Implementing Multidisciplinary Research Center Infrastructure–A Trendsetting Example: SUNUM

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Abstract

Sabanci University Nanotechnology Research and Application Center (SUNUM) became operational in January 2012. SUNUM is a trendsetting example of a green and flexible research facility that is a test bed for the cost-effective operation of a Centralized Demand-Controlled Ventilation (CDCV) system, a state-of-the-art cleanroom, and world-class high technology equipment. The total investment in the facility was US$35 million.

KEYWORDS
SUNUM, nanotechnology, green building, CDCV, cleanroom, nanofabrication

INTRODUCTION

Sabanci University Nanotechnology Research and Application Center (SUNUM), located in Istanbul, Turkey, is a 7500 m^2 (80,729 ft^2) state-of-the-art facility (Figure 1). The design of the facility provides an efficient, highly functional integration of education and research applications, in accordance with the strategic vision of the university to create social and economic added-value out of knowledge and to disseminate knowledge within society.

In line with the emphasis on applied research with greater community impact, members of the Sabanci University Faculty of Engineering and Natural Sciences (FENS) joined forces in 2009 to form a new multidisciplinary nanotechnologies research center. SUNUM was developed with US$35 million provided by the State Planning Organization and Sabanci Foundation and became operational in January 2012. The center provides valuable additional capabilities to the existing research infrastructure of FENS. SUNUM offers highly effective multidisciplinary research programs, bringing together researchers with expertise spanning advanced materials, nano-bio technology, nano-electronics, micro-nano fluidics, micro-nano-electromechanical systems, and nano-engineering.

Figure 1. Sabanci University Nanotechnology Research and Application Center (SUNUM).

Sabanci University is attempting to set a good example for multidisciplinary studies with its “creating and developing together” strategy and “no departments, no walls” approach. SUNUM allows application oriented research in synergy with the research expertise of FENS. The center is a hub and a leading example for the implementation of “open innovation” and “innovation campus” concepts in Turkey by establishing precompetitive research consortiums and strategic research alliances with academic and industrial partners, which address human and safety-focused applications in advanced materials, environmental, health, food, energy, and defense sectors. Collaborative research efforts at SUNUM are led by drivers such as expanding scientific results, transforming knowledge into public service, creating economic value, initiating interdisciplinary studies, and establishing academic and professional partnerships. SUNUM enables the path to production for new and beneficial intellectual property and end-products by bringing together science, education, research, and technology.

DESIGN CONCEPT

Situated adjacent to the existing FENS building, the location and the architecture of the facility is in line with the Campus Master Plan to ensure continuity of scale, building hierarchy, and materials. SUNUM is housed in a 2.5-story building, and its architectural design, inspired from a human cell, includes two main parts:

1) The precast concrete structural façade, the membrane of the cell, encloses a column-free open and flexible office area. The unique aspects of the southern and western façades include an intricate pattern inspired from hexagonal carbon structure (C-60, fullerenes). The façade is both a massive window and a load-bearing wall. The sloped surface of the façade creates a lattice to infuse daylight during the day while allowing the spread of internal atrium lighting at night, increasing its visibility and eliminating the need for external façade lighting (Figure 2).

Figure 2. SUNUM lobby area and office levels.

The lobby features a “Nano” sculpture representing a carbon nanotube at large scale. The lobby also houses a café, classroom, and computer laboratory. Interior finishes and materials were selected for function, durability, and as an expression of the high-technology environment.

2) The inner core, the nucleus of the cell, is the laboratory block which houses the multidisciplinary laboratories, a CleanRoom (CR), an office suite for staff, students, and faculty, and common areas. Research laboratories, the CR, and auxiliary spaces are located on the main level. The upper level is devoted to the heating, ventilation, and air-conditioning (HVAC) system. A half-basement houses all other fluidics, mechanical, and electrical systems. This floor plan supports the ability to adapt and change spaces and requirements without disruption of the activities. The outside walls of the high-bay research building are clad with “Sabanci” brick and limestone that compliments the existing university buildings, thus preserving the architectural integrity of the university.

DESIGN AND IMPLEMENTATION DETAILS

The International Building Code (IBC) 2006 edition is used as an applicable building code for SUNUM.[1] Laboratory and offices fall under Business Group "B" Occupancy. Lobby and classrooms fall under assembly occupancy A-3. Some laboratories and cleanroom areas are classified High-Hazard Group H-5 Occupancies. All mechanical and electrical infrastructures are implemented in accordance with IBC: 2006, International Mechanical Code 2006 edition, and National Electrical Code and National Fire Protection Association NFPA 70 (2006 edition).

The building is equipped with automatic sprinkler systems in main areas. A dry-pipe sprinkler system is used in the CR and in general laboratory areas. All areas are monitored with optical smoke detectors combined with a Centralized Demand-Controlled Ventilation (CDCV) system. A Very Early Smoke Detection Apparatus system (VESDA) is used in the CR. Toxic-flammable gas monitors and ultraviolet- and infrared-based flame detectors are installed wherever appropriate.

Istanbul is located in an earthquake region. An earthquake monitoring sensor is installed in the SUNUM basement, coupled with fire and building automation systems. The entire enclosed area of the building is monitored with closed-circuit television (CCTV) at 66 points, including all laboratories and cleanroom fabrication and service areas. Security personnel are located on the premises to monitor the CCTV, Access control, and Fire System Repeater panel. According to the "buddy rule," no user is allowed to work alone in lab premises where chemicals or gases are in use.

EQUIPMENT

The SUNUM state-of-the-art tool set consists of approximately 40 major pieces of equipment for the fabrication of micro- and nano-system prototypes for applications in the communications, health, defense, environmental, and energy sectors. A complete list of the equipment at SUNUM, along with applications, research conducted, and communication information can be located on the SUNUM website at: http://sunum.sabanciuniv.edu/facilities-0

Some examples of this equipment are an Electron Beam Lithography (EBL) system with 8 nm feature size and an Ultra High Resolution Transmission Electronic Microscope (UHRTEM) with pico-meter spatial resolution allowing single atom identification both spatially and chemically by energy levels (Figure 3).

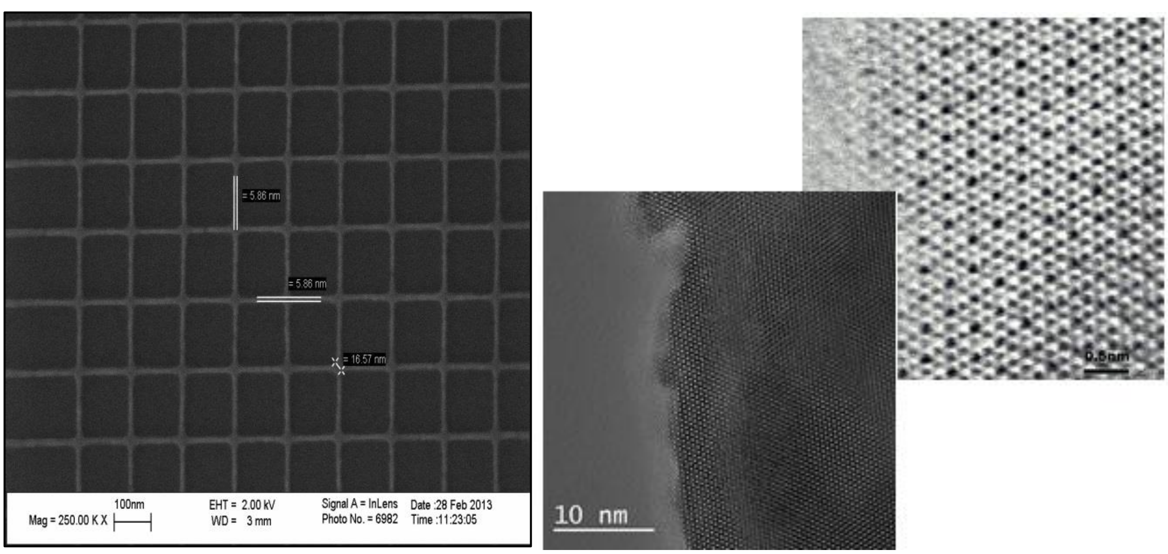

Figure 3. a) EBL pattern resolution; b) Sr-Aluminate HR-TEM and Brightfield STEM pictures.

CENTER OPERATIONS, STAFFING, AND COST MODEL

SUNUM is currently operating on a 24-hour/7-day basis. All users must complete Emergency Health & Safety (EH&S) Training and then Lab Specific Safety Training before they are granted access to unlock the lab doors using their key cards. Equipment users must have a minimum of two additional training cycles before they are allowed any use of equipment. Cleanroom users must also participate in a CR-Orientation Seminar before they are granted access to controlled areas.

Equipment users are required to attend training conducted by an advanced user (a researcher or the service engineer) or by the vendors. After a trial period of 6 months, users are granted permission to schedule equipment. The equipment scheduling is currently managed by dedicated electronic-based calendars for each major tool. SUNUM had 279 users in December 2013, including 46 faculty members and 36 external users from 12 different institutions. The 2014 projected-users number is 350, and the yearly equipment use in 2014 is expected to exceed 40,000 hours. Paper-based log books and user access-card logs are employed to monitor equipment use, and the results are reported monthly to the University management. Sabanci University Faculty members currently do not pay a fee for using the equipment, but external users are charged a nominal fee based on their tracked usage of tools and laboratories. SUNUM is planning to implement an internally developed equipment tracking system in the near future based on smart interlocks and card access readers.

SUNUM support staff currently consists of a director, four service engineers, two technicians, a facility manager, and two administrative assistants. The center also has eight professional researchers and eight post-doctoral researchers. SUNUM uses a three-part control system for each major tool or laboratory area: one main researcher or faculty member, one support personnel, and at least two advanced users. Selected researchers share the responsibility for the equipment with the service engineers in the cleanroom areas for the development and implementation of standard operating procedures, process development, support of external service demands, and training of new users. Service engineers and technicians are also responsible for daily tracking, maintenance, and installation. Each piece of equipment has its own Standard Operation Procedure and Processes List. Every new process must be approved by the service engineer/researcher and Principal Investigator (PI) team.

SUNUM runs as a cost center independent from academic or administrative units. The overall goal is to balance income and expenditures. The income consists of funds provided by the Sabanci University Foundation, project overheads, external service charges, and government subsidies. SUNUM costs include personnel fees, operational charges, and equipment maintenance and service contracts. According to the data submitted by Grimard et al.,[2] average cost recovery of US nanofabrication facilities is 27.2% from subsidies and 27.8% from external users, while internal cost recovery is 45.1% with respect to total recovery cost. The situation is similar for SUNUM. Cost recovery from external sources is approximately 19.5% and subsidies are 24.2%. Internal usage is not being charged at SUNUM at this time, but amounted to 43.9% of total usage in the second operational year.

ENERGY SUSTAINABILITY

SUNUM is Leadership in Energy & Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM) certified. The center is an environmentally friendly research laboratory building conforming to international “green” approaches for using minimum energy and creating minimum waste. The final cost of achieving a green building was only 5% higher than conventional technology and research and development (R&D) centers. Creation of a sustainable environment was a key factor in the design of SUNUM. The most visible features are the use of natural lighting, the solar heating panel arrays located on the office block, and the reuse of collected roof rainwater for gardening. Most of the interior partitioning systems are glass, which admits more natural light, even into the perimeter of the research spaces. The frontal windows that surround the building use an insulating glazing with low emissivity coatings (solar low-Ɛ) on surfaces, and are filled with argon gas in the cavities (65% visible light transmission, 0.27 solar heat gain coefficient, VNE 15-63 insulation) to keep the energy consumption under control. For the same reason, specially designed pre-tensioned, heat-insulating, metal and glass doped modular concrete elements were constructed without any support of columns for carrying the load coming from the roof of the building as an integral part of the frontal façade.

The HVAC system for the enclosed space (except for the CR) features an active chilled beam system coupled with a CDCV system. This combined system not only achieves savings in energy usage over comparable conventional air-handling systems, but can also be easily and quickly relocated to match the requirements of changing scientific functions.

Dedicated control of energy consumption at every possible point, enhanced training of users for waste minimization and energy conservation, and utilization of ISO 14001:2004[3] standards throughout the center help SUNUM conform to LEED and BREEAM regulations.

FLEXIBILITY

The open office area is designed to allow change and growth and to easily accommodate future needs. Interior walls in the office section use a flexible system that easily allows change of layout and material. The main laboratory is divided into two distinct areas. The first area is the CR. This 830 m^2 (8934 ft^2) area consists of ISO Class 5-8[4] nano-fabrication and characterization suites. The second area is a flexible laboratory for investigation of a range of nanotechnology research fields: molecular and cell biology (Biosafety Level 2 [BSL2]), micro fluids, micro devices, optics, physics, and chemistry. To ensure the highest level of flexibility and adaptability, the laboratory has been designed with minimal physical interruptions. All internal partitions are demountable. All mechanical, electrical, and plumbing services are fed from an overhead mechanical space via overhead service carriers, allowing "plug and play" for any piece of complex instrumentation in any location. The site location and planning of the facility were designed for easy expansion (Figure 4).

Figure 4. Typical ductwork in Mechanical mezzanine and CR areas.

CENTRALIZED DEMAND-CONTROLLED VENTILATION (CDCV) SYSTEM IN SUNUM

SUNUM comprises 16 research laboratories. Depending on the requirements for minimal air change per hour (ACH) for different laboratory sections, from micro-electronics to BSL2 laboratories, the use of a demand-controlled ventilation (DCV) system is the most viable option to reduce energy costs resulting from optimized ventilation rates by incorporating sensors to monitor real-time laboratory air quality.

The in-house set-up CDCV system captures air samples from specific rooms or from air-supply ducts and then routes these samples to a centralized suite of sensors for monitoring variable threshold levels of temperature, humidity, CO_2, Total Volatile Organic Compounds (TVOC), and airborne particles. The sensor analysis is then used to inform the building automation control system to optimize ventilation rates. The CDCV system reduces energy consumption in SUNUM laboratory spaces by reducing the average daily airflow by 53.5% as shown in Table 1. The estimated reduction of the total energy cost is approximately 60%. Additionally, by utilizing a centralized suite of sensors, life-cycle costs to maintain calibration are minimal compared to maintaining a large number of distributed sensors in every laboratory area.

Table 1. Estimated annual savings from CDCV system.

	Base Design in m^3/h	CDCV system in m^3/h	m^3/h flow savings
Average Daily Airflow	44,863 (100 %)	20,785 (46.5 %)	24,078 (53.5%)
	Annual Total Energy Units	Annual HVAC Total Energy Units	Annual Total Energy Units Saved
Cooling kWh	298,651	129,051	169,600
Heating kWh	371,947	193,287	178,660
Reheat kWh	1,465,948	506,208	929,740
Supply Fan kWh	234,131	62,732	171,398
Exhaust Fan kWh	254,638	127,122	127,516
Total kWh	787,420 (100 %)	318,906 (39.2 %)	468,514 (60.8 %)
Total Htg kWh	1,807,895 (100 %)	699,495 (38.7%)	1,108,400 (61.3 %)

Note: The coefficient of performance (COP) of the refrigeration system was assumed as 3.5. Heating efficiency was assumed as 75%, supply fan efficiency as 70%, and exhaust fan efficiency as 60%.

CLEANROOM

The SUNUM CR consists of 830 m^2 (8934 ft^2) of enclosed areas that are designed as E-shape chase-and-bay, laminar/unidirectional flow, ISO Class 5-8 modules. Figure 5 shows the layout of the CR. The modules are ISO Class 5-7, the hall is ISO Class 7, and the chase is ISO Class 8. The E-shape layout design with perforated raised floor, easily demountable aluminum side walls, and suspended ceiling units enhances the flexibility of connection of support services like pumps, exhausts, gases, and deionized (DI) water to process equipment with minimum effort and cost.

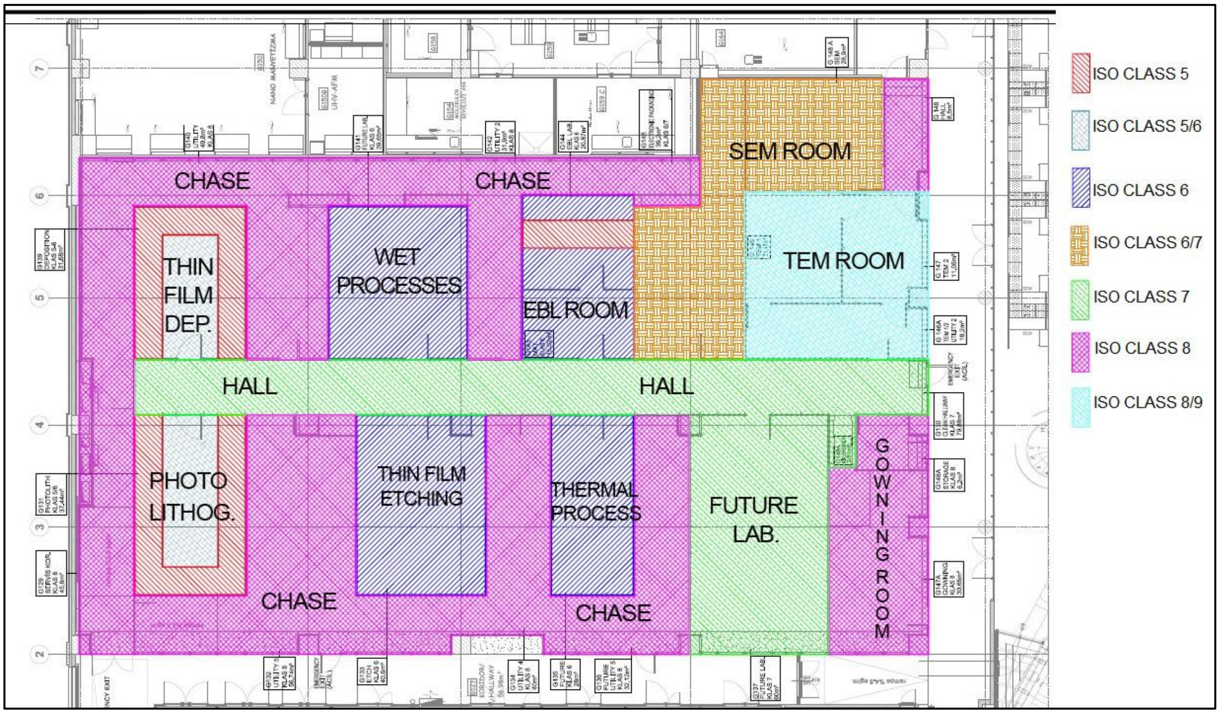

Figure 5. The layout of the SUNUM CR.

Bays are specifically planned so that equipment sharing the same type of services is set up in the same area (Figure 6). This approach decreases the energy consumption of the CDCV system, as unoccupied laboratories do not need to be conditioned.

Figure 6. SUNUM CR interior: Thin Film Etching and Wet Processes rooms.

The Photolithography Room is a combined ISO Class 5-6 area. The areas where the clean processes are conducted are ISO Class 5, whereas the remaining part of the room is ISO Class 6. This approach is also used in the Thin Film Deposition and EBL rooms. The transmission electron microscope (TEM) equipment and scanning electron microscope (SEM) equipment are also located in the CR due to their stringent requirements of temperature and humidity control. The acoustic and vibrational noise of HVAC units in these rooms is prevented by replacing the fan filter units (FFU) with low turbulent, low noise, unidirectional flow air-supplying units supported by spring isolators. All major ductwork and pipes are also supported by spring isolators.

A high degree of vibration isolation of the CR area is ensured by separating it from the main building slab. The EBL, TEM, and SEM rooms are placed on concrete pedestals floating on high-density XPS (extruded polystyrene) layers. The CR radial base is also sandwiched between high-density XPS layers standing on lean concrete (Figure 7).

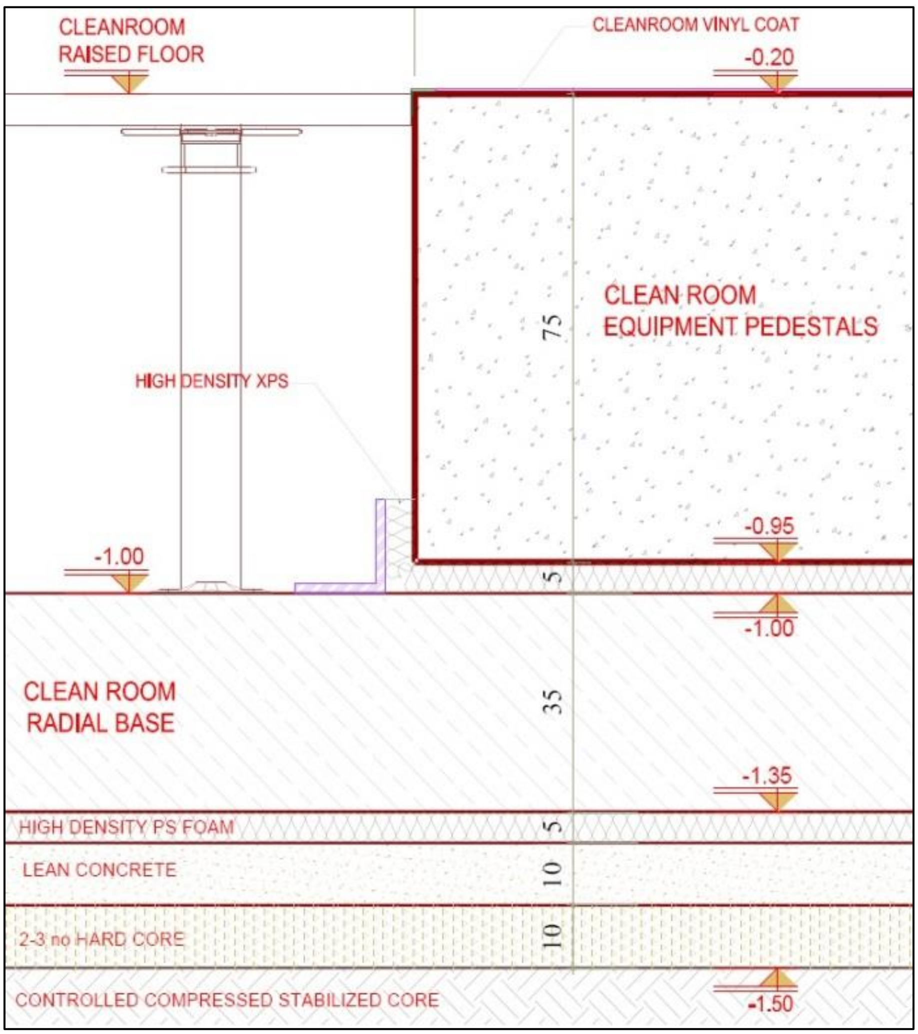

Figure 7. SUNUM CR base (side view).

The vibrational sensitivity of the EBL system was tested by the manufacturer. The results show the conformity of this section to NIST-A and VC-D criteria at 1-20Hz and 20-100 Hz (Figure 8).[5] All electrical services are also fully shielded to ensure there is no electromagnetic interference with the equipment.

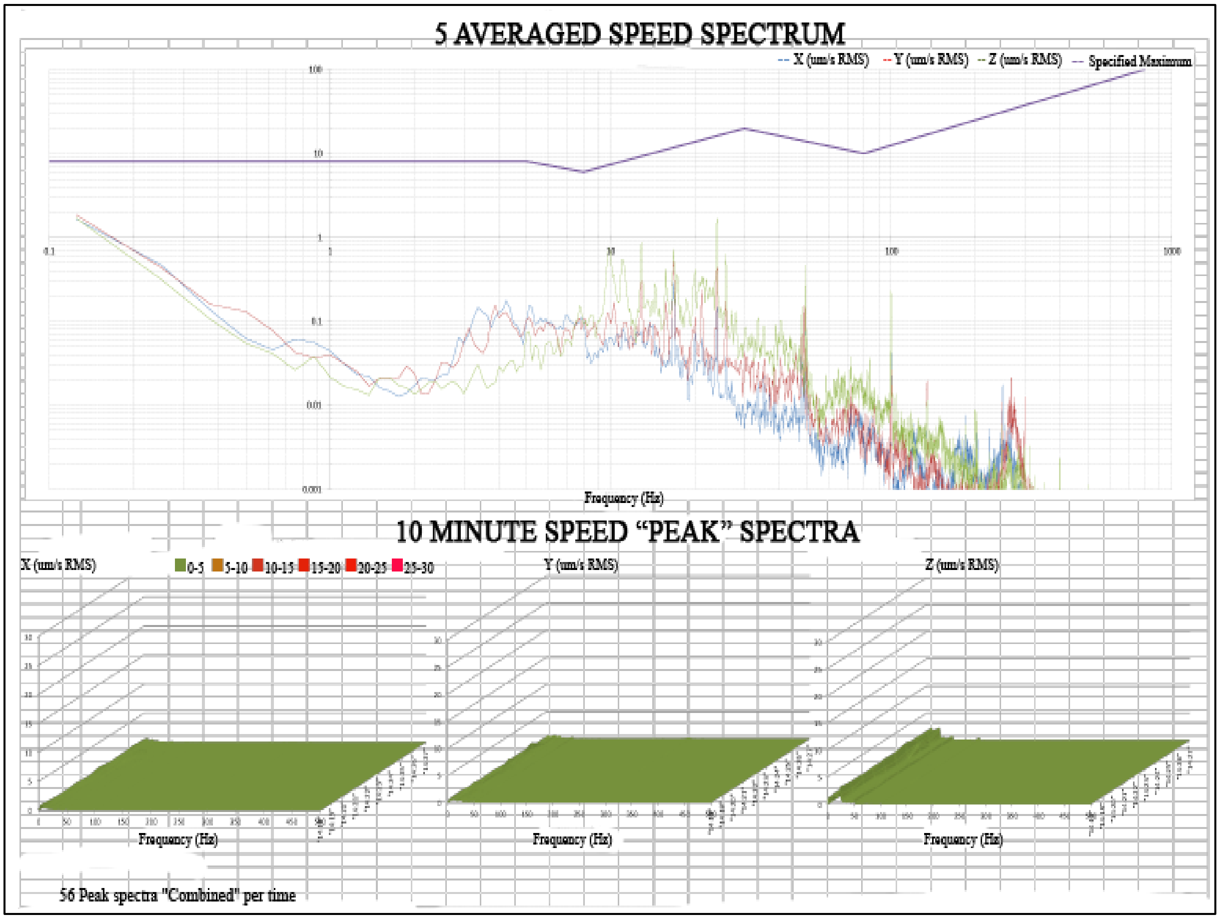

Figure 8. Velocity spectrum for vibration testing of EBL equipment pedestal.

Make-up air is supplied by two different air handling units (AHU): one for the plenum (AHU-1) and the other for wet benches (AHU-2). The AHU-1 conditions 15,000 m^3/h (529,720 ft^3/h) of outside air at 22±1 ^oC/h in 45% ±5% RH into the plenum where individual fan coil units (FCU) recondition the plenum air using the temperature and humidity inputs from the automation system. Each individual room is monitored by a control system with temperature, humidity, and pressure sensors. FFUs provide laminar/unidirectional air flow according to the class of the room.

The return air into the chase area from the perforated raised floor is either exhausted in the plenum duct or reconditioned in ceiling FCUs. The AHU-2 supplies a maximum of 21,600 m^3/h (762,797 ft^3/h) of conditioned wet-bench air, which is totally exhausted using chemical resistant ductwork. Process equipment exhausts are connected together except for hazardous/flammable and pyrophoric exhausts. The schematic of the HVAC of the CR is shown in Figure 9.

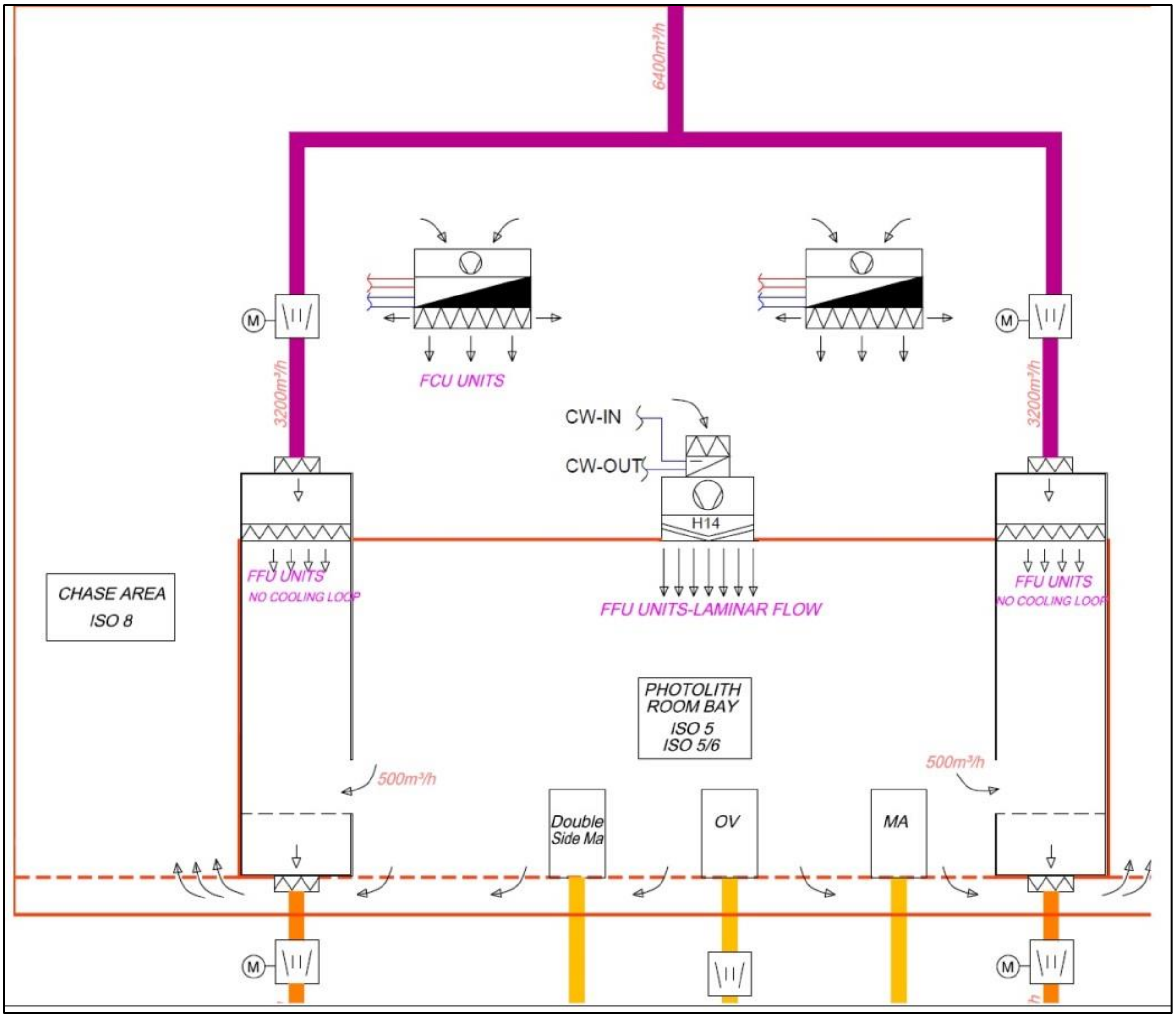

Figure 9. HVAC schematic of the SUNUM CR.

Figure 10 shows the 5-hour relative humidity (RH%) and temperature (^{o}C) trend data for the EBL room. The air in each room in the CR is reconditioned by individual FFU cooling loops against the heat loads (Table 2). The data show the automation system control is capable of keeping the room at acceptable levels with differential control on temperature and humidity. The variation of the relative humidity of the room is on average 45.19RH% ± 0.27RH%, and the variation of the temperature is on average 21.98 ^{o}C ± 0.12 ^{o}C according to 5-hour trend data.

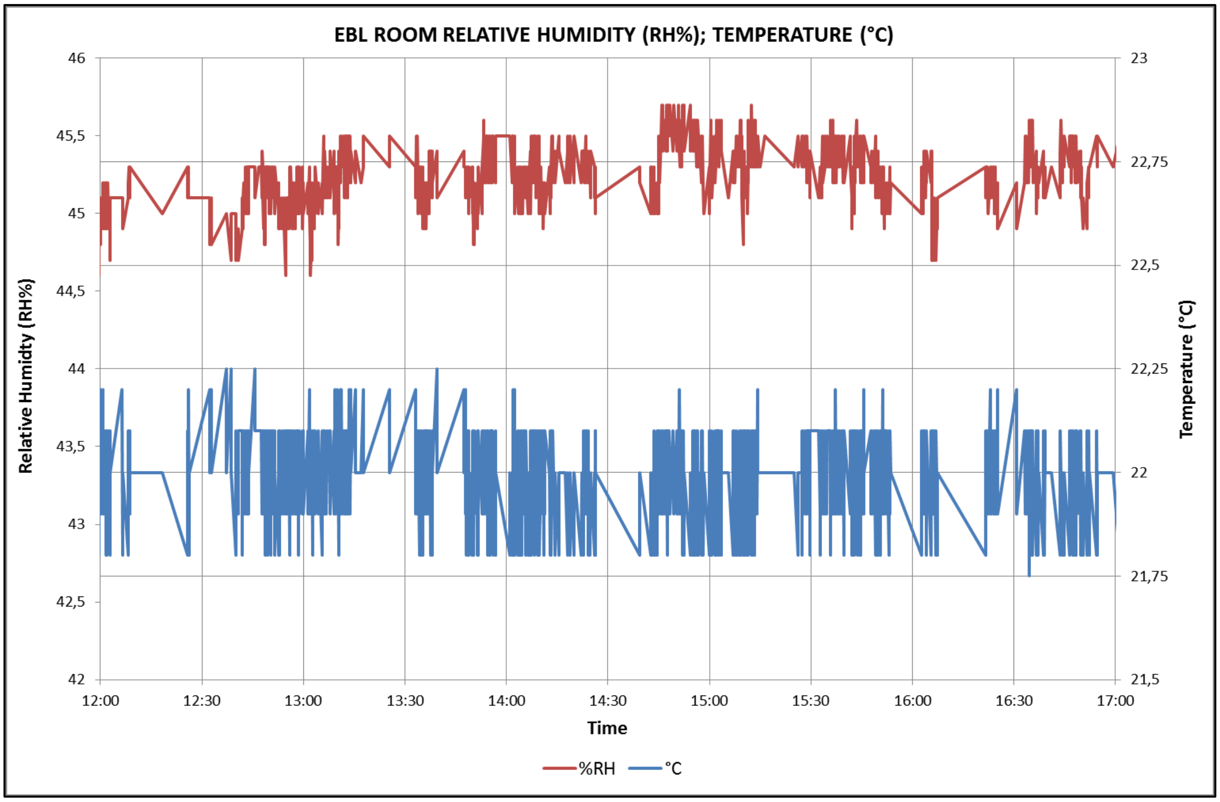

Figure 10. EBL room Relative Humidity (RH %) and Temperature (^{o}C) trends for 5-hour period.

Table 2. SUNUM CR labs design specifications.

Room Name	Cleanroom Class	Size in m^2	Temp/Rel. Humidity
Photolithography	ISO Class 5-6	37.5	22°C ± 0.5 °C / 45% ± 5%
Thin Film Etching	ISO Class 6	40.5	22°C ± 0.5 °C / 45% ± 5%
Thermal Processing	ISO Class 6	28.0	22°C ± 0.5 °C / 45% ± 5%
Future Laboratory	ISO Class-7	60.0	22°C ± 0.5 °C / 45% ± 5%
Thin Film Deposition	ISO Class 5-6	31.5	22°C ± 0.5 °C / 45% ± 5%
Wet Processes	ISO Class 6	40.6	22°C ± 0.5 °C / 45% ± 5%
EBL	ISO Class 5-6	26.0	22°C ± 0.5 °C / 45% ± 2.5%
Microsystems Packaging	ISO Class 6-7	39.5	22°C ± 0.5 °C / 45% ± 5%
TEM	ISO Class 8-9	50.4	22°C ± 0.25 °C / 45% ± 5%
SEM	ISO Class 6-7	37.5	22°C ± 0.25 °C / 45% ± 5%
Gowning	ISO Class 8	39.5	22°C ± 0.5 °C / 45% ± 5%
Hall	ISO Class 7	80.0	22°C ± 0.5 °C / 45% ± 5%
Chase Area	ISO Class 8	319.0	22°C ± 0.5 °C / 45% ± 5%

CONCLUSION

SUNUM was designed to be a trendsetting research facility. A "green" building approach has been followed, with this concept incorporated in the design to build a flexible research environment for different research fields. The use of a CDCV system reduced energy costs by approximately 60% compared with similar buildings running on constant air ventilation rates for different laboratory areas. The cleanroom area is designed to address the needs of both electronic micro-fabrication and micro-packaging. The current environment and equipment allow printing control line widths of approximately 8nm and atomic level manipulations and characterization of materials.

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