Why Does One Nano Lab Cost More Than Another?

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Abstract

Construction costs of nano labs reflect the differential between the required performance criteria and the in situ conditions. Nano retrofits in existing buildings range from $300 to $1000 NSF, depending on the isolation required. New construction can be prepared for nano occupancies with strategic investments to the shell and core construction. Topics covered include decisions for: siting / utilities; foundation; super structure; high bay; low vibration; clean room; construction delivery; and testing and commissioning. Examples from seven current projects will be used – three renovations and four new construction.

Keywords

low vibration labs, clean rooms, high bay labs, shell and core decisions, fit-out decisions, construction cost

The label "nanotechnology" covers a host of research applications, some of which require vastly more costly infrastructure than others. Basic engineering issues, research themes, and design choices determine the budget of the nanotech facility.

The relative cost of nano labs is based primarily on five factors: 1) the level of performance that the research requires; 2) the means by which it is achieved; 3) the proportion of high performance space to the overall program; 4) the "baseline" conditions of the site; and 5) the builder's experience with this type of construction.

For the purposes of this manuscript, the most frequently asked questions in the design of a nano lab are examined. They are organized into themes, and include recommendations about which direction is most advantageous. When the cost difference between one solution and another is known, it is so stated. When the cost difference is not immediately available, general guidance is given. The building's end user, or the user representative, should participate in answering these questions because they are in the best position to evaluate whether or not the end justifies the means.

Instrument-Driven Science

Nano science is different from conventional bench science because of the reliance on tools and instrumentation needed to work at atomic scales. The operating requirements of the instruments used to conduct nano experiments are restrictive and severe. They simply do not work with precision and high resolution if they are jiggled, bumped or disturbed in any way at the scale of the atom.

Many manufacturers of sophisticated instruments, particularly in high resolution tunneling electron microscopy, won't guarantee results unless the spaces conform to their specifications. Research in microelectronics and materials involving etching, lithography, masking and deposition all require clean and stable environments in which precise patterns can be imparted onto a variety of substrates for testing and analysis. The instrument-driven sciences, therefore, rely on the stability of the space in which they are housed. Performance is key.

High Performance Space

Nano labs are "high performance spaces". That description starts to suggest the unique qualities of these labs and begins to differentiate them from typical laboratories. When the term "performance" is used, it refers to the stability and uniformity of the temperature, humidity, electro-magnetic fields, and vibration within the space.

Also included are issues of special construction such as high-bay spaces, and labs with pits. These are often needed for condensed matter physics in which probes are inserted into super-cold magnetic fields contained in dewars.

High Bay Lab
Harvard University, Cambridge, MA

And, perhaps the most costly space to create are clean room environments, where many of the high performance needs converge and tend to act against each other. Therefore, “high performance spaces” are generally characterized in four ways:

- **Low vibration labs.** The performance is defined by VC (vibration class) curves which plot velocity of displacement against frequency. To achieve VCE and lower (less than 125 micro inches/sec) inertia blocks are utilized and isolated from surrounding floors and structure by specialized springs.

- **Clean rooms.** The performance is defined by Class 1 through Class 100,000. The number refers to the number of particles of a specified size allowed in a volume of space. A Class 100 space has less than 100 particles greater in size than 0.5 microns per cubic foot. The lower the class number, the cleaner the space. These spaces are achieved with continuous air circulation using HEPA and ULPA filtration, specialized wall panel and flooring systems and gowning protocols to avoid the introduction or circulation of particulates. Support equipment, such as pumps, are often in a separate chase area or subfab area to limit particle generation in the clean room.

- **High bay labs.** These typically range from 20 to 25 feet in clear height. They are often outfitted with a 2 ton crane at the top to allow for the raising and lowering of dewars and chambers into specific experimental positions.

- **Cryogenic labs.** These labs are similar to high bay labs, except that the required height is achieved through the use of pits rather than high bay. The height is required to allow long experimental probes to be raised and lowered into low temperature liquids housed in dewars. The use of powerful magnets in the dewars precludes the use of magnetic rebar in the surrounding area.

In programming “high performance space”, standard “Room Data Sheets” with “Room Condition Sheets” are often included to get at the true performance needs. These “room conditions” provide the first opportunity to start to gauge the relative cost of one space to another.

Clean Room – LISE Building
Harvard University, Cambridge, MA

Means and Methods

However, room conditions only go so far when it comes to cost. The next major cost factor is tied up in the means and methods by which the designer achieves the required stability. To achieve temperature and humidity stability, individual air handling units may be required for each experiment. For EMI stability, conduit may need to be shielded, wiring may need to be twisted and non-magnetic construction materials may be required. For vibration control, isolation blocks on springs may be installed. For clean environments, multiple air changes through HEPA filtration is needed. The list of problems and solutions is long and extensive and often expensive.

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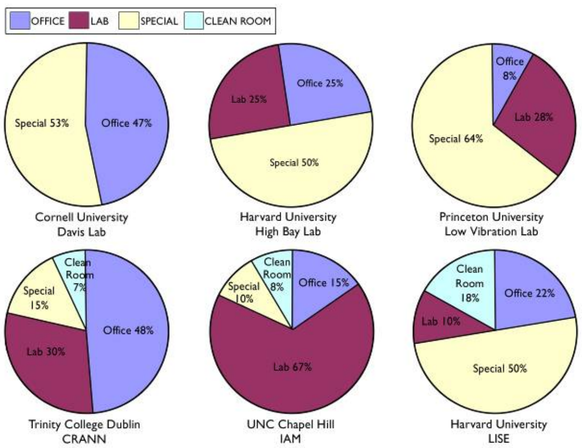
Program Distribution

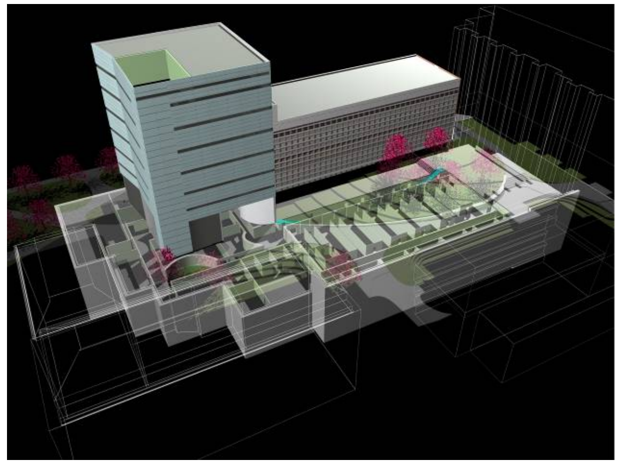
Because achieving high performance space can be costly and difficult, the relative proportion of high performance space to the overall space program is the next major cost driver. When evaluating the cost of a nano lab at one institution versus another, it is important to understand the proportion, because it can dramatically skew the price comparison.
In a comparison of six recent projects, the proportion of high performance space was found to range between 20 and 70 percent of the overall program (called out as "special" and "clean room" in the figure below). The difference in cost of facilities is reflective of this range.



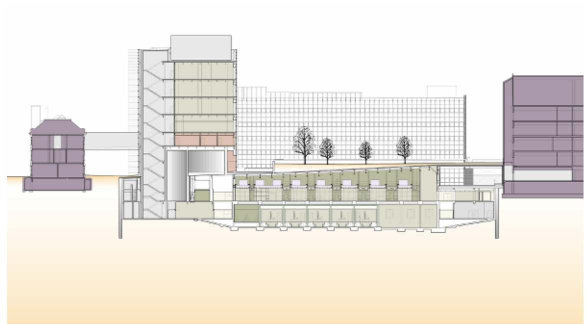
Space Allocation

Site Conditions

Another great cost factor for nano labs is the baseline condition of the site that is chosen for the facility. Clearly, if a nano facility is placed next to a heavily trafficked road, a railway or subway, the baseline vibration and electromagnetic fields that will need to be mitigated is much higher and costlier than a quieter site. The need for low vibration and cryogenic pit space often dictates a slab on grade location which can generate the need for a large, deep basement footprint (as referred in the following two figures). The existing site utilities (relocation costs), the soil conditions (slurry walls) and the adjacency of other buildings (underpinning) greatly affect the budget.



3-D Rendering-underground nano portion of LISE
Harvard University, Cambridge, MA
Drawing by Wilson Architects
Design Credit: Rafael Moneo with Wilson Architects



Section of the LISE Building
Harvard University, Cambridge, MA
Drawing by Wilson Architects
Design Credit: Rafael Moneo with Wilson Architects

Builder's Experience

Ultimately, the final judge of how much a space costs is the builder who successfully bids on the work. The same design will be priced differently by different bidders based on their experience with this type of project. An experienced builder will most likely price the project close to its actual worth, because they understand the complexity and the specialty trades necessary to build and commission the work. An inexperienced builder will tend to either grossly overestimate the work because of a "fear factor" about the restrictive requirements, or will underestimate it because of lack of understanding of the complexity. It is important to evaluate the bids with this in mind, and properly "scope" each bidder in a post-bid meeting.

Risk Management: Is the cure worse than the disease?

Once the room conditions, the means for meeting them, and the costs are identified, it is time to engage the users and project managers in a discussion of what to do next. In this case, it becomes a question of risk management, as the efficacy of many of the solutions is either apocryphal ("they did it this way at X institution, and they never had a problem"), or academic ("our calculations show that you will experience X perturbations...etc.), or just intuitive ("I don't care what your calculations show, there is no way I'm going to put the instrument there.."). As a researcher, or an owner, you are forced to make cost decisions based upon your intuitive sense of whether or not the effort of the solution matches the criticality of the criteria.

There have been clients who have chosen to give up on specific stability criteria once they saw the cost and draconian means that were taken to meet it. These same clients have chosen to move forward with costly solutions for some of the criteria because they believe in the necessity and legitimacy of the stated need.

Vibrationally isolated piping and conduit to experiment.
J.C. Davis Group Nanotechnology Lab
Cornell University, Ithaca, NY

Recommendations

Having been through a number of these "risk management" discussions about scope and cost, a list of recommendations and general guiding principles has been assembled. By organizing cost choices thematically, we have identified 14 menus of choices for achieving high performance space. A "check" is next to solutions that clients have chosen to use, and a "dollar sign" symbol is next to additional investments. They are additional not because they are necessarily without merit, but because they trigger costs that may be prohibitive.

Conclusion

The costs of nano labs are relative and dependent upon a number of factors, from the needs of the science, the experience of an architect and engineer, to the comfort level of a builder. Therefore, estimating the cost of a nano lab will not likely be as precise as the science that will go on inside it.

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