Energy Consumption In Cleanrooms
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TUS

Aim of the Project

This research investigates energy consumption patterns in industrial cleanroom facilities, The study documents and analyses measurable data regarding HVAC system performance, air change rate requirements, and environmental control parameters across different ISO classifications.

Background

Modern cleanrooms represent exceptionally energy-intensive environments, with studies confirming they consume 30-50 times more energy per square foot than conventional office buildings. This disproportionate consumption stems primarily from HVAC systems, which account for 50-75% of total facility energy use in semiconductor applications. The requirement for ultra-clean conditions mandates extraordinarily high air change rates - ranging from 150 air changes per hour (ACH) for ISO Class 6 cleanrooms up to 700 ACH for ISO Class 4 environments. A case study facility examined in this research operates 18 air handling units to maintain precisely controlled conditions of 21˚ C (±0.5˚ C) and 42% relative humidity (±4%), demonstrating the substantial infrastructure investment required for contamination control.

What is Cleanroom

Cleanrooms are built to achieve different levels of cleanliness, depending on the specific needs of the products being produced. Ideally, their design should be based on scientific principles and engineering calculations. Clean environments are crucial in fields like healthcare, where they are used for patient care in hospitals, as well as in industries such as microelectronics, pharmaceuticals, biotechnology, aerospace, medical devices, and food production, where they support product testing and manufacturing.

ISO Standards

Cleanrooms are classified based on the cleanliness level of the air inside, determined by the number and size of particles per cubic meter of air. The ISO 14644-1 standard governs these classifications, with cleanroom classes ranging from ISO 1 to ISO 9. ISO 1 is the cleanest, while ISO 9, despite being the "dirtiest" class, is still cleaner than a typical room. The most common cleanroom classes are ISO 7 and ISO 8.

CLASS	Number of Particles per Cubic Meter by Micrometer Size					
	0.1 micron	0.2 micron	0.3 micron	0.5 micron	1 micron	5 microns
ISO1	10	2				
ISO2	100	24	10	4		
ISO3	1,000	237	102	35	8	
ISO4	10,000	2,370	1,020	352	83	
ISO5	100,000	23,700	10,200	3,520	832	29
ISO6	1,000,000	237,000	102,000	35,200	8,320	293
ISO7				352,000	83,200	2,930
ISO8				3,520,000	832,000	29,300
ISO9				35,200,000	8,320,000	293,000

Table of: Number of particles in ISO

Each ISO class has a recommended range of air changes per,

Class ISO 146144-1 (Federal Standard 209E)	Average Airflow Velocity m/s (ft/min)	Air Changes Per Hour	Ceiling Coverage
ISO 8 (Class 100,000)	0.005 – 0.041 (1 – 8)	5 – 48	5 – 15%
ISO 7 (Class 10,000)	0.051 – 0.076 (10 -15)	60 – 90	15 – 20%
ISO 6 (Class 1,000)	0.127 – 0.203 (25 – 40)	150 – 240	25 – 40%
ISO 5 (Class 100)	0.203 – 0.406 (40 – 80)	240 – 480	35 – 70%
ISO 4 (Class 10)	0.254 – 0.457 (50 – 90)	300 – 540	50 – 90%
ISO 3 (Class 1)	0.305 – 0.457 (60 – 90)	300 – 540	60 – 100%
ISO 1 – 2	0.305 – 0.508 (60 – 100)	360 – 600	80 – 100%

Uni-directional air flow in cleanroom applies to ISO 6 and above

300 ACH = 45 CFM/SF in a cleanroom with a 9' ceiling

% of cleanroom ceiling area occupied by filter modules

Table of: Number of Air Changes per Hour

Energy Consumption in Cleanrooms

Cleanrooms operate under rigorously controlled conditions, requiring precise management of three critical parameters: dry-bulb temperature, relative humidity, and particle concentration. The need to maintain these stringent environmental controls leads to exceptionally high energy consumption.

Energy Consumption Factors

High energy consumption in cleanrooms can be attributed to several critical systems that must operate continuously to maintain the strictly controlled environment. These primary factors work in concert to ensure cleanroom conditions meet required specifications e.g.: Airflow management, HVAC,AHU,RCU

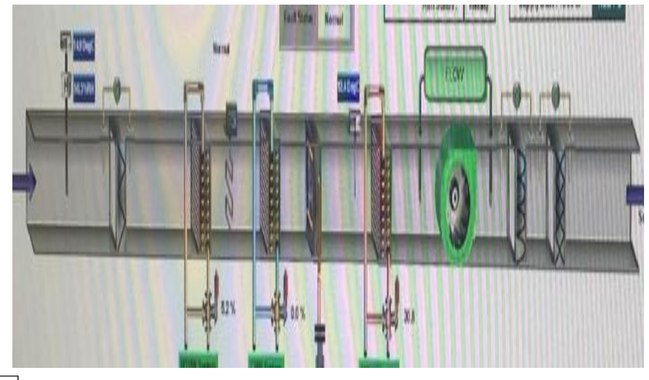

Photo of: Air Handling Unit (AHU)

Both (AHUs) and (RCUs) play a crucial role in maintaining controlled environmental conditions,

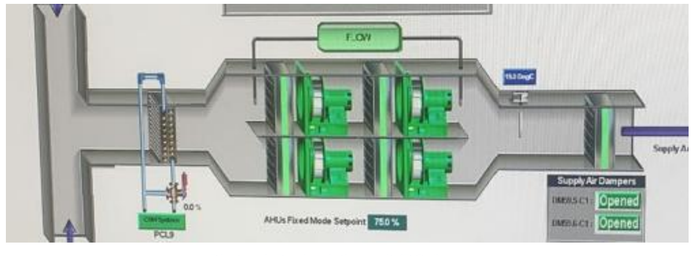

Photo of: Recirculating unit (RCU)

Conclusion

This research establishes concrete, measurable benchmarks for cleanroom energy consumption through direct facility surveys and case study analysis. The documented data on HVAC system loads, ISO-class-specific airflow requirements, and environmental control parameters provides valuable reference points for both academic research and industrial applications. These findings offer a foundation for future studies investigating energy efficiency opportunities while maintaining critical contamination control standards in cleanroom environments.

References

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