a massive impact on the lifetime performance of the system.

Fan unit lifecycle cost



Production losses / Downtime

Depending on the application, downtime costs can vary significantly. One minute of data center downtime can cost over

5 000 USD

Energy

Energy is often the largest lifecycle cost for fan applications. This cost can be optimized with more efficient fan technologies, high-efficiency motors, and variable speed drives:

Belt drive vs Direct drive

- Depending on the motor size, the power transmission loss of a belt-driven fan vs. a direct-driven fan can be **2% to 5%**

Standard motor vs Energy-efficient motor

- The efficiency difference between IE3 and IE5 motors can be over **3%** at nominal loads and even higher at partial loads

Damper vs Variable speed drive

- Energy savings of **25%** and higher can be achieved by adding a variable speed drive on top of the motor

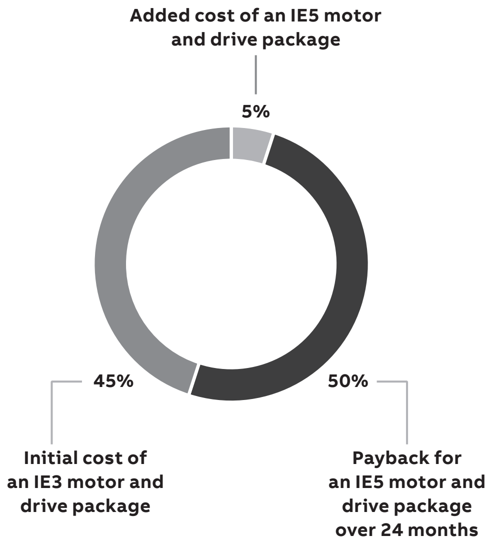
Maintenance

Maintenance costs vary depending on if it's corrective, time-based, condition-based or predictive maintenance. Corrective maintenance doesn't involve continuous costs, but the equipment replacement cost is higher than repair or upgrade costs over time.
The return on investment from the predictive maintenance cost vs. the equipment replacement cost in the event of a catastrophic failure can be

10 times

Investment

The decision on the fan technology should be made considering the impact on the overall system. The initial investment might be higher with e.g. a more efficient fan package, but it will pay off with reduced operational costs.



Note: Examples of investments and savings are from implementing drive control with an IE5 fan motor, running 4 380 hours a year at 80% load with an electricity price of 0.1 €/kWh.

1. Mechanical build quality and overall system reliability

Making a ventilation system robust to various external factors – power supply quality, pressure challenges in the ductworks, dusty or corrosive environments, and vibrations, – should be in focus when selecting air movement solutions for it.

Subject / Feature	Specification requirement	✓	Reasoning for choices
1.1. Tolerance to vibration during operation	Speed controller is able to withstand the following vibration level according to the IEC 60068-2:2024 standard “Environmental testing”: - max. 1 mm (0.04 in), 5 to 13.2 Hz - max. 7 m/s² (23 ft/s²), 13.2 to 100 Hz sinusoidal	☐	Longevity of the solution, as the speed controller will experience high vibrations able to damage electronics inside, when mounted directly within or onto an air handling unit (AHU). It might be useful to mount the drive within an AHU (utilizing a remote keypad kit if necessary) as an additional enclosure is not required.
1.2. High static pressure capabilities	Fan solution should be able to manage high static pressures caused by fine filtration systems	☐	Systems requiring fine air filtering create high static pressure due to the complex filters installed. Most EC fans are not able to overcome the pressure created by filters due to torque limitations and therefore need to be installed in series, which increases the size and cost of the fan unit. Fans with conventional motor technologies such as induction, permanent magnet, or synchronous reluctance don’t have such issues and can maintain higher pressure for the same air flow.
1.3. Coated electronic boards	Special coating on all printed circuit boards to meet contamination/corrosion requirements of IEC 60721-3-3:2019 standard “Classification of environmental conditions”, which specifies the severity of the environmental conditions to which products are subjected when installed for stationary use.	☐	Contamination in the air can degrade and damage sensitive electronic components within an electronic speed controller. The sensitive circuit boards should be coated to protect them.
1.4. Air contamination by ventilation system components	No electronics are allowed in the airstream, to prevent air contamination.	☐	Some mission critical businesses like pharma or automotive painting have strict requirements on permitted materials in the airstream. Gasification from electronics in the airstream can affect production quality in clean room environments. Furthermore, there’s an extended risk of contamination from failed and burned electronics.
1.5. High tolerance to under-voltage events like brownouts and blackouts, and auto-restart capability	Fan speed controller should be equipped with a suitably rated/sized DC link capacitance that can be programmed to recover energy from the load to extend ride-through time for the power dip. • Tolerance in accordance with SEMI F47 “Specification for semiconductor processing equipment – voltage sag immunity”	☐	Different fan speed control technologies give different resilience to problems with the electrical network. So-called “thin” DC link designs do not give as much resilience as “full” DC link designs. Active front end (AFE) and 6-pulse drive designs contain full DC link. Also, some speed controllers can detect the dropping mains voltage and utilize energy from the rotating fans to maintain power and control over the ventilation system, making recovery after a dip much easier.
	Controller should have an auto-restart function.	☐	Auto-restart allows the system to restart automatically after power was lost completely. It helps reduce the downtime.
1.6. Ability to catch spinning loads	The fan speed controller should be able to catch a freely spinning fan when starting without tripping or damaging the fan mechanics, irrespective of the fan speed or rotation direction. The function should be documented in the product manual.	☐	In case of power supply interruption, fans can be left spinning freely, without control. Once the power supply is recovered, the speed controller should be able to detect that spinning load, “catch it”, and bring the fan back to the desired operating speed for effective ventilation, with minimized downtime, and without tripping and putting undue stress on the fan mechanics.

2. Effect on power quality

When selecting components for air movement control, their impact on power quality should be considered, as negligence can lead to adverse effects for the entire facility.

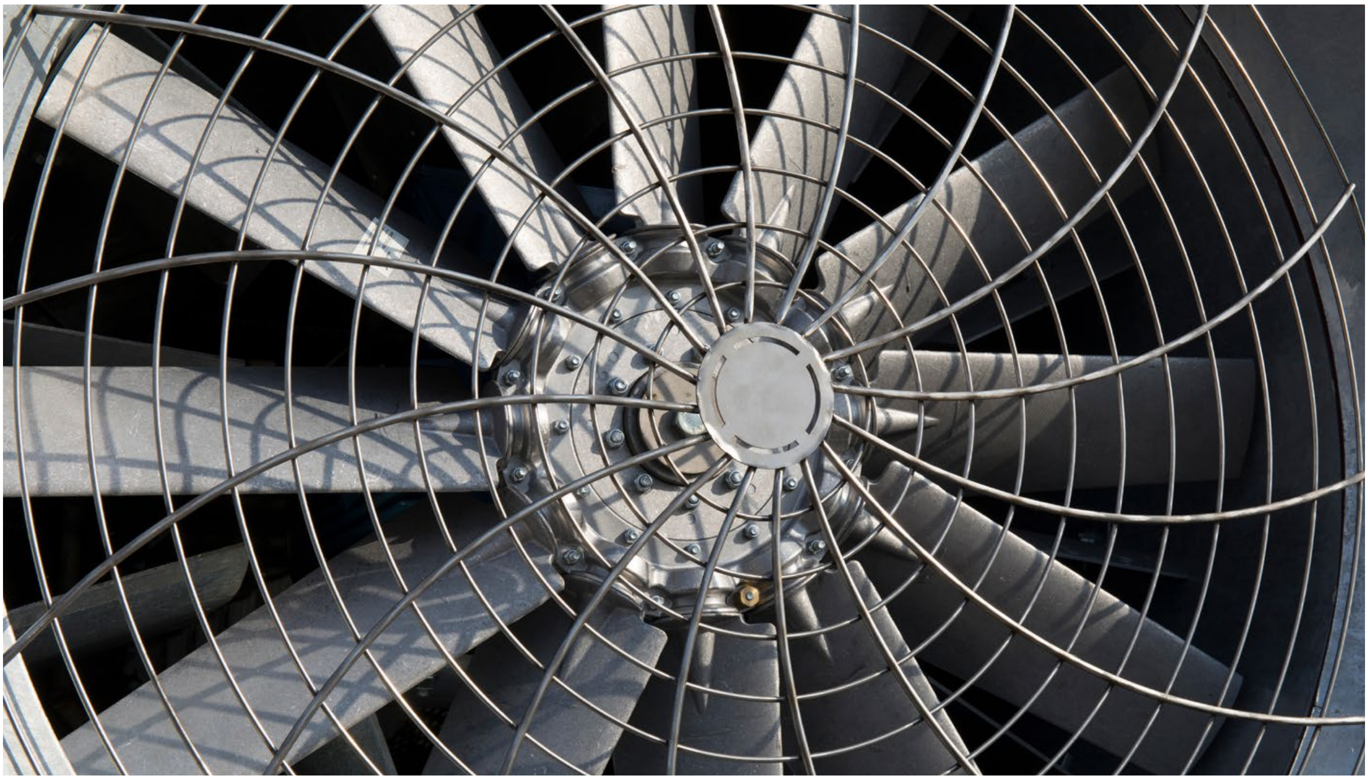
Power quality aspects can include low-frequency disturbances called harmonics and radio frequency interference. Harmonics come from switched-mode power supplies, which are also present in speed control solutions for fans. Harmonics are measured in THDi (total current harmonic distortion). The higher the THDi, the more distorted the current and the higher the risks for the network failure.

Subject / Feature	Specification requirement	✓	Reasoning for choices
2.1. No harmonic mitigation	System operates at more than 100% harmonic current or THDi	☐	Simplest system solution overall. High amount of harmonics pollute the entire electrical system. The overall reliability of the system is challenged – transformers, cables and motors can overheat, fuses blow, circuit breakers trip and sensitive electronics can get damaged. The power system losses can be more than double that of a system with no harmonic currents – this has a direct impact on energy cost.
2.2. Intermediate harmonic mitigation	System operates at 30 - 60% harmonic current or THDi	☐	Although harmonics are partly handled, power network components such as transformers and generators need to be oversized to mitigate harmonics effect, which has an impact on both capital and operating expenses. The power system losses are 10 to 30% higher than in a system with no harmonic currents.
2.3. Maximum harmonic mitigation	System operates at 3 - 5% harmonic current or THDi	☐	Lowest possible harmonic levels make the system more stable, less lossy, and more reliable overall, delivering better lifetime outcomes. Transformers and backup generators can be sized correctly. As a result, there will be significant savings on capital and operating expenses.
2.4. Fan controllers should meet electromagnetic compatibility (EMC) product standard for power drive systems (PDS)	Installed speed control equipment should comply with IEC 61800-3:2022 standard “Adjustable speed electrical power drive systems – EMC requirements and specific test methods for PDS and machine tools”.	☐	Compliance with the standard means that the fan controller has been tested to ensure its high-frequency (radio-frequency) emissions meet the standard, and that the fan controller will neither be affected by the emissions from the equipment installed nearby, nor will it affect the equipment in return. It also means that the installation requirements have to be met.

3. Efficiency

When selecting an air movement solution, it's important to consider the overall package efficiency (fan wheel, motor and variable speed controller). It is even more important to consider the package efficiency at partial load operation and make the choice based on the efficiency of the duty point where the HVACR system operates most of time.

Subject / Feature	Specification requirement	✓	Reasoning for choices
3.1. Support for high-efficiency motor technologies	Besides conventional induction motors, a variable speed controller should be able to control high-efficiency motor technologies, including permanent magnet (PM) motors, synchronous reluctance motors (SynRMs), and permanent magnet assisted synchronous reluctance motors (PMaSynRMs).	☐	Selecting the most efficient motor technologies helps to minimize losses in the system and optimize operating costs.
3.2. Power drive system efficiency	IEC 61800-9-2 standard "Adjustable speed electrical power drive systems (PDS) – Ecodesign for motor systems – Energy efficiency determination and classification" should be followed.	☐	Selecting a speed controller compliant with the most recent efficiency requirements helps to minimize losses in the system and optimize operating costs.
3.3. Part load fan package efficiency	Fan package (incl. fan wheel, motor and speed controller) to be selected based on its part load efficiency at the duty point where the system operates most of the time.	☐	Different motor technologies can show similar efficiency numbers at their nominal (100%) loads, but the efficiency numbers might significantly differ (3% and more) at partial loads where the actual duty point is. Similar approach is valid for fan wheels of different designs. If selecting between integrated fan control solutions and standalone ones, base your choice on the overall fan package efficiency at the duty point, for highest energy savings.



4. Communication capabilities

A fan speed controller should be able to provide required communication capabilities to avoid system complexity, additional points of failure, and added costs due to external elements like protocol converter gateways. Wireless communication built-in ensures future-proofing of the fan speed control solution and can minimize troubleshooting efforts substantially.

Subject / Feature	Specification requirement	✓	Reasoning for choices
4.1. Data transfer to enable diagnostics, telemetry, and system monitoring	Fan controller should be able to supply diagnostics data about its own operational status and maintenance requirements, and route local telemetry information back to the control system.	☐	This allows system performance to be monitored and actions to be taken to improve efficiency and reliability through e.g. predictive maintenance.
4.2. BACnet and other HVACR protocols built into fan controller as standard	Fan speed controller should directly communicate using industry standard HVACR protocols – BACnet, Modbus, FLN Apogee, and N2 Metasys.	☐	BACnet is an open serial communication protocol and is fast becoming the HVACR industry standard due to its open nature. The fan speed controller should have this and other common HVACR protocols built-in to avoid the cost of external protocol converters. The speed controller can also then act as a gateway for sensors and system telemetry, avoiding the need for external I/O interfaces.
4.3. Wireless communications capabilities	It should be easy to add communication interfaces for future needs, e.g. Bluetooth enabled user interface. These connections must be optional, so they can also be excluded.	☐	Additional wireless communication devices can bring cyber security concerns, so it is important these devices are optional but can be added later if remote monitoring/control is needed e.g. in dangerous or hard-to-reach places.

5. Tolerance to control failures

Recommended features to consider as part of the fan control solution in case of building management system failure or fan control solution failure.

Subject / Feature	Specification requirement	✓	Reasoning for choices
5.1. Manual (hand/local) control possibility	Fan speed controller is required to have hand/local control built-in.	☐	If the external controller (building management system) fails, it should be possible to operate the fan speed controller locally. If hand/local control mode is not offered by the fan speed controller itself, and is present only in the intermediary controller, that controller becomes a single point-of-failure, which can take an entire air handler/fan array offline, thus defeating the whole reason the hand/local control function was included.
5.2. Backup control modes in case of fieldbus loss	Fan speed controller must have programmable choices to be made if the fieldbus fails, it must not simply stop. Choices can be made about operating states and required speed without a functioning fieldbus communication.	☐	This makes the overall ventilation system more robust and fail-safe.
5.3. Bypass switch in case of damaged electronics	If the electronic speed controller fails, it should be possible to bypass it and run the motor and fan directly via a bypass switch. Note: permanent magnet and synchronous reluctance/permanent magnet assisted synchronous reluctance motor technologies do not allow direct control with the speed controller excluded. Note: not needed with an auto backup fan configuration.	☐	If the control electronics for the fan controller fail, this can cause the fan to stop. In critical situations, it might be needed to get the fan system operational as quickly as possible. This could be achieved with a bypass switch, or by directly re-wiring the fan motor to the mains for temporary direct-on-line operation. Alternatively, for a more controllable and robust system (and for systems using the most efficient motors), a duty assist fan arrangement could be used so the fan automatically swaps to the backup, with no delays or interruptions.

6. Additional features

Below are valuable features that are recommended to be part of fan speed controllers and are related to the safety of people and equipment, ease of operation and maintenance, and energy use monitoring.

Subject / Feature	Specification requirement	✓	Reasoning for choices
6.1. Emergency fireman's mode	Fan speed controller can be programmed to ignore most of its faults and warnings that would normally stop it, via a digital input signal.	☐	If a safety situation arises that requires the speed controller to run "at all costs" to ensure the safety of the building occupants and property, a dedicated input can be triggered to force the drive into override mode to keep the controlled fan operational as long as possible.
	The fireman's override mode should allow the speed controller to run a motor at an adjustable, predefined or PID-controlled speed in any direction (if bidirectional fans are applied).	☐	This ensures that the required overpressure level can be maintained in escape routes – high enough to keep the smoke away but not so high it can block the doors and trap people.
6.2. SIL3, PL e STO as safety input	Safe Torque Off is a safety input that guarantees the motor cannot produce any torque. It can be incorporated into e-Stop circuits or used to disable the drive to allow maintenance of the mechanical components of the system.	☐	Contactors can perform safety functions, but "drop out" if there are power dips, triggering false e-Stops. To achieve SIL 3, two contactors have to be placed in series. STO is safer and cheaper to implement – external input contactors and the safety switch can be eliminated.
6.3. I/O connections in the speed controller, for telemetry needs	Fan speed controller can be used to connect system sensors, damper controllers, etc. and local telemetry back to the building control system, via its built-in I/O and fieldbus connections.	☐	Connecting sensors and system controls back to the building controller requires additional I/O connections and fieldbus interfaces. Using the fan controller reduces costs and allows the fan controller to act independently if communication with the building controller fails.
6.4. Real-time clock	Fan speed controller should contain a real-time clock (RTC) onboard, with time and date functionality for exact fault time recording.	☐	The RTC will give time-stamped records of faults, warnings, and other events that interfere with ventilation operation. This helps with maintenance and diagnostic activities.
6.5. Mechanical resonance prevention	Fan speed controller should be able to be programmed to avoid damaging resonance frequencies in the motor and ductwork of the ventilation system.	☐	Noise in the ventilation system is a health and safety concern for building occupants. Uncontrolled resonances can damage mechanical systems, sometimes to destruction. There should be a possibility to resolve the issue with speed controller functionality, without complex measures like installing vibration absorbing elements.
6.6. Energy efficiency counters	Onboard energy counter calculates energy savings compared to equivalent direct-on-line motor control, showing savings in kWh, CO_2 emissions, and money.	☐	Energy is a major cost issue for businesses today. Onboard energy saving calculations show the savings that are being made and can be sent via telemetry to the building control system for further analysis.
6.7. Automatic energy optimization	This speed controller function optimizes the fan motor flux in the motor winding (the source of excessive losses) so that total energy consumption and motor noise level are reduced when the ventilation operates below the nominal load.	☐	This is to ensure the lowest energy consumption for any given fan speed and operating condition. The total efficiency (motor and speed controller) can be additionally improved by 1…20% depending on load torque and speed.
6.8. Maintenance assistants (preventative maintenance triggers)	Fan speed controller should be able to sence electrical and mechanical changes in the driven load and contain programmable maintenance triggers that can send an alarm (via I/O or fieldbus) to report when the ventilation system – its filters, mechanical fan parts or motors – require maintenance.	☐	This enables detection of imminent fan bearing failure, clogged air filters, or about-to-break fan belts. Preventative maintenance is therefore possible before the system collapses.
6.9. User interfaces, user control panel	Fan speed controller should have a user-friendly keypad (or panel) for control, programming, and fault detection and resolution. It should be mounted directly onto or near to the speed controller. There should be no need to refer to user manuals of decode LED sequences.	☐	User-friendly interface, preferebly in a local language, makes it easier for facility managers to set up the speed controller, resolve faults and get help in unclear situations saving time.
6.10. Motor preheating	The drive can prevent condensation in a stopped motor by feeding it a fixed current.	☐	It is useful in humid or cold conditions to prevent further corrosion.


FIRE
ACTIVATED
PUSH IN
PULL DOWN

7. Circularity

Due to the Paris Agreement on the climate change, responsible businesses worldwide are setting up carbon targets with the aim of achieving net zero. Circularity is one of the pillars, helping to reach this goal through waste elimination and reuse of materials used as part of the business activities.

Subject / Feature	Specification requirement	✓	Reasoning for choices
7.1. Design the system for circularity and resilience	Fan controller package should be designed for reuse, repair, refurbishment and recycling.	☐	EU regulations demand circularity considerations to be part of any system design. System repairability brings higher resilience, lower downtime, and better environmental credentials overall. The system components need to be easily maintained, or replaced and recycled.
7.2. Carbon and environmental footprints	Every component within the fan application should come with an environmental product declaration (EPD), and be labelled in accordance with ISO 14025:2006 Environmental labels and declarations.	☐	EPDs bring environmental impact transparency to the products used in the ventilation system. EPDs detail what the product is made from and how it impacts the environment through its lifecycle. EPDs help customers to compare products from the environmental impact perspective and meet their own environmental targets, avoiding greenwashing.
7.3. Rare earth materials	Rare earth materials should be avoided. If included in a product, certification for sustainable extraction is to be included.	☐	Rare earth materials, by definition, are rare. There are 15 elements in the periodic table in this class. Because of their rarity their extraction is often damaging to the environment, so suppliers should demonstrate their commitment to sustainable extraction.
7.4. Critical raw materials (CRM)	Solution should comply with the CRM Act and not include more than 60% materials sourced from a single country.	☐	CRM Act ensures that mining operations are spread more ecologically to diversify critical raw material supply.
7.5. Component easy repair or replacement possibility	In case of breakdown it should be possible to repair or replace the fan speed controller, motor, or fan wheel as separate components in accordance with the consumer right to repair.	☐	In the event of failure, replacing a complete fan unit – containing many components – is not a sustainable approach and can bring longer downtimes. Making a system from individually repairable subsystems increases sustainability and system resilience.
	Motors should comply to standardised (e.g. IEC) motor sizes and footprints to ensure easy replaceability, even via a 3rd party supplier.	☐	Components which are expected to wear, like motor and fan bearings, should be easily replaceable and easy to maintain.
	Motor and fan bearings should be serviceable and replaceable.	☐	
7.6. Recycling capabilities	Products included to the system should be able to be recycled in accordance with ISO 140001 Environmental management systems standard. Relevant declarations regarding the Waste from Electrical and Electronic Equipment (WEEE) and Control of Substances Hazardous to Health (COSHH) directives should also be presented the product manufacturers.	☐	Carbon footprint reduction for the business or facility where the product is applied. To conform to ISO 140001, the product should have a high recyclable content. Ideally, the manufacturer should be capable of “taking back” their product for further recycling either directly or via a partner.
7.7. Disassembly guide	Every product should have a recycling guide providing recycling information in accordance with the Waste from Electrical and Electronic Equipment directive (WEEE).	☐	This is to maximize material recovery and reduce the business or facility carbon footprint where the product has been applied.

Subject / Feature	Specification requirement	✓	Reasoning for choices
7.8. Substances of concern	The fan unit should not include substances that inhibit circularity.	☐	The equipment shall not contain toxic or hazardous substances or elements above the maximum concentration values as specified by the European Chemical Agency (ECHA).
7.9. Durability	Fan units should be robust and designed for a long lifetime. Mean time between failures (MTBF) figures should be provided by the supplier, as well as field failure rates. Industry-leading MTBF figures are typically >700,000 hrs (~80 years), with many achieving ~850,000 hrs (~97 years).	☐	Long-lasting products benefit the environment. In a circular economy for electronics, products will be kept in use for as long as possible. Products or components will be used repeatedly for their intended purpose without significant modification. At the end of a product's lifetime, the valuable components within it will be separated and recycled.
7.10. Packaging	Units should be delivered in packaging that is sufficiently protective and made out of materials that are fully recyclable and are accepted by the majority of curbside recycling services.	☐	This enables easy packaging recycling for the product users, with no high recycling costs involved.
7.11. Responsible end of life	Manufacturer should offer a take-back solution and should provide a CO_2e recovery report for sustainability reporting.	☐	The goal is to use products and materials for as long as possible and then recirculate those materials back into the economy at the end of the product's lifetime.
7.12. Scope 3 emissions	Product should have Ecodesign data to calculate emissions for Scope 3 Category 11: Use of sold products.	☐	Scope 3 emissions are indirect emissions from upstream and downstream activities in a business's value chain. A comprehensive Scope 3 strategy helps businesses reduce their environmental impact, build brand equity, improve the efficiency of their procurement, implement circularity principles, and meet expectations from consumers and investors.

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