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ENERGY PERFORMANCE OF CLEANROOM FACILITY

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ABSTRACT

The evaluation of overall energy utility and performance of clean room facilities has become necessary due to by rapid growth of clean room facility in India. This paper intends to gives a peak into evaluating energy usage viz-a-viz optimal performance opportunities through improvement in energy efficiency. In Comparisons with IEST recommended practice are made to examine the performance of cleanroom air systems. These results can serve as a step -up to identify efficient cleanroom design practices in term of energy usage and relevant issues in cleanroom operation and maintenance. Results from this study shows that there are opportunities to improve energy efficiency of clean room environment systems while maintaining effective contamination control.

1-INTRODUCTION

Contamination control is the basic principle to operate a clean room as per standard IS -14661 Code which provide guiding factors to maintaining the cleanliness for the usage of commercial and research activities. A clean room is a control mechanism to regulate the concentration of airborne particles and to maintain certain environmental conditions {1}. The heating ventilation and air-conditioning system (HVAC systems) for such facility are highly intensive energy consumption units in respect to commercial environmental control. Some industries which carry out research oriented for future products and up gradation of technology are measured as watts per unit in the term of production metrics. {2} Energy plays a critical role in cost analysis of assets and cost of products in markets. At present, India seems to have boarded a bullet train in all the fields. The number of cleanrooms has grown rapidly in the last decade specially in industries using special technology and development in medical field as operation theatres, pharma products etc. Such industries require energy continuously even when production is not in operation. Therefore, improvement in energy efficiency is becoming all the more important.

The variation in energy consumptions shall be considered with the system design of cleanliness levels. {3} A Clean room environment and certification are critical to maintenance of the parameters such as temperature, humidity, pressure gradient, flow rate, noise level, vibration, type of airborne particles etc. According to an earlier study [3], it is found that estimate of clean room electricity intensity for the energy use are floating in the range of 159 kWh/ft^2 to 945 kWh/ft.^{2} and fan energy intensity ranged from 5 W/ft^2 to 96 W/ft^2. {4}. With reference to ISO classes 3,4,5 these are most widely used and energy intensive in all classes. Various studies have been done on cost effectiveness proved and resulted that energy cost could be approximately 65-75% of the total annual cost for operation and maintenance. {5} The maximum energy usage through HVAC system are variable in each facility and range from 36-67% of the total cleanroom energy.

To evaluate energy performance of clean room environment systems, real time data is needed to evaluate actual performance. The true data are examined, reviewed and compared with designs of other facilities.

2-OBJECTIVE

The objectives of this paper are to
(1) Benchmarking of performance related to present energy intensive clean room facility
(2) Examine the performance of air systems as compared to relevant codes.
(3) Identify opportunities for improving energy efficiency
(4) Proposal for alternative solutions
(5) Energy management techniques for improving energy efficiency with minimum cost
Such facilities run multi-tasking activities of various fields and operate round the clock 24x7x365 even when not in production mode to maintaining cleanroom contamination control. The benchmarking results can serve as a tool to identify energy efficiency in designing most innovative concepts and to resolve issues in operation and maintenance with cost effective methods.

2.01 All relevant system informations which are essential, have been complied based on layout plans, design parameters, certification reports, vendor’s submittals, computer record and trends, fields conducted measurements, interactions with engineers and system drawings of the serving clean room facility. Other procedures were carried out to locate field measurement points and to monitor collected data to understand and analyse the clean environment systems.

2.02 A case study of cleanrooms of different cleanliness classes, includes field measurements and monitoring of air systems in 6 cleanrooms classified as ISO Cleanliness classes 4,5 and above. {6}. which respectively correspond to Cleanliness Classes 10,100 and above in Federal Standard 209. Federal Standard 209E has been recently taken over by adopting the ISO cleanliness classification. The measurements were collected on performance of system and data base for further analysis was prepared.
2.03 A relevant metric has to be developed to evaluate energy performance for various designs, cleanliness classes and processes occurring within the facility. This metrics helps to allow direct comparison of energy intensive systems based on design or measured data. The air circulation in air-

conditioning system is related to air system efficiency as the airflow rate per unit of total electricity input (cfm/kW). Cleanrooms are used for many activities and wide variations in process loads for either heating or cooling dealt with HVAC systems. The process load was characterized based upon the process of heat output per unit of clean room floor area (W/ft^2). Performance matrix of air system and process load is explained in Table-1. {7}

Table 1.

Performance Matrix of Cleanroom Air Systems and Process Load

Metrics	**Definition**	**Unit**
Re-circulation Air Handler Unit Efficiency	Re-circulated airflow rate per kW of electricity used by all re-circulation air fans	Cfm/kW
Power Intensity for Re-circulation Air Handler Unit	Total fan power of re-circulation air handler unit per unit of primary cleanroom floor area	W/ft^2
Re-circulation Air Change Rate	Re-circulation airflow rate divided by primary cleanroom volume	1/hr
Average Cleanroom Air Velocity	Re-circulation airflow rate divided by primary cleanroom floor area	Fpm
Make-up Air Handler Unit Efficiency	Make-up airflow rate per kW of electricity used by make-up air fans	Cfm/kW
Process Load Intensity	Process load per unit of primary cleanroom floor area	W/ft^2

3-CONCEPT OF AIR SYSTEMS IN CLEAN ROOM FACILITY.

3.01 This study includes field measurements and monitoring to evaluate the performance of air systems in six cleanrooms facility whose outside design data is same. All the facilities are a combination of ISO Class-5, ISO Class-6 (including combined with Class-7 and 8). {8}

3.02 HVAC systems is associated with water/air cooling machines, pumps for water circulation, air handling units/re-circulation units along with make-up air and exhaust systems to the cleanroom facility. The supply and return air in various cleanrooms are re-circulated as clean conditioned air through high efficiency particulate air (HEPA) or Ultra Low Penetration Air (ULPA) filters. Re-circulation systems are utilized through three common designs as given below

a) Fan-tower with pressurized-plenum (FT-PP).

b) Distributed re-circulation (DRC) air handler units with ducted-systems.

c) Fan-filter units (FFU).

d) Make-up air systems provide fresh air in RAH Units to replace air lost through exhaust or leakage and thereby maintain pressure gradients.

3.03 Performance of Re-Circulation Air Systems-

Technical details and vendor submittal approved by authority are indicated in Table 2 {8} and also showed the energy efficiency of different types of re-circulation air systems used to re-circulate clean conditioned air within the clean room of specific class.

Table 2

Performance Data of Re-Circulation Air Systems

Cleanroom Cleanliness Class (ISO[1])	Cleanroom Cleanliness Class (FS 209E[8])	RC-AHU Efficiency (cfm/kW)	RC-AHU Power Intensity (W/ft2)
Class 4	Class 10	4839	16.3
Class 4	Class 10	3152	37.5
Class 4	Class 10	3301	31.3
Class 4	Class 10	3086	32.9
Class 4	Class 10	1898	30.5
Class 5	Class 100	1466	20.5
Class 5	Class 100	1556	16.4
Class 5	Class 100	1334	21.6
Class 5	Class 100	1667	17.4
Class 5	Class 100	1891	18.2
Class 5	Class 100	2334	12.4
Class 5	Class 100	1680	16.6
Class 5/6	Class 100/1000	2400	16.4

The above table summarises the efficiency and power consumed by air circulation system through pressurisation of ducts up to the ceiling of cleanroom where the filters are housed to resist the air flow. The efficiency of re-circulation air systems of Class-5 cleanrooms ranged from 1334 to 2334 cfm/Kw because more space is required for supply and return ducts for connecting air handling units and individual controlling device to maintaining the flow rate of air passing through the bank filters and within the conditioned environments. On the other side., energy efficiency of the FT pressurized-plenum systems varied 1334 to 4839 cfm/kW were found relatively more efficient compared to other types of re-circulation systems (DRC and FFU) serving ISO Class-5 cleanrooms. The pressure drops in FT pressurized-plenum system were lower than DRC air handler units.

Ceilings are covered with pressure ducting and fan coil units with filter banks directly mounted on ceiling grid.

Table 3

Selected ISO 14644-1 airborne particulate cleanliness classes for Cleanrooms

ISO Classification	**Maximum concentration limits (particles/m3 of air) for particles equal to and larger than the considered sizes shown below**					
	≤0.1um	≤0.2um	≤0.3um	≤0.5um	≥1um	≥5.0um
ISO Class 1	10	2				
ISO Class 2	100	24	10	4		
ISO Class 3	1 000	237	102	35	8	
ISO Class 4	10 000	2 370	1 020	352	83	
ISO Class 5	100 000	23 700	10 200	3 500	832	29
ISO Class 6	1 000 000	237 000	102 000	35 200	8 3200	293
ISO Class 7				352 000	83 200	2 930
ISO Class 8				3 520 000	832 000	29 300
ISO Class 9				35 200 000	8 320 000	293 000

Table 4

Comparison between selected equivalent classes of FS 209 and ISO 146440-1

ISO 14644-1 Classes	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
FS 209 Classes	Class 1	Class 10	Class 100	Class 10 000	Class 100 000	Class

Table 5

Air velocities in cleanrooms

Class of cleanroom	Airflow Type	Average velocity (ft/min)	Air changes/hr
ISO 8 (100,000)	N/M	1 – 8	5-48
ISO 7 (10,000)	N/M	10-15	60-90
ISO 6 (1,000)	N/M	25-40	150-240
ISO 5 (100)	U/N/M	40-80	240-480
ISO 4 (10)	U	50-90	300-540
ISO 3 (1)	U	60-90	360-540
Better than ISO 3	U	60-100	360-600

3.04 The study shows that on an average the energy effectiveness for three types of re-circulation air systems was 0.168 W/cfm for a fan tower (with a pressurized-plenum), 0.202 W/cfm for a distributed RC-AHU, and 0.212 W/cfm for a fan-filter unit [9]. The result indicated that the low energy efficiency was due to a combination of inefficient motors, design and layout of the re-circulate pathways in distributed RC-AHU while with fan tower pressurized plenums were much more efficient. The major impact is on the chilling machine which feed to the chilled water to the air handling units for make conditioned environment within the facility. The energy consumption

3.05 Dramatic variations were observed from cleanroom to cleanroom for power intensity, due to specific cleanroom process for higher cleanliness levels. Where the re-circulation fan power intensity was high, efficiency was less. It is felt that consultants generally designed higher cleanroom cleanliness than what is needed. Therefore, power demand of fan would be high during the operation and it will be uneconomical due to higher cleanliness levels. The electrical demand (kW) for fan power at the same time is largely affected by system design and process equipments needed for cleanroom cleanliness. Air system design and space allocation play a significant role in affecting the system efficiency. The planning and eventual design of the cleanroom should provide necessary adjustments and space for efficient air systems and its component.

3.06 To obtain the specific class of cleanroom air velocity is calculated based on the number of factors involved such as the operating protocol, flow direction, filter performance, equipment and space configuration layout plan etc. In practice, acceptable contamination levels have been achieved with either significantly lower or higher than recommended air change rates. There is difference of opinions among designers and engineers in use of guidelines, rules of thumb, and their experience.

3.07 Make-up Air System supplies fresh air to the re circulation units to cope up exfiltration to maintain pressurization associated with the cleanroom which are due to general exhaust, heat exhaust, process exhaust etc. the energy efficiency of make-up air systems can be improved by integrating mechanical design with architectural design at early stage of the project, and by adopting fans and motors which are more efficient.

3.08 Process Load-Cooling load required to remove process heat is one of the major considerations during the design and operation of HVAC systems and varies significantly from cleanroom to cleanroom. It is however a designing challenge to estimate process loads in order to achieve accurate HVAC systems. The process loads are dependent on cleanroom activities which are generally over - estimated. Although oversizing may be intentional for additional reasons such as the provision for future expansion, reliability, etc., tendencies to add extra cushion in the design process often result in extra energy wastage. It is therefore process generated heat load that tends to be over-estimated and oversized in practice. It is therefore necessary and critical to have more accurate estimates of process load for an energy efficient system design.

4-DISCUSSION

4.01The designing of Cleanroom facility as per ISO standard and recommended practices and guidelines of environment sciences and technology(IEST) are to be followed for HVAC systems depending on cleanroom classification standards ,turbulently ventilated and ancillary, clean air devices ,construction materials, high efficiency air filtration, air quantities and pressure differences, air movement control, testing and monitoring, details of materials ,equipment and machinery within the facility, cleanliness requirements cleanroom size, utilities system design, certification and operation for operating 24 hours per day for the whole year (8, 760 hours). The cost may vary from size to size along with classification and utilities.

The selection of accurate rating of re-circulation fan power for energy intensive cleanrooms through careful space planning, design, operation, and control would be lead to reduction in cost of operating the cleanrooms.

4.02 Air management system is the best selection criteria for a given cleanroom application. The consultant must be thoughtful to consider initial cost, operating cost, process load, and requirements for cleanroom performance and contamination control. The appropriate amount of re-circulation airflow is critical to the satisfactory performance of cleanroom environment systems as well as effective contamination control. Apparently, there is a need to further examine the scientific basis for appropriate ranges of air change rates and corresponding average cleanroom air velocities currently recommended by IEST. An energy management team may be organised for re-examining scientific factors that affect yields in cleanrooms such as protocol, air turbulence, human occupants, molecular contamination, filtration, and their impact on various activities. This would help cleanroom designers and operators achieve high performing and reliable cleanroom systems. These teams also look into all the technical details as well as have a scientific approach to provide energy efficient system in terms of cost effectiveness.

5-CONCLUSIONS AND RECOMMENDATIONS

To understand the effective way of energy, use in complex cleanroom facilities, the design details, vendors' submittal, information on electrical and mechanical system, current trends of component performance are considered as baseline for tracking energy performance over time. The energy performance evaluation is supposed to measure and provide improvements

in energy system and goal for energy efficient design and energy-saving opportunities in cleanrooms.

a. Flow rate for re-circulation air systems and make-up air systems as per ISO reference are widely accepted for the same cleanliness classes. Accurate blower rating with selection of energy efficient system is required to reduce the cooling load. Those components which are linked with circulation system are also critical to maintenance and control for energy saving.

b. The range for air change rates from 240 to 480/hr recommended by IEST from ISO Class-5 (Class-100) cleanrooms tested appears to require more airflow than needed. It is further evaluated on scientific basis for cleanrooms recommended air change ranges as per classification.

c. Air management systems is the key factor. It has to be considered with respect to initial cost, operating cost, current energy prices load, performance and control mechanism for better energy efficiency.

d. While planning air management system, we have taken care of accurate process loads and their diversification to avoid over sizing blower rating while maintaining the cost- life -cycle savings, thus improving productivity and contributing to power reliability.

Maximized efforts are put to make benchmark for air management system with high energy efficient to obtain technical data, the current performance of individual system with respect to cost (including capital., operation and maintenance, energy consumed) and airflow rate. A strong and sound data book shall be prepared to help in selecting most efficient energy management system with appropriate technical details. Future research may include investigations for continuous energy performance as compared to the design intent for identifying good design practices and new energy-saving opportunities. In best of my opinion users should make data banks for futuristic plan for consideration of cleanroom energy performance as benchmark and associate with computer interface to be treated as a tool for energy efficient air management system.

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