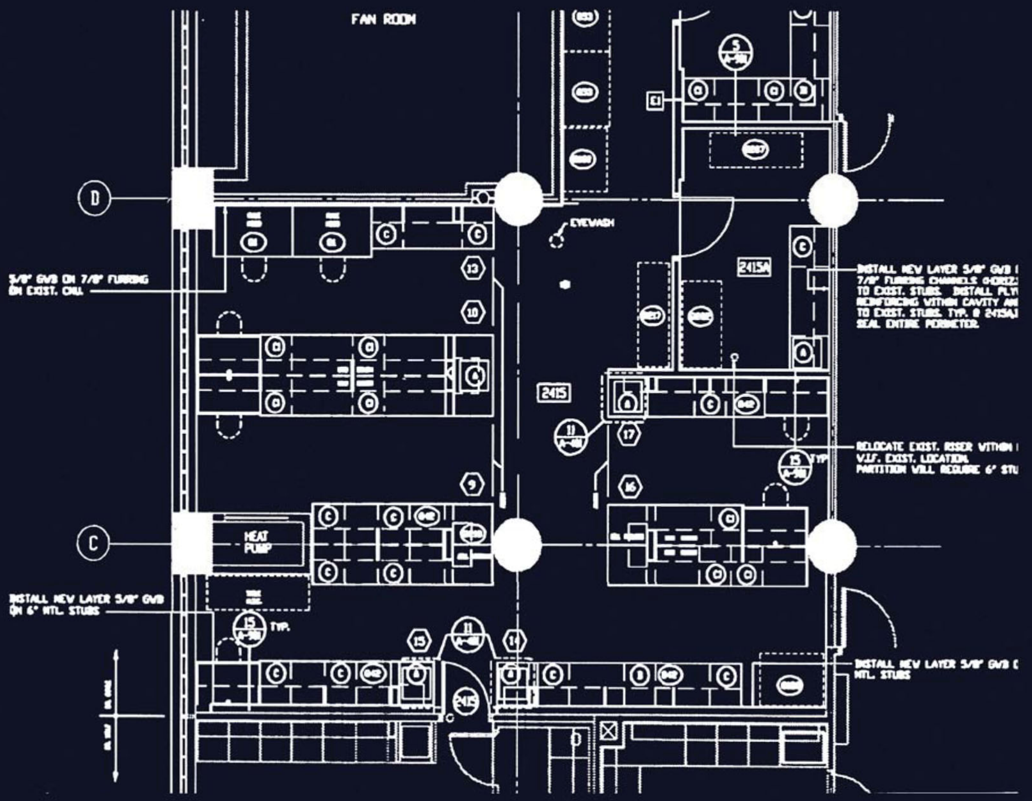
Laboratory Design Handbook

E. Crawley Cooper



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CRC Press
Boca Raton Ann Arbor London Tokyo

Library of Congress Cataloging-in-Publication Data

Cooper, E. Crawley.
Laboratory design handbook / E. Crawley Cooper.
p. cm.
Includes bibliographical references and index.
1. Laboratories—Design and construction. I. Title.
TH4652.C66 1994
727'.5—dc20 93-44971
ISBN 0-8493-8996-8

Direct all inquiries to CRC Press, Inc., 2000 Corporate Blvd., N. W., Boca Raton, Florida 33431.

International Standard Book Number 0–8493–8996–8
Library of Congress Card Number 93–44971

Preface

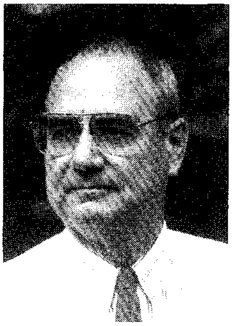
This book is intended to assist those involved with creating new laboratories, remodeling existing laboratories or adapting an existing building to become a lab. Architects, engineers, scientists, facility managers, lab administrators, code officials, insurance underwriters, construction managers and builders may find it contains useful information. We have attempted to describe the process, motivation, constraints, challenges, opportunities, and specific design data related to the creation of a modern research laboratory facility. It is a reality that much of the information contained in this text will be completely outdated within a decade due to the rapid changes taking place in the sciences.

It is based on a large pool of experience in the development of new and renovated laboratory buildings for universities, teaching hospitals, pharmaceutical companies, start-up biotechnology companies and other types of industrial technology.

I am indebted to many people in gathering this information. Harry Orf, an organic chemist with the Massachusetts General Hospital in Boston and a Principal in Cambridge Laboratory Consultants, shared his knowledge with us when the MGH Lawrence E. Martin Labs in Charlestown, Massachusetts were under design. His partner at Cambridge Laboratory Consultants, Donald J. Ciappenelli, was kind enough to perform the technical review for this book. He made many valuable suggestions during that process. Robert Hsiung, a colleague at Jung/Brannen Associates, Inc., and designer of many outstanding laboratory facilities gave us some valuable insight into the design process. Richard G.

Burnham of Dick Burnham Technical Sales and David Lupo of B & V Testing, Inc. contributed their valuable comments on the intricacies of lab equipment. Bruce MacRitchie of MacRitchie Associates, Inc. and Mike Zimmerman of Zimmerman Consulting contributed their engineering perspective. William Watson helped with advice related to the chapter on animal facilities. Ronald Prachniak, Corporate Projects Director at Massachusetts General Hospital, provided valuable insight on a wide range of research related issues.

The illustrations relating to chemical fume hoods and biological safety cabinets are reprinted by permission of the American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, Georgia, from the 1991 ASHRAE *Handbook–HVAC Applications*.



E. Crawley Cooper, AIA, earned his BS in Architecture at the University of Cincinnati and his Master of Architecture degree from the Massachusetts Institute of Technology. His current position is as Principal, Jung/Brannen Associates, Inc., in Boston, Massachusetts, and his previous experience was as Associate with Pietro Belluschi and Eduardo Catalano in Cambridge, MA; as Chief Designer with James Associates of Indianapolis, IN; and as Architect with Anderson Beckwith and Haible in Boston, MA. Mr. Cooper has served as Lecturer at the Massachusetts Institute of Technology, the Harvard Graduate School of Design, Purdue University, the University of Wisconsin, and at the Recombinant DNA Research Laboratory of the National Institutes of Health in Bethesda, MD.

In addition to directing numerous laboratory projects, Mr. Cooper has headed or been a member of groups such as school building committees, a long-range planning committee, a town planning board, a planning task force, and a rezoning study committee. He has also acted as Consultant for Arthur D. Little, Inc., at the United Nations Conference Center in Vienna, Austria.

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Introduction

Firmness, commodity, delight: the three elements of architecture according to the great Roman architect and teacher, Vitruvius. This book has little to do with firmness or delight. It is mostly about commodity, or function, of the buildings where scientific research is conducted.

Modern research facilities provide usable space for laboratories, lab support areas, offices, and interactive spaces for formal and informal gatherings. The special equipment and environments required for research make these buildings extremely complex. A successful lab must also provide a safe and humane place for people to work. A well designed laboratory can be a significant tool for recruiting the best minds available. It can encourage the sharing of ideas in a culture that seeks the truth with an interdisciplinary team approach. And, laboratories are expensive facilities to build and operate.

The pace of discovery and the potential hazards of research have dictated that sophisticated mechanical and electrical systems and services are available to create pleasant, productive, and safe environments for scientific inquiry. It is not unusual for the building volume devoted to systems and services to exceed the usable, or served spaces. The relationship between the service volumes and served volumes in a laboratory facility is of paramount concern to the designer. However, a machine-centered design approach must be tempered by an understanding of how teams of researchers work and interact with each other and their environment.

The research scientist and the architect play complementary roles in the design process that results in a successful new laboratory. Generally, scientists are concerned with the micro scale. Studying a system's components in minute detail under a microscope is how they excel. Scientists are used to dealing with specifics; being precise is second nature to their culture. Things need to be quantified!

Architects, on the other hand, have been trained as generalists. Initially, they are inclined to look at the big picture. How will the project interact with the community, the available infrastucture, the environment? How will the laboratory users interact while performing their tasks? How can the proposed facility enhance and contribute to research? These questions are paramount to generalists. Issues need to be qualified and priorities established!

Before attempting to initiate a design concept, the scientists should prepare a mission statement about their work. What are their goals? How will they be achieved? Who will contribute in the achievements? What is the image for the facility? Identify the constraints. This exercise will help the research institution establish priorities and communicate among themselves and with their architect.

The architect should not have preconceptions about laboratory design. Often the best ideas for design concepts come from the building's users. The talented designer will listen to the mission statement for ways of creating opportunities out of challenges. Innovative concepts should be explored at both the micro and macro scale as a collaborative effort between the research scientist and the architect. By nature, many of the activities that occur in a laboratory setting are on the cutting edge of technology. The development of new and better processes and discoveries is the goal of research. Change, then, is inevitable over time. This establishes adaptability as a virtue for the lab facility.

Many research laboratories are developed around modular concepts that can provide maximum flexibility with a minimum of underutilized investment. The key ingredient is to provide appropriate structural volume arranged in a modular way that can accommodate a wide range of mechanical and electrical environmental systems.

Control of the environment is crucial to the success of scientific research. Over half of a "wet" lab facility construction costs are devoted to the mechanical and electrical systems. ("Wet" labs are defined as those labs with pure water and chemical fume hoods.) These systems contribute to the safety, reliability, efficiency, and productivity of the research work.

A generous vertical floor-to-floor dimension is essential for pharmaceutical or biological research laboratories in order to provide adequate space for the horizontal mechanical and electrical distribution systems. These systems can be placed above a suspended, accessible ceiling or within a dedicated interstitial service floor sandwiched between alternate laboratory floors. Either arrangement can be applied to a number of plan options. Obviously, the interstitial services floor concept is more costly, but it provides good long-term adaptability and a more efficient maintenance program. The Office of Management and Budget (OMB) under recent federal administrations would not permit federal funding for the interstitial floor concept because of the high initial cost premium for the larger building volume.

Wet labs consume staggering amounts of energy. In fact, they are energy "monsters."(One six-foot fume hood requires 1,100 to 1,200 cfm of 100% fresh, conditioned air 24 hours/day, year-round.) Strategies for reducing energy consumption include variable air volume (VAV) systems for the building and hoods, heat recovery techniques, such as plate exchangers and heat wheels, electronic direct digital automatic controls (DDC). Unfortunately, these relatively sophisticated measures only make a small dent in reducing operating costs and energy consumption.

Funding for research is expected to continue and grow over the next decade. In 1992, federal funding from the National Institutes of Health totaled 7.3 billion dollars. According to the Boston Redevelopment Authority, over the next ten years the medical research institutions in the Boston area alone will add an estimated 2.6 million square feet of research space and employ an estimated 3,100 to 5,500 new scientists and support staff.

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"Hot" Areas of Research

Over the past several decades we have been experiencing the age of "microscience," research at the scale of the micron, one-millionth of a meter. Now, we are crossing the threshold from "microscience" to "nanoscience." The nanometer is 1,000 times smaller than the micron, or one-billionth of a meter. Current research is occurring at the molecular level without the aid of optical microscopes. This fascination with smallness and the quest to understand the basic building blocks of matter is changing the research laboratory in all fields of science, and it is integrating the sciences of chemistry and physics. Some of the major areas of research will occur in the following laboratory types.

Biomedical and Pharmaceutical

Drug research takes place on several different levels of experimentation. A drug's chemical reactions and structural modifications at the molecular level are the particular concerns of basic science. In the next stage, the pharmacological action of the drug on organisms is studied either at the cellular level (which includes viruses and bacteria) or in multicellular organisms (such as rodents and other mammals). Animal experimentation can be scaled to varying degrees of complexity, ranging from use of lower animals, such as worms, to more sophisticated studies with primates. Naturally, the more highly developed the experimental model, the more clinically applicable to humans are the expected results. With drugs that have selective pharmacological action, the organ affected, whether the liver, heart, or kidney, can be removed from the animal and studied as isolated tissue. Only after a drug has been thoroughly studied—not only for physiological effects but also toxicity—is human experimentation considered. The final step, clinical testing, involves administering the test drug to humans, according to the provisions of well designed guidelines provided by the Food and Drug Administration (FDA).

Each stage of drug research has its own significance, but the results do not necessarily carry over from one stage to the next. For example, the effects of the drug being studied on isolated rat liver in the test tube may be observed and measured. When the same drug is given to a living rat, however, the effects may not be similar. The rat liver in its normal anatomic setting is affected by multiple factors that may reinforce, distort, or otherwise alter the action of the drug being studed. Clinical testing is even more complicated. Humans are more complex than other animals, as well as chemically different in some respects. Futhermore, people have highly developed nervous systems, hence emotions and feelings, which affect them in elaborate and as yet poorly understood ways.

Biomedical and pharmaceutical research usually includes a vivaria, a special environment for holding animals or plants. The laboratories are wet labs with benches, sinks, pure water, chemical fume hoods, and standby power to protect the experiments.

Electronics and Computers

The backbone of modern technology is electronics. From sophisticated defense strategies such as "Star Wars," or SDI, to everyday consumer products like the personal computer, videocassette records and television, electronic and computer technologies are ubiquitous. A strong argument can be made that these technologies have improved our efficiency in information processing and communications to the point of causing massive personnel layoffs in businesses around the world. Nevertheless, the demand will remain strong to continue making improvements to these technologies.

Generally, electronic laboratories are considered "dry" labs, without much need for sinks and chemical fume hoods, although recently, experimentation is occuring in neural networks of electrochemical energy. Some scientists believe there may be the possibility of creating an electrochemical computer that would more closely mimic the brain's methods of processing data.

Optics and Lasers

Elimination of vibration is paramount for most facilities where optics are studied, especially using lasers. Light waves are measured in angstoms, a unit that is one ten-billionth of a meter. Stability is supreme in measuring in these units! Some types of laser systems require dedicated exhausts and chilled water cooling systems.

Magnets

Powerful electromagnets are used in physics, chemistry, and biology research. Controlled magnetic fields have proved to be a valuable tool in improving the technology of semiconductors, superconductors, and the imagery of living tissue. Electromagnets require powerful direct current rectifiers. They can also require tremendous cooling systems and a sophisticated shielding technology to contain the potentially harmful transmission of the high energy fields given off by the high voltage direct current. Some special magnets are operated under very low temperature conditions for superconductivity.

Materials

Materials science laboratories often have extreme temperature test chambers for both heat and cold. These labs usually require a high bay space with an overhead "H" crane for building large test mock-ups.

SUMMARY

Laboratory configurations can differ widely according to use and service requirements. Classification categories include discipline (chemistry, physics, biology), level of study (routine, teaching, research), equipment provisions (rigs, benches) and level of services (wet, dry).

Regardless of the classification, the modern research lab should not be so rigid as to accommodate just a single fixed use. Even the most short-sighted institutions are recognizing that rapid changes in technology demand adaptable, multi-use research facilities. New fields of study and changing state-of-the-art equipment require that adaptability be a prime concern in lab design.

One strategy for flexible planning is to group the wet waste drains that are gravity dependent, thereby preserving large areas with services only feeding from overhead. This will allow more freedom for future changes when adjusting to new technologies. Wherever possible, tables rather than fixed benches also make it easier to reconfigure space when necessary. The most important strategy for facility adaptability is to provide modular systems, where possible, that can expand incrementally, and to provide enough physical space initially to house that growth.

Planning a research facility cannot be a unilateral endeavor. Unlike other building types, ventilation and exhaust systems, the lungs of the beast, play a primary role in determining how the various spaces are organized. Cost trade-offs must be considered at every turn. Occupant safety is a major concern, as with any building type, but with the presence of potentially hazardous materials and processes, safety must be considered with every decision. Zoning issues, institutional regulations, and code constraints need to be thor-

oughly analyzed initially. Above all, good communications among all participants, especially the scientists, administrators, engineers, safety officer, cost estimators and architect, are required.