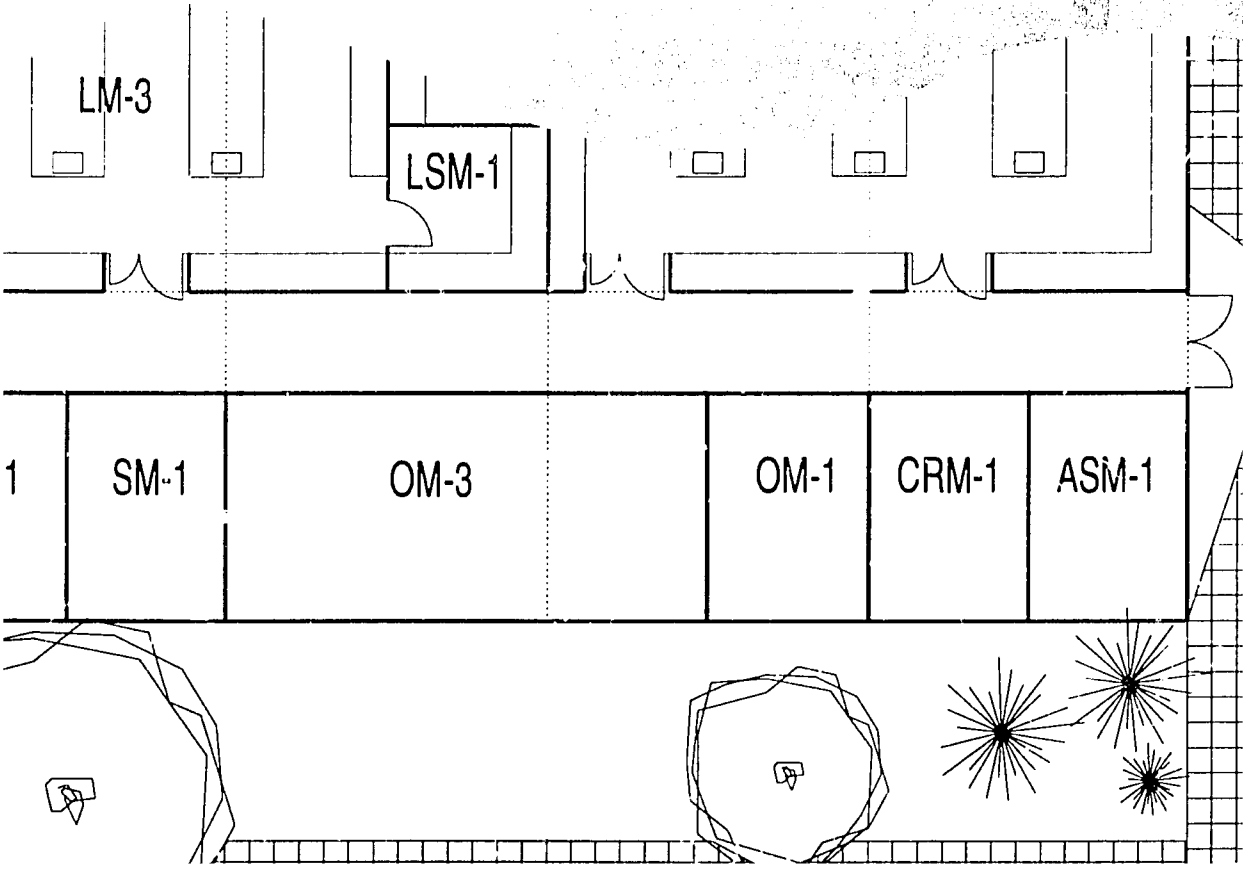
ISNAR

RESEARCH MANAGEMENT GUIDELINES

Guidelines for Planning and Designing Agricultural Research Buildings



The mandate of the International Service for National Agricultural Research (ISNAR) is to assist developing countries in bringing about lasting improvements in the performance of their national agricultural research systems and organizations. It does this by promoting appropriate agricultural research policies, sustainable research institutions, and improved research management. ISNAR's services to national research are ultimately intended to benefit producers and consumers in developing countries and to safeguard the natural environment for future generations.

ISNAR offers developing countries three types of service, supported by research and training:

- For a limited number of countries, ISNAR establishes long-term, comprehensive partnerships to support the development of sustainable national agricultural research systems and institutions.

- For a wider range of countries, ISNAR gives support for strengthening specific policy and management components within the research system or constituent entities.

- For all developing countries, as well as the international development community and other interested parties, ISNAR disseminates knowledge and information about national agricultural research.

ISNAR was established in 1979 by the Consultative Group on International Agricultural Research (CGIAR), on the basis of recommendations from an international task force. It began operating at its headquarters in The Hague, The Netherlands, on September 1, 1980.

ISNAR is a nonprofit autonomous institute, international in character, and apolitical in its management, staffing, and operations. It is financially supported by a number of the members of the CGIAR, an informal group of donors that includes countries, development banks, international organizations, and foundations. Of the 18 centers in the CGIAR system of international centers, ISNAR is the only one that focuses specifically on institutional development within national agricultural research systems.

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Guidelines for Planning and Designing Agricultural Research Buildings

isnar

International Service for National Agricultural Research

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This manuscript was prepared by Robert W. Etheredge, Jr., A.I.A., an architect and international development consultant with more than 25 years' experience in designing a wide range of agricultural research buildings for projects in developing countries. His work was assisted by the ISNAR internal advisory panel on research buildings.

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Preface

ISNAR's reviews of agricultural research systems in developing countries have repeatedly identified problems in developing and managing physical resources as an important factor among other critical factors determining the effectiveness of national agricultural research programs. Insufficient, inaccessible, or unusable information on most aspects of development, planning, design, and maintenance of buildings is a common constraint on agricultural research managers.

With these "Guidelines for Planning and Designing Agricultural Research Buildings" ISNAR aims to fill that information gap. The guidelines contain a wealth of observations and experience collected during field visits to more than 100 agricultural research institutions and universities in six regions of the world. During these visits, research institutions in all major ecological zones were studied under prevailing conditions and desirable design features were identified.

The following chapters bring that experience—previously unpublished in a single source—to managers, scientists, administrators, and numerous others.

The Hague, September 1993.

Christian Bonte Friedheim.

Christian Bonte-Friedheim
Director General

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FOREWORD

In the past, little information has been available to assist agricultural research managers in the planning and design of facilities such as laboratories, offices, and research support areas. Modern technology in both laboratory and field equipment has far outpaced the design of research buildings. Many research institutes occupy buildings that are poorly suited for the sophisticated equipment they house. That is why today, more than ever before, agricultural research managers are seeking professional guidance and advice in the planning, design, and redesign of buildings for agricultural research.

These guidelines aim to provide managers with ideas and practical advice on planning and designing buildings for agricultural research. The main focus is on offices, laboratories, and ancillary support buildings in developing countries, primarily in the tropical regions.

The presentation of material has been made as simple as possible, both to stimulate thinking and imagination and to make issues of design and construction easily understood by a wide audience. These guidelines do not intend to answer every question about public works development. Instead they aim to inform managers of what to expect in the process of facilities development. The guidelines should be used judiciously as an information source. Ideas presented herein should be modified and varied to suit each situation individually. Just as agricultural research itself must remain flexible, these guidelines should also be flexible and not be applied as rigid rules.

Who are the intended beneficiaries?

Research managers, although a prime target, are not the only people who will benefit from the information presented. Others associated with planning and developing facilities for agricultural research will also benefit. Administrators, agriculturalists, architects, engineers, builders, lenders, government planners, and finance agencies are just a few of these additional beneficiaries.

Within the text institutional beneficiaries are referred to as "managers" or "management" as a generic term without regard to their actual professional capacity. Where the words "lender," "grantor," or "donor" appear, they are intended to be synonymous and refer to any external agency providing funds for agricultural research facilities. The term "planner" or "designer" is also generic and refers to architects, engineers, and others associated with the technical aspects of design and planning.

PART 1

Planning a Building Program

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Chapter One—Predesign Development

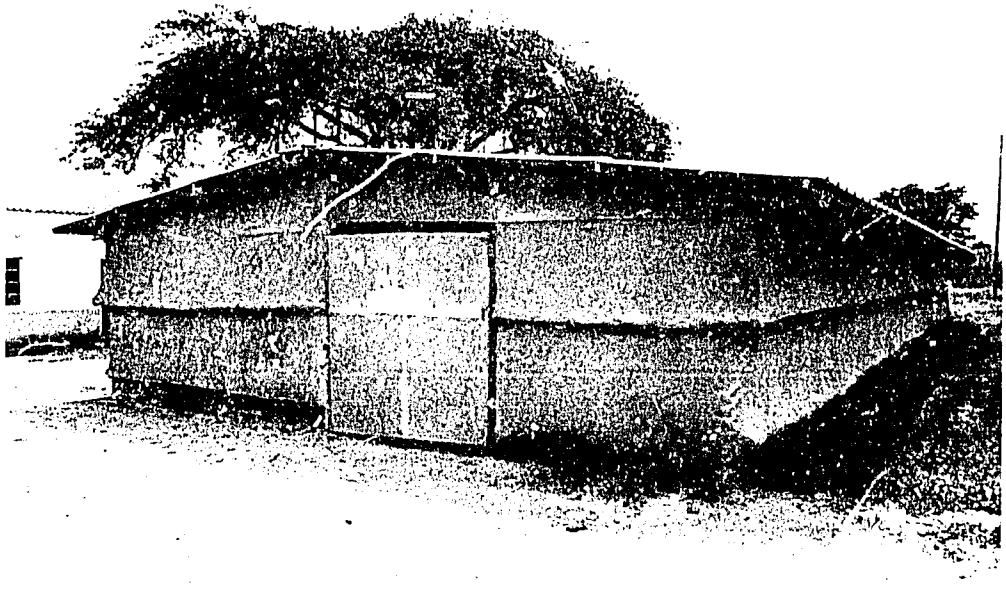
Assessing the Needs of Research Programs

Managers of agricultural research are usually faced with planning and design decisions very early in the physical development process. As an example, managers may be asked to estimate how much space is required to accommodate a specific research program or to provide estimates of building costs long before financing actually becomes available to begin construction.

Determination of the physical requirements of buildings is done by designers working in close collaboration with research managers and their scientific staff. Interaction among designers, management, and scientists can help to ensure that the research programs and physical facilities complement each other.

Managers are urged to plan modest facilities closely tuned to the needs of the research programs to be housed. To be most effective, facilities should tie in with a national strategic plan for agricultural research. This 10- to 12-year plan should be prepared by a working group with representatives from the ministries of agriculture, planning, and finance as well as from institutions such as national agricultural research apex bodies and the country's main agricultural research institutes. Only by being closely involved in the preparation of the national strategic plan can individual institutes develop operating plans that clearly define how they intend to help the country to achieve its strategic goals.

Zimbabwe. This is an example of postharvest research that can be adapted by local farmers. The very inexpensive onion storage building is constructed from simple poles, burlap, and a cement wash applied over the burlap.



Basis for determining physical requirements

Six major factors determine the physical requirements of a particular location or research program:

- the scope and nature of the research to be carried out,
- present staffing,
- immediate and short-term expansion or reduction in staff,
- projection of future staff requirements,
- the size and quantity of equipment to be accommodated and the number and frequency of tests to be conducted,
- in case of modification of an existing facility, a utilization study of the existing space.

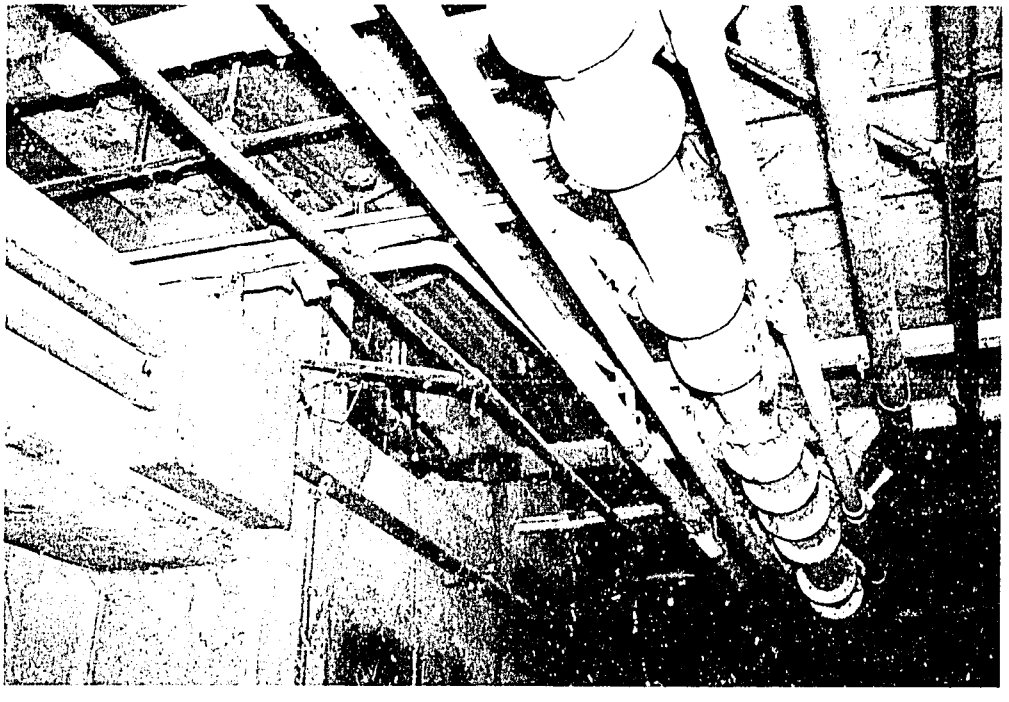
In determining the physical requirements of offices, the number and grade level of staff or their position within the organizational structure are the primary considerations. For most laboratories, however, physical requirements depend more on the type of research to be carried out and the quantity and size of the equipment to be installed.

Plan for expansion

Only a few years ago managers were encouraged to plan buildings for personnel expansion over a five- to seven-year period. In most developing countries, however, staff growth has not been as rapid or as extensive as was anticipated. In many new facilities, managers have been faced with the immediate problem of using extra space. Whether to allocate excess space or allow it to remain empty until additional staff is employed is often a complex issue. Once allocated, however thinly spread out the staff may be, it can be difficult to unallocate space to accommodate new staff.

The importance of making reasonably accurate predictions of how research programs will be strengthened cannot be underestimated. Constructing too much space wastes valuable financial assets. Constructing too little space results in overcrowded facilities. Most institutes are now planning buildings to accommodate slower increases in staffing. Overbuilding is being discouraged. Buildings now must be designed to permit extensions and additions to be made when needed with minimal interruption of ongoing operations.

Nigeria: Exposed utilities make future modifications and repairs easy.



Maintain design flexibility

Regardless of how well design parameters were set in the planning stages of a project, the likelihood is great that at least some parts of the buildings will need to be modified once construction is complete. Managers should be prepared for change. Changes may be as simple as the relocation of a door or the rearrangement of one or two laboratory benches. Or they may result in a complete remodeling or relocation of a research program to a different building.

Modifications to laboratories often result in utility services being disconnected and lines being relocated. Nonetheless, only very few laboratories have been designed to make such changes as simple as possible with the least disruption to adjacent construction. Plumbing and electrical supplies are often either buried in concrete floors or built into walls covered with plaster or tile. Installations such as these complicate later modifications and therefore should be avoided.

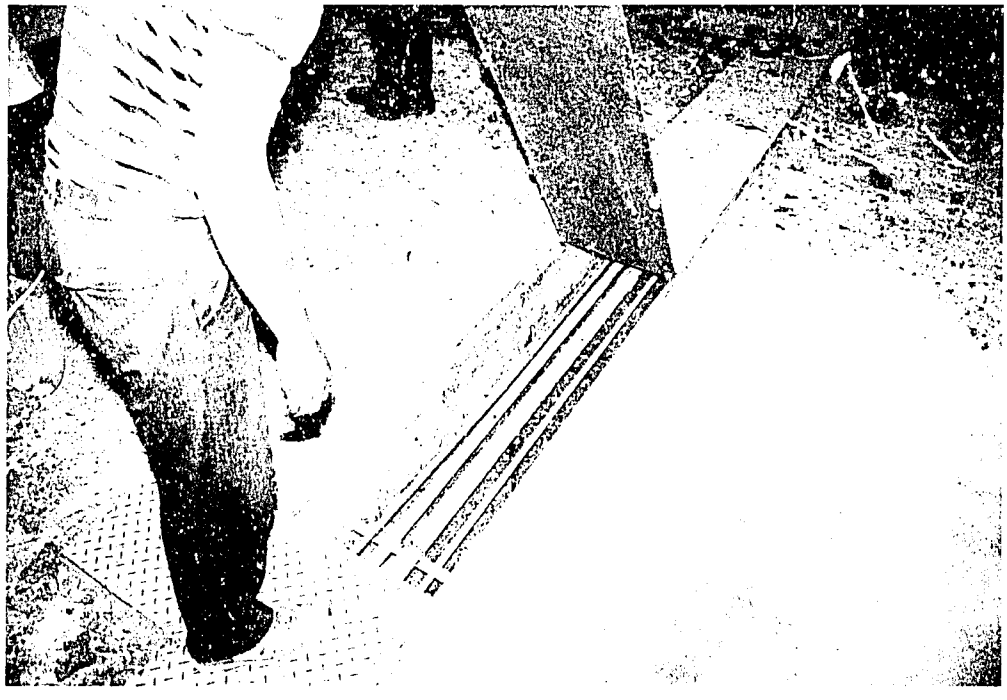
In planning buildings for agricultural research, early consideration should be given to providing ready access to all utilities. Utilities should be either surface mounted or strategically placed in excavated areas, chases, tunnels, or other easily accessible locations. Examples of excellent exposed utility systems are those used at the agricultural research station in Palmira, Colombia and at two international research institutes: the International Center for Tropical Agriculture (CIAT) in Colombia and the International Institute of Tropical Agriculture (IITA) in Nigeria.

Remember, no matter how well a facility is initially designed, changes and modifications are inevitable. Be prepared. Modifications should be anticipated and provisions made for them in the very early stages of design.

Management Planning Groups

Agricultural research managers should avoid making unilateral decisions in planning physical facilities. From the very early stages of design, planning should be an integrated effort involving research managers, administration, and scientific staff, as well as the building designers themselves. Within the research organization small working groups should be formed to supply and exchange information with the design service. These groups should consist of program and

Zambia. *As an alternative to exposing all utilities, a trench with a removable cover can be used effectively.*



commodity leaders and others directly associated with the facilities being planned. Working group should be as small as possible, preferably with no more than four to six members.

Design Services

Any team providing design services for agricultural research should aim primarily to provide an infrastructure suitable for the research envisaged to be carried out. Additionally, the infrastructure must provide a safe shelter for its inhabitants and be economical both in original cost and in future maintenance cost. Facilities should also be pleasing to look at, both individually and as an entire complex. To accomplish these ends, management should seek the services of individuals with as much experience as possible in planning, designing, and constructing facilities for agricultural research.

Seldom do agricultural research organizations need to maintain as a part of their permanent cadre a design team capable of producing drawings and bidding documents for the facilities proposed to be constructed. More frequently an organization may have one or two staff members capable of preparing simple drawings for remodeling existing facilities. Two exceptions are the excellent design departments that have been maintained by Brazil's national agricultural research institute (EMBRAPA) and the agricultural research institute of Colombia (ICA) for about the last 15 years.

Public works versus private firms

An institute anticipating entering into a development program of even moderate size most likely would request the services of a government agency, such as public works, or would employ a private firm (or individual) to assist in planning new buildings. There is about an even split between private and public planning for agricultural research facilities.

Public agencies are chosen over private firms usually due to their accessibility and availability, and for reasons of economy. There is normally no charge for services performed by public works or similar agencies. Given the opportunity, however, most managers of research institutes prefer to have planning done by the private sector. Public works departments normally have a large backlog of work, which tends to cause frequent delays in completion of designs and bidding documents. During delays construction costs are likely to rise due to inflation. In the long run, there is a good chance that any financial savings accrued by using public works will be lost as a result of increased construction costs.

A viable alternative to maintaining an in-house design capability or having public works prepare the bidding documents is to employ a private firm to plan and supervise construction of the project. In selecting a firm, management should pay careful attention to the firm's experience and present workload. Preferably, a firm with some degree of experience in designing facilities for agricultural research should be chosen. Managers should be prepared to pay a total of six to 10 percent of the cost of construction for design and supervision services.

In certain cases, especially for sophisticated buildings such as animal diagnostic laboratories or similar high-technology installations, the services of a specialized consultant should be sought. Special techniques involving air handling, materials movement, radioactive elements, and the like also dictate a more thorough study of the engineering aspects.

Overview of design services

What type of design and planning services should an organization seek in developing a building program? Regardless of whether a public agency or private firm is chosen a high level of professionalism should be expected.

First and foremost, an institute should expect the selected design service to allocate sufficient time to become familiar with all phases of the research envisaged to be done in the proposed buildings. There must be a close working relationship between the person in charge of the physical design—most appropriately an architect—and the scientists who will be using the facilities. Designs must be directly related to research programs as well as to the numbers, disciplines, and levels of staff to be accommodated. Perhaps most importantly, to properly prepare a project the designer must have a good estimate of how much money is or will be available for construction. An architect or planner has a professional obligation to design a project that can be constructed within the budget established by the client.

The design service should be expected to provide the following professional services:

- provide the client with an analysis of the area required to support the proposed research and its required staff,
- estimate the cost of construction,
- prepare the physical designs of the project,
- prepare technical documentation to allow the client to competitively bid the project,
- assist the client in receiving and evaluating bids,
- supervise the quality of materials and workmanship during construction,
- approve modifications to the construction contract and periodic payments to the contractors,
- assist the client in final inspection and acceptance of the project once it is complete.

Terms of reference

Regardless of whether a government agency or private concern designs the facilities, terms of reference (TOR) must be prepared. The TOR clearly describe the responsibilities and duties of the organization chosen to design and supervise the project. If a private concern is selected, the TOR should form a vital part of and be attached as an annex to the contract. The sample TOR on pages 17 and 18 has been used for many agricultural development projects. With suitable modifications, it should serve in almost any situation. The words "architects and engineers," "a/e firm," and "architect" should be changed to suit the individual situation.

Steps in Developing a Building Program

Securing adequate financing to construct the required facilities is one of the most important steps in any building program. Financing can be provided by the country government itself or by other financial assistance agencies: donors making outright grants, lending agencies providing both long- and medium-term loans, and other situations combining one or more of these options.

Before financing is made available, however, agricultural sector studies are generally made. Also, strategic plans are usually prepared for agricultural research. These studies and plans generally define the type and extent of agricultural research needed by the country. Facilities are then designed based on these studies and plans.

Immediately after sector studies and strategic plans are developed, the research organization should solicit professional services to assist in designing the facilities. By accelerating the planning work at this initial stage valuable time can be saved. Time saved now will mean advanced implementation of the actual construction and savings later in building costs.

One of the first tasks of the selected design team is the preparation of conceptual designs for the facility. These designs reflect a rough estimate of the space required to accommodate each research program, as well as accurate projections of staff expansion or reduction. Conceptual designs combine tables of accommodation (see pages 64-69) and freehand sketches of floor plans, graphically indicating the relationships of the areas required.

After financing is secured and the conceptual designs completed, physical development programs are normally carried out in five sequential stages: preparation of schematic designs, design development, preparation and distribution of the construction documents, bidding, and construction.

Schematic designs

Schematic designs are single-line, scaled drawings of the proposed facilities indicating use of space and circulation within the buildings. At this point in the design process, major building materials are selected and a rough estimate of cost is submitted to management. Prior to advancing to the next phase, management should approve the schematic presentation package.

Design development

Design development is the second stage of the development program. It is during this stage that plans, facades, construction details, engineering aspects, and finishes within the buildings begin to be studied. No longer are drawings schematic. Thickness of walls is shown on floor plans, doors and windows are indicated in their proper positions, and building cost estimates become more refined to ensure that the facility is being planned within the budget. Once approval is given to this

Terms of Reference for Executive Firm of Architects & Engineers

Following are terms of reference (TOR) defining the qualifications, responsibilities and duties of the firm of architects & engineers (a/e firm) scheduled to be employed by the (name of institution) to provide master planning and architectural/engineering services for agricultural research stations at (list of stations).

Qualifications

The selected a/e firm must be licensed (or satisfactorily registered) to perform architectural/engineering services in (name of country) and must be able to perform the duties outlined in the following TOR without subcontracting the whole or any part greater than 20 percent of the contract work which the firm is expected to carry out without prior approval of (name of institution). The firm shall have at least five years' experience in designing agricultural research facilities including rural edification, irrigation schemes, electrical distribution, water supply systems, and sewerage schemes.

Terms of Reference

Specifically, the a/e firm will be expected to perform the following functions.

1. Prepare a detailed master plan of the research stations (list of stations), at a convenient scale to be determined by (name of institution), indicating the location of

   (a) existing buildings and appurtenances;

   (b) electrical supply and distribution lines;

   (c) telephone distribution lines;

   (d) water supply and distribution lines;

   (e) sewerage systems;

   (f) property boundaries, internal roads, and fences; and

   (g) new infrastructure. Contours will be shown on plot plans at appropriate differences in grade levels.

2. Prepare preliminary designs with probable cost estimates for each of the following projects:

   (names of each individual station to be developed)

   (Institution to complete a detailed description of projects and insert here)

3. After approval of preliminary designs by (name of institution), the a/e firm shall advance the approved designs into working drawings with dimensions, notes, and details suitable for competitive bidding using (local or international) bidding procedures. Simultaneously with preparation of detailed drawings, the a/e firm shall prepare technical specifications, bid conditions and, where applicable, bills of quantities.

4. Provide assistance to (name of institution) as required, in advertising for competitive bids in agreement with (local or international) competitive bidding procedures.

5. Assist (name of institution) as required in preparing and formalizing contracts for construction of the facilities for which bids have been received.

6. Supervise the quality of construction by making at least weekly visits to the site(s) during the construction period. After each visit the a/e firm shall submit a report to (name of institution) which clearly defines, inter-alia:

   (a) physical progress since the previous visit;

   (b) cumulative value of work done to date;

   (c) total paid to contractor to date;

   (d) cumulative percent completion, both physically and financially;

   (e) changes made in the contract or amount of work to be done;

   (f) outstanding issues needing attention; and

   (g) estimated date of contract completion.

7. Maintain books on each contract indicating the financial status of the contract and, after receipt and approval of payment requests made by the contractor, issue authorizations for (name of institution) to pay the certified amount.

8. Ensure that the contractor has the proper types and amounts of guarantees and securities during the process of construction and that proper insurance coverage is maintained.

9. Review and submit to (name of institution) change orders representing modifications in the contracted amount of work to be done with the corresponding value of such work. After authorization of such changes by (name of institution), the a/e firm shall issue an order to the contractor to carry out such changes in the work as may be required.

10. Upon completion of the work as prescribed in the contract, the a/e firm shall make a final inspection of the work with the contractor and representatives of (name of institution), and certify that the work has been carried out in agreement with the terms of the contract between (name of institution) and the contractor. The a/e firm shall issue a final certification for payment based on satisfactory completion of the work.

phase of the design only very minor modifications should be made by management.

Construction documents

Construction documents are the documents that provide bidders with the information they need to prepare and submit competitive proposals for the construction of the project as designed. They include completely detailed drawings, technical specifications, and bidding conditions—all clearly describing exactly how the project is to be constructed and with what materials. Most countries also require a materials quantity survey to be prepared as a part of the construction documents. Before the construction documents are begun, the facility designs should be approved by management. Further modifications to the designs should be held to an absolute minimum.

Bidding

Bidding a project should begin only after the construction documents are complete and approved by management in consultation with their legal advisors. Prospective builders are invited by management, either privately or publicly depending on legal restrictions, to submit sealed bids for the construction of the project. During the bidding period, normally 30-45 days, the design team and management jointly hold periodic meetings with the bidders to clarify any questions or doubts that may have arisen. Addenda can be issued to each of the bidders. These make official any changes or modifications to the original bid documents. In this way all bidders are kept advised of decisions or changes made during the bidding period. After all bids have been received, proposals should be opened publicly and tabulated. Management can request specialists to assist in the opening of the bids.

Evaluation of bids should be completed as rapidly as possible, usually within 30 days after all bids have been received and opened. The organization in charge of design should assist in evaluating bids and should make a recommendation as to the successful bidder. The successful bidder is not necessarily the one submitting the lowest bid, but should be the lowest *evaluated* bid. This distinction takes into consideration price, construction time, contractor's equipment, personnel, financial capability, and past performance.

Construction

Construction may last from a few months to a few years, depending on the size and scope of the project as well as on the availability of financing. During the entire construction period management should ensure that qualified personnel are on hand to supervise the work being done by the contractor. Only with qualified supervision can there be assurance that materials and workmanship will be equal to, or better than, those originally contracted for. Preferably, supervision is carried out by the group that designed the project. There are no hard and fast rules as to the best schedule for inspection of the work. Most importantly, supervision must be frequent and thorough enough to protect the organization signing the contract from receiving a quality of construction inferior to that agreed upon.

Côte d'Ivoire: Quality is sacrificed when concrete is mixed manually.

Use of Existing Facilities

In some aspects, planning a new research center is easier than making decisions involving the use of existing facilities. In developing a new research complex, the major problem is how to design buildings to accommodate the research programs and the estimated number of staff. With existing research centers, decisions must be made as to the renovation or recuperation of facilities, reassignment of space, demolition and removal of facilities, and removal and replacement of existing facilities with new ones. The word "facilities" can include buildings, utilities, or even land, fencing, roads, and parking. However, these guidelines focus mainly on buildings.

Renovation

The need for renovation, or upgrading of facilities, may result from a simple reallocation of space or from deterioration. Maintenance is another reason to renovate. This can include "patch and paint" work, hardware repair on doors and on windows, replacement of broken glass and screens, utility upgrade or replacement, and refurbishing of furnishings and finishes that have deteriorated through normal use. Renovation work often can take advantage of modern technology in materials and finishes that were not readily available at the time the facility was constructed.

It is sometimes difficult to separate renovations from recuperations. Renovation should be considered to cost no more than 20-25 percent of the replacement cost of the facility. Contracts for renovation seldom attract anyone except local builders who work primarily on small-scale projects. The work usually is carried out under a cost-plus type of contract. Some simple renovations can be performed by the research institute's own labor force. This type of work is often referred to as "force account." Renovation costs can be budgeted as a capital expense financed with either local funds or with funds from loans and grants.

Recuperation

Recuperation of a facility is more extensive than renovation and can easily cost 50-60 percent of the facility's replacement cost. Recuperation is best done under contract as opposed to force account. This contract may be for a fixed sum. However, it is more often based on the direct cost of materials and labor plus a fixed percentage or fee to cover the contractor's profit and overhead. Profit and overhead normally run no more than 25-35 percent of the cost of labor and materials.

Although the builder may be able to give a fairly accurate estimate of recuperation costs, the final figure cannot be determined until the project is complete. This is due, in part, to unforseen circumstances such as concealed utilities and variances in construction methods. The builder should be furnished with a clear description of the work to be carried out to enable him to prepare an estimate of cost and implementation time as accurately as possible. About 10-20 percent of the total estimated cost should be added to cover physical contingencies and unknown factors likely to arise during the course of construction.

Reassignment

Prior to designing any new buildings, an analysis should be made of the use of the existing space. Managers may find that by readjusting and reassigning space within existing facilities, the cost of constructing new facilities can be reduced. Reassignment of space always brings some problems. Once an area has been assigned to a person or an entity within an organization, that entity is usually reluctant to give the space up. However painful reassignment may be, it is in the best interest of the organization to establish a clear-cut policy preventing an occupant from feeling that an area is permanently assigned.

Demolition

Demolition is the complete removal of existing facilities and clearing the site of rubble. It should be done under a lump sum contract that stipulates that all materials are to be removed from the site and become the property of the demolition contractor (except any that are specifically mentioned in the contract). Upon completion of demolition the site should be left clean and ready for new construction to begin. Most demolition contractors do not have the organizational setup to construct new buildings.

Removal and replacement

Where replacement of another facility is anticipated after demolition, two distinct contracts should be signed. Frequently, portions of buildings must be demolished in order for new portions to be built through an expansion program. In these cases, management must clearly define which portions of a facility are to be removed and

insist that demolition contractors physically protect the portions expected to remain free from damage. In the demolition contract, the contractor should be made liable for any damage to other buildings or utilities. Again, the site should be left clear of all debris and rubble after buildings have been removed.

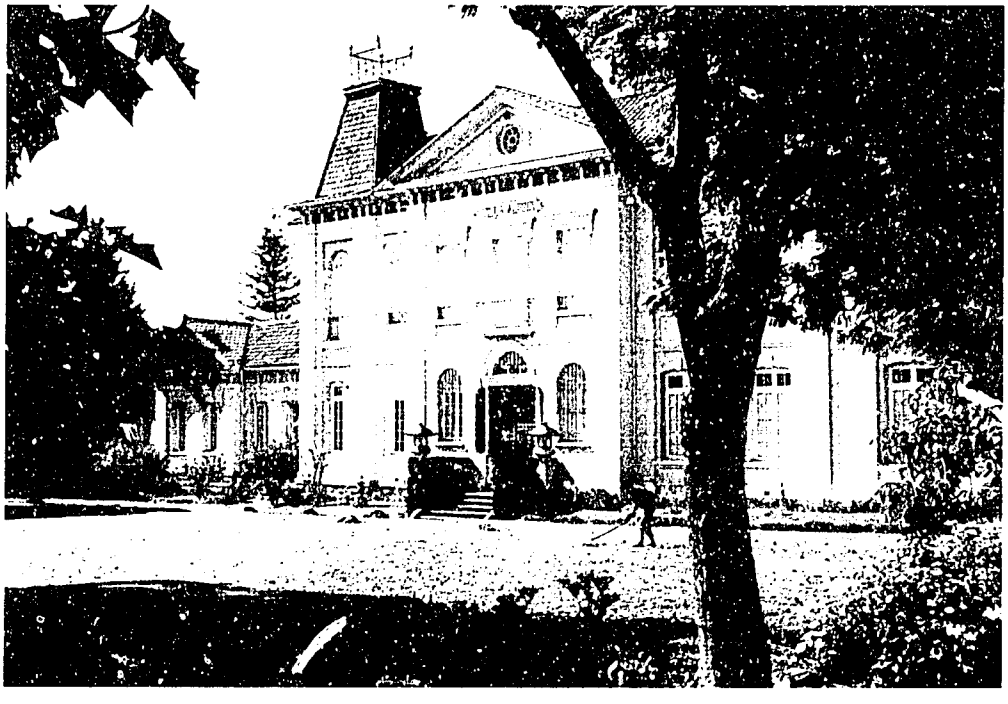
Chapter Two—Adequacy of Facilities Maintenance

Funds for Maintenance

Without doubt, it is much easier today to get funds for new construction than it is to get proper funding for the regular maintenance of existing facilities. Annual funds for maintenance are insufficient in virtually every developing country. In most cases it is very obvious that buildings for public-sector agricultural research are not being adequately maintained. But why not?

Are maintenance funds really inadequate or is it primarily that appreciation of the importance of maintenance is lacking? Inadequate funding usually gets blamed. Yet simple maintenance that only requires labor is also being ignored. One research manager explained the situation: "When you are accustomed to a problem, you no longer see it as a problem." How true! Managers must begin to see lack of maintenance as a serious

Bolivia. With proper care, research buildings 60-70 years old can still effectively serve agricultural research needs.



problem rather than accepting it as something that cannot be improved.

National budgets are normally divided into two major sections: operating and capital (sometimes referred to as development). Capital monies are normally used for new construction and for the purchase of equipment. Funds from outside sources to be used for these purposes also enter the national budget in this category. Operating funds, on the other hand, are used to pay for research operations including salaries, operation of vehicles, purchase of consumables, payment of utilities, cleaning of facilities, and maintenance and repair of buildings and equipment. Almost without exception, operating funds for agricultural research in developing countries have shrunk to critical levels over the last decade.

To illustrate this, a research manager in Brazil reported that his fixed operating costs used to represent 35 percent of his total operating budget. The remaining 65 percent was available for maintenance, the purchase of inputs, travel, and subsistence. Over the years, however, this ratio has reversed. The amount now available for variable operating costs is no longer sufficient to cover expenses. Salaries cannot be reduced and institutes are reluctant to reduce personnel. To compensate for funding deficits, maintenance of buildings and equipment is usually the first budget item to be reduced.

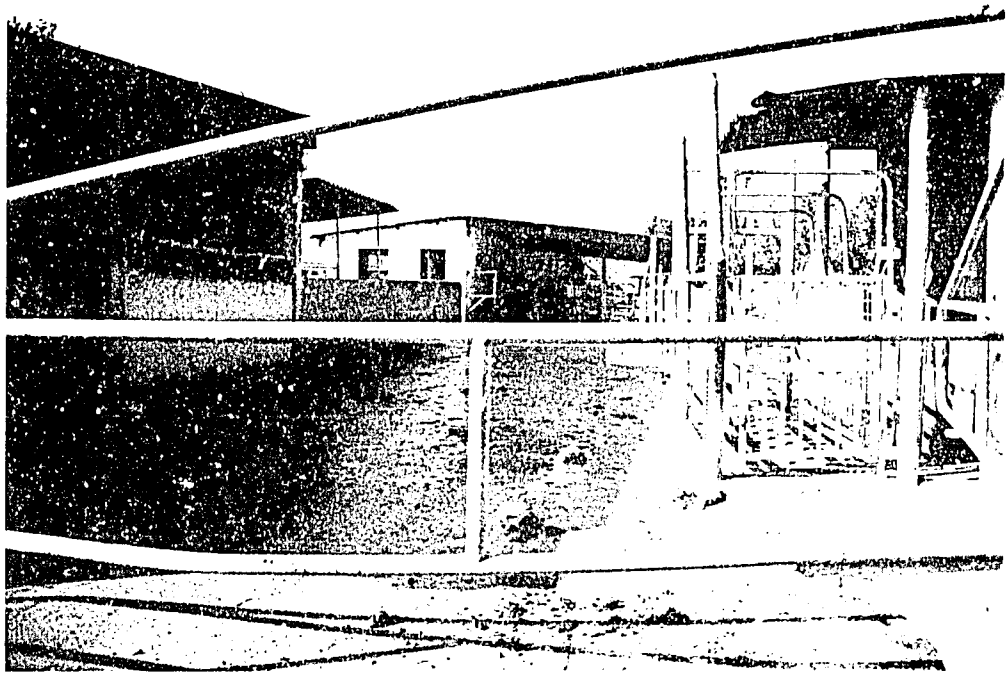
As a minimum, operating funds should be increased in line with the annual rate of inflation. In countries with high rates of inflation, however, increases of less than one-half the inflation rate are common.

To overcome the problem of decreasing operating budgets, one international agricultural research center, CIAT in Colombia, categorizes maintenance expenses over the equivalent of US $1,000 as a capital expenditure. Projects costing less are paid from operating funds. Although there is nothing magic about this figure, it does appear to be a reasonable limit and a guide as to whether repairs should be done with in-house capacity or through outside contracts. Each organization should establish its own limits in accordance with the strength of its maintenance section and the availability and cost of materials and labor in a particular region.

What funding level is needed?

How much money is really needed for maintenance? Currently, most institutes spend only

Spain *Animal facilities require extra operating funds and maintenance.*



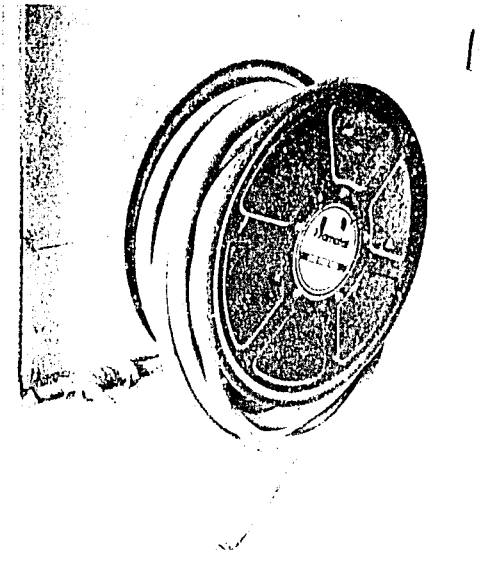
about 0.3 to 0.6 percent of the replacement value of a facility on maintenance. This amount must cover the cost of physical maintenance, such as repairs and painting, as well as cleaning and utility costs. It is estimated that no less than two to three percent of the **present-day replacement cost** of a facility should be spent annually to adequately preserve and maintain a facility. If there are extensive animal facilities, such as pasture fencing, corrals, and stables, this percentage for maintenance, according to an institute director in Spain, should at least be doubled.

Where does the fault lie?

In an attempt to curb inflation in the construction industry, governments sometimes establish an official maximum unit cost permissible for construction of government buildings. Often these unit costs are set so low as to strain and challenge the ingenuity of both architects and contractors to design and construct buildings within the acceptable price limits. Although these official unit prices usually are revised annually, they are seldom brought in line with inflation. By establishing unrealistic constraints on the construction industry, government must assume a portion of the blame for the accelerated deterioration of physical facilities. They must also realize that by constructing facilities of inferior quality, there will be a need for higher than normal funding for maintenance.

If little work is available, builders might submit a bid for a project with less than their normal profit and overhead in an attempt to avoid losing business or causing layoffs of core personnel. They might then try to make up the difference by reducing the quality of materials or workmanship. When such a compromise is made the quality of construction suffers. Buildings deteriorate more rapidly than would normally be expected and within a few years require extensive rehabilitation. Under these conditions construction supervision by highly qualified professionals is especially important.

Finally, lending and donor agencies must strengthen their positions with regard to maintenance. Already the terms of many grants and loans legally oblige governments to adequately maintain facilities. However, specific maintenance procedures are seldom specified and maintenance obligations are rarely enforced.



Security is sacrificed when fire protection systems are compromised by missing valve handles.

Maintenance Categories

Maintenance of facilities can be divided into three categories: that requiring no cost other than staff labor, that requiring minimal materials and staff or day labor, and that requiring considerable materials and skilled labor. The first two categories can best be described as preventive maintenance. If performed correctly and in a timely manner, work of this type will significantly reduce the overall long-term cost of maintaining facilities.

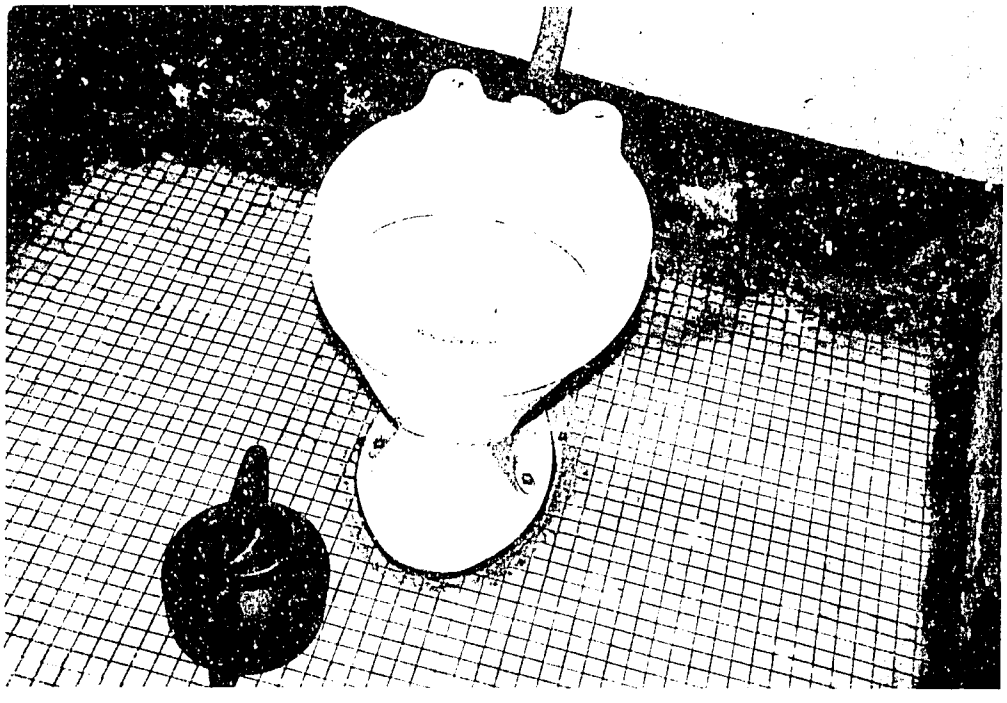
No-cost maintenance consists of sweeping, mopping, dusting, washing windows, replacing displaced roofing tiles, cleaning leaves from gutters, and other similar tasks. These are usually carried out by staff of the research institute or by day laborers at a very minimal cost. Proper no-cost maintenance reduces the overall cost of maintaining facilities by minimizing deterioration. For example, leaky roofs with tiles that are not immediately replaced cause deterioration of interior ceilings. Gutters that are not cleaned eventually collapse and fall. Floors that are not swept and cleaned of dust soon lose their finish and are subject to further damage. Repair of loose boards and tightening of hinges on doors are also examples of maintenance that can be done by labor with virtually no investment in materials.

The next higher level of maintenance requires minimal materials with labor provided by the institute or contracted as day labor. Minor painting and touch-ups, replacing the occasional broken glass or screen, patching and repairing concrete walks and curbs, replacing damaged window and door hardware, and repairing toilet fixtures all fall into this category.

The highest degree of maintenance generally requires labor with a level of skill not found in most research organizations. Usually contracts must be negotiated and signed with outside companies. The key to minimizing these often expensive contracts is to establish an effective preventive maintenance program as soon as construction of a building is complete.

Unfortunately, most developing countries do not begin their program of preventive maintenance early enough and are later faced with costly repairs and even total replacement of facilities. In many countries, buildings no older than five to 10 years have deteriorated to such an extent that management now feels financially incapable of providing the repair that is needed.

Mali: The need for "no cost" maintenance is demonstrated.



Improving Maintenance

Preventive maintenance programs

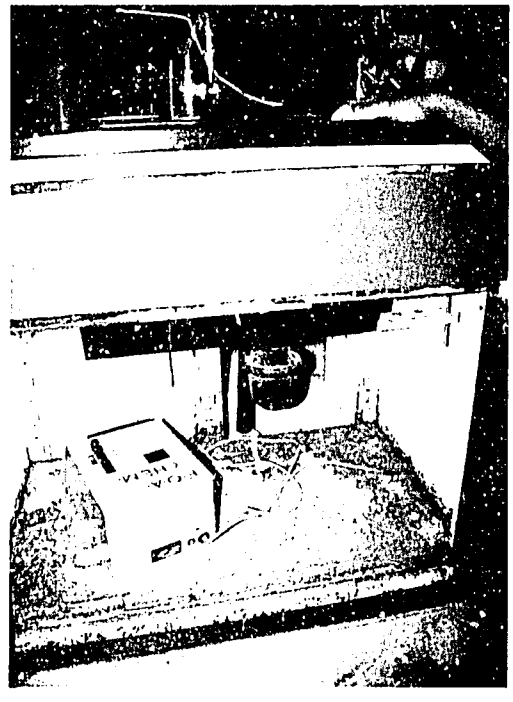
Every research organization, regardless of its size, should develop a preventive maintenance program. The sample preventive maintenance checklist on pages 26-28 summarizes such a program. Included is a general list of maintenance activities that most research institutes should carry out in the course of their day-to-day operations. For each item in the schedule, a frequency of occurrence is suggested. This will assist management in establishing and tailoring a customized program. This checklist is indicative only and should be adjusted to fit each organization's needs.

In addition to performing regular preventive maintenance, an organization should make provision for staff to notify one central office of items requiring immediate maintenance, repair, or modification. Logically, this office is best located in an appropriately staffed maintenance section. In this section, work orders are prepared and carried out in order of importance or urgency, and secondly in chronological order. Accurate accounts of time and materials should be kept to enable management to calculate the exact cost of maintaining the institute. Armed with this information an institute's annual budget request for maintenance will have increased credibility.

Maintenance training

One of the first steps in improving the quality of maintenance is to improve the thinking of management regarding maintenance. This can be most effectively done in a short time with minimal expense by training. Not only should a maintenance cadre be trained but also administrators and managers should attend seminars and conferences at universities, international institutes, and in private industry where the importance of maintenance is stressed.

In addition, personnel at higher levels of government service, in ministries for example, should be trained in the philosophy of maintaining facilities. This also can be done through seminars and short-term courses. Once an awareness of the need for adequate maintenance has been implanted at the ministry level, it should easily and effectively filter down to the level of operations. An example of this has already been seen in Sri Lanka where the Office of the President recently issued a standard format to all levels describing



Nigeria: Lack of maintenance has caused this very expensive laboratory bench to deteriorate beyond repair. Note also that the electrical transformer is in a very precarious and dangerous location.

Preventive Maintenance Checklist

Name of research station:
Location:
Name of building/facility:

Description of maintenance item	Maintenance frequency						Other		
	Daily	Weekly	Monthly	Quarterly	Semi-annually	Annually	Every 3 to 5 years	Estimated cost	Notes
1. Sweep and clean floors	X								
2. Wax and polish floors			X						
3. Paint all walls, ceilings, woodwork, and metal flashing where required inside and outside							X		
4. Adjust door and window hardware			X						
5. Check all ceramic tile and replace or regout as required					X				
6. Clean and repair gutters and downspouts					X				
7. Check flooring and replace loose or missing tiles				X					
8. Check, adjust, and replace roof tiles					X				
9. Lubricate all electric motors				X					
10. Revise functioning and gas level of all cold storage compressors			X						
11. Check and adjust all air-conditioning units			X						
12. Check and repair where necessary all insect screening on windows, doors, and ventilators				X					
13. Check all faucets and valves for broken handles, leaks, drips, and repair where needed				X					
14. Examine all electric supply and distribution panels for overloads, etc.				X					
15. Check all electrical outlets and switches to ensure proper functioning				X					
16. Check entire sewerage system, including floor drains and sink traps for proper functioning				X					
17. Check all light fixtures for proper functioning and replace bulbs and tubes where missing or burned out		X							
18. Patch and seal all paved parking areas and roads where cracked or damaged						X			

Name of research station:

Location:

Name of building/facility:

Description of maintenance item	Maintenance frequency						Other		
	Daily	Weekly	Monthly	Quarterly	Semi annually	Annually	Every 3 to 5 years	Estimated cost	Notes
19. Check and repair damaged concrete sidewalks and curbs						X			
20. Check and repair or dispose of all damaged furniture						X			
21. Check and replace or attach loose boards and other woodwork items inside and outside					X				
22. Check all plaster for damage and patch, replace, and paint where needed					X				
23. Check all fire extinguishers to ensure their viability				X					
24. Check all alarm systems and other warning devices to ensure their ability to function in an emergency			X						
25. Check all fire hoses for leaks and ability to function in an emergency						X			
26. Check all emergency safety showers and eyewash devices in laboratory areas				X					
27. Check all fume exhaust systems for proper functioning		X							
28. Inspect all gas lines, valves, and cutoffs for leaks and proper functioning			X						
29. Inspect all walls and floors for moisture penetration and repair as necessary					X				
30. Check entire facility for damage from insects, vermin, and pests, especially termites; take action to eliminate cause, repair damage						X			
31. Check all plumbing fixtures for proper functioning and repair or replace as required			X						
32. Inspect all mirrors for damaged or missing items and replace			X						
33. Wash windows and other glass, inside and outside				X					
34. Check stair handrails for damage and safety		X							
35. Check for frayed electrical cords and damaged plugs and replace immediately			X						
36. Check elevators and vertical lifts for proper functioning, maintain or repair if necessary				X					

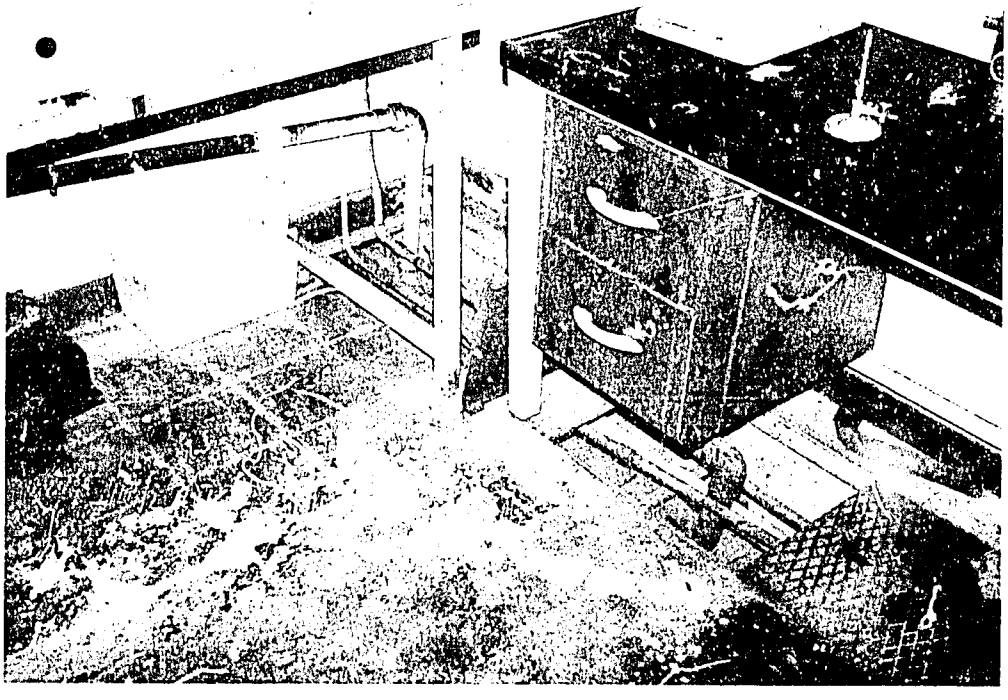
Name of research station:

Location:

Name of building/facility:

Description of maintenance item	Maintenance frequency						Other		
	Daily	Weekly	Monthly	Quarterly	Semi-annually	Annually	Every 3 to 6 years	Estimated cost	Notes
37. Check building for uneven settling or cracks in structure, walls, floors, or ceilings; repair as needed					X				
38. Check entire telephone system and repair as required		X							
39. Check storm drain system for proper functioning			X						
40. Clean and remove dirt and debris from the tops of all horizontal surfaces such as walls that do not reach the ceiling, the tops of cabinets, door transoms, etc.		X							
41. Check all sun control devices such as venetian blinds, shades, curtains, etc., and repair or replace as needed				X					
42. Start and perform routine maintenance on all emergency electrical generators			X						

Zambia: Chemical spills must be neutralized and cleaned as soon as they occur.



the importance and requirements of facilities maintenance.

Currently, most developing-country research organizations have very few people in their maintenance sections—perhaps one carpenter, a painter, and a handyman. Only in a very few instances do institutes report having a crew of more than about three to five people working in maintenance. Fortunately, training a maintenance staff should present few problems. Many countries have vocational education programs where youths who are unable to continue their formal education can receive training in electricity, carpentry, masonry, auto repair, and the like. Research organizations are urged to employ these youths to fill maintenance vacancies and, alternatively, to enroll regular staff members in special courses aimed at improving their maintenance skills.

Loans and grants to developing countries generally allocate substantial amounts of money to national and international studies and training. Training for facilities maintenance has, for the most part, been completely omitted from the financing scope of these projects. Management of internationally funded research programs should insist on maintenance training parallel to the training of administrators and scientists. An alternative to seminars and conferences on maintenance is to include a technical assistance component on maintenance as a part of the project scope.

Alternative funding sources

In addition to requesting increases in maintenance funding in the annual operating budget, research institutes should investigate alternate sources of monies for maintenance. At some institutes, supplemental maintenance funds are provided through the sale of produce and farm goods. However, if these and other budgeted funds are left unspent at the end of the fiscal year, they generally revert back to the national treasury. Private organizations and some national and international research institutes make provision for unused funds to be placed in escrow as a maintenance fund to be used in subsequent years. Organizations already using this system of fund management include the Kenya Forestry Research Institute (KEFRI), CIAT and the sugarcane research center (CENICANA) in Colombia, and IITA in Nigeria. Unspent funds continue to increase through earned interest. They are earmarked for maintenance and can be used as needed.

Mali: Plant tissue is ground for analysis outside because the grinder inside the laboratory is inoperative.

Nigeria: This scene shows some effects of the lack of maintenance. Note that the roof leaks, plaster is missing from the wall, the hollow-core door is delaminating, and broken furniture is in the background.

Chapter Three—The Infrastructure Master Plan

Location of a New Research Complex

If a building program envisages construction of an entirely new agricultural research complex, deciding the location may be a major task for management. First, management must be assured that the quality and quantity of land is adequate for the research to be carried out. For this, topographical maps or air surveys are made as a first step in determining if land boundaries and slopes lie within acceptable limits. Soil surveys also must be made to assess the suitability of the soil

to support the proposed research. Availability of groundwater in sufficient quantities and location and reliability of electrical and communication service lines are other considerations.

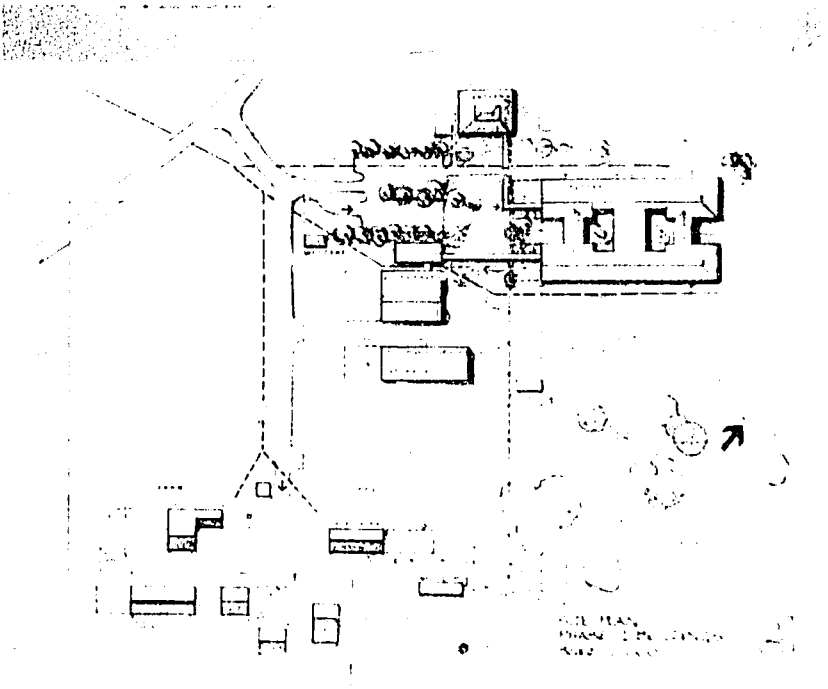
Second, social issues such as the proposed site's proximity to markets, schools, and religious and medical facilities must be evaluated. Availability of sufficient farm labor is also an important factor because most of the work on research and production plots will be done by local day labor.

Relocation of staff is another important issue. The pay of young scientists in most developing countries is traditionally low. Spouses generally work to help support the family. Research institutes that are constructed far away from sizable villages with work opportunities almost always have a problem recruiting and retaining qualified permanent staff. The area where the institute is to be built must have adequate amenities to help attract and retain both staff and their families.

The proximity of cement plants and other industries using gypsum and the proximity of sugarcane producing areas to the proposed building site also should be determined. In due time, depending on the principal direction of wind, dust from industries working with gypsum (including stone crushing operations) will prevent plant biological processes and modify the pH of the land used for research. Even if the pH of the soil is not changed, residues from such installations settle on buildings and are a constant maintenance problem.

Black ash from farmers burning sugarcane fields at harvest time is another annoyance, presently being experienced by an agricultural research institute located in the Cauca Valley of Colombia. Depending on the winds this lightweight black ash can be transported 30-40 kilometers from the fields. If research facilities must be located in these areas, mechanical air-conditioning will be an absolute necessity. Otherwise, ash enters the buildings and settles on laboratory benches, desks, computers, and all horizontal surfaces. The slightest movement of air, even a person walking, will transfer the material from one surface to another.

Côte d'Ivoire: *Master planning involves clearly allocating areas for specific functions at the site of a research station.*



Finally, it should be remembered that while the person or organization proposed to plan and design the facilities can be called on to assist in selecting an appropriate site, the final decision regarding location always remains management's responsibility.

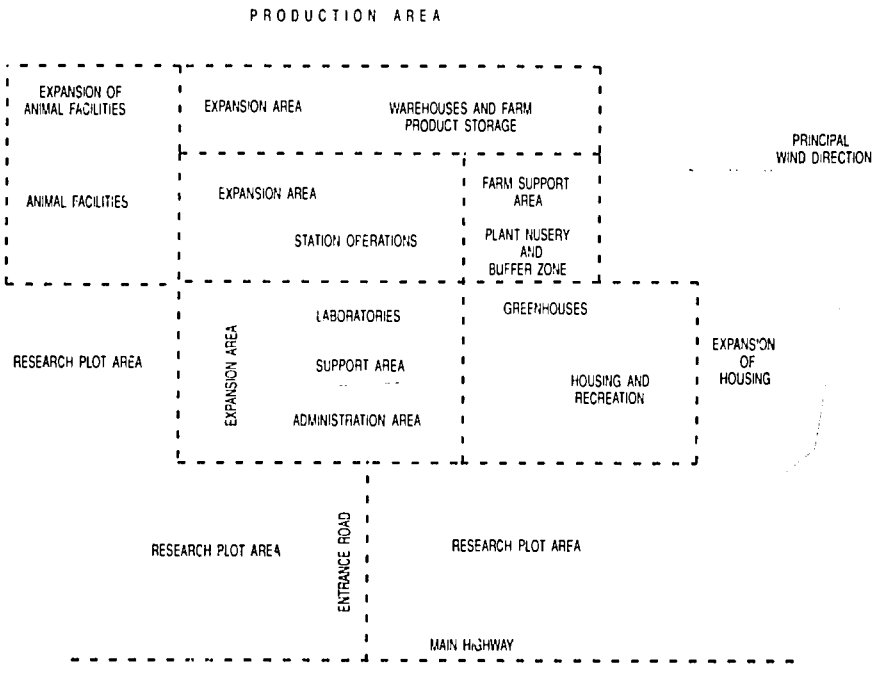
The Master Site Plan

Once the site has been chosen a long-range master site plan, or zoning plan indicating how land is to be used during the upcoming 20-25 years, is prepared. The master plan indicates which land parcels are to be designated for research and which for production. It clearly shows the placement of existing buildings, utilities, roads, and parking as well as property boundaries and other features affecting the overall institute layout. In addition, the plan should locate proposed buildings in relation to existing facilities.

Proposed construction should be phased in five-year increments unless it is all to be included in one stage of development. Hence, if research results were less satisfactory than originally envisaged or if staff growth were less than anticipated, the additional space might not be constructed. It would, however, be planned and located in relation to other components of the institute as an integral part of an overall planned growth pattern. Management must make every effort to see that the master site plan is followed in order to ensure order in the physical development process.

Some research stations have been developed haphazardly with apparent disregard for clear-cut assignment of areas for specific use. For example, staff housing might be constructed downwind from an area dedicated to animal facilities or from a dusty, noisy crop threshing area. Both locally and internationally financed research programs have contributed heavily to the physical disorganization of a number of research stations. At the conclusion of many of these programs, buildings especially built as a part of a project are abandoned in a state of disrepair.

Typical zoning plan for an institute showing areas defined for various uses. Note that areas have been allocated to accommodate future expansion.



Individual Planning Elements

In developing the physical layout for an agricultural research institute, the individual needs of each component of the proposed research must be considered. The first of these, the scientific laboratories, is the very nucleus and heart of a research organization. Closely aligned with work done in the laboratories are the field research plots and production areas. Others, not in order of importance, are administration areas, scientists' offices, information services, research support areas, animal facilities, greenhouses, station operations, parking areas, field service buildings, staff housing, recreation and sports fields, and utilities.

Again, it is much easier to plan and design a new research complex than it is to integrate good planning practices into the design of an existing station. One of the difficulties with planning expansion of an institute is that the use and remaining life expectancy of existing buildings must be taken into account. The planner should advise management on funding required to replace these facilities within the long-range planning scheme.

Placement of buildings

Together with management and scientists, the designer of the proposed facilities should choose the land least desirable for research and production for locating buildings. Of the land reserved for research and production, sufficient area should be left to accommodate the needs of the researchers and the mandate of the station. For example, a breeder of a cereal crop needs at least 2 ha of land for experiments; an agronomist needs 1 ha; and a research program on a fruit commodity may need an area as large as 4 ha.

Where possible, the central building complex for the research institute should be set back about 1000 to 2000 meters from principal highways. Although the actual distance may vary, separating buildings from main routes helps to minimize noise and fumes from traffic and reduces the likelihood of casual theft. When the central building site is farther than 2000 meters from principal highways the overall building mass cannot be seen by the general public. Relatively high visibility of agricultural research operations is important from a public relations standpoint. A sign describing the facility and the work being carried out should be conspicuously displayed at the entrance to the institute.

For security reasons, it is advisable to have only one entrance/exit road, preferably paved, leading to the research institute. One or more security persons should be stationed at the entrance day and night as a protection measure. By having only one entrance, all vehicles pass through a security checkpoint and pilferage is likely to be reduced.

Research plots

Research plots can be located on either side of the road leading into the main research center and can extend to the side boundaries of the available land. If additional land is needed, the plots can be extended parallel to both sides of the main research buildings. Although some managers feel that research plots should be secluded from public view, research plots that are highly visible are more accessible to scientists and in the full view of the public. Also, pilferage of products will probably be reduced. It is advisable, however, to carefully fence plot areas to reduce the possibility of intrusion by outsiders or animals, either of which could ruin research results.

From the standpoint of presenting a high profile, research plots should be clearly and uniformly labeled describing the research being done. In this way the general public is kept advised of the type of research in progress.

Production land

Unfortunately, production of commodities has become necessary for the survival of many research stations. Production areas usually require extensive land, the operation of which is normally accompanied by considerable noise and dust. For this reason, land used for production should be as remote as possible from the main research buildings. All-weather access to this land should be made convenient with all-weather roads for the movement of equipment and farming inputs to and from the station operations area. Storage buildings and warehouses for farming inputs and implements should be located convenient to both the research and the production areas.

Laboratories

Regardless of the design chosen, laboratories, as the heart of the research effort, should be centrally located and readily accessible to each of the other physical elements comprising the research complex. In some institutes, such as the research

center in Tibaitatá, Colombia and the Department of Research and Specialist Services (DRSS) in Zimbabwe, laboratories are located in one large multistoried building, which also contains scientists' offices, administration, support areas, and other sections. This style of design is especially common among older institutes. However, buildings such as these restrict and limit flexibility for future expansion and modification.

Depending upon the availability of suitable land, agricultural research facilities are better designed as a cluster of small, single-story buildings. These can be organized in the form of a very pleasing research campus, such as Brazil's national center for rice and bean research (CNPAF), or grouped according to function and connected by covered passageways, such as the animal research center in Cuernavaca, Mexico.

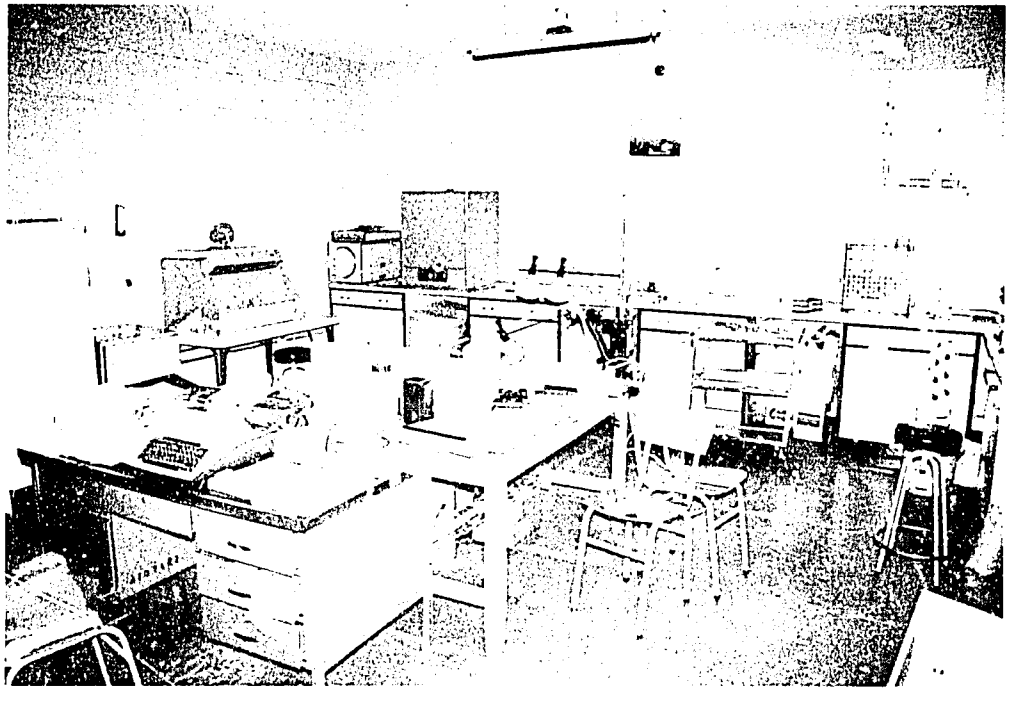
Single-story buildings are especially appropriate for laboratories for many reasons. Natural lighting and cross ventilation are improved. Heavy-use areas such as auditoriums, cafeterias, or conference centers can be located away from the quiet, relatively tranquil laboratory environment. Finally, this type of design facilitates expansion with minimum disruption of ongoing work. It also permits utilities to be installed and modified with greater flexibility – a definite asset when remodeling or expanding.

Scientists' offices

There are widely differing thoughts as to where scientists' offices should be located: within the laboratories themselves (as at the plant pathology research station in San Benito, Bolivia), in separate offices opening into the laboratories (Rowett Research Institute, Scotland), across the hall from the laboratories (as at the national center for rice and bean research in Brazil), in separate buildings located very near the laboratories (Colombia's sugarcane research institute), or remotely located from the laboratories (as at the animal research station in Cuernavaca, Mexico). The consensus among scientists, however, is that offices are most effective when they are located as close as possible to the laboratories in which the scientists work.

Offices are best located either directly adjacent to and opening into the laboratory or immediately across a hallway from the laboratories. Offices

Bolivia: *Combining laboratories and offices often results in cluttering and an inefficient use of space.*



within the laboratories are not recommended, as they often result in an inefficient design and create a general confusion in the laboratory. Several schemes exploring these possibilities are shown on pages 91-93.

Information services

The library and information services section of the research complex should be centrally located and easily accessible to scientists, administrators, and the general public. The library at CIAT in Colombia is an excellent example of such a location. In addition to providing information from other sources, research results published at the institute are disseminated by this section. Bulletins are produced and distributed to assist the extension effort. Also, slides, films, and videotapes can be produced in photographic laboratories, also to aid extension.

In addition to pedestrian traffic, this section will have considerable vehicular traffic bringing in supplies and removing produced materials. Information services must therefore have easy access to roadways and adequate parking near the building.

Administration

Administration personnel are in constant contact with staff and the general public. For this reason, the administration section should be directly accessible to both. Since administration is usually the first stop for visitors, access should be easily identifiable. Adequate parking is vital and should be separated from staff parking. A covered entrance into the main administration building as a protection from rain and sun is a welcomed design feature that frequently is overlooked.

Station operations

The station operations complex is the focal point of all field work and is therefore normally noisy and dusty. Facilities for these activities should be located remote from clean operations such as laboratories, scientists' offices, and administration. It is not uncommon to find fertilizer and crop harvests stored, seeds cleaned and sorted, and even vehicle and facilities maintenance shops headquartered in this area. Also, the office for field labor management and an area where meals can be served to the labor force are frequently located in the same general area.

Station operations must be easily accessible to both the research plots and the production areas of an institute. Since there will likely be equipment as well as a considerable quantity of materials stored in and around the station operations complex, this area is best enclosed by high walls, hidden from the general public's view. Station operations facilities should be well lighted at night and patrolled frequently by the security force of the institute.

PART 2

Designing the Facilities

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Chapter Four—Climate-Related Design Issues

Developing countries in the tropics comprise a great variety of ecological zones and climatic features that must be considered in the design of research buildings. The discussion here focuses on some general climate-related design issues. For a more detailed technical reference on climatic design two books are recommended: "Tropical Architecture in the Dry and Humid Zones," M.J. Fry and J. Drew (Melbourne, Florida: Robert E. Krieger Publishing Company, 2nd ed., 1982) and "Manual of Tropical Housing and Building Design," O. Koenigsberger et al. (London: Longman, 1974). Many features described in these books also pertain to locations outside the tropics.

Temperature and Humidity

Temperature in the hot dry tropics (such as the African Sahel) can reach as much as 45-50 degrees Celsius during the day and fall to 10-15 degrees at night, depending upon the region and the altitude. Temperatures drop about two degrees Celsius for every 300-meter increase in altitude. At the higher altitudes, freezing temperatures at night are common. In the hot humid tropics (such as the costal regions of West Africa), temperatures average 18-20 degrees Celsius. During the warmer seasons, temperatures in the hot humid tropics may climb as high as 38-40 degrees.

With the exception of certain areas, relative humidity in the dry tropics seldom exceeds 50 percent except during occasional rainstorms

Côte d'Ivoire: Termite hills in the tropics commonly reach a height of 2.0 to 2.5 meters above ground level.

when up to 50 mm of water can fall in a very short time. Seldom is the annual rainfall in these areas more than 300-500 mm. The hot humid tropics, on the other hand, can have a mean humidity of 90 percent or more, with an annual rainfall of 1500-2000 mm and higher. Frequently rainfall in these areas is bimodal, with principal winds reversing direction from one rainy season to the next.

Within these two humidity zones there are variances or "micro climates" which undoubtedly will affect the location of research stations and also of villages and populated areas. Some factors that affect humidity within a particular zone are topography, including altitude, slope, and orientation; ground surface, including permeability and soil temperature; and objects such as trees and buildings, which may influence air movement.

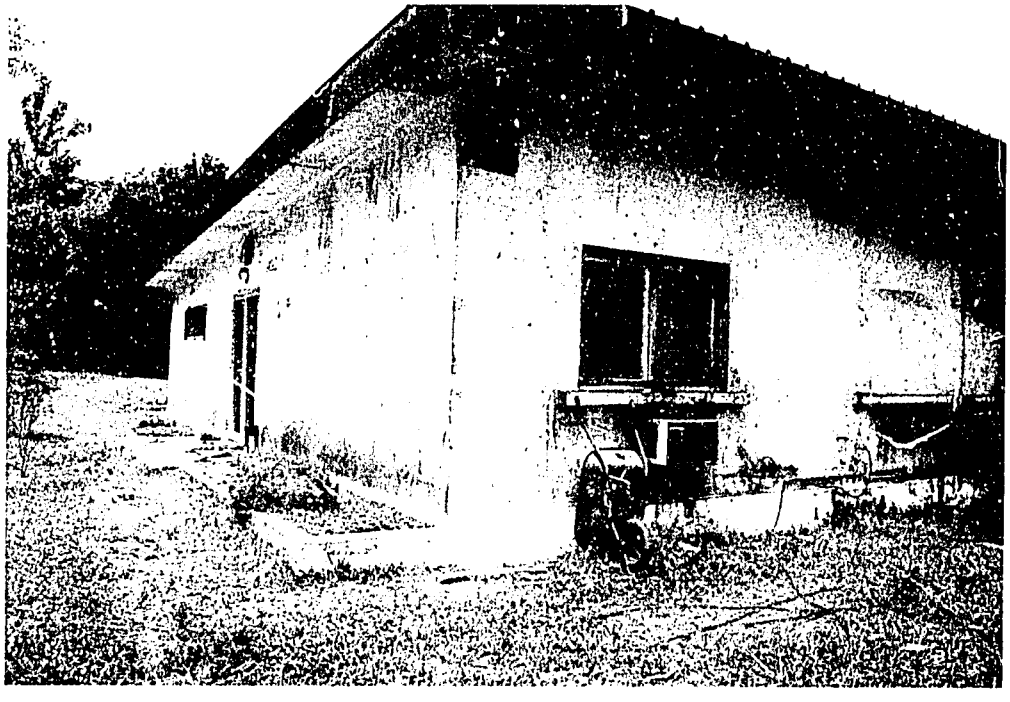
Other Climate-Related Issues

In areas of high humidity, especially where temperatures are also high, buildings are often adversely affected by fungus and mildew on masonry and wood surfaces. After only a few years the exterior walls of new buildings can begin to turn black and appear to be seriously neglected from a maintenance standpoint. Although this condition does not affect the building's structural integrity, it is unsightly and, with time, tends to worsen and is more difficult to correct.

Fungus and mildew can be minimized by the use of paints with special additives in their formulas. Surfaces can also be cleaned periodically with a dilute solution of 1.5 percent sodium hypochlorite or a similar solution of trisodium phosphate then repainted as necessary. In buildings where there is a large difference between inside and outside temperature and humidity, insulation may be required in the exterior wall construction to prevent the formation of moisture (see also the section on building ventilation, pages 50-53). As little as five centimeters of insulation is often sufficient to prevent the formation of mildew or fungus.

Termites are another major problem in both the dry and humid tropics. In unoccupied buildings termite tunnels from floor to ceiling can appear in only a week to 10 days. Even after being removed, they may suddenly reappear as if they

Côte d'Ivoire: This building in the humid tropics shows the effects of fungus. The difference in temperature between the inside and the outside walls causes condensation of moisture. Insulation and a vapor barrier would improve this situation.



Termites have damaged these office bookcases. Use of properly treated wood would have prevented this deterioration.

This temporary solution keeps water from the roof from entering the basement.

never were removed. In addition to being unsightly, termites can severely damage wood portions of buildings unless adequate precautions are taken during construction. In some instances termites have been known even to devour furniture.

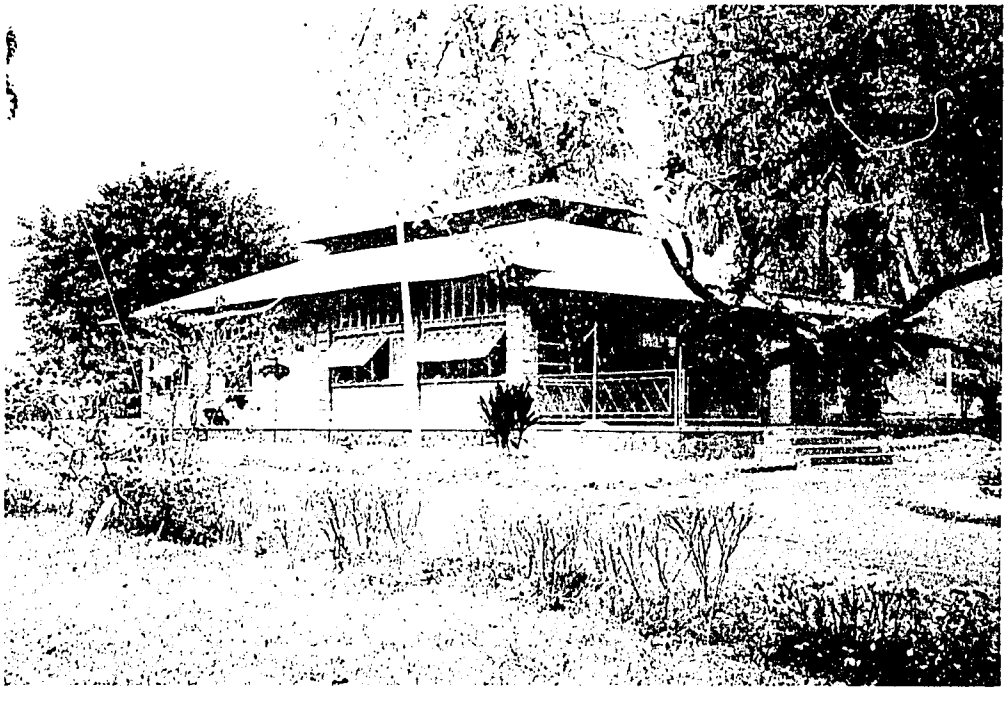
Disposal of rainwater and surface drainage can also be an issue. In the tropics, gutters and downspouts on buildings are often inadequate to accommodate the rainwater that falls during short periods. Accumulating leaves are a constant source of worry since they tend to fill gutters and clog downspouts. In areas of high humidity where the mean rainfall is spread over longer periods, proper drainage becomes extremely important. Water must be carried away from the buildings as rapidly as possible to prevent the buildup of water pressure against walls and foundations. In some cases open trenches around buildings are a very effective method of dispersing rainwater (DRSS, Harare, Zimbabwe).

Both the dry and the humid tropics have extremes that must be compensated for in the design of buildings. Extreme differences between day and night temperatures cause building elements to expand and contract, sometimes stressing construction materials to the point of breaking or cracking. Also, strong ultraviolet light has been known to damage some exterior construction materials, especially paint and roofing.

Due to a general cloud cover, natural daylight levels in the humid tropics is generally lower than in the dryer areas. Since there usually is no cloud cover in the dry tropics, heat from the sun's direct rays and glare present problems that need extra attention in building design. Although occurring infrequently, rainstorms are also a cause of concern. Often these are accompanied by lightning and high winds. Lightning has caused considerable damage to roofs of buildings at the horticultural research institute in Marondera, Zimbabwe. Buildings in areas of high lightning frequency require grounded protection.

These examples illustrate just a few of the climate-related problems that architects and planners will face in designing buildings for the tropics. Management should be assured that as many of these factors as possible have been taken into consideration in the design of facilities. Although some of these problems are more common in the tropics, many of the same or similar difficulties are also found in temperate zones.

Côte d'Ivoire *This building, constructed during the colonial period, is ideally suited for the humid tropics. Notice the use of horizontally pivoted shutters, wide overhangs, outside passageways, and good roof ventilation at the ridge. Grilles above windows permit additional cross ventilation to remove hot air trapped at the ceiling level.*



Suggested Comfort Measures

Some of the best designed agricultural research buildings are those that were constructed some 50-60 years ago. Most of these older structures are better suited to the climatic conditions found in tropics than buildings being designed today. Because mechanical air conditioning was unavailable, natural environmental conditions were respected and buildings designed to take full advantage of natural ventilation. Ceilings during this period were commonly four to five meters high and usually there were high windows and openings near the ceiling to permit hot air to escape.

Natural cross ventilation

Ventilation is one of the most common deficiencies in today's building designs. This is mainly because virtually all facilities are being planned dependent on mechanical air conditioning. Many buildings are constructed with fixed windows, which ignore the possibility (and the likelihood) that someday air conditioning will fail and natural ventilation will be needed.

At the national agricultural university library at Chapingo, Mexico, there are some 5000 students and 900 professors using a building with broken air conditioning and no provision for natural cross ventilation. The building was designed without operable windows and the air-conditioning only functioned for a short time after construction was complete. There was no money to make repairs. Fans placed to circulate the air only circulated hot air. The building surely would have been better utilized with some natural ventilation!

In most developing countries electrical power is inadequate and unreliable. Therefore all buildings should be designed as though no air-conditioning would ever be installed. Air-conditioning can then be considered an added comfort as opposed to an absolute necessity.

In libraries, computer facilities, and laboratories where highly sophisticated scientific equipment or optical equipment is used, mechanical air-conditioning is often necessary as a dehumidification measure to protect books and equipment from humidity-related damage. Even in these areas,

***Indonesia**: This staff housing is equipped with wide overhangs as protection from sun and rain. Note the excellent attic ventilation at the peak of the roof.*

however, provision must be made for the cross ventilation of air for times when the air-conditioning fails.

Ideally, cross ventilation enters a building low, passes across a room, then exhausts at a height of between one and two meters above the level of the finished floor. When intake air enters low and exhausts higher, occupants are able to feel the flow of moving air. In dry climates, intake air passing over a grassed area or over shrubbery will be naturally cooled by moisture evaporating from the plants.

Building orientation

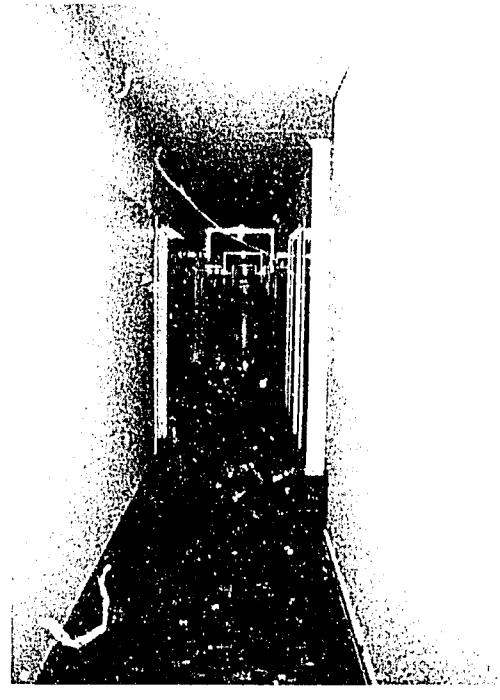
Especially in the humid regions, designers must take care to ensure that breezes are allowed to pass through and around blocks of buildings. Cross ventilation, or the movement of air through a building, can be maximized by orienting buildings to take full advantage of the prevailing direction of wind.

In hot dry climates, buildings should be oriented with their long axis in an east-west direction. This minimizes the sun's rays falling directly on the long side of the building. The opposite is true in cooler climates or at altitudes where the sun can provide needed warmth to the building's interior. In these cases buildings should be oriented with their long axis in a north-south direction.

In some cases there may be a trade-off between the east-west orientation to compensate for the sun or some other orientation to capture the breeze. In such instances, casement or vertically pivoted windows that swing out much like a sail can be used to help direct the breeze into the building. Glasshouses and plastic houses should always be located with a north-south orientation.

Ceiling height and building depth

Buildings in tropical areas should have higher than normal ceilings and should be designed as open and free to the outside as possible. In humid climates, especially, ceiling heights of 3.3 to 4.0 meters above the finished floor are not unreasonable. In the dry climates ceilings can be lower (3.0 to 3.2 meters above the finished floor). Also, buildings in dry climates can be deeper than those in humid areas. Again, however, care should be taken that buildings do not block any breezes that may be available.



Zimbabwe: *The effect of a too-narrow hallway is shown. The hall in this picture was only 1.5 meters wide. A wider hallway facilitates easy movement of materials.*

Corridors and passageways

Outside corridors and passageways are preferable in tropical climates, especially the hot humid areas. These should be designed as open as possible to the free air and should be protected from the sun and the rain. Corridors should be from 2.5 to 3.0 meters wide with deep overhangs. In cooler climates and at higher altitudes, where inside corridors are more practical, these should be no less than 2.0 meters wide, 2.5 being more desirable. When corridors are two meters or more in width, personnel are able to pass, stop, converse, and move equipment without creating an obstruction. Today corridors are frequently constructed only 1.5 meters wide—sometimes less. These are entirely too narrow and restrict movement within the building.

In discussing this topic in Kenya, one architect said that a corridor 1.2 meters wide would meet international standards. However, in addition to restricting traffic flow, corridors that are this narrow and long tend to create a tunnel effect, which is aesthetically displeasing and can be excessively dark, hot, and psychologically confining.

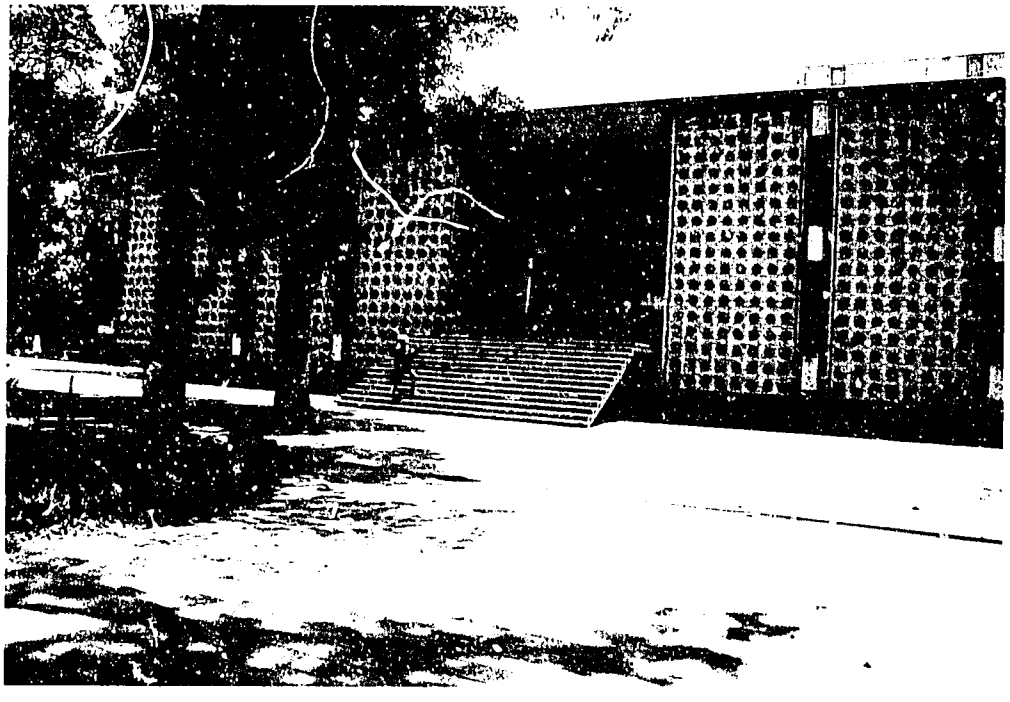
Protection from the sun

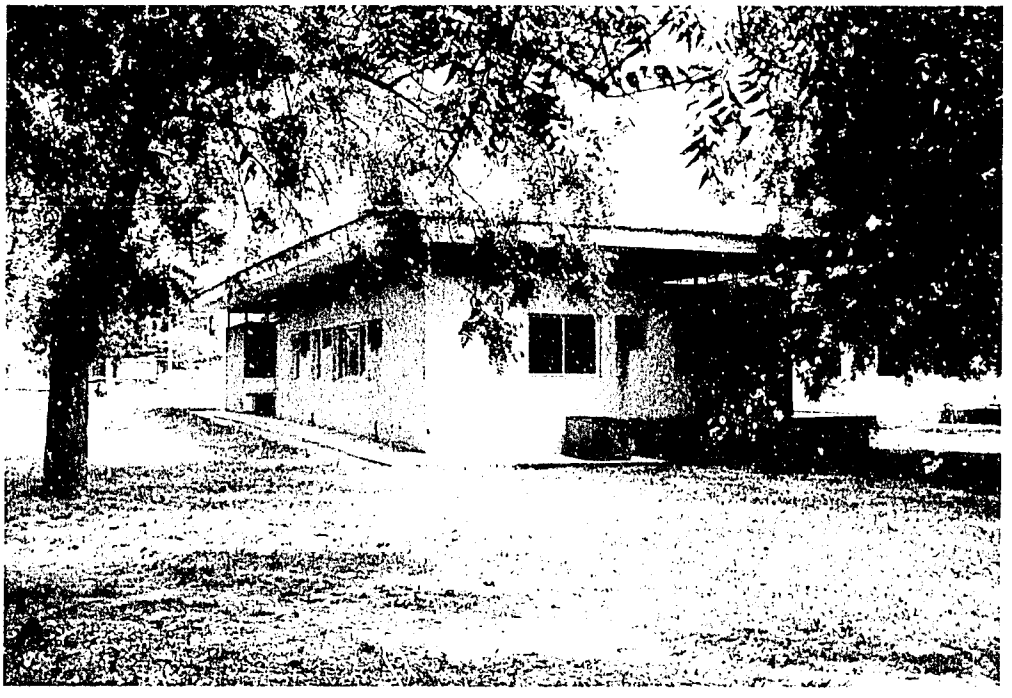
In hot dry climates the sun should be prevented from shining directly on exterior walls by proper building orientation and by landscaping. In the more humid climates, however, the sun is usually not the principal source of discomfort since its rays pass through clouds and water vapor and are ultimately diffused. Nonetheless, in all hot tropical regions it is good practice to protect windows from both the direct and indirect rays of the sun. Louvers, grilles, or other window elements can provide this protection, as well as decoration (Agrarian Research and Training Institute, Colombo, Sri Lanka). Protection can also be achieved by using adjustable outside hinged or roll-up shutters, or venetian blinds inside the rooms. The latter, however, are a constant source of maintenance since they are easily damaged. Venetian blinds should be avoided whenever possible.

Protection from dust

In the hot dry tropical climates winds frequently blow up to 30-35 kilometers per hour across the dry, parched earth, causing frequent dust storms during the summer. Dust storms force a powder-like dust into buildings through every window

Mexico: The sun's direct rays can be shielded very effectively with perforated screen walls constructed of concrete or other material.





Côte d'Ivoire: *This is a building that provides good ventilation between the roof and ceiling. Additionally, it has an adequate overhang as protection from the sun and rain and is shaded from the direct sun by trees and planting.*

Sri Lanka: *Wide overhangs protect against sun and rain. Light is diffused by wooden grilles over windows.*

and door crack, ultimately damaging scientific equipment. To guard against this, all windows and doors should be closely fitted and provided with tight weather seals, preferably the interlocking type. In areas where severe dust storms are frequent and lengthy, double windows with weather seals should be used. Trees can be used as a windbreak against dust storms. However, care must be taken to ensure that breezes available for cross ventilation are not blocked.

Landscaping

Landscaping can help keep buildings cool, especially in the hot dry climates. In addition to grass or shrubbery cooling the air entering buildings, patios with fountains, grass, and other shrubbery can assist in the cooling process. Patios should be made attractive to encourage staff to use and enjoy. However, design need not be complicated. A simple frame, for example, can support grapevines, bougainvillea, or other climbing plants thereby providing shade and color. A good example is provided by Kenya's horticultural development project for Macadamia.

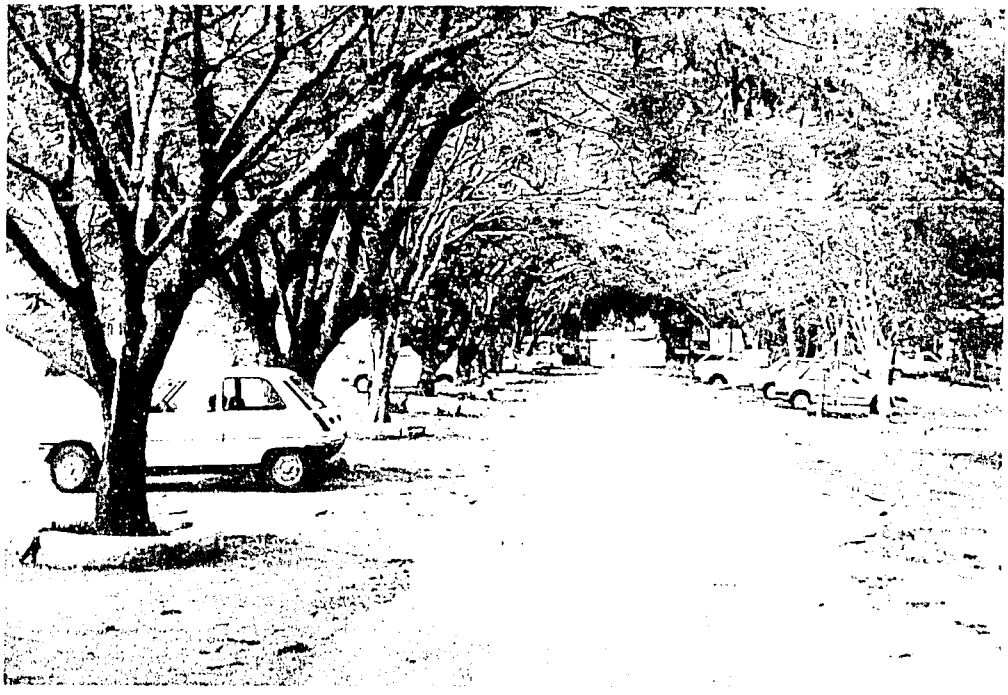
Trees can be planted to provide shade on walls that receive the sun's rays during the hottest part of the day. Depending upon the type of tree, a distance of about five to six meters from the wall will suffice. Care must be taken to plant trees far enough from buildings that roots do not damage footings and foundations.

Parking areas too should be shaded, especially in the hot dry tropics. One method of providing this shade is to construct low sheds under which automobiles are parked. Natural vegetation, however, is more pleasing from a design standpoint. In some parts of Africa, the "flame of the forest" (*Butea frondosa*) tree has been used very effectively along parking areas as an alternative to parking sheds (DRSS, Harare, Zimbabwe). Larger shade trees can be planted throughout the research complex as added protection from the direct sun and to encourage staff to use out-of-doors areas.

Insects and pests

Flying insects in the vicinity of the principal buildings of a research center are not usually a problem unless work is being done at night. Housing, on the other hand, because it is used at night, is plagued by many insect species, especially in the hot humid regions. In areas subject to nightly insect invasions all window and door openings should be securely screened. In all food service areas—dining rooms, kiosks, snack bars,

Brazil: *Patios with plants are a relatively inexpensive and effective means of cooling through evaporation*



Zimbabwe: This is a good example of how parking and buildings can be shaded simply by planting a row of trees.

Mali: Trees help to reduce the temperature of outside walls by providing shade and also by evaporating cooling moisture through the leaves.

and kitchens—all openings should be properly protected with screens. Fine mesh fiberglass screens are preferable to other types and have proven to be durable, nonrusting, and relatively inexpensive.

One of the biggest pest problems in the tropics is the damage caused by termites, both subterranean and dry-wood species. The greatest damage is caused by the subterranean species, which builds tunnels across walls, floors, and other non-wood materials in search of cellulose material. Termite hills in many areas, especially West Africa, have been found to reach a height of more than two meters and infestations frequently cover many hectares.

To guard against damage from termites, the ground contact area below buildings should be poisoned according to the recommendation of a local entomologist or a reputable pest control company. Provision should be made to poison the area again on a regular basis to prevent recurrence of the pest. In buildings elevated above grade, there is usually less of a problem with termites, although the ground surface should still be poisoned. If the building has a concrete floor slab laid directly on the ground, provision should be made during construction to allow for future preventive treatment against termites. This is accomplished by installing a small-diameter perforated pipe along the perimeter of the building. Termite protection solution can be pumped through this pipe periodically as needed.

Chapter Five—General Design Issues

By this point it is assumed that either public works has become involved or an architect or planner has been contracted by management to design the research buildings. The infrastructure master plan for the project should be begun. It is further assumed that by now financing has been made available or is reasonably assured. A final assumption is that by now the research organization should have a good idea of what buildings need to be constructed.

Suitability of Land

Earlier it was said that buildings should be situated on the least desirable land at a research station. That does not mean that buildings should be located on land inappropriate for construction, such as solid rock, an improperly managed landfill, or an area where the water table is so high that pilings must be used to support the buildings. To ensure that the land chosen is suitable for constructing buildings a careful survey and categorization of each area within the general site should be made. Results are then evaluated as to the suitability of each section of land for its proposed use.

Often land that at first appears acceptable upon closer examination will have subsurface conditions making it completely unsuitable for building. Too often construction begins on sites only to find upon excavation that the area contained hidden rock or was previously used as a dump. After construction begins, removal of unsatisfactory material and the subsequent modifications to the footings and foundations of buildings can be costly and time consuming.

Subsurface conditions that cause differential settlement in buildings pose the most serious problems for construction. Differential settlement causes cracks in walls, floors, and even within a concrete structure itself. The most common causes of differential settlement are uneven bearing capacity or excessive expansion and contraction of the soil beneath the construction.

One type of soil that fits into this category and is frequently found in the tropics is black "cotton soil" or "gumbo" (vertisol) as it is commonly known in some regions. Due to its high coefficient

of expansion, cracks 10-15 cm wide extend from one to two meters below the surface of the ground during the dry season in areas with this type of soil. Before a building of even average importance is designed for these areas, a detailed engineering study should be done to ensure that the structure is designed to counteract the forces that will be generated by the soil.

Soil surveys

In most parts of the world there are engineering companies that are able to prepare comprehensive reports on subsurface soil conditions. These reports, based on test borings or excavations, provide information on the physical makeup of the soil and its bearing capacity. Using these data, architects and engineers are able to design buildings to accommodate the physical characteristics of the soil.

In areas where soil engineering is not available, the institute itself should make pit excavations and use any other method available to analyze the physical characteristics of the soil. Qualified soil scientists should be consulted to provide this information to the design team. Under no condition should a building of even average size be designed without exploring, to the fullest extent possible, the subsurface soil conditions at the building site.

Single- or Multiple-Story Buildings

Notwithstanding the recommendation that single-story buildings are more practical for research facilities, the question invariably arises during building planning: "Isn't it more economical to build multistory instead of single-story buildings?" However, there is no standard reply. In each case the answer must be determined by a detailed analysis of construction costs for the specific geographic area for which the buildings are proposed. The final decision to construct single- or multistory buildings is made jointly by the architect and management. Construction costs and the availability of land are two factors that must be considered.

Just to see how prices vary from one area to another, estimates for similar buildings ranged from a unit cost of US $50 to $100 per square

Yemen: Example of cracks in the surface of "cotton soil" caused by contraction due to drying prior to the rainy season.

meter in Zambia to US $350 in Mali. This difference likely would be equally pronounced between rural and urban areas, even within the same country. One should expect unexplainable differences when comparing cost estimates for building projects.

For multistory construction, better soil structure is needed to support the additional weight of the building. Footings and other structural members also must be increased and reinforced. Finally, higher scaffolding and vertical movement of building materials during construction can significantly increase construction costs.

Aside from the cost factor, distribution and future accessibility of utilities is almost always more convenient in single-story buildings. In addition to easing the movement of materials into laboratories, single-story constructions also facilitate future renovation. From the standpoint of expansion, installation of utilities, flexibility, and movement of manpower, it is highly recommended that facilities for agricultural research be limited to a single story if at all possible.

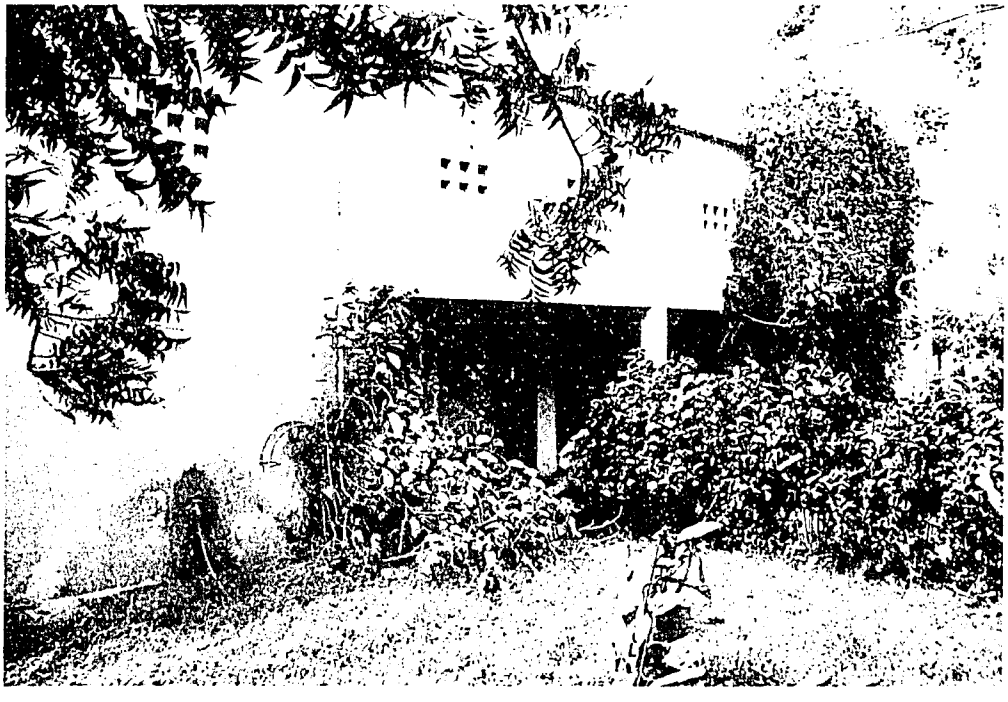
Differences in levels should be bridged by gently sloping ramps instead of steps wherever possible. This facilitates the movement of equipment. Elevators, dumbwaiters, and other mechanical lifts should be avoided.

Building Ventilation

Ambient heat buildup in laboratories, offices, and other areas is a problem common among research stations in the tropics. Naturally, such situations are more pronounced in areas without mechanical air-conditioning. However, even with air-conditioning, steps can be taken to reduce ambient heat and thus increase the efficiency of air-conditioning. Universally, ambient heat buildup within buildings is caused by four major factors:

- inadequate ventilation in the attic areas of buildings with pitched roofs,
- lack of or inadequate insulation between the finished ceiling and the roof,
- lack of proper cross ventilation through habitable areas of buildings,
- lack of or improper design of screen devices to shade windows from the direct sun.

Mali: Openings for cross ventilation in this building are inadequate. Additionally, the excessive planting cuts off natural ventilation but provides little shade to protect the building's facade.



Designers must carefully seek methods of reducing the temperature difference between inside and outside areas. For example, in a research station in Kaolack, Senegal, air trapped in an attic space without proper ventilation reached a temperature 15-20 degrees Celsius higher than the temperature (without air-conditioning) of the office immediately below. In some locations this difference will be even higher. Extreme differences in temperature must be resolved in the design process.

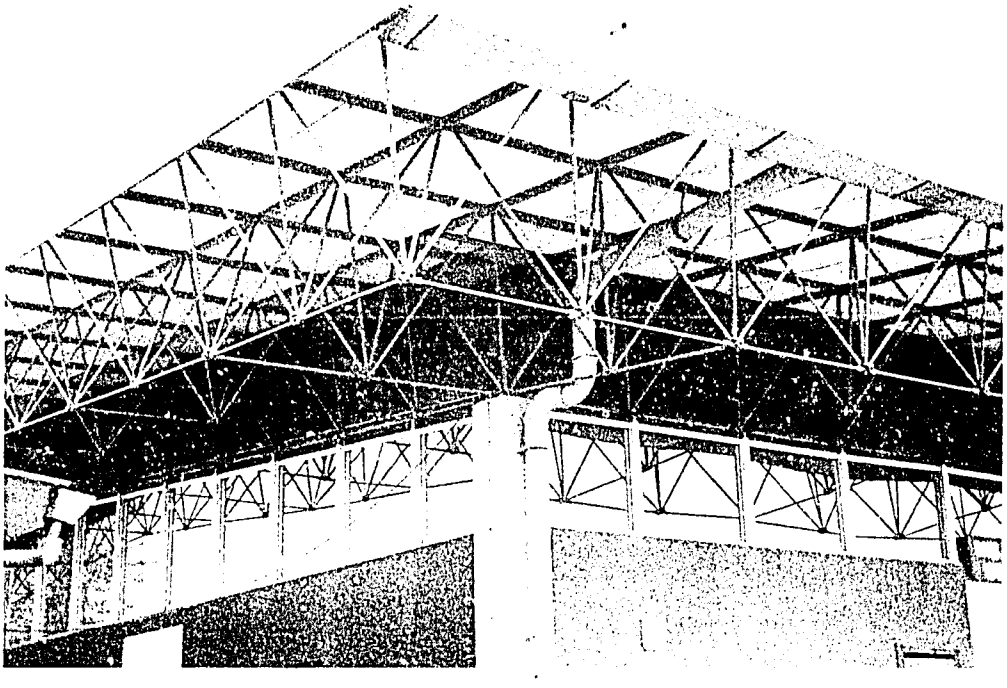
Thermal insulation and ventilation

The addition of insulation above the ceiling and sufficient ventilation of the space between the ceiling and the roof will make the area immediately below more comfortable. For this at least 10 cm of fiberglass or rock wool insulation or its equivalent, with a vapor barrier, is installed immediately above the ceilings in all areas. In addition, ventilation for the attic area should be provided at a minimum of one square meter of **free area** per 150 square meters of floor area. This ventilation can be installed at the ridge or high point of the roof, in the gable wall ends, or a combination of the two. Equally important is the need to provide for ventilation in the soffits of the overhangs where fresh air can enter and be exhausted by convection through the exit points that have been provided.

All ventilation devices must be adequately screened to prevent the entrance of birds and pests. Care should be taken to ensure that the free area provided after making the necessary reduction for screening and louvers is equal to the area required for proper ventilation. When mesh screening is used in buildings where adequate louvers and other devices cannot be installed easily, mechanical ventilation may be needed to exhaust trapped hot air. Mechanical ventilation may be a simple device that is rotated or activated by wind power or it may be electrically operated when the internal temperature of the air in the attic reaches a predetermined level.

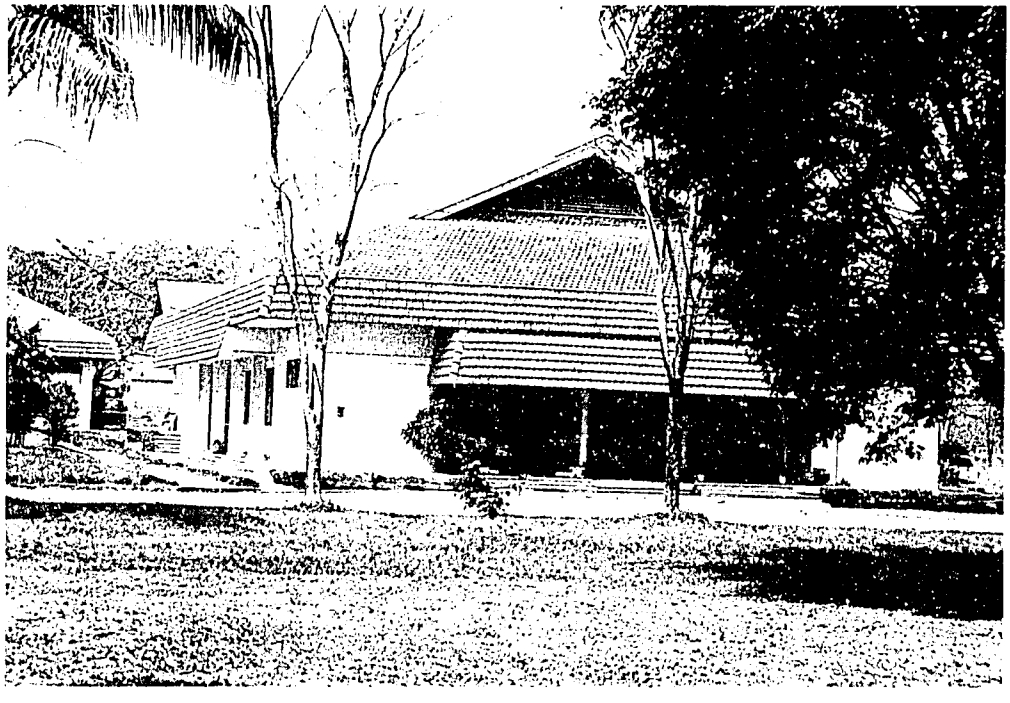
Ceiling insulation and roof ventilation are also needed in areas that are located in the tropics yet may be cold, such as Quito, Ecuador or La Paz, Bolivia. Buildings in these areas need the same amount of thermal insulation, but to hold the heat in the building rather than to prevent heat from entering. In cold climates also the attic area

Nigeria: Steel space frames afford excellent ventilation between roof and ceiling and are an economical structural system.



Indonesia: *Adequate ventilation at the peak of this roof reduces heat retention inside the building.*

Indonesia: *This conference center illustrates ridge ventilation of the space between the ceiling and roof.*



should be well ventilated, although only about half the area recommended for the hot tropical regions is required. In all climates ventilation allows the escape of humidity, which may build up in attics and cause damage to construction materials.

Development of Renewable Resources

Development of methods to use renewable resources is often overlooked by planners and designers of agricultural research institutions. As operating funds continue to shrink in almost all research organizations, more importance must be placed on reducing dependence on nonrenewable resources. The following are a few comments on use of four renewable resources: water, solar energy, farm wastes, and wind.

Water

Water is perhaps the single most important natural resource for any agricultural research station. Development of plants as well as survival of humans and animals depend heavily on a relatively constant source of water. However, in many developing countries, especially those in the semi-arid regions, water is a major constraint.

Designers of facilities in these areas should work closely with management and scientists to determine the annual water requirements for all phases of research. Availability of this amount of water must be a vital consideration in site selection. Planning facilities for water conservation, storage, and distribution so that it is available even during dry periods is a critical design function which should be integrated in the design of the overall building project.

Emergency water is necessary primarily for human and livestock consumption and for maintaining plant nurseries. Water for general consumption is best stored in an elevated tank. For nurseries, however, water should be stored below grade in closed cisterns to reduce evaporation. Using this method, rainwater can be easily trapped to be used at a later date.

At higher elevations where streams and rivers are usually prevalent, the force of a water stream can be used to generate economical electricity. Power generated in this manner is usually limited to small research substations in remote areas.

Solar energy

Solar energy is a renewable resource that is being underutilized in many developing countries, probably due to the need for foreign exchange to purchase the solar panels. In constructions financed with foreign exchange, the use of solar energy is feasible. Considerable electrical energy can be saved by using solar panels to generate hot water for kitchens, laboratories, and housing in research centers. Solar panels are virtually maintenance free and are easily mounted on almost any type of roof structure. Designers should explore the savings that would be generated by using solar energy and make an attempt to better utilize this energy as a renewable resource.

Farm wastes

Farm wastes obtained from animals and plants are a readily available source of fertilizer and compost. Additionally, in the 1980s research stations in many developing countries experimented extensively with development of biogas as a possible source of energy. Models of motors, lights, and refrigerators were made. However, since this time large-scale practical use of biogas on research stations has not advanced to any appreciable degree.

To collect wastes, buildings housing animals should be constructed with slatted floors. Such floors allow animal wastes to fall into a holding tank. Slurry from this tank can be periodically pumped onto pastures and other areas as an important source of fertilizer. Residual plant material also can be easily transformed into compost and returned to the soil to improve its workability and fertility. This is another important source of renewable energy that has been overlooked at most research stations. Designers should work closely with the scientific staff to design facilities to better produce and utilize decomposed plant material.

Wind power

As an energy source wind power has a very limited scope in agricultural research stations. Wind is undependable and is also more predominant in some areas than in others. Usually wind power is more dependable in coastal areas and at higher elevations. In these areas, windmills have long been used as a means of pumping water. Experimental designs have been developed to generate electricity using wind power. However,

these mechanisms are expensive and out of range for use at most research stations. Perhaps the most efficient use of wind power in research installations is to provide natural ventilation in habitable areas and to cool attic areas of buildings. Proper use of ventilation reduces the need for mechanical air conditioning. (See the section on ventilation, pages 50-53.)

Chapter Six—Building Materials and Finishes

Use of Local Materials

Sand, gravel, natural stone, clay, gypsum, iron ore, wood, and bamboo are all natural products that can comprise a major part of any construction project. From these raw products, building materials such as cement, concrete, bricks, windows, doors, ceramic tile, quarry tile, plaster, and roofing tiles are produced. These basic materials are found to be readily available in almost all developing countries.

In countries where sufficient quantities of raw materials are available and processing and marketing of these products is feasible, factories and industries usually are established to produce building products. Sometimes, however, government price controls, availability, and distribution can be major constraints to these local industries. Shortages frequently occur, resulting in artificially inflated prices.

Nevertheless, increased use of locally produced building materials has been found to be advantageous in the long run. Use of local materials can lower construction costs, decrease construction time, and stimulate the local economy. Using local materials also can save valuable foreign exchange. Today this is an important consideration for every developing country. Another reason to use local materials is the likelihood of their immediate availability. Imported materials are commonly delayed up to six months in shipping and are often more expensive than local materials. In most countries, at least 75-80 percent of the total project cost can usually be attributed to local labor and materials.

There will be times, however, when locally produced materials are not available. This is especially true for items such as electric motors, transformers, lighting fixtures, fluorescent tubes, plumbing fixtures and accessories, and heavy-duty piping. If items are not manufactured locally, or not even available locally, the designer must make provision for future replacements and spares. This is a serious consideration in many developing countries. Unless adequate quantities of replacement parts are made available at the time of construction, users of facilities will begin to rob from one location to replace a broken part in another.

To avoid or at least minimize this piracy, architects should specify sufficient quantities of spares to remain in storage until they are needed. Floor tiles, fluorescent tubes, ceramic tiles, door and window hardware, valves, and controls are just a few of the items that warrant stockpiling.

Structures

Reinforced concrete and steel are two of the most commonly used materials for the structural systems of buildings for agricultural research. Seldom, if ever, is wood used as a structural material for principal buildings except perhaps in farm structures or for the roof trusses in smaller institutes.

When reinforced concrete is used in structures for buildings, care should be taken to ensure that it is properly proportioned, machine mixed, carefully placed, and well vibrated while being poured. Vibration during pouring causes the mixture to fill all corners of the forms and produces a smoother, more uniform surface, relatively free of imperfections. Tight, well-fitted formwork and good vibration improve the quality of the concrete. In most cases it also eliminates the need to add an additional finish, such as plaster or cement wash, to the concrete surfaces to improve their appearance. Concrete structures are often left with their natural finish. If exposed concrete is to be painted, a paint specially recommended by the manufacturer should be used. Low-quality paints should be avoided, as they tend to flake and dust off surfaces.

Steel structures are usually delivered to the job site with a coat of antirust paint already applied. Almost always this paint is damaged in transit and the structure begins to rust even before the building is complete. As soon as the steel structure is put into place, a thorough check for rust should be made. Any rust is then carefully removed by wire brushing. An additional coat of rust-inhibiting paint should then be applied to the entire structure. Normally, all steel structures exposed to view after construction is complete should be painted with a good-quality finish paint.

Use of prefabricated structures, employing both steel and concrete, is often the most economical method of construction. This is especially true in cases where inclement weather is likely to cause construction delays. The conceptual designs for the research center at Eskishehr, Turkey were developed around prefabricated units due to extreme weather conditions in the area during the winter. Often this prefabrication can save many months of on-site construction time when weather prohibits delivery of materials or work on the job site. Architects and planning teams should investigate and analyze the alternative costs and construction time for using prefabricated units if these are available in the area.

Roofing Materials

Perhaps the most important element of any building is its roof. Without a proper roof to protect its interior, the building will be unusable. Unsuitable roofing materials allow water to enter and damage expensive scientific equipment. In one prestigious research center in Brazil, improper roofing has led to leakage. Scientists have had to fabricate gutters within laboratories to divert water away from spectrophotometers and other equipment.

Materials for roofing vary depending on whether the roof is flat or pitched. Most reinforced concrete buildings use flat roofs. Other types of structures use roofs that slope; these are described as either hipped, gable, or shed roofs.

When flat roofs are used on reinforced concrete buildings, they must be waterproofed and well flashed. One common waterproofing method is to use several overlapping layers of an asphalt-impregnated fibrous material (felt). These are held in place by first mopping the concrete roof deck or layer of rigid insulation with a layer of hot asphalt. Afterwards, alternating, overlapping layers of hot asphalt and felt are applied until at least four layers have been built up at any vertical point through the roof. Usually gravel is applied to the top surface to reflect the sun's ultraviolet rays, provide extra weight to secure the layers of felt, and allow the roof to be walked on without causing damage to the final coat of felt. If properly applied, roofs of this type should have a useful life of 15-20 years. Nonetheless, in most developing countries flat roofs have not proven satisfactory. Research institute managers and architects alike suggest that flat roofs should be avoided whenever possible.

Sloping roofs are the simplest type to waterproof and most countries have an abundant supply of relatively inexpensive materials that can be used for their construction. The materials most frequently used are corrugated galvanized iron sheets, corrugated aluminum sheets, corrugated sheets of a fibrous cement product, and clay tiles used alone or in combination with any of the corrugated sheets. Depending on the area, and especially on its proximity to the ocean or other corrosive atmospheres, which can reduce the life by 50 percent, corrugated iron has a useful life of eight to 10 years, aluminum 10-15 years, and fibrous cement products 15-20 years. Clay tiles last virtually the life of the building (30-40 years). In addition to galvanized iron, aluminum, and fibrous cement being supplied in the corrugated form, these materials are also produced in the form of channels of varying depth. Depending on their depth, fibrous cement channels are capable of spanning up to five meters or more.

Certain precautions should be taken when using metal roofing materials. Galvanized iron or aluminum should not come in direct contact with mortar, plaster, or other lime-based materials. Aluminum roofing materials should not be secured with dissimilar metal attachments or come into direct contact with fasteners.

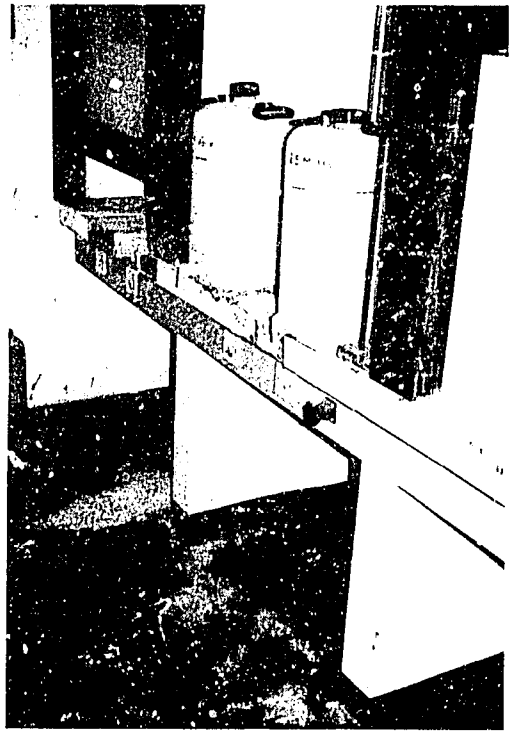
Flooring

A wide variety of flooring materials suitable for use in research buildings is available today. While among these there is an equally wide range of prices, the most appropriate materials are not necessarily the most expensive. However, unless occupants of the buildings are made to take care of floors—keep them clean and polished and immediately neutralize acid spills—no material can be expected to endure more than a very few years. The following is a list of materials commonly used for finished floors in research facilities and some of their good and bad characteristics.

Quarry tile is seldom used in agricultural research buildings except in special situations specifically requiring an acid-proof floor. In these cases a special epoxy must be used in the joints since a strong concentration of acids can quickly destroy regular cement grout. Quarry tile is one of the most expensive materials used for finished flooring. It is therefore not recommended except in highly corrosive situations.

Ceramic tile is sometimes used as a flooring material in laboratories as well as in toilets. Again, this material can be expensive and is not as resistant as is commonly assumed. As with quarry tile, the weakest part of ceramic tile floors is the cement mortar joints. Also, being a very brittle material, ceramic tiles are subject to damage by dropped items. In an average research institute unless the material is readily available and the price is very competitive there can be little justification for use of ceramic tile in laboratories. Other materials, such as terrazzo and concrete pavers, are equally durable and normally cost much less.

Vinyl tile has been used with great success in offices, conference rooms, libraries, laboratories, and even toilets in research buildings all over the world. Coved vinyl tile bases are also frequently used, as well as sheet vinyl, which has fewer



Zimbabwe: Acid has been dripping from these carboys for many years. The fume hoods and concrete floor are now damaged and must be replaced.

joints. Vinyl has many advantages: moderate cost, easy installation and replacement, and a wide choice of patterns and colors. It is highly resistant to impacts, moderately resistant to acids, needs little maintenance, and should have a life under normal use of about 10-15 years.

Asphalt tile, much like vinyl tile, has been widely used in research buildings although its disadvantages far outweigh its advantages. Although an inexpensive material, asphalt tile does not resist impacts and easily deforms under loads. It is easily broken, difficult to maintain, does not wear well, and has a life of only five to eight years under normal use in a laboratory. This material has little resistance to acids and petroleum-based products and is not recommended for use in laboratories or offices except as a last resort.

Terrazzo pavers are a composite material made of marble chips of varying sizes and cement. They are produced in a number of sizes, usually from about 20 cm square to 40 cm square. The thickness is about five centimeters. Terrazzo pavers make a very good floor with excellent wearing qualities and easy replacement if damaged. Without protection, however, this flooring is highly susceptible to damage from acids. There are many excellent products on the market today that strengthen, seal, and shine terrazzo, giving additional protection from wear, stains, and damage by acids. Again, even with additional protection acid spills should be neutralized immediately.

Poured terrazzo is much the same material as terrazzo pavers with many of the same physical characteristics. The main difference is that the mixture of marble chips and cement is poured in-situ as opposed to being prefabricated into smaller pavers. Poured terrazzo is more difficult to patch and repair if one expects to match the original flooring. The material is very effective in large unobstructed areas such as multipurpose rooms, cafeterias, or large conference rooms. Also, for added interest designs can be poured into the floor using different colors and mixtures of marble chips and cement.

Concrete pavers are perhaps the most inexpensive flooring available in many developing countries. The sizes and manufacturing techniques are similar to those used in manufacturing terrazzo pavers. However, because no marble chips are used the result is a floor that is not as durable as terrazzo. Pigment can be added to the concrete to produce a colored paver. Again a sealer and hardener should be applied to prevent dusting and to improve wear resistance.

Poured concrete floors are inexpensive, but generally are not considered "finished" or acceptable for use in principal laboratories. The use of poured concrete floors is usually limited to warehouses, storage areas, patios, and sidewalks. However, in the interest of cost savings, poured concrete has also been used widely in the laboratories and offices of many outlying research stations.

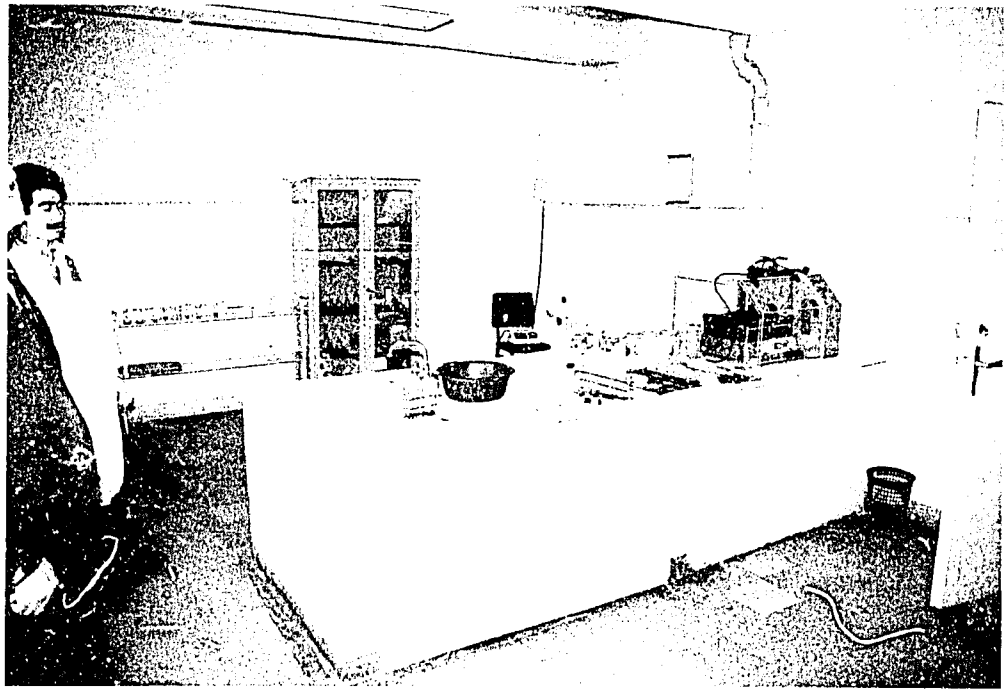
Wood has been used for many years for floors in offices, conference rooms, libraries, and other prestigious areas of buildings. During the colonial period especially there was considerable use of wood for finished floors in laboratories and in hallways. Wood has many advantages. It adds warmth and beauty to a building and when damaged it can be easily refinished. However, shortages of suitable material and the high cost of wood flooring in most of the world now make its use prohibitive.

Carpeting is not often recommended for use in agricultural research facilities. Although commercial grade, stain-resistant carpeting is available in most countries, it is expensive and difficult to clean and maintain. Carpeting must also be replaced more often than other more durable materials. Its use should therefore be limited to only the offices and conference rooms of top management in a research organization.

Walls and Partitions

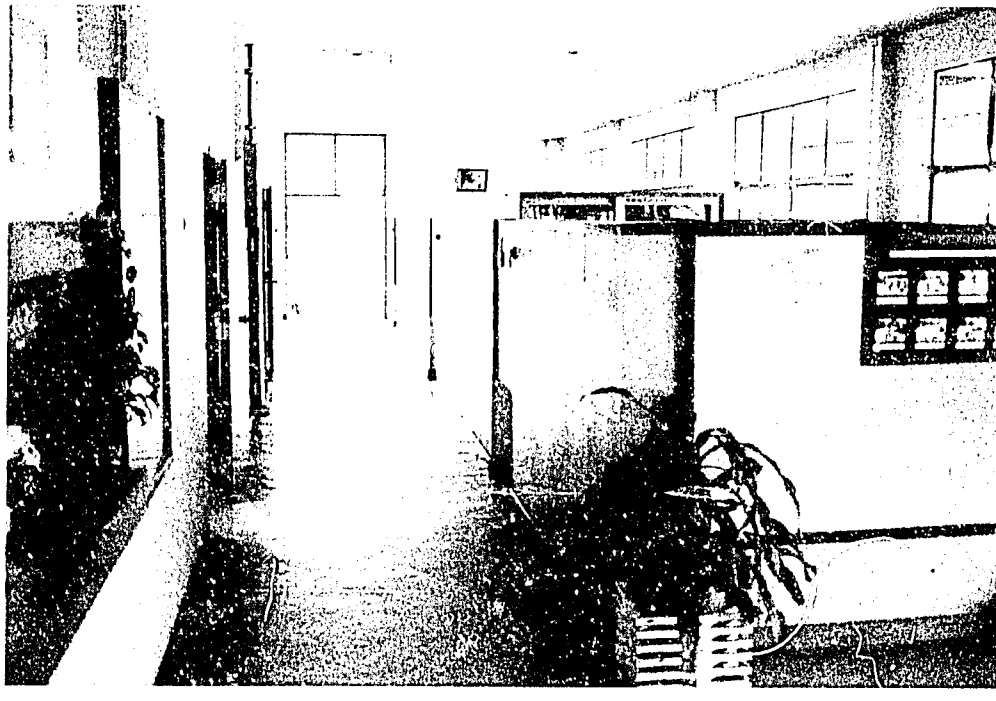
Outside walls and, in many cases, inside partitions for research institutes are usually constructed of reinforced concrete, bricks, concrete blocks, or extruded hollow clay tiles. Walls extending below grade level should have through-wall flashing installed to block any moisture which can "wick" upward and cause efflorescence or plaster to deteriorate inside the building.

Normally designers specify a finish to be applied to walls to improve their final appearance. However, concrete, bricks, and concrete blocks can be left natural and painted. More likely than not, except for decorative effects, walls will be finished with plaster composed of a mixture of sand and cement. The final texture can vary from very smooth to rough, depending on the design and



Turkey: Excessive use of ceramic tile on laboratory walls and counters is common in agricultural research institutes. In most cases a good-quality paint is sufficient.

Thailand: Movable partitions about 1.9 meters high can be used to divide office spaces. These allow cross ventilation and flexibility in office design.



aesthetic appearance that the designer wishes to achieve. Seldom is a plastered surface left natural. Normally paints and other finishes are applied. Ceramic tile or other wall coverings can be used instead of paint.

Two general observations should be made in dealing with wall finishes: First, ceramic tile has been used excessively in many research institutions. Second, paints used on both inside and outside walls, for the most part, have been of low quality and short durability. With the availability of good-quality enamels and other specialty paints such as epoxies, there is little to be achieved by using ceramic tile on walls in either toilets or normal laboratories. It may be justifiable, however, to continue to use ceramic tile in kitchens and other areas where frequent washdown is likely and for which high-technology finishes are unavailable. Because thus far capital monies have been easier to get than maintenance funds, institutes should discontinue using inexpensive paints on inside and outside walls. These paints dust off and begin to need replacement within a couple of years. Invest a little more on wall finishes in the initial construction and get better value for the money.

Many research organizations, especially in Southeast Asia and Latin America, have used movable partitions extensively. These partitions may be factory produced or built on the job site. If factory produced, they usually consist of a series of steel or aluminum shapes with filler panels of plywood, plastic laminate, or gypsum board. If constructed at the job site, they are usually made of wood profiles, again using fillers similar to those in factory-produced units. The word "movable" is a misnomer, however; reusable would be more correct. Most partitions of this type are difficult to dismantle, usually becoming partially damaged in the operation and difficult to reconstruct. Their initial cost has been estimated at around 2.5 to 3.0 times the cost of normal construction using masonry materials. This means that to be economical all partitions must be moved many times. They seldom are. Careful thought should be given to the use of these partitions.

Ceilings

Lay-in ceilings are very appropriate for use in agricultural research buildings. They allow access to wiring and utilities and make future modifications relatively easy. Lay-in ceilings are usually constructed by using a series of interlocking channels and tees which are suspended by wires from the structure above. The modular pattern formed by these elements varies but usually takes the shape of squares or rectangles within which light fixtures can be located.

The grid formed by the channels can be filled with a variety of materials. Some of these are soft and sound absorbing, others are more durable with holes to assist in sound absorption. Some are even prefinished and do not require painting. It is up to the architect to recommend the most appropriate material to be used. One point has been noted, however. In areas where humidity is high, care should be taken to use a filler material that will not absorb moisture and begin to sag after a few years. Also, a backing material with insulating qualities is advantageous and will help to regulate the temperature inside the building.

Windows

Windows are usually made from wood, steel, or aluminum. Wood, however, is not usually recommended for a variety of reasons. Wood requires constant refinishing, tends to expand and contract with variances in temperature and humidity, and is subject to damage by termites. Aluminum and steel are more resistant and require less maintenance. In areas where mosquitos are a problem, insect screening also should be installed on windows in housing and in recreation and dining facilities. All windows should be weatherstripped, tightly fitted, and the perimeters carefully caulked to prevent the entrance of rain. In Indonesia and Kenya, rainwater entering buildings through poorly caulked windows has caused severe damage inside.

Windows may be double hung, vertically pivoted, horizontally pivoted, casement type, or may operate by any other method that is readily available. Windows should not protrude into the room since this tends to interfere with the installation and operation of sun control devices such as blinds or draperies.

Aluminum windows should be anodized if such treatment is available. Anodization prevents oxidation and darkening of the regular aluminum

mill finish. Aluminum windows should not come in direct contact with masonry or mortar containing cement. Fasteners should be cadmium plated.

Steel windows should be tightly fitted and are best if constructed from tubular profiles rather than "T" or "Z" sections. Care should be taken to protect steel surfaces from mortar stains during construction. Steel also should not come in direct contact with masonry or mortar containing cement. Chrome-plated screws should be used to fasten steel windows.

One word of caution, windows are frequently installed using wooden plugs set into the masonry walls to receive the screws fastening the window frame in place. These wooden plugs are food for termites and should not be used. Plugs used to receive screws and other attachments should be made of lead, steel, plastic, or fiber and should be resistant to termites.

Glass installed in all windows should be back puttied. This prevents it from coming into direct contract with the window frame. Clips should be used to secure the glass in place and not the putty itself.

Protection from theft is a problem that often must be dealt with. Most countries have found it necessary to install nonremovable bars over windows to protect equipment. This is especially true in laboratories and in computer installations. If bars are to be used they should be designed to be attractive as well as utilitarian. Remember, bars are a deterrent only. They will not stop a dedicated thief from entering and removing equipment.

Doors

Doors generally are constructed of wood, the main exception being those used as security doors. These may be constructed of steel. The most commonly used wooden doors are flush panel doors, which are manufactured in what is termed hollow core and solid core. Both are usually faced on both sides with a thin plywood or plastic laminate layer.

Hollow-core doors are for interior use, away from humidity and high moisture. They are constructed using an egg-crate core to which a thin facing is attached on either side. These doors are not extremely durable and will not withstand hard use as well as solid-core doors. If exposed to the outside weather, hollow-core doors will tend to delaminate and will likely need replacement after a few years. Solid-core doors are for use outside and in heavy traffic areas within a building. They are constructed with a solid core, usually of an exterior-grade plywood specially made for resistance to the weather.

Regardless of which type is used or where it is installed, all sides and edges of doors should be thoroughly sealed by varnishing or painting to prevent the entrance of moisture. To prevent deterioration, doors exposed to the outside of a building should be refinished every year or two, depending on the severity of the climate.

Lighting Fixtures

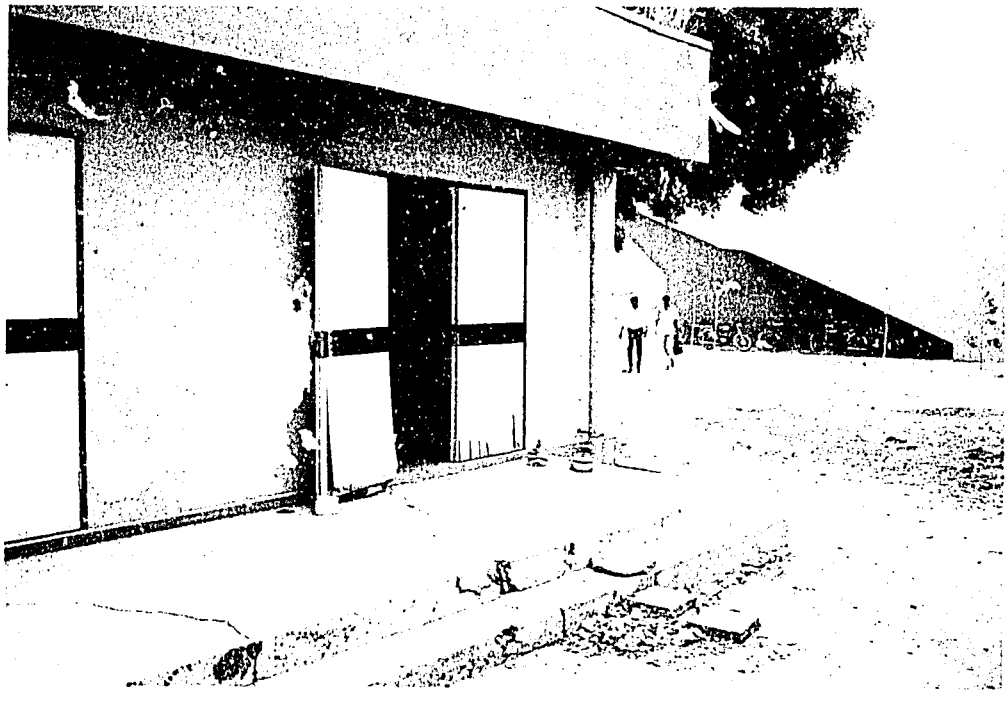
Except for special effects, the best lighting fixtures for use in research centers are the fluorescent type. The bottoms of these fixtures should not be enclosed but should be open to prevent dust, dirt, and insects from being trapped inside. Fluorescent fixtures should be selected with care to ensure the local availability of replacement tubes. Cannibalization of fluorescent tubes from some of the buildings at the Institute for Agricultural Research (IAR) in Zaria, Nigeria, over the past 12 years has reduced most of the fixtures to about 50 percent of their original light potential. In this case, the fluorescent tubes originally installed are not compatible with those in the local market. Foreign exchange in the country has become so difficult to obtain that the import of replacement tubes is now virtually impossible.

Laboratory Cabinetwork

In order to maintain as much flexibility as possible in the design of agricultural research facilities, institutes should install laboratory benches that can be removed and reused. Too often laboratory benches are constructed of reinforced concrete with surfaces faced with ceramic tile or some similar material. In addition to providing a very uneven work surface, glassware breakage is increased with the use of ceramic tile bench tops. When the time comes to renovate,

Nigeria: Security of goods inside laboratories is an issue that must be addressed in the design of facilities.

Nigeria: Hollow-core doors deteriorate rapidly when exposed to the weather. Note the lack of maintenance on the walls and also on the concrete walk. Solid-core doors should have been used and maintained to prevent this deterioration.



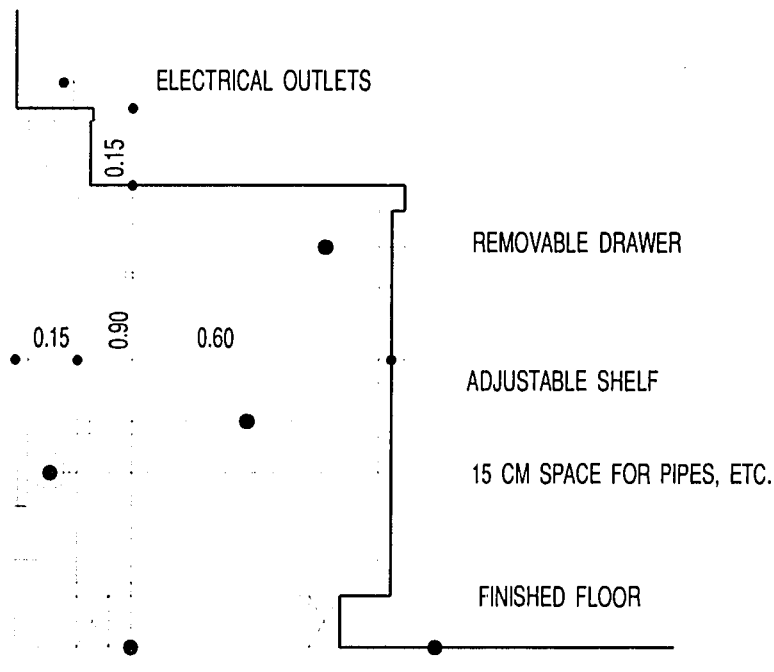
these benches must either be demolished and rebuilt or accepted and the new design developed around their present location. The solution and the recommendation is to purchase ready-made, reusable laboratory cabinetwork, either in wood or metal.

The decision as to wood or metal cabinetwork should be well thought out. Wooden cabinets can present problems in areas where termites are widespread. In humid areas wood tends to expand and contract with seasonal changes. This sometimes makes frequent adjustment of cabinet drawers and doors necessary. Metal cabinetwork can be more difficult to install and to repair when damaged. The final selection—wood or metal—should be based on climatic conditions at the site.

If wood is chosen, it should be adequately treated against termites and other wood-devouring insects. The finish should be a good-grade polyurethane, professionally applied, preferably in the factory where the cabinets are made. Cabinetwork made at the job site should be avoided. Wood cabinets should be made in a factory where humidity and temperature can be accurately controlled. If metal cabinetwork is chosen, the finish should be a good-quality baked-on enamel that has been factory applied. Care should be taken in using metal cabinets near the sea due to the possibility of rusting. Also, corrosive chemicals must be used with care and spills must be immediately cleaned if cabinets are expected to last more than a few years.

Perhaps the weakest part of laboratory cabinetwork is the part most frequently used—the top surface. Materials for laboratory bench tops vary considerably, plastic laminates being the most popular and perhaps the most widely used in projects where restricted development budgets are a factor. This material is adequate for most cases where strong chemicals are infrequently used. Where strong chemicals are used on a daily basis, such as in chemical analysis laboratories, a more acid-resistant substance should be used. An inexpensive material, sheet neolite, has been used on top of the plastic laminate in certain locations at CENICANA in Colombia. This material was reported very satisfactory. Also, several manufacturers make epoxies and other substances that can be applied to a variety of base materials such as a fibrous cement product or wood. It has even been found that solid hardwood laboratory tops that have been finished with polyurethane, either colored or clear, give good service for many years

Many companies manufacture base cabinets with accessible space behind them for utilities.



and can be refinished with excellent results at modest cost (Chemistry and Soils Research Institute, Harare, Zimbabwe).

Many manufacturers construct laboratory base cabinets with a space behind where utilities can be installed. These cabinets add flexibility since water, gas, electricity, and drain lines can be installed horizontally behind the base cabinets and made available to the user at any point. This style of base cabinet is recommended since it can be easily removed to make modifications to utilities.

Chapter Seven—Building Categories and Components

There are about six major categories of buildings for agricultural research:

- laboratories,
- offices,
- research support facilities,
- ancillary facilities,
- housing and recreational facilities,
- specialized installations.

Management, administration staff, and scientists should be involved in determining the number and types of each of these areas required by the institute. The final determination is summarized in a table of accommodations (TOA). A table of accommodations lists the numbers of staff presently employed in each capacity and section of the research institute. A projection of staff growth is also included. By multiplying the number of staff by the amount of space required for each, a good estimate of the total floor space can be calculated. See pages 64-69 for a sample TOA.

Estimating the Space Required

One of the first questions asked when a building is being designed is "How does one know how much floor area to allocate to the individual building units?" There are several norms that have been found acceptable almost worldwide. These can be used in making estimates of floor space requirements for preliminary designs.

Under normal circumstances, a scientist (usually at PhD or MSc level with research experience) working in a private office requires about 14-15 square meters for comfortable accommodation. This space is adequate for a desk, a desk chair, a couple of side chairs, a bookcase, a cabinet for immediate supplies, and one or two file cabinets.

Technical personnel, including technicians and recent university graduates, need about half of the space required for a scientist. Seven to eight square meters usually will suffice. In certain cases, especially when large amounts of information are to be stored or when frequent interviews or meetings are involved, even 10 square meters per occupant can be justifiable. Occupancy for technical personnel varies from two to eight persons per office, depending on the customs and habits of the country for which the facility is being planned. Seldom are private offices for technical personnel justifiable.

In addition to providing office space for scientists and technical personnel, desk space and file drawers in each laboratory are highly desirable. There researchers and technicians can work while carrying out routine laboratory duties.

Directors of research stations should be provided with about 30 percent more space than that for a scientist. The same applies to deputy or assistant directors at these locations. Directors of principal research institutes and second-echelon personnel such as deputy directors generally require 2.5 to 3.5 times the amount of space allocated to a staff scientist. This additional floor space accommo-

Sample Tables of Accommodation (3 tables)

Table 1. Current staff and five-year projection of staff growth for each department

Administration Personnel

Title	Present staff	Proposed additions	Total staff
Research Institute Director	1		1
Assistant Director (Research)	1		1
Assistant Director (Administration)		1	1
Executive secretaries	1	1	2
Head of Finance Department	1		1
Head of Internal Finance Section	1		1
Internal finance assistants	1	1	2
Secretary to Internal Finance		1	1
Paymasters	1	2	3
Head of External Finance Section		1	1
External finance assistants		1	1
Secretary to External Finance		1	1
Head of Personnel Department	1		1
Personnel assistants	1	1	2
Secretary to Personnel		1	1
General administration typing pool	2	2	4
Head of Files and Records	1		1
Files and records assistants	2	1	3
Head of Purchasing Department	1		1
Purchasing assistants	1	2	3
Secretary to Purchasing	1	1	2
Subtotal	17	17	34

Research Support Personnel

Title	Present staff	Proposed additions	Total staff
Head of Information & Documentation Department		1	1
Librarian	1		1
Library Assistant		1	1
Secretary to Information & Documentation		1	1
Photographer		1	1
Graphic Artist		1	1
Editor		1	1
Printers		3	3
Telephone Operator	1	1	2
Civil Defense		1	1
Research Station Manager	1		1
Head of Labor Relations		1	1
Labor relations assistants		2	2
Storekeepers	1	2	3
Head of Maintenance Department		1	1
Secretary to Maintenance		1	1
Vehicle and farm equipment maintenance personnel	2	3	5
Facilities maintenance and shops personnel	1	5	6
Groundskeepers	3		3
Electronic equipment repair personnel		1	1
Subtotal	10	27	37

Research Personnel

Department	Present staff	Proposed additions	Total staff
Plant Breeding			
Senior scientists	1		1
Junior scientists		2	2
Technicians		2	2
Laboratory assistants		2	2

Research Personnel (continued)

Department	Present staff	Proposed additions	Total staff
Agronomy			
Senior scientists		1	1
Junior scientists	2		2
Technicians		2	2
Laboratory assistants			-
Plant Protection			
Senior scientists	2		2
Junior scientists		4	4
Technicians		6	6
Laboratory assistants	2	4	6
Genetic Resources			
Senior scientists	1		1
Junior scientists		2	2
Technicians		2	2
Laboratory assistants		4	4
Farming Systems			
Senior scientists	2		2
Junior scientists		4	4
Technicians		6	6
Laboratory assistants			—
Soil, Water, and Plant Tissue Analysis			
Senior scientists	2		2
Junior scientists		4	4
Technicians		4	4
Laboratory assistants	3	3	6
Animal Production			
Senior scientists	1		1
Junior scientists	1	2	3
Technicians		2	2
Laboratory assistants	2	2	4
Economics			
Senior scientists	1		1
Junior scientists	1	1	2
Technicians		4	4
Laboratory assistants			—
Subtotal Research Personnel			
Senior scientists	8	3	11
Junior scientists	4	19	23
Technicians	—	28	28
Laboratory assistants	7	15	22

Table 2. Nominal floor area required to accommodate staff

Administration Areas

Name of area	Number of occupants	Floor area per person	Total area in m²
Research Institute Director	1	40	40
Assistant Director (Research)	1	25	25
Assistant Director (Administration)	1	25	25
Executive secretaries	2	10	20
Conference room	12	1.5	18
Supplies and storage			15
Head of Finance Department	1	15	15
Supplies and storage for Finance Department			15
Head of Internal Finance Section	1	15	15
Internal finance assistants	2	7	14
Secretary to Internal Finance	1	10	10
Paymasters	3	7	21
Head of External Finance Section	1	15	15
External finance assistants	1	7	7
Secretary to External Finance	1	10	10

Administration Areas (continued)

Name of area	Number of occupants	Floor area per person	Total area in m²
Head of Personnel Department	1	20	20
Personnel assistants	2	7	14
Secretary to Personnel	1	10	10
General administration typing pool	4	7	28
Supplies and storage			15
(2) Conference rooms	8 each	1.5	24
Head of Files and Records	1	15	15
Files and records assistants	3	7	21
Central record storage			25
Mail room			7
Head of Purchasing Department	1	15	15
Purchasing assistants	3	7	21
Secretary to Purchasing	2	7	14
Supplies and storage			15
Visitors' offices	2	15	30
Subtotal			**539**

Research Support Areas

Head of Information & Documentation Department	1	15	15
Librarian	1	10	10
Library Assistant	1	10	10
Secretary to Information & Documentation	1	7	7
Photographer	1	10	10
Graphic Artist	1	20	20
Editor	1	15	15
Reading room	12	2	24
Stack area (Estimate 18 books or 25 journals per lineal meter of shelf space)			170 (assumed)
Book receiving and repair			15
(2) Conference rooms	6 each	2	24
Telephone Operator	2	7	14
Civil Defense	1	15	15
Research Station Manager	1	20	20
Head of Labor Relations	1	15	15
Labor relations assistants	2	7	14
Storekeepers	3	(in ancillary area)	
Head of Maintenance Department	1	15	15
Secretary to Maintenance	1	15	15
Vehicle and farm equipment maintenance personnel	5	(in ancillary area)	
Facilities maintenance and shops personnel	6	(in ancillary area)	
Groundskeepers	3	(in ancillary area)	
Electronic equipment repair personnel	1	20	20
Cafeteria and kitchen (2 seatings, 75 each)	75	2	150
Snack bar, coffee, tea, and recreation room			95
Subtotal			**693**

Scientific Areas

Name of area	Number of occupants	Total area in m²
Plant Breeding		
Physiology Laboratory		40
Storage		15
Offices		
Senior scientists	1	15
Junior scientists	2	15
Technicians	2	15
Laboratory assistants	2	in laboratory
Subtotal		**100**
Agronomy		
Laboratories		40
Storage		15
Offices		
Senior scientists	1	15
Junior scientists	2	15
Technicians	2	15
Laboratory assistants	—	
Subtotal		**100**

Scientific Areas (continued)

Name of area	Number of occupants	Total area in m²
Plant Protection: Entomology		
Laboratories		40
Insect rearing rooms		30
Food preparation area		4
Sterile room		2
Taxonomic collection		15
Storage		15
Offices		
Senior scientists	1	15
Junior scientists	1	15
Technicians	2	15
Laboratory assistants	2	in laboratory
Subtotal		**151**
Plant Pathology: Virology		
Material receiving area		20
Laboratories		20
Media preparation area		20
Sterile room		15
Glassware washing and sterilization area		15
Storage		15
Offices		
Senior scientists	1	15
Junior scientists	1	15
Technicians	2	15
Laboratory assistants	2	in laboratory
Subtotal		**150**
Plant Pathology: Mycology and Bacteriology		
Material receiving area		20
Laboratories		40
Media preparation		20
Sterile room		15
Growth rooms: light and dark		20
Glassware washing and sterilization area		15
Storage		15
Offices		
Senior scientists		
Junior scientists	2	15
Technicians	2	15
Laboratory assistants	2	in laboratory
Subtotal		**175**
Genetic Resources: In-Vitro Research		
Material receiving area		20
Laboratories		20
Media preparation		20
Sterile room		20
Glassware washing and sterilization area		15
(2) Growth rooms		30
Storage		15
Offices		
Senior scientists	1	15
Junior scientists	1	15
Technicians	1	15
Laboratory assistants	2	in laboratory
Subtotal		**185**
Genetic Resources: Germplasm Storage		
Material receiving and preparation area		20
Seed drying area		15
Cataloging and records area		10
-20 Degree long-term storage		40
+4 Degree medium-term storage		40
Seed cleaning area (outside the building)		20
Compressor room		20
Storage		15
Offices		
Senior scientists		
Junior scientists	1	15
Technicians	1	15
Laboratory assistants	2	in laboratory
Subtotal		**210**

Scientific Areas (continued)

Name of area	Number of occupants	Total area in m²
Farming Systems		
Offices		
Senior scientists	2	30
Junior scientists	4	30
Technicians	6	30
Laboratory assistants	—	
Subtotal		**90**
Soil, Water, and Plant Tissue Analysis		
Soil		
Receiving and login area		15
Storage area awaiting testing		20
Sample grinding and preparation – outside building		20
Sample drying area		20
Physical determination laboratory		40
Post-analysis storage		20
Plant tissue		
Receiving and login area		10
Storage area awaiting testing		10
Sample grinding and preparation room		20
Sample drying room		15
Post-analysis storage		10
Quality laboratory		
Chemical analysis laboratory		40
Glassware washing and sterilization area		20
Kjeldahl room		15
Instrumentation room		20
Glassware and chemical storage		20
Storage area		15
General		
Offices		
Senior scientists	2	30
Junior scientists	4	30
Technicians	4	30
Laboratory assistants	6	in laboratory
Subtotal		**420**
Animal Production		
Sample preparation area		15
Physiology laboratory		40
Instrumentation room		15
Glassware washing and sterilization area		15
Storage		15
Offices		
Senior scientists	1	15
Junior scientists	3	30
Technicians	2	15
Laboratory assistants	4	in laboratory
Subtotal		**160**
Economics		
Computer laboratory		20
Storage area		15
Offices		
Senior scientists	1	15
Junior scientists	2	15
Technicians	4	30
Laboratory assistants	—	
Subtotal		**95**

Table 3. Summary of staff and accommodations

Offices and Other Nonresearch Areas

	Number of personnel	Net area in m^2
Administration personnel	34	539
Research support personnel	34	693
Subtotal administration and research support personnel	**68**	**1232**

Area Required for Laboratories, Other Scientific Areas, and Scientists' Offices in square meters

	Offices	Labs & scientific areas
Plant Breeding	45	55
Agronomy	45	55
Plant Protection		
Entomology	45	106
Plant Pathology		
Virology	45	105
Mycology and Bacteriology	30	145
Genetic Resources		
In-Vitro Research	45	140
Germplasm Storage	30	180
Farming Systems	90	—
Soil, Water, and Plant Tissue Analysis		
Soil	30	135
Plant Tissue	30	65
Quality Laboratory	30	130
Animal Production	60	100
Economics	60	35
Subtotal	**585**	**1251**
Subtotal for principal buildings		**3068**
35% grossing factor for toilets, hallways, entrances, and other miscellaneous areas not included in the above tables		**1074**
Total design area for principal buildings		**4142 square meters**

dates casual furniture and a small table with chairs where meetings with four to six persons can be held.

General office space for administration and support staff should be calculated at 15 square meters per person except in cases of multiple occupancy. Multiple occupancy requires about 7.0 to 7.5 square meters per person.

An institute will normally need an auditorium and one large conference room for groups of 12-16 persons. Several smaller conference rooms accommodating six to 10 persons should also be provided. About one to two square meters should be allocated in conference rooms per occupant. An auditorium requires about one square meter per person. This makes allowance for a small to medium-sized stage and aisle space for easy circulation.

Libraries are generally designed around the number of books proposed to be accommodated. Designers should assume 18-20 volumes per lineal meter of shelf space. Most stacks are six shelves high. Some are single faced, others double faced.

Dining facilities should allow from 1.0 to 1.4 square meters of floor area per person, depending on how the tables are laid out and the number of places at each table. The kitchen and serving area should have an area of about one square meter per person being served per seating. This varies with the number of persons being served, whether the food is to be prepared and stored in the kitchen, and if food is to be catered and only served at the institute. If meals are to be catered, the kitchen area can be reduced by as much as 50 percent.

Refer to the drawings and designs on pages 89-102 for examples of designs for other building areas.

Laboratories

From a design standpoint, laboratories are one of the most difficult and critical elements of the entire research complex. There is no simple formula for determining the proper size for a laboratory. The space required depends on the research program(s) to be housed, the size and quantity of equipment, and the workload of the scientists. Occupancy, although less important, also must be considered.

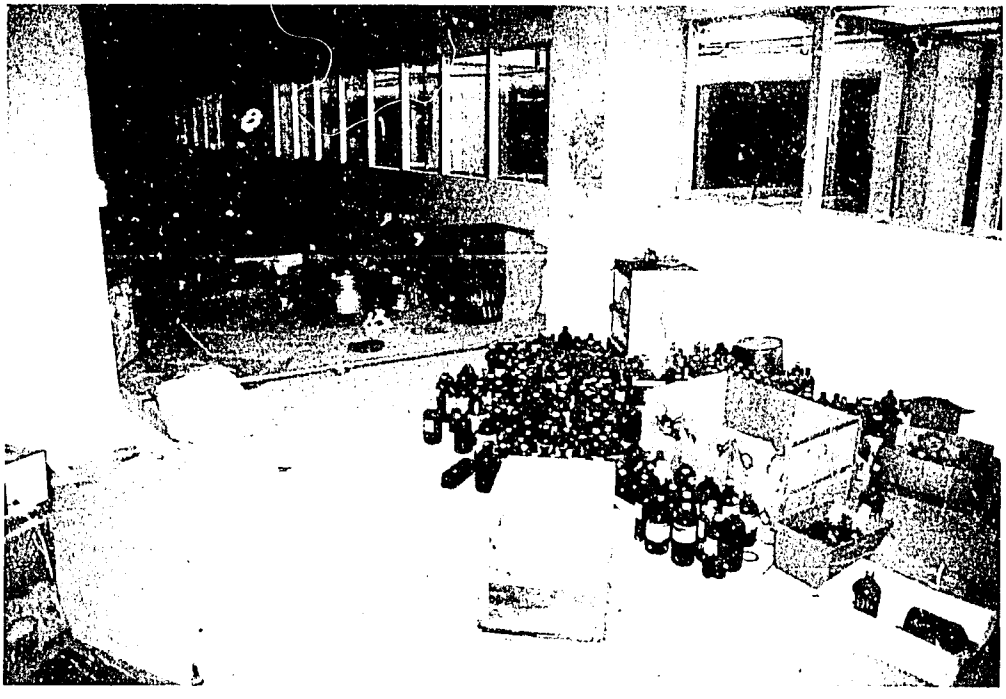
The number and types of laboratories proposed for a particular institute depend on that institute's operating plan, its research program, and its strategy for carrying out its mandate. To make the final decision as to which laboratories will be designed, the research programs and their requirements must be discussed with management, administration, and the scientific staff. The outcome of these discussions should be summarized in a table of accommodations.

It is important to provide optimal floor area in laboratories to permit staff movement. Care must be taken to avoid too little space, as well as too much space. Too little space can inhibit activity. Too much space tends to encourage visitors and other distractions. As a general rule, about one-half of the total floor area in a laboratory should be allocated for equipment or laboratory benches. The other one-half is used for the movement of personnel.

Peninsular laboratory benches have been found to be the most effective from the standpoint of space utilization. However, regardless of their layout, a space of about 1.50 to 1.75 meters should be maintained between the faces of laboratory benches or equipment where technicians will be working. Also, if an island-type layout for laboratory benches is used, narrow alternate routes around the benches are a definite advantage, particularly if occupancy is more than three or four persons.

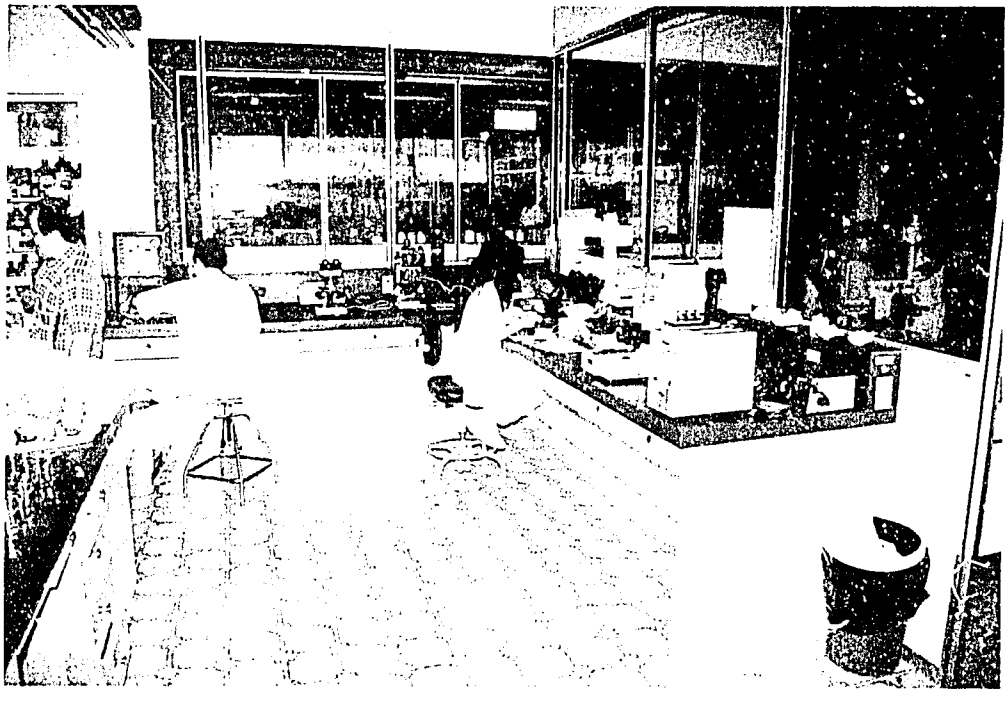
In visits to various research institutes at national, regional, and local levels, it was found that almost universally laboratories were cluttered with nonfunctional or outdated equipment. Sometimes equipment was moved out of the laboratory and placed in corridors. It is expensive and unwise to use laboratory space to house equipment that should be either stored in a warehouse or disposed of by some means acceptable to the local government.

Turkey: This poor laboratory design allows excessive floor area and inadequate and inefficient laboratory bench space.



Mexico: Chemicals are being improperly stored in an unused space above the laboratories. Storage of chemicals in out-of-the-way areas such as this is dangerous.

Colombia: Nice windows usually add dimension to an area.



Colombia: *Storage of chemicals at the feet of laboratory technicians is hazardous and should be avoided.*

Zimbabwe: *Chemicals should be safely stored in closed cupboards to reduce the risk of accidents.*

Expensive, sophisticated analytical equipment should be isolated from the general public's view and maintained under lock and key. Rooms containing this equipment should be located so as to discourage the entrance of anyone except the person(s) actually designated to work in these areas. To protect delicate equipment, temperature and humidity within the area should be maintained within the limits recommended by the equipment manufacturer. Where heat and offensive odors are likely to occur, mechanical ventilation to the outside should be installed to avoid contamination of adjacent areas.

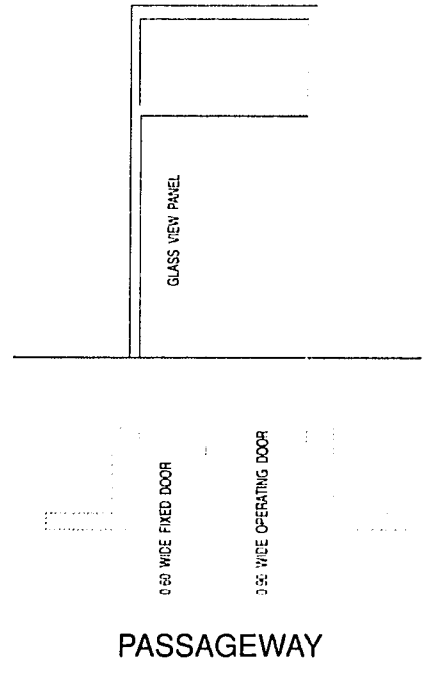
Windows that can be opened during electrical power failures are always required. In addition, view windows should be provided between laboratories and the adjoining areas. Visually, these windows create the feeling of more space and allow the scientist in charge to supervise the work even while outside the actual laboratory.

Doors should be wide enough to permit large equipment to be easily moved in and out of laboratories without removing walls. One option is to install double doors with the principal active door 90 cm wide and the other 60 cm wide. Only the wider of the two doors is normally active and should be equipped with a closer; the other door is fixed with top and bottom devices. For safety reasons, both doors should swing out of the laboratory and be recessed as shown on the floor plan below. Hardware on the active door should be only a pull bar outside and a push plate on the inside. The active door can be secured with a dead bolt operated by a key.

Natural lighting in an average agricultural research laboratory will generally be sufficient if windows are provided equal to about 15 percent of the floor area. Supplemental lighting should be installed for night work and for days when the level of natural lighting is reduced due to inclement weather. Supplemental lighting is best provided by fluorescent fixtures with four tubes, each about 1.2 meters long. One fixture for every 10-15 square meters of floor area should suffice.

All laboratories should be equipped with a safety shower and eyewash sink. These should be conveniently located near the main exit and, for safety reasons, should be checked at least monthly for proper functioning. A floor drain should be installed beneath the safety shower! Although this may seem obvious, floor drains below safety showers have been overlooked in many laboratories.

It is not necessary to install ceramic tile on laboratory walls. A good grade of semi-gloss enamel, if



Laboratory doors should be wide enough to permit equipment to be installed and removed after the building is completed.

properly applied, will last for many years without replacement.

For research buildings in normal climates ceilings in laboratories and offices should be about 3.00 to 3.10 meters above the finished floor. For buildings in humid areas it is advisable to construct all areas with ceilings 0.50 to 0.75 meters higher than normal.

A work room with an area of about 15 square meters should be located near both laboratories and offices for minor repairs and calibration of electronic equipment.

Although not specifically written for agricultural research, "Laboratory Planning for Chemistry and Chemical Engineering," edited by H.F. Lewis (New York: Reinhold Publishing Corporation, 1962), provides a number of ideas that are applicable to a wide variety of laboratories.

Offices

The amount of floor space required for offices is easily determined on an occupancy basis. Naturally, the grade and the level of the person(s) to occupy the space must be taken into account. The tables of accommodation (TOA) and drawings included on pages 89-94 give an idea of the area that should be allocated for each of the different types of offices. Administration offices at national-level institutes can be larger than those shown for local-level research centers.

Like laboratories, offices must be provided with natural lighting and ventilation. The same proportions as those recommended for laboratories should suffice. Artificial supplemental lighting at the same level as for laboratories is also adequate.

Offices arranged within an open area with work stations or low movable divisions about 1.9 meters high allow flexibility and convenience. These were effectively used at an animal health and production institute in Thailand. As special-task working groups are formed, the offices can be easily rearranged to encourage group interaction.

A lack of general storage space has been noted in many research institutes. As a result, offices, hallways, and laboratories are often cluttered with old records, broken equipment, and a wide

Kenya: An example of a well organized research director's office.

variety of other objects (including motorbikes in some cases) which should be stored out of sight. An area of at least 20-25 percent of the space dedicated to offices should be allocated to general storage in an institute.

Research Support Facilities

Library and information services

Libraries and information services units can vary from very simple areas where scientists can read and research topics of interest to more complex information centers with equipment for electronically locating information from a wide number of sources. Any moderate-sized research institute should have library resources consisting of stack area(s), casual reading area(s), a search center for both electronic and manual searches, offices, and a charging desk. Also a book repair area is advantageous as are one or two rooms that can be used for meetings of 25-30 people. These rooms can be subdivided by movable partitions into smaller rooms.

Consideration should be given to centralizing the library's collection of professional journals and electronically interfacing with other national libraries to avoid duplication of subscriptions and to provide a more efficient library system. As an example, there are three libraries in the area of Chapingo, Mexico that are duplicating subscriptions to more than 100 professional journals and triplicating subscriptions to more than 50 journals. Journal indexes can be sent to outlying institutes by a central library on a regular basis with abstracts or copies of articles furnished to the institutes on request.

Cafeteria and kitchen

Most research institutes operate a cafeteria-kitchen to serve lunch to staff. Other meals are prepared and served in cases where training facilities are part of the institute. Often the feeding operation is contracted out and the meals are catered without the direct participation of the institute. This form of food service reduces the amount of kitchen equipment needed. The size of the dining area, however, remains about the same regardless of the method of food preparation.

Many institutes prefer to serve lunch in two shifts. In this way the physical size of the cafeteria

Thailand: Disorganization is likely to have a negative effect on the work pattern throughout an organization.

can be reduced. However, there is one problem with the two-shift method: after eating, people tend to remain at their table and talk, taking up space needed by the second shift. This problem was resolved at a training institute in Zaragoza, Spain. There coffee and tea is served after the meal in another area located outside the cafeteria. A room of about 0.5 square meters per person located adjacent to the cafeteria should be adequate for such a "social" room where coffee and tea would be served and some of the first shift could visit while the second shift is eating. Addition of a small recreation room, constructed adjacent to the cafeteria and the "social area," is another way to make the lunch period more enjoyable. Here staff can play cards, darts, table tennis, and other games that do not require excessive space.

Publications and information dissemination

Small research institutes normally have only a very limited publications department. Printing of extension information bulletins, annual reports, and other publications is generally contracted out to a local company. However, even if an institute is involved with publication on a very small scale, a certain amount of floor area and duplication equipment will be necessary.

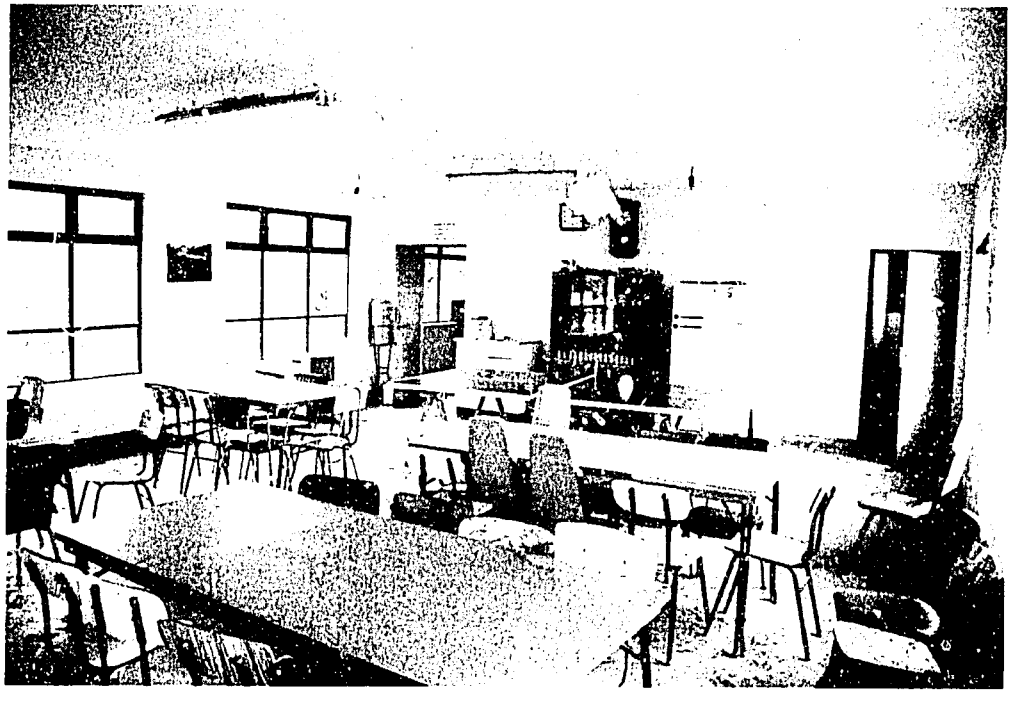
Every institute needs some form of printing device for making multiple copies, even if it is only a Xerox-type copy machine. Only the very largest institutes should attempt to maintain a full-scale print shop with offset presses. With commercial photographic processing available worldwide, darkrooms at institute level are now all but obsolete. However, every institute will require an area for preparation of artwork, design, and layout.

Television and tape recordings are extremely effective methods of information dissemination. The equipment and physical space required to prepare audio- and videotapes is minimal. Medium-sized institutes should plan to have a small studio for preparing and editing audio- and videotapes. About 40 square meters would suffice for the filming studio, 10 square meters for the control booth, 15 square meters for the workroom, and another 15 square meters for equipment storage. It is also important to ensure that all audio and video equipment is portable and can be brought to the field for farmer demonstrations.

Auditorium

Many agricultural research institutes propose construction of an auditorium with the capacity to accommodate the full staff contingent. Addi-

***Bolivia**: This small multipurpose dining room has recreational facilities.*



tionally, institutes may request simultaneous translation facilities, roll-up theater screens, upholstered seating with folding desks, sloping floors, and decorative fabric-covered sidewalls just to mention a few. With the present budget restrictions facing almost every nation, care should be taken to ensure that these requests are for utilitarian purposes and not purely for show.

A multipurpose room with a flat floor that can be used for conferences, dances, and banquets is far more practical than an auditorium with sloping floors for most institutes. Sufficient emergency exits must be provided to permit the evacuation of all occupants in at least 60 seconds after the occurrence of an emergency. These exits should be clearly identified. Emergency lighting should also be installed.

Instead of fixed seating, movable seating that can be stacked and tables that can be folded and stored are practical. Ventilation is important, both mechanical and natural. Provision must be made to darken the room for projection and the area should be as nearly acoustically perfect as possible. In case of doubt, special assistance can be sought in acoustical design. The auditorium at the plant genetic resources center in Gannoruwa, Sri Lanka is an excellent example of such a multipurpose area.

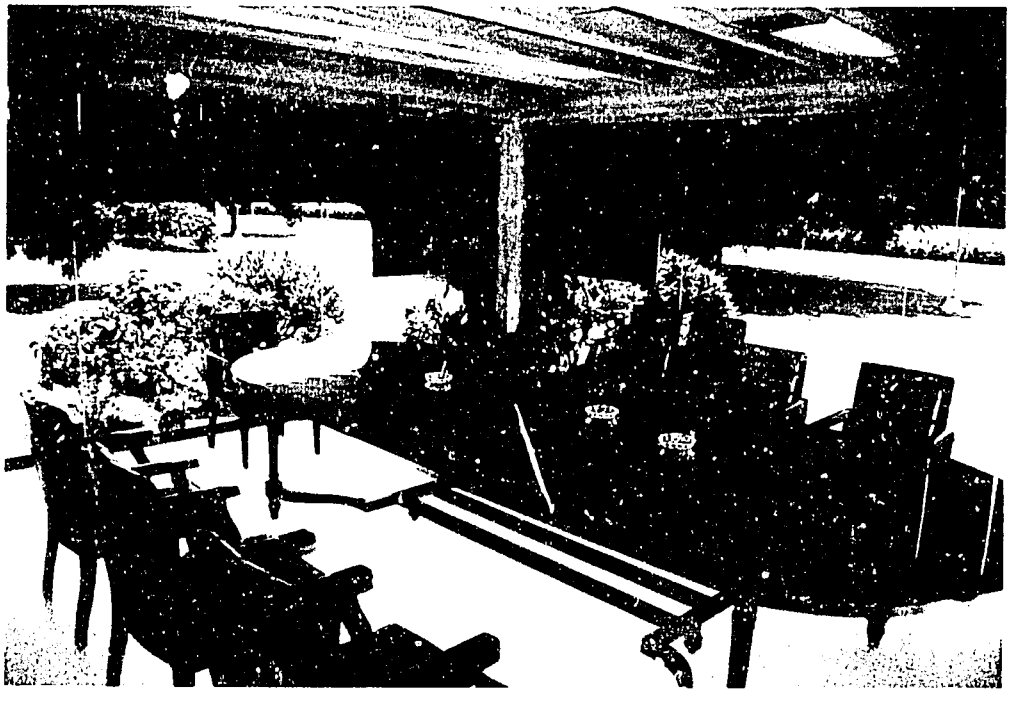
Glass, plastic, and screenhouses

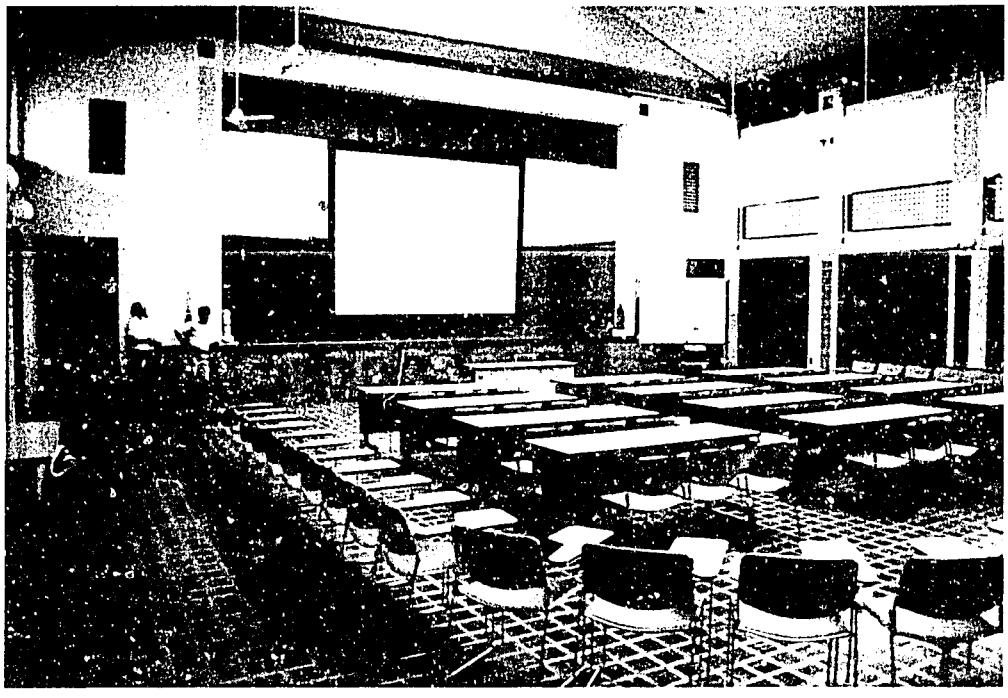
At least 80 percent of all institutes planning new facilities or planning to expand existing facilities propose the construction of glass, plastic, or screenhouses. Construction of glasshouses is usually discouraged, however, except in special cases such as for work involving plant diseases. Many glasshouses that were built as part of agricultural research facilities are now abandoned or underutilized for a variety of reasons. One principal reason is lack of funds to operate and maintain the heating, cooling, and humidification systems that were thought to have been so important at the time of construction.

Although construction of glasshouses cannot always be avoided, alternatives should be sought for large glasshouses with sophisticated equipment. One institute, KEFRI in Kenya, used several small modules of glasshouses (four by six meters) in lieu of large units. These are very practical and are being effectively used.

Plastic houses or "tunnels" have proven very useful for plant breeding if adequate ventilation is provided. Also, the institute's recurrent maintenance budget must be adequate to replace the plastic covering once about every three years. Screenhouses have also been used very effectively

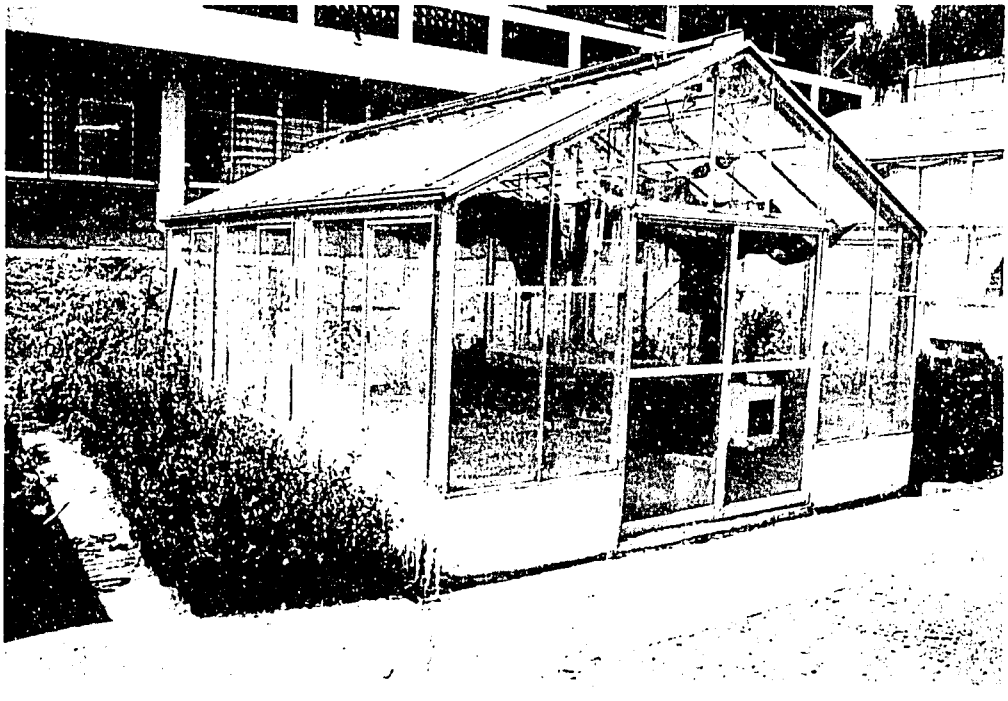
Colombia *Conference rooms that look out onto gardens or patios create a pleasant atmosphere*





Sri Lanka *This auditorium and multipurpose room has excellent ventilation. Openings near the ceiling provide light and natural ventilation. These can be closed with roll up shutters.*

Kenya *This small glasshouse (four by six meters) is suitable for most work with small plants. Construction of several of these is more cost effective than one large glasshouse.*



to raise plants especially in areas where temperatures do not fall below about 10 degrees Celsius.

Instead of using glasshouses or plastic houses, breeding research should be done under less expensive natural conditions in bird-proof screenhouses wherever possible. Aside from the initial construction cost being lower, the annual maintenance cost is also less than for other structures. Screenhouses can be as small or as large as required since only a very lightweight structural system is required to support the netting. Structural systems vary from bamboo to reinforced concrete, depending on the available funds and supply of materials.

Regardless of whether an institute chooses to construct large or small glasshouses, screenhouses, or plastic houses, a work center or head house should be built nearby. Here, inputs are stored, soil is prepared, pots are cleaned and refilled, and other miscellaneous items of equipment are stored and maintained. Although convenient, it is not absolutely necessary for this head house to be physically connected to each of the growing units.

Ancillary Facilities

Ancillary facilities are those that are located outside the main research complex or those that provide services to the overall research effort. They consist of, inter alia, warehouses, vehicle and farm machinery storage, garages, workshops, agricultural chemical storage and preparation buildings, field laboratories and storage areas, animal facilities, sewage treatment, water supply and storage, and others.

Warehouses

Farming operations at agricultural research stations require considerable storage space for farm inputs and for crop harvests. Warehouses for storage are relatively inexpensive compared with other facilities. From a design standpoint warehouses should blend well with the main research complex. Rather than construct one large unit in a centralized location, it is preferable to construct several smaller warehouses which can be allocated to the individual research divisions. A good economical size for warehouses is about 500 to 800 square meters.

Storage areas for fertilizers and similar farm inputs should be physically isolated from seeds, machinery, and crop harvests. A separate building is preferable, although in some cases floor-to-roof walls may be adequate. Fertilizers are corrosive and easily damage construction materials, especially steel. Care should be taken in construction to ensure that fertilizer will not come in direct contact with any steel structural elements.

Doors into warehouses should be carefully fitted to prevent entrance of vermin. Large doors, about 3.5 to 4.0 meters and square, either overhead or rolling, are preferred to swinging doors. The walls inside warehouses are usually not finished with plaster. The material used to construct the wall is left exposed but painted.

Warehouses normally have no ceilings. The lowest point of the roof line should be about five to six meters above the finished floor. Therm. I insulation should be installed below the roofing in tropical climates. Buildings with no interior columns are preferable and easily built using steel or wood trusses and purlins. Steel or concrete bents are commonly used as an alternative to trusses to provide economical wide-span structures.

Light and ventilation in warehouses are also important. Skylights installed in the roof reduce the importance of artificial lighting. Ridge ventilation is very effective. Free-air intake area should be at least twice the area for exhaust. Again, all ventilation openings must be screened against entrance of insects, birds, and vermin.

Concrete is a standard material used for floors in warehouses. Since warehouse floors are often subject to heavy loads, they should be reinforced to prevent cracking and settling. The surfaces should be smooth and finished with a metal trowel. This must be done as an integral part of laying the floor as opposed to dusting the top surface of the floor with pure cement as is frequently done to speed the finishing process. When the surface is dusted, or if a separate coat of cement is applied to help produce a smooth finish, it is only a matter of time before the top layer begins to flake off and the surface of the floor is ruined.

Concrete floors for warehouses should be poured well above grade to reduce moisture penetration through the floor. If the finished floor is higher than the natural grade outside, ramps can be constructed to allow vehicles to enter. Below the nor-

mal 15 cm thick slab of reinforced concrete, a vapor barrier should be installed consisting of a polyethylene sheet about 40 mm thick. Concrete slabs for warehouse floors are usually poured in sections three to five meters square. Adjoining sections are connected with dowels about 50 cm long made of reinforcing bars spaced at about 40-50 cm centers. This prevents one section from settling more than another, causing an uneven floor. Provision should be made for lateral movement between adjoining slabs by greasing the dowels or wrapping them with plastic. This prevents the concrete from bonding and restricting horizontal movement.

Vehicle and farm machinery storage

Many research institutes store vehicles and farm machinery outside without protection from the elements. This is discouraged. Even the simplest protection from the sun and rain adds to the effective life of equipment.

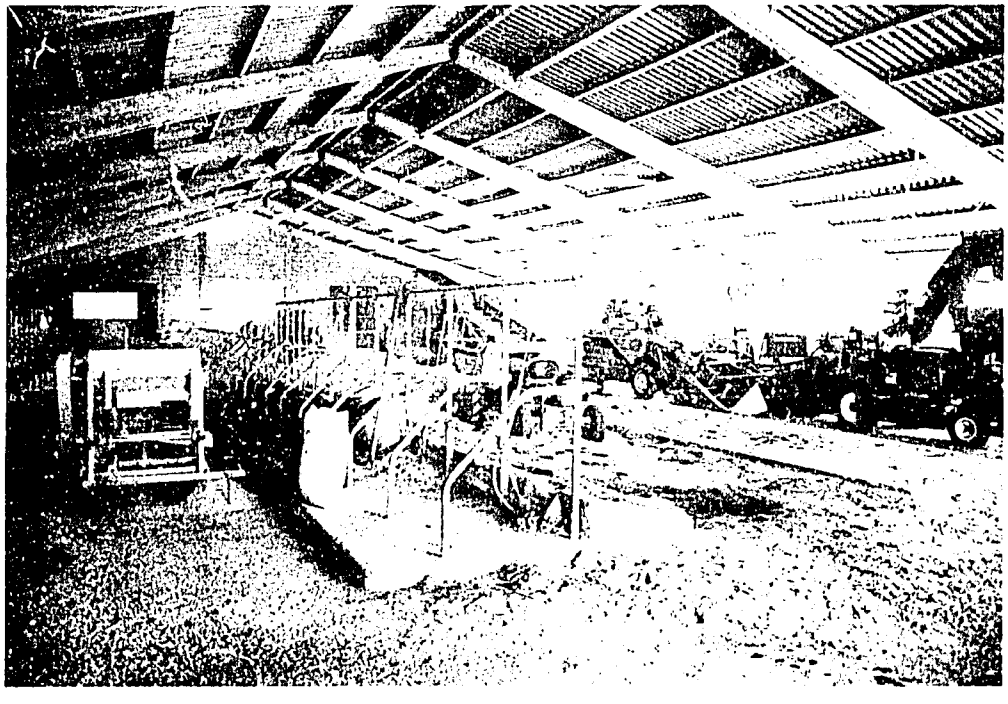
Except in special cases, facilities for storage of farm machinery need not be elaborate nor is there need to provide enclosed storage. Simple lean-to sheds with only a roof and columns usually are adequate. Sheds can have a structure of wood, steel, or concrete depending on the design and the amount of money available for construction. There really is no preference among these materials. In some countries a simple thatched roof and bamboo supports are being used very effectively.

Garages

Machinery repair areas and garages should be located at a good distance from the main research complex, such as at the West Africa Rice Development Association (WARDA) in Côte d'Ivoire. This area will be noisy, disorganized, and generally less attractive than the other research buildings. Depending on the climate, machinery repair may even be done outside a building, perhaps under a simple shed. More usual, however, are garages that are at least partially enclosed due to the costly equipment that is required. Also a secure location must be maintained to store spare parts.

Like warehouses, garages should have ample floor area free of columns or vertical supports. Construction features may be similar to those of warehouses. Roof trusses or beams should be designed to support the load of removing engines from vehicles and agricultural machinery. Adequate natural lighting and ventilation are important. Artificial lighting should be provided near

Spain. Warehouses with clear span structures can be used as multipurpose buildings.



the area of work as opposed to lighting the general area.

Workshops

Agricultural research stations should have specific areas allocated for workshops. Perhaps the two most important workshops would be those for woodworking and sheet metal work. Depending on the size of the research station and the amount of equipment required, the workshop area may vary from a space no larger than 50 square meters to four or five times that amount.

Ceilings, if installed, should be from 3.5 to 4.0 meters high. Interior finishes should be similar to those recommended for warehouses. The interior depth of a typical workshop should be at least 10-12 meters. In most cases, depending on the type and size of the equipment to be used, single-phase electrical service should suffice. Only in very few cases will equipment require three-phase electrical service. These items should be identified early in the planning phase of the project.

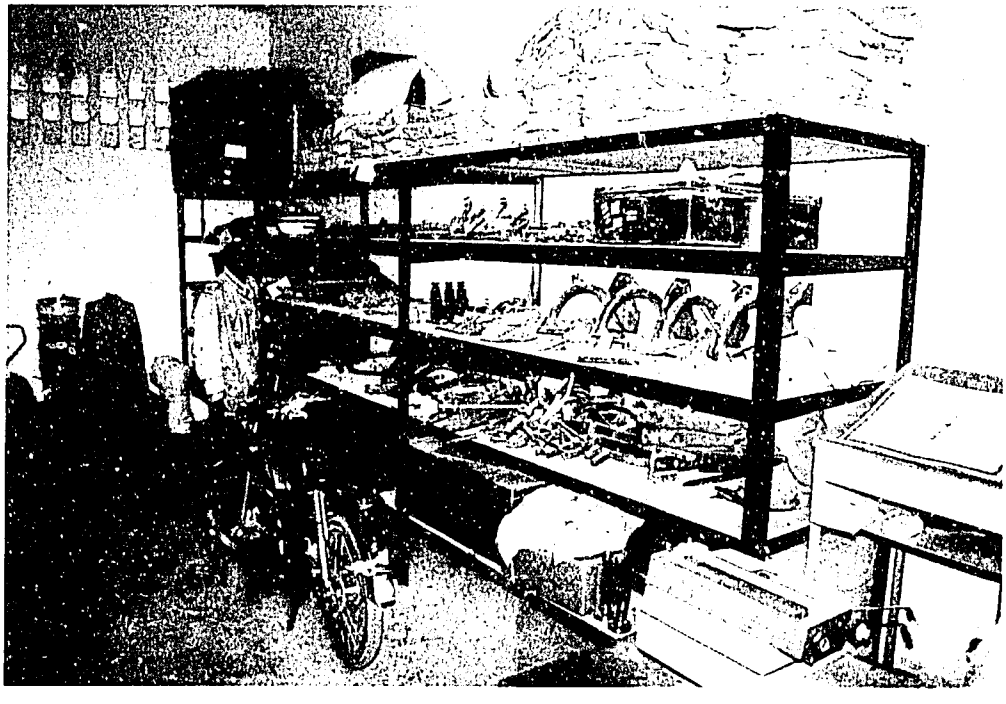
The following workshops are generally required at every research station: carpentry, plumbing, and sheet metal. If necessary, painting, heating, and air-conditioning trades can share the use of one of the three main workshops. Adequate area should be provided for storage of raw materials used.

Agricultural chemical storage

Agricultural chemicals should be stored, mixed, and disposed of at a location remote from other agricultural inputs. Application equipment should be stored near the chemicals. In some cases this may present the problem of one department using equipment belonging to another. All equipment should be adequately washed in a special area adjacent to the storage area. Residual chemicals should be properly disposed of immediately after use. Proper protective gear should be kept near the storage site, but in a separate room. Ventilation of the area is important. In addition to natural ventilation, it is often recommended that mechanical ventilation be connected with the lights in areas for storing agricultural chemicals. In this way, any time a light is turned on the extra ventilation is activated.

Disposal of clean-up water is always a problem. What should be done with the residual? Opinions vary from putting it in a hole and covering it up to emptying it into an open pit that has been

Mali: A well organized warehouse storage system is complemented by a good inventory scheme



filled with gravel. One of the best ways to dispose of certain residuals is to designate an uncropped area where the chemical may be sprayed at the same rate of application as was used on the crop. Institutes are urged to contact a representative of one of the local agricultural chemical companies for their recommendation regarding disposal of the clean-up liquids of specific chemicals. Special care must be taken to ensure that groundwater is not contaminated. Periodic testing of groundwater by appropriate authorities should be routine.

Field laboratories and storage buildings

Some of the preliminary tasks now being done in the principal laboratories of many research institutes easily could be done away from the main research complex. Material samples from research plots, for example, could be cleaned and prepared for analysis in field laboratories. Combination field laboratory, office, and storage buildings are very useful both at main centers and at satellite research stations. If the satellite station or subcenter is too far from the home base to safely make the journey and return in the same day, a combination hostel should be added. The hostel is simply an addition of one to three rooms with beds and a toilet where workers can spend one or two nights. For an example of such a facility, see the drawing on page 94.

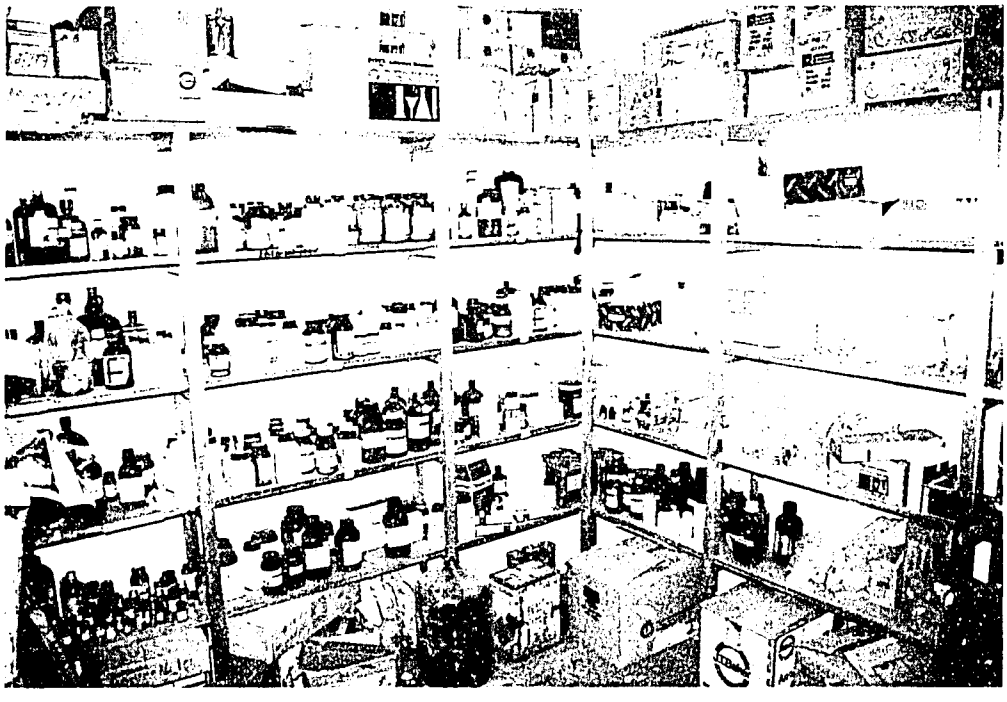
Sewage treatment

Depending on the location of the research center, treatment of sewage can vary from use of a public treatment system or pond oxidation augmented with mechanical aeration, to installation of a septic tank with open tile drain fields, construction of a simple filtration pit filled partially with stones, or construction of a series of treatment lagoons. The choice depends on the soil porosity, temperature and humidity, amount of sunlight, amount of available land, and the occupancy factor of the institute. Naturally, the decision will also be affected by budget and by the recommendations of a competent sanitary engineer.

There are many reputable manufacturers of prefabricated sewage treatment systems for moderate-sized loads. Most of these operate on the principal of aerobic digestion and final disposal of effluent through tile drainage fields.

Wastewater from laboratories, especially those extensively involved in chemical analysis, should be kept separate from domestic sewage. Laboratory wastewaters should be piped in separate col-

Bolivia: Bulk chemicals should be stored in an own principal buildings



lectors and directed to a chemical neutralization tank prior to entering into the domestic treatment system. Such neutralization tanks, too, should be purchased as prefabricated units as opposed to being constructed on site.

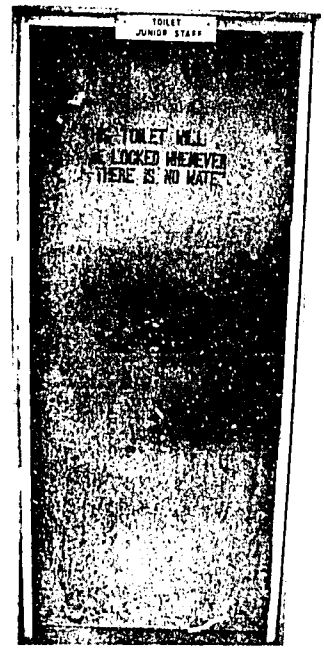
Some types of wastewater, such as that from facilities associated with contagious animal diseases, may contain pathogens, which must be destroyed before being passed into any treatment system. For this, two holding tanks are usually constructed, one being filled while pathogens in the other are being "cooked" with live steam for a period sufficiently long to destroy any likelihood of further contamination. The need for such a system at an agricultural research station is rare, however. The design of such systems must be dealt with by specialists.

Water supply and storage

Water for research institutes located in urban areas is usually furnished by the municipality. However, because the large majority of institutes are located in more remote locations, most have their own water supply. Of the individual supply systems, boreholes or deep wells are preferred. Other sources include lakes, streams, and rivers. Some institutes have constructed cisterns to collect rainwater for domestic and laboratory use.

Storage methods vary from overhead tanks to pressurized systems with either buried tanks or tanks installed at grade level. Pressurized tanks require electrical power at all times to maintain water pressure. Elevated storage tanks, where water pressure is a function of the height of the tank, only require electrical power to fill the tank. Water will always be available in case of fire. With electrical power being so undependable in most developing countries, elevated tanks are the preferred method of water storage. Storage systems should be designed to accommodate a minimum of two days' water requirements for domestic purposes.

All water for human consumption and that used in laboratories should be chemically treated, periodically tested, and guaranteed to be free of harmful bacteria. Water from most municipalities and public sources is generally believed to be safe for use without further treatment. Institutes should be prepared to install their own treatment system where water is not certified to be safe. Small chlorination units are relatively inexpensive, simple to install, economical to operate, and require little maintenance. Untreated water can



Nigeria: The notice on the door acknowledges that there is a water problem but does nothing to remedy the situation.

be piped through a separate system to toilets as a means of reducing the cost of chemically treating the entire water supply.

The quantity of water used in a 24-hour period will vary considerably depending on the type of research that is being done, the physical make-up of the station, and the type and number of users. One of the biggest factors affecting quantity of water is whether cattle are maintained at the institute. For purposes of preliminary estimates of the daily quantity of water required for an institute, the table below can be used.

Design criteria for daily water requirements (liters per day per person or as indicated)

Offices and laboratories	50
Single-family residences	150
Bachelor apartments	100
Training quarters	100
Kitchen (per person per meal served)	10
Cattle (per head)	60
Sheep (per head)	6
Swine (per head)	10

Note: Water required for irrigation and other exceptional uses is excluded from these estimates and depends on the area to be irrigated as well as climatic conditions.

Electrical supply and distribution

Every research location must be assured of adequate and reliable electricity. This not only means electrical supply from the public utility company but also back-up or emergency power sources in the event that the public service fails. High-tension power should be brought into the station and distributed to individual areas according to the distribution of the electrical load of the buildings. At key points the high voltage must be lowered by transformers to the normal operating voltage that will be supplied to the individual outlets and lighting systems. Distributing high voltage throughout a research center serves to reduce the power loss caused by the length of the lines used to make the distribution.

At each research center emergency generators should be installed to be used in the event of a principal power failure. The importance of emergency generators should not be underestimated! In many cases, research results will depend entirely on the power furnished by them. Generators can be started either manually or automatically. They are generally only used to prevent loss of power to certain refrigerated areas, plant growth rooms, germinators, storage areas for genetic material, and other areas where research would be adversely affected by power failure.

Emergency generators should at least be installed in pairs to permit one to be maintained and worked on while the other is on standby. All should be tested and started at least once every two weeks to ensure their ability to function in case of emergency. The actual size of the emergency generators depends on the load of the equipment being proposed for the research center. In most cases the capacity of the generators would not exceed one-fifth to one-eighth the total mechanical load of the center.

Housing and Recreational Facilities

Research managers differ widely in their opinions as to where staff housing should be located. Some feel that staff should be housed in a nearby village. Others want staff housing to be located on institute grounds. Regardless, the final decision as to location is most often made by management. All housing areas should be located so as not to disturb or be disturbed by the normal working operation of the institute. Ample outside area should be allocated to permit recreational activities such as soccer, tennis, and basketball.

Housing can be divided into three types: staff, training, and labor. Staff housing for regular personnel can be in the form of individual houses or apartments. Depending on the location of the institute and the amenities made available, staff may choose to live at the institute during the week and return to towns and cities to live with their families on weekends. In this case the requirements for living accommodations will be more modest than those for permanent staff living at the institute with their families. Staff normally require two- to three-bedroom houses with an area of 75-100 square meters each. These are often constructed in the form of a small planned community. Special protected areas are required for small children to play outdoors and a social area is needed for community gatherings.

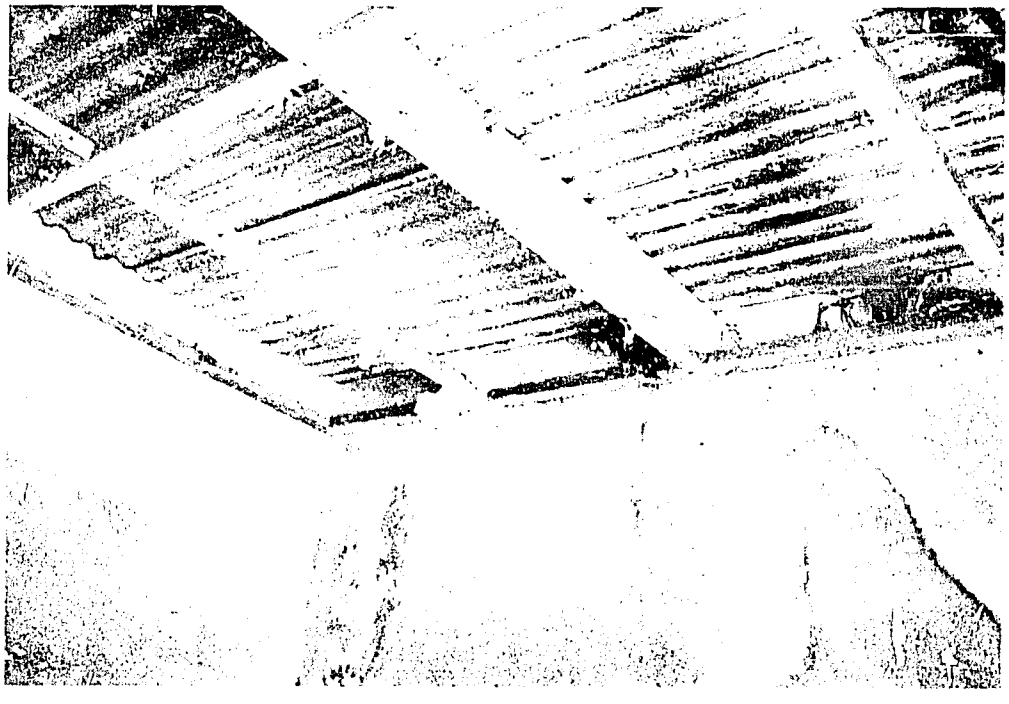
Apartments for single staff members should include a private bedroom and bath for each occupant. A recreation room and small kitchen with an adjoining area for snacks allow the occupants to prepare breakfast and light meals. Depending on the climatic conditions, and also on the budget available, balconies add another area which can be well used by occupants. About 25 square meters per occupant are required for single-staff housing.

Housing for trainees is usually constructed in the form of dormitories accommodating from two to four persons per room. Trainees stay at the institute for a period of one day to two weeks while attending short-term courses or seminars. Trainee facilities should consist of furnished bedrooms, a lounge where trainees can watch television or play cards in off hours, common toilet facilities, and sometimes a small common kitchen. Provision should be made in the same building for washing and drying clothes. Two areas, or wings of a building, separated by a lounge permit both males and females to attend training sessions simultaneously and live within the same building. An average of about 10 square meters per person should be used in estimating the area required for trainee housing accommodations.

Labor housing is much more modest than any of the above facilities. It usually is constructed closer to the farming area than housing for other staff. Labor housing units can be either single-family units, duplex units, or units housing multiple families. Toilets are frequently located outside the living area and are used by multiple families. A community wash area also should be provided. Since the actual living area in the houses is usually small, outside recreation areas are extremely important. Depending on the number of occupants in the labor housing area, a community center may be a valuable asset. For planning purposes, an area of about 20-25 square meters per labor housing unit should be allowed.

At institutes where large numbers of staff are permanently housed and where numerous training sessions are held annually, construction of a small social club is justifiable. The club may even have a swimming pool and other recreational facilities available for members. Although it is doubtful that a full-fledged food service operation would be economically feasible, a small kitchen and food service area should be planned where small groups can occasionally have dinners and parties. One word of caution, however. Many lending organizations do not favor financing recreational facilities as a part of the research package. Insti-

Zambia. This staff housing has a construction flaw: lack of ventilation between the metal roof and the ceiling.



tutes should be aware of this possible restriction in planning facilities for agricultural research. It is highly likely that funds for the construction of recreational facilities will have to be provided by local government.

Specialized Installations

Almost every research institute will require some form of specialized facilities that require specific engineering expertise. Such facilities include buildings for large and small ruminant management and housing, poultry, fisheries, areas for production and storage of genetic material, production of liquid nitrogen, animal disease laboratories, radioactive facilities, and installations for chilled water, steam, and sewage treatment. In any of these and similar cases advice should be sought from specialists throughout the design process.

Large and small ruminants

Facilities for research on large and small ruminant management may constantly change as researchers investigate new techniques. In this case, interaction between scientists and designers is very important and should be constant, not only in the design stage, but also during implementation. For designers, a good source of information might be the equipment manufacturers themselves. Buildings for large and small ruminant housing can be open or enclosed. This depends on the climate as well as on local customs.

Poultry

Facilities for poultry can be designed to be more flexible than buildings for larger animals. Depending on whether the building is for egg production or meat production, its interior should be easily modified. Buildings for poultry research are usually smaller than those for industrial applications. A good size for research is about eight to 10 meters wide with a central hall. The building can be as long as needed. The distance between poultry buildings should be about three to four times the width of the building. This reduces the risk of transmission of disease between flocks.

Two of the most important precautions that must be taken in the design and construction of poultry buildings is to prevent the entrance of vermin and to design buildings that can be easily cleaned and

Mali: Research on typical grain storage facilities for local farmers is often an important component of postharvest research.

decontaminated. Ventilation and sanitation are also extremely important. Under normal conditions, poultry is housed in very simple buildings subdivided inside with wire divisions as needed. Open buildings can be easily transformed into closed buildings by providing drop curtains or panels to cover openings in the outside walls.

Fisheries

Fisheries research is done in tanks, both outside and inside; ponds; lakes; and even the open sea. Specialized knowledge is required in the design of facilities for this type of research. Again, advice should be sought from a specialist in the field and a very close working relationship must be maintained between designers and scientists.

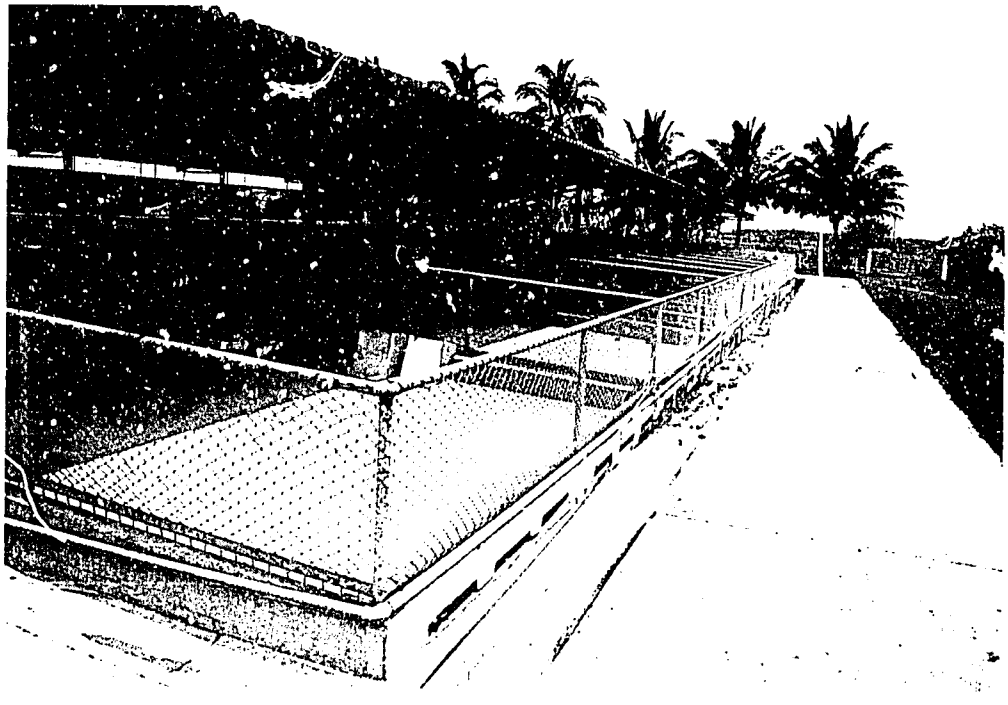
Genetic material

Storage of genetic material, especially seed, has become such an important factor in every research organization that it is worthwhile mentioning some of the basics affecting building design. The size of the seed storage facility depends on the quantity of material to be stored as well as on the length of time it will be stored. Some centers plan to store only from one season to another, others will need longer term storage—five to 50 years and perhaps longer. From a design standpoint, storage from one season to another usually presents no problem as long as the material can be kept relatively dry and free of vermin. Longer storage requires special attention to both temperature and humidity.

One agricultural research institute in Wageningen, the Netherlands uses a very efficient prefabricated cold room for seed storage. Other facilities using prefabricated units include Kenya's national gene bank in Muguga, Kenya, and the plant genetic resources center in Gannoruwa, Sri Lanka. These three facilities are large, possibly housing collections of 12,000 to 15,000 accessions each. Other research centers store properly dried and packaged material in chest-type deep freezers. Where funds are limited, this method of storage can be used to maintain small quantities of seeds in a viable state for 10-20 years.

Preferably, seeds should enter the storage area already cleaned and tested for viability. This reduces the storage area required. Seeds are dried in a room with 12 percent humidity at 16 degrees Celsius for about two weeks. Under these conditions, seeds will reach a humidity level of three to six percent. They are then normally vacuum sealed in aluminum and plastic bags (sometimes

Colombia: Some facilities in the tropics can be inexpensively constructed and easily maintained.



tin cans and properly sealed plastic containers are also used), cataloged, and stored in cold rooms. Short-term storage (10-20 years) is at four degrees Celsius; long-term storage (40-100 years) is at -20 degrees Celsius.

In situ construction of cold rooms using local labor and materials should be avoided. Such construction is highly technical and requires experience seldom found in developing countries. Some research organizations have had to demolish locally constructed cold rooms due to damage by moisture and the extremely low temperatures. In most cases these are being replaced with prefabricated units.

Due to their reliability and flexibility, prefabricated cold rooms, complete with prepackaged refrigeration equipment, are recommended for use at all locations where the quantity of genetic material is sufficient to warrant such an installation. Prefabricated cold rooms usually consist of a series of easy-to-handle factory-built panels which are bolted together to form the final room. They can be installed, free standing, in a warehouse or other area and, if desired, can even be left exposed to the weather.

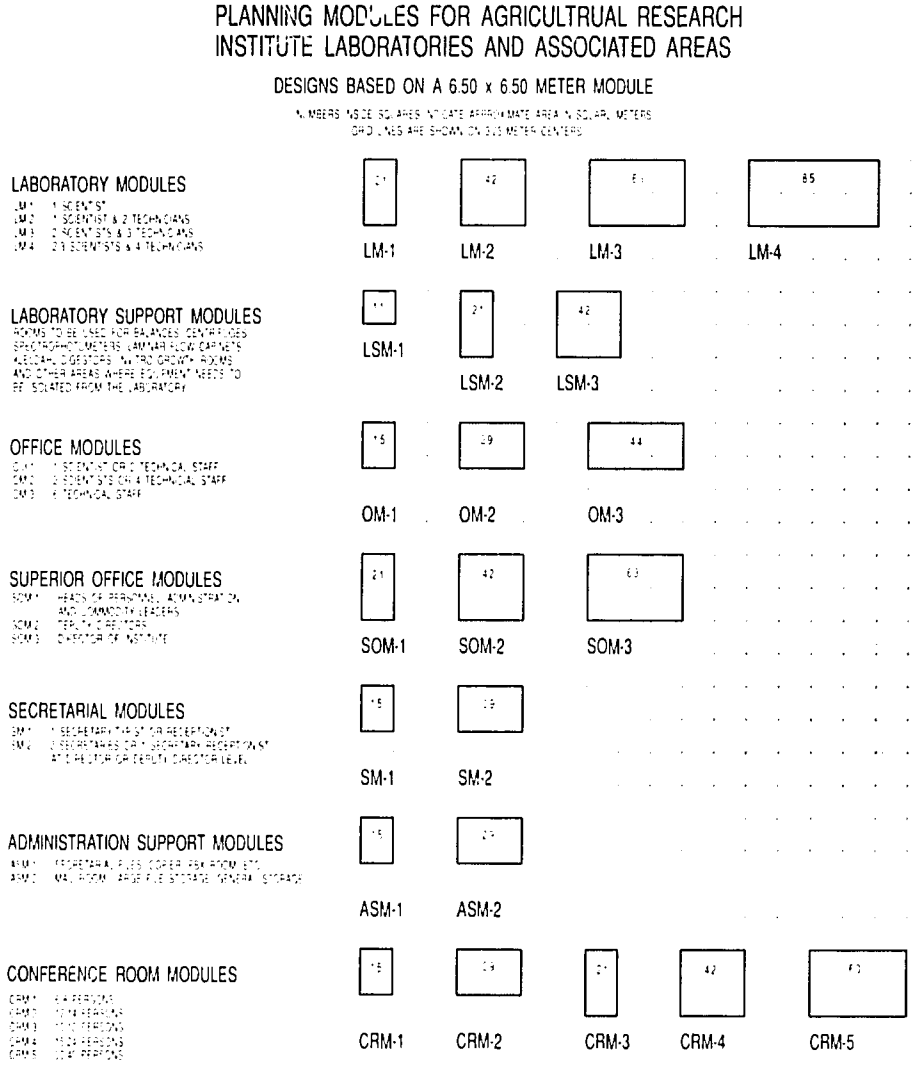
A final word of advice regarding storage of genetic plant material—do not plan either short-term or long-term storage without simultaneously making provision for emergency electrical generators and adequate warning systems for all refrigeration equipment.

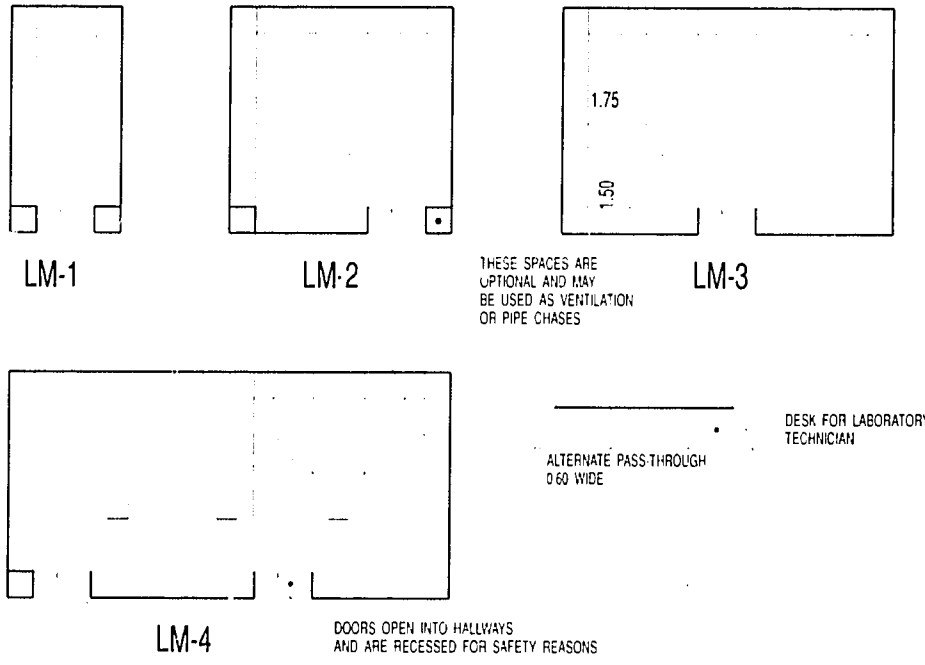
Brazil: *Prefabricated germplasm storage facilities can be located in warehouse areas. For long-term germplasm storage, prefabricated units are more effective than cold-room facilities constructed on site.*

Appendix to Part 2—Selected Designs

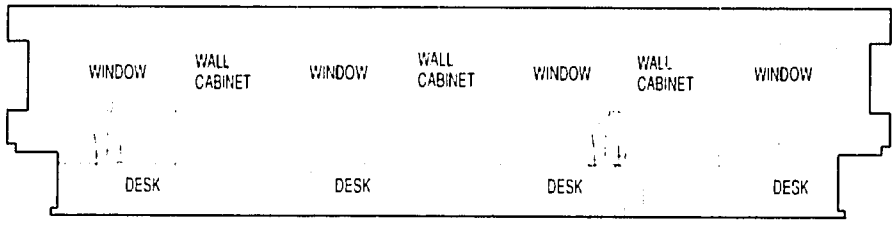
No fixed set of designs can be recommended for all agricultural research buildings. For each facility, the design chosen will reflect many things such as mandate, research programs, numbers and types of personnel, and equipment to be used.

Therefore the examples included in this section were chosen to be representative and not restrictive in nature. Agricultural research managers are urged to use these examples as design aids and to be imaginative in the design of facilities.

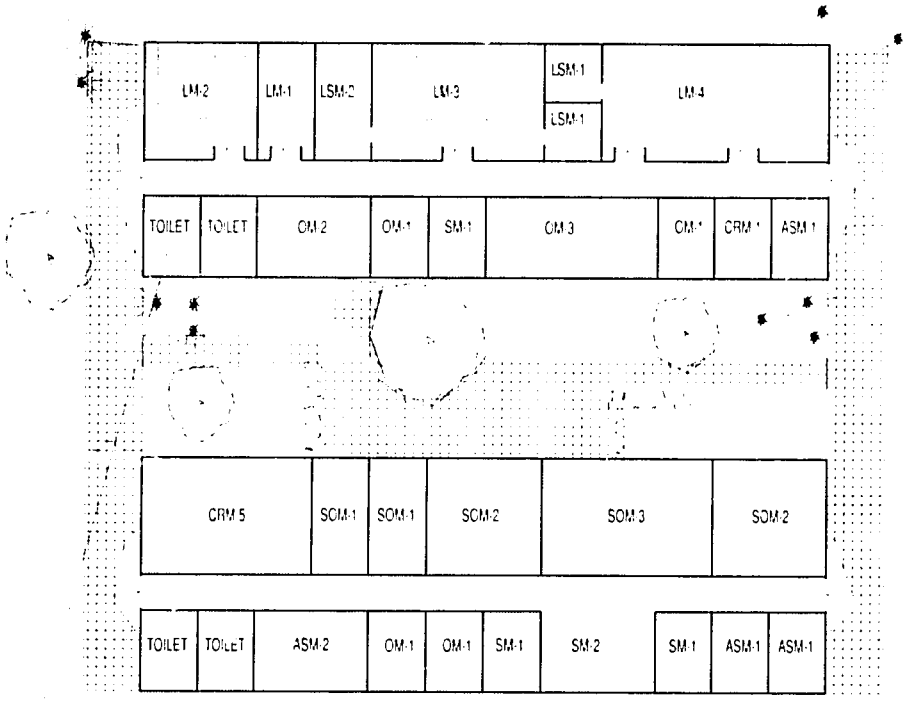




LABORATORY LAYOUTS FOR THE
FOUR PRINCIPAL LABORATORY STYLES



TYPICAL SECTION THROUGH LM-4 LABORATORY

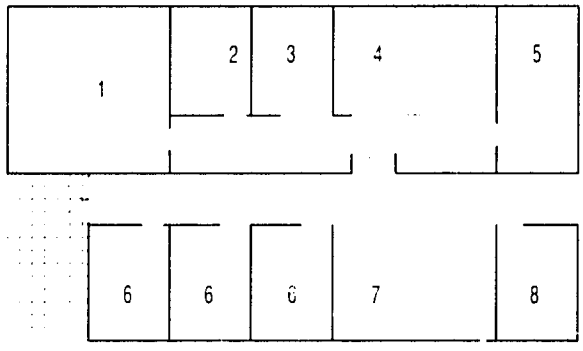


EXAMPLES SHOWING HOW BUILDING MODULES CAN BE JOINED TO FORM ADMINISTRATION AND LABORATORY FACILITIES

SCHEDULE OF TOILET FIXTURES

No. OF USERS	MEN			WOMEN	
	W.C.	URINALS	LAVS	W.C.	LAVS
1 TO 8	1	*	1	*	*
9 TO 20	2	1	2	2	2
21 TO 30	3	2	2	3	3

SHOWERS SHOULD BE PROVIDED IN EACH BUILDING FOR BOTH MEN AND WOMEN RETURNING FROM FIELD

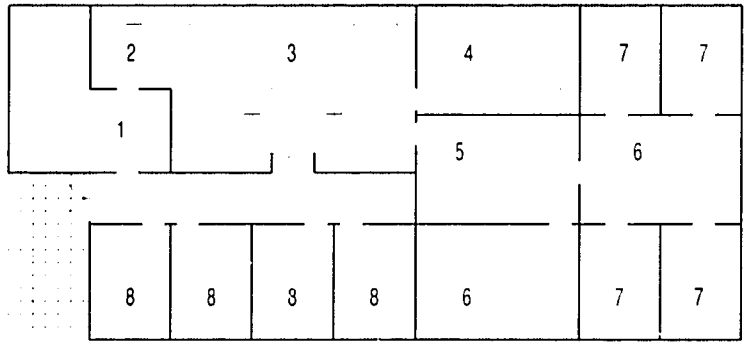


TISSUE CULTURE LABORATORY

GRID SIZE [illegible] SHOWN DOTTED

KEY TO AREAS

1. PHYTOTRON
2. INVITRO CONSERVATION
3. STERILE ROOM
4. LABORATORY
5. GLASSWARE WASHING STERILIZATION
6. OFFICES
7. SECRETARIES
8. STORAGE MISCELLANEOUS

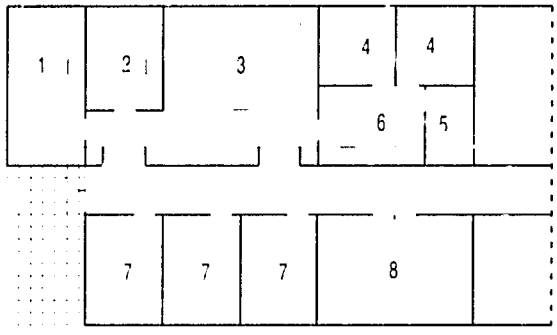


SEED LABORATORY AND GENETIC RESOURCES UNIT

GRID SIZE [illegible] SHOWN DOTTED

KEY TO AREAS

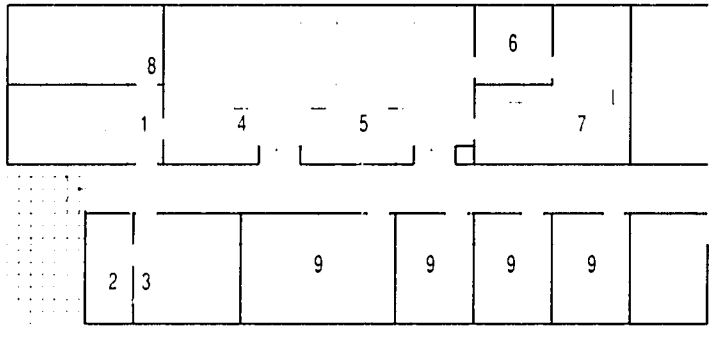
1. RECEIVING AND STORAGE
2. PREPARATION AREA
3. SEED TESTING LABORATORY
4. DRYING ROOM
5. SEED MANIPULATION AREA 10-15 DEGREES C
6. SHORT-TERM STORAGE 2-4 DEGREES C
7. LONG-TERM STORAGE -20 DEGREES C



TYPICAL LABORATORY LAYOUT FOR BIOLOGICAL CONTROL OF PESTS

KEY TO AREAS

1. RECEPTION OF MATERIAL FROM FIELD
2. GLASSWARE WASHING STERILIZATION
3. LABORATORY
4. INSECT GROWTH ROOMS
5. STERILE ROOM
6. FOOD PREPARATION
7. OFFICES
8. COLLECTIONS

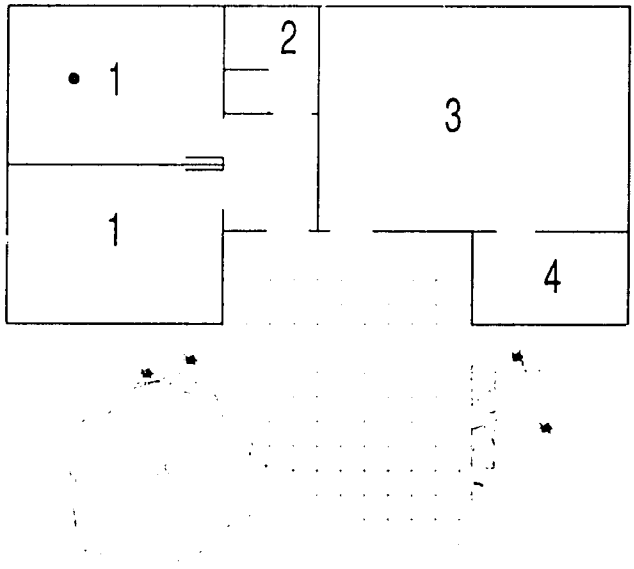


TYPICAL LABORATORY FOR SOIL, WATER, AND PLANT TISSUE ANALYSIS

KEY TO AREAS

1. SAMPLE RECEIVING AND CATALOGING
2. GRINDING AND PREPARATION OF SAMPLES
3. SAMPLE DRYING ROOM
4. PHYSICAL ANALYSIS LABORATORY
5. CHEMICAL ANALYSIS LABORATORY
6. KJELDAHL ROOM
7. ANALYTICAL EQUIPMENT ROOM
8. SAMPLE STORAGE
9. OFFICES

BEDROOMS ARE OPTIONAL AND MAY
DOUBLE AS FIELD OFFICES IF NEEDED.
BEDROOMS ARE NORMALLY ONLY USED
IN DISTANT SUBCENTERS

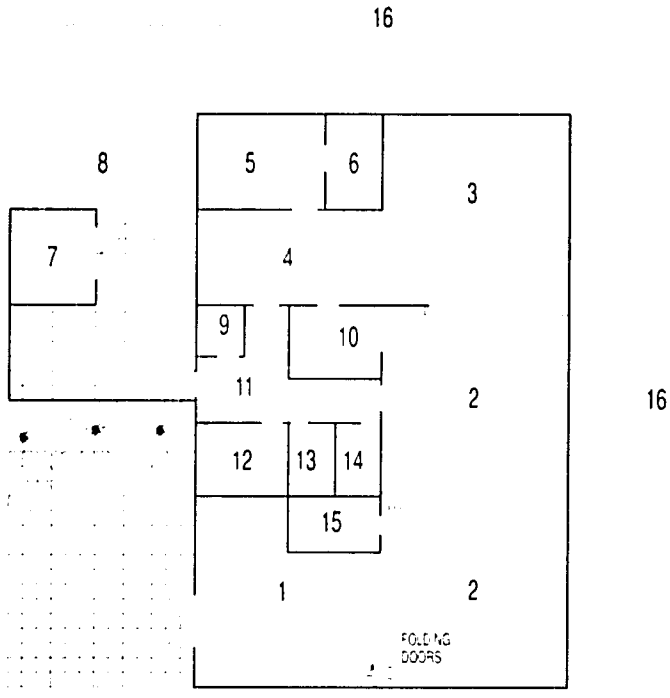


FIELD LABORATORY MODULE

GRID SIZE 3.25 × 3.25 SHOWN DOTTED

KEY TO AREAS

1. BEDROOM
2. TOILET
3. FIELD LABORATORY/OFFICE
4. WAREHOUSE/STORAGE

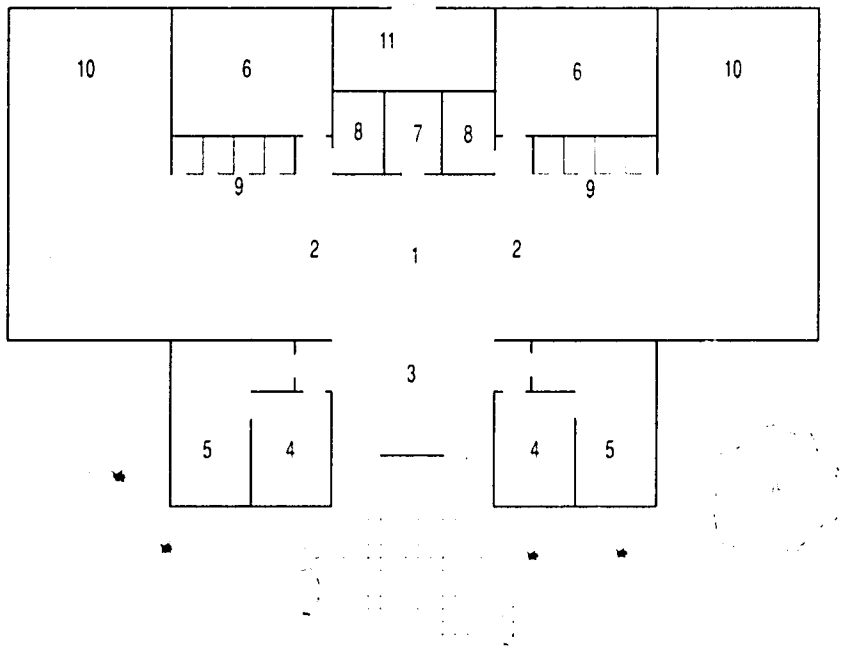


CAFETERIA-KITCHEN COMPLEX SEATING 80 PERSONS

SCALE: 1/8" = 1'-0" (1:96)

KEY TO AREAS

1. ENTRANCE-RECREATION AREA
2. DINING ROOMS
3. KITCHEN
4. FOOD PREPARATION AREA
5. DRY STORAGE AREA
6. COLD STORAGE ROOM
7. GARBAGE STORAGE
8. UNLOADING DOCK
9. STORAGE
10. DISHWASHING AREA
11. EMPLOYEE ENTRANCE-EXIT
12. CAFETERIA MANAGER'S OFFICE
13. TOILET
14. TOILET
15. TEA-COFFEE PREPARATION
16. FUTURE EXPANSION

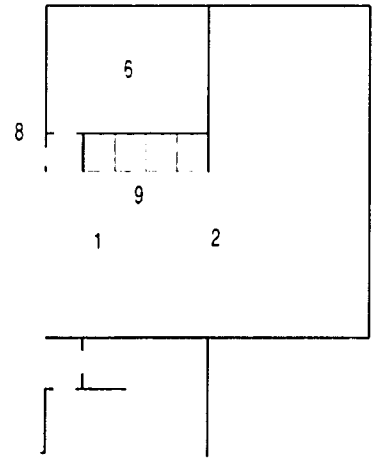


SMALL LIBRARY FOR A RESEARCH INSTITUTE

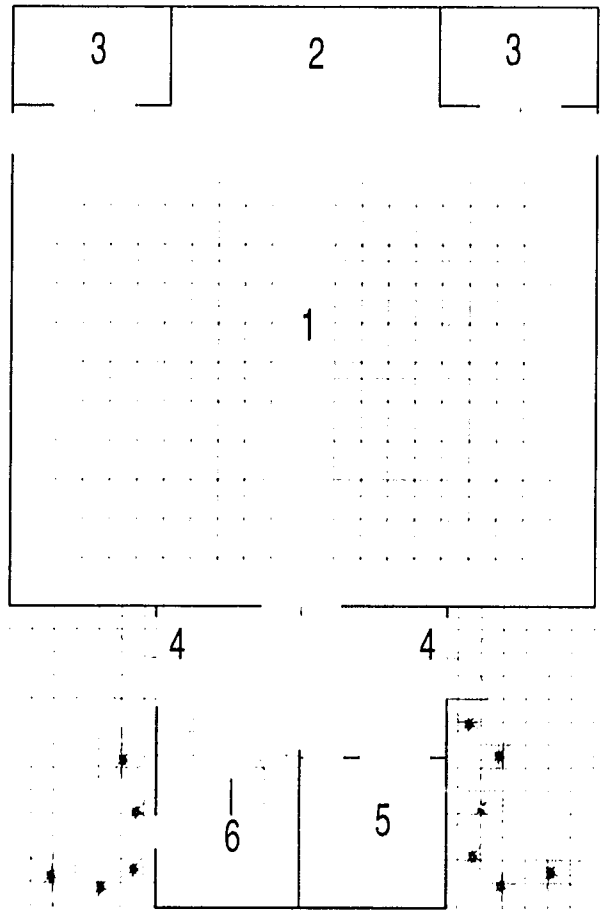
GRID SIZE 3.25 × 3.25 SHOWN DOTTED

KEY TO AREAS

1. READING AREA
2. STACK AREA
3. CHARGING DESK
4. OFFICE
5. WORKROOM-STORAGE-REPAIR
6. MEETING ROOMS
7. CLEANING ROOM
8. TOILETS
9. STUDY CARRELS
10. STACK EXPANSION AREA
11. MECHANICAL ROOM



ALTERNATE SCHEME SHOWING HOW READING AREA MIGHT EASILY BE EXPANDED BY RELOCATION OF STACK AREA

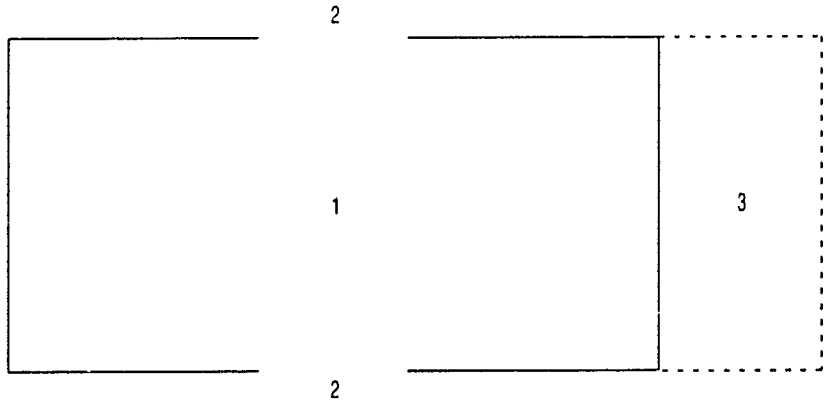


AUDITORIUM AND MULTIPURPOSE ROOM COMPLEX

GRID SIZE 3.25 x 3.25 SHOWN DOTTED

KEY TO AREAS

1. AUDITORIUM-MULTIPURPOSE
2. STAGE 0.50 HIGH
3. STORAGE ROOMS
4. ENTRANCES
5. CONCESSION STAND
6. STAIRS UP TO PROJECTION AND TOILETS



TYPICAL WAREHOUSE WITH DOUBLE ENTRANCES

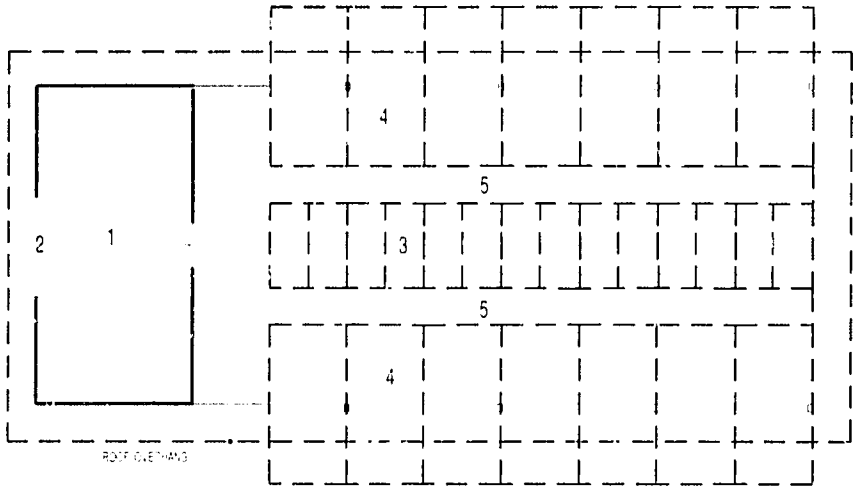
KEY TO AREAS

1. GENERAL WAREHOUSE AREA
2. ROLL-UP DOORS
3. POSSIBLE EXPANSION

GARAGE AND EQUIPMENT WORKSHOP AREA

KEY TO AREAS

1. REPAIR AREA
2. WASH AND GREASING BAY
3. ROLL-UP OVERHEAD DOORS
4. PARTS CHECK-OUT COUNTER
5. PARTS STORAGE AREA
6. MECHANICS ROOM
7. SHOWERS AND LOCKERS
8. TOILET

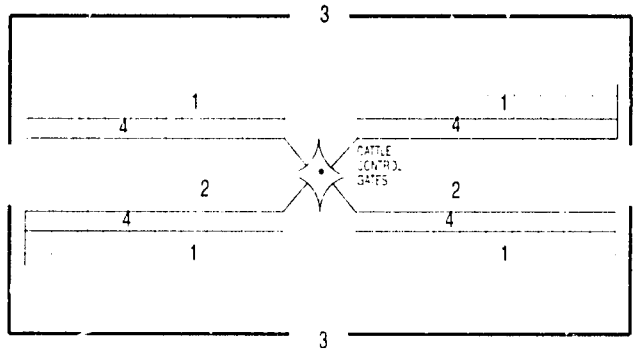


TYPICAL SWINE UNIT

GRID SIZE 3.25 x 3.25 SHOWN DOTTED

KEY TO AREAS

1. STORAGE AREA AND FEED PREPARATION
2. ROLL-UP OVERHEAD DOOR
3. FARROWING PENS
4. WIRE ENCLOSURES FOR SWINE CONTAINMENT
5. PASSAGEWAYS FOR FEEDING, ETC.



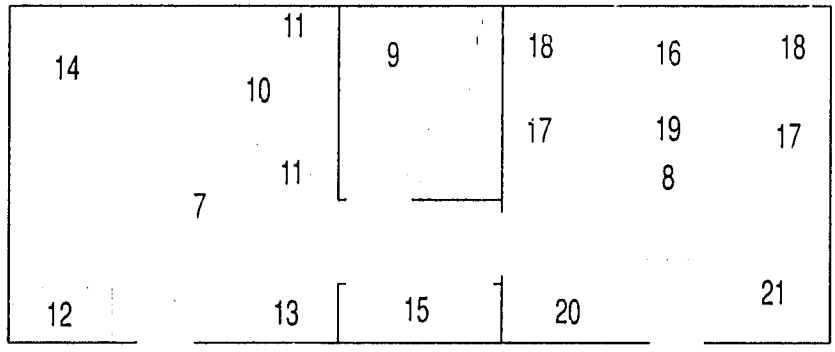
CATTLE UNIT WITH INDIVIDUAL FEEDING STALLS

GRID SIZE 3.25 x 3.25 SHOWN DOTTED

KEY TO AREAS

1. INDIVIDUAL STALLS
2. CONCRETE PASSAGEWAY
3. CATTLE ENTRANCES
4. CONCRETE FEED TROUGH

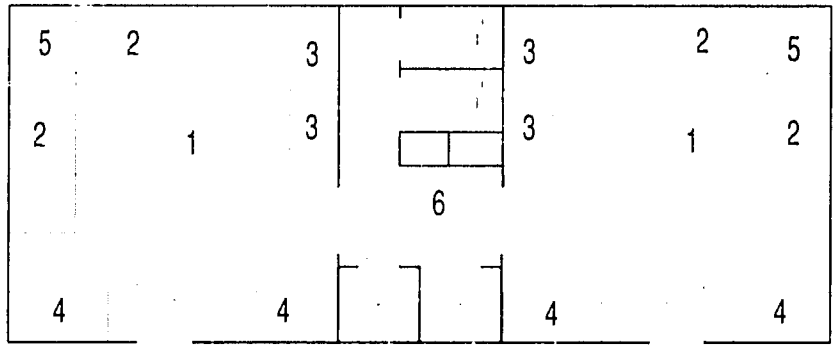
NOTE
BUILDINGS MAY BE VARIED TO SUIT THE INDIVIDUAL SITUATION AND CLIMATE
OUTSIDE WALLS MAY BE CONSTRUCTED OR ELIMINATED ACCORDING TO LOCAL CONDITIONS
CATTLE UNITS MAY BE VARIED FOR OPEN CONTAINMENT AND OUTSIDE FEEDING AS DESIRED. SLATTED FLOORS ARE ONE OPTION THAT IS EASILY ADAPTED TO CATTLE FACILITIES AND THAT ASSIST IN THE CLEANING AND MAINTENANCE OF THE FACILITY
FIELD BUILDINGS SUCH AS THESE SHOULD BE FREE OF INTERIOR COLUMNS



BACHELOR APARTMENT MODULE

SINGLE OCCUPANCY

GRID SIZE 1.00 x 1.00 SHOWN DOTTED



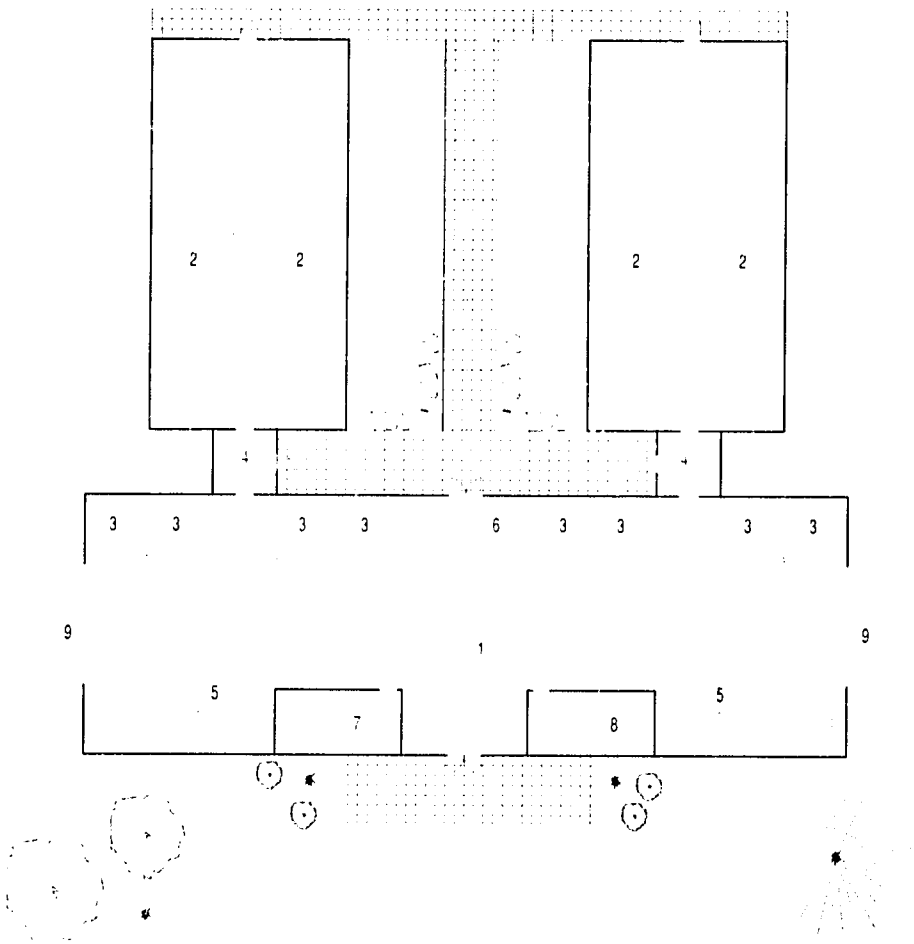
TRAINEE DORMITORY MODULE

QUADRUPLE OCCUPANCY

GRID SIZE 1.00 x 1.00 SHOWN DOTTED

KEY TO AREAS

1. TWO PERSON BEDROOM
2. SINGLE BED
3. STUDY DESK
4. WARDROBE
5. CORNER TABLE
6. TOILET FOR FOUR PERSONS
7. SINGLE PERSON BEDROOM
8. LIVING ROOM
9. PRIVATE TOILET
10. DOUBLE BED
11. END TABLES
12. DESK
13. CHEST OF DRAWERS
14. SIDE CHAIR
15. CLOSET WITH SLIDING DOORS
16. SOFA
17. OCCASIONAL CHAIRS
18. END TABLE WITH LAMP
19. COFFEE TABLE
20. CABINET WITH DOORS
21. BOOKCASE



HEAD HOUSE AND GLASSHOUSE COMPLEX

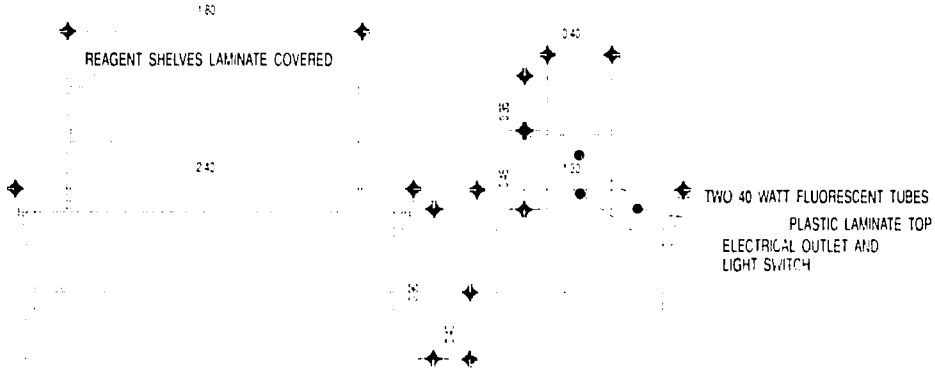
GRID SIZE 2.5 × 3.25 SHOWN DOTTED

KEY TO AREAS

1. DRIVE-THROUGH HEAD HOUSE WITH CENTRAL DRAIN
2. GLASSHOUSES
3. SOIL STORAGE BINS
4. ANTE-COMPARTMENT
5. POT CLEANING, WASHING, AND STORAGE AREAS
6. MIXING AND STERILIZATION AREA
7. TOILETS
8. SECURE STORAGE AREA
9. ROLL-UP OVERHEAD DOOR

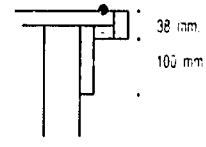
NOTE:
SPACE BETWEEN GLASSHOUSES SHOULD BE NO LESS THAN THE GLASSHOUSE WIDTH

GLASSHOUSES SHOULD HAVE THEIR MAIN AXIS SITUATED IN A NORTH SOUTH ORIENTATION



ALTERNATE SCHEME FOR SUPPLEMENTAL LABORATORY TABLES FOR USE IN RENOVATION OF EXISTING LABORATORIES OR WHEN ADDITIONAL WORK SURFACES ARE REQUIRED

PLASTIC LAMINATE



LARGE SCALE DETAIL OF TABLE EDGE

NOTE:
THE BASIC DESIGN FOR THIS MOVABLE LABORATORY TABLE WAS TAKEN FROM A DESIGN BEING USED IN THE PROYECTO DE INVESTIGACIONES DE LA PAPA IN TORALAPA, BOLIVIA. SEE PHOTO BELOW OF ORIGINAL LABORATORY TABLE.

PART 3

Managing and Administrating the Project

Chapter Eight—Bidding Documents and Procedures

Development of Bidding Documents

The first time that management becomes involved in planning a new research center, they will probably have no idea which documents should be drafted in order to ensure that the project is completed in line with the designs that have been prepared. At first it may be logical to think that drawings and a few pages of technical specifications are sufficient. Not so. The legal consequences of bidding documents and contracts can be serious. The legal adviser for management must carefully study and approve of these documents before they are issued to prospective bidders.

Before a contract can be signed, most of the following documents are prepared and included as part of a bidding package:

- drawings and construction details,
- technical specifications,
- an invitation to bid,
- instructions to bidders,
- general conditions,
- special conditions,
- formats for sureties and guarantees,
- a bid form,
- bills of quantities.

Other documents may also be included such as a format for the breakdown of unit costs, overhead, and the operating costs of equipment.

After bids have been received and the contract awarded, the documents that were included as a part of the bidding package form an integral part of the agreement between management and the contracting company. Each document in the bidding package is then legally binding upon both parties to the contract.

Drawings and construction details

Drawings showing plans, sections through buildings, facades, and construction details should be prepared to show the builder exactly what is expected and to demonstrate graphically how the building components will fit together to produce the final result. These must be clearly drawn and as free of dimensional errors as is humanly possible. Depending on the size and complexity of the project, drawings and construction details vary in length from only a few pages to 50 or more individual sheets.

Often both the quantity and the quality of drawings are insufficient to fully describe how the architect intended the final construction to appear. In such cases the architect must spend innumerable hours at the job site explaining his ideas to the builder. This invariably opens the possibility for charges for extra work not originally envisaged by the builder.

Technical specifications

Technical specifications are complementary to the architect's drawings and details. They serve to clarify any doubts that the bidder or contractor might have regarding constructing and finishing the project. It is here that the technical characteristics of each item of building material and the workmanship required to install these materials are defined in a clear, concise manner. Technical specifications should be divided by trade sections such as concrete, masonry, structural steel, carpentry, roofing, plumbing, and electrical.

Regardless of the size of a project, three questions should be clearly answered in the technical specifications for each different type of building material to be used in the work: What? How? and Where?

First, what is the material to be employed in the construction? Here a complete description of the

technical characteristics of each item of material must be included. In cases where technical characteristics cannot be clearly specified, manufacturers' trade names can be used. "Tied" specifications must be avoided by specifying at least three manufacturers whose materials are acceptable. If three manufacturers are impossible to specify, the words "or approved equal" can be used. In this case the bidding documents should clearly define **who** has the final authority to determine whether an alternate material is equal to that specified.

Second, how the builder is to install each item of material is described. Special care should be taken to specify how the builder is to protect materials and adjacent surfaces from damage as the work progresses. Special methods of attachment and other installation devices also should be included here.

Finally, where the material is to be installed is indicated. In addition to being shown on the drawings and details, technical specifications should describe the exact location of each item.

Invitation to bid

The invitation to bid is normally prepared after all other bidding documents have been completed and the architect and management are assured that the project will be bid. This invitation is a notice to interested bidders that the documentation is complete and that it can be either examined or obtained at a specific location. Normally, on projects with international financing, the entity providing the financing should give its approval prior to the invitation to bid being issued.

The invitation to bid should clearly specify the following:

- the source of funding,
- any restrictions concerning bidder eligibility,
- a brief description of the project being bid,
- where the bidding documents can be examined or obtained,
- the cost, if any, of the bidding documents,
- the amount and type of bid security,
- the time and date of the bid opening.

Instructions to bidders

The instructions to bidders document provides the prospective bidders with all the information they will need to prepare an accurate bid for the proposed work. This includes a complete description of how bids are to be submitted, how bid envelopes are to be sealed and marked, the procedure to be used for bid opening and evaluation, the time and place where bid envelopes are to be delivered, and the disposition of late bids. The procedure whereby bidders will be allowed to modify their proposals prior to the date and time of the bid opening should also be clearly defined. The methodology to be used to evaluate the bids also must be clearly stated. In international bidding, the preference factor for domestic bidders should be made known if such is to be used in the evaluation process.

A list of all documents comprising the package of bidding documents forms an integral part of the instructions to bidders, as does a full description of the method of clarification of any doubts which bidders might have concerning the documents. Bidders should be encouraged to attend bidders' meetings where issues are discussed and resolved. Amendments to the bidding documents should be sent to all bidders early enough to allow them to be accounted for in the bidders' price proposal.

Bidders must be made aware of the importance of visiting the site and becoming familiar with the local conditions. They assume full responsibility for any errors or omissions in their bids due to their failure to understand the site conditions. They also must understand that the full cost of bid preparation is to be borne by each individual bidder.

For international bidding a definition of the official bid language is especially important. Bidders should be allowed to submit supporting documentation in another language as long as it is accompanied by the appropriate translation into the official bid language. The currency(ies) in which the contract amount will be paid is also specified here.

The period of bid validity should be clearly indicated. Normally, 30 days is sufficient for projects being bid locally. International bidding procedures usually require more time, 45-60 days being considered minimum in most cases.

A full description of the type and amount of bid security also is necessary. This security is nor-

mally required for a period of 30 days past the date of opening of bids. Provision can be made for extension if necessary. Bid security furnished by unsuccessful bidders should be released as soon as possible, preferably no later than 15-30 days after the expiration of the period of bid validity.

Lastly, bidders should be advised that the institution receiving the bids reserves the right to reject any and all bids without incurring any liability. Also bidders are informed of the time within which the successful bidder must provide the performance security and sign the construction contract. Noncompliance with these time limits subjects the bidder to relinquishing the bid security.

General conditions

The general conditions set forth the rights, responsibilities, and relationships of each of the parties to the contract. These usually vary in complexity depending on the size of the project and its financing. Many projects use general conditions that have been prepared by an agency of the government such as public works. In some cases these conditions are too general and do not fully cover all the legal ramifications that may arise during construction.

A standard set of general conditions has been developed by the Switzerland-based International Federation of Consulting Engineers (FIDIC—Fédération internationale des ingénieurs-conseils) based on the principles of common law. These conditions have been found acceptable by most international lending institutions and are in use worldwide. The use of FIDIC standard conditions ensures uniformity, saves time, and has been found legally much more acceptable than having proprietary general conditions prepared. Where differences occur between what is written in the FIDIC conditions and local conditions, these differences can be taken care of in a special conditions section of the bidding documents. Institutes are urged to use the FIDIC general conditions as a model for all projects regardless of size.

Special conditions

As stated, special conditions are used to modify the standard terms of the general conditions. As an example, if one of the clauses in the general conditions specifies a materials-testing procedure that is not applicable to the particular project, this can be modified by the addition of a clause in the special conditions section. In other words, clauses in the general conditions always remain intact but may be eliminated, modified, or supplemented by subsequent clauses inserted in the special conditions document.

Sureties and guarantees

Every project must have both the bid and the performance of the successful contractor guaranteed. If the contractor is given an advance to begin work, this too needs a guarantee of repayment. Usually guarantees are obtained by a letter from a bank or an insurance company. Sometimes a percentage of the amount being guaranteed is required to be deposited in the institute's bank account. Certified checks are also acceptable in most cases. Regardless of what type of guarantee is required, it should be in an amount sufficient to protect the institute from financial loss in case of nonperformance on the part of the person or company offering the services.

Bid sureties are used to protect the institute if the successful bidder refuses to sign a contract within a specified time for the amount of the award. The amount of the surety should be no less than the costs incurred in advertising the project plus the effect of inflation on the project costs from the issue date of the invitation to bid to the proposed date of contract signing. In theory, these monies would be used to offset the increase in the cost of bidding the project again at a later date.

Performance guarantees should ensure that the company signing the construction contract will fulfill its obligations or, in case of failure to perform, that the institute will not have to pay additional monies to have the work completed. Performance guarantees are often only token sums that do not provide adequate protection. Again, the amount of the performance guarantee should be calculated based on the rate of inflation, the rate of construction implementation, and the value of the work remaining to be done. Ideally, a performance guarantee should ensure that the contractor or surety company would fulfill the terms of the contract and complete the facility as designed at no additional cost. However, institutes seldom require sufficient protection. Contracting companies with financial difficulties have caused management problems in virtually every country.

Bid form

Every bidding package should include a bid form, prepared in collaboration with management to be signed by each company making a

price proposal. In connection with the other bidding documents, the bid form constitutes a legal and binding agreement on the part of the bidder to complete the work as described at the agreed price. Management must ensure that individual bidders are not allowed to prepare their own version of the bid form. In certain cases the wording in a bid form prepared by a bidder could change the entire framework of the bidding conditions.

Bills of quantities

The United States is perhaps the only country that does not require architects to prepare a quantity survey of the materials that will be required in a project. In other countries, the services of an architect include this "take-off" or bill of quantities showing a materials list for all elements of the project. An example of a format often used for a bill of quantities is provided below.

Although the architect does not guarantee the survey to be without errors in quantities, accuracy is expected to be within five percent of the actual quantity required to complete the facility as designed.

Bills of quantities are a big asset to bidders and also to management. They ensure that all bidders provide quotations on identical quantities of materials and work. There is less guesswork on the part of the estimators. The bids are more uniform and therefore easier to evaluate.

BILLS OF QUANTITIES FOR: (PROJECT NAME) **PAGE 1 OF ... PAGES**

ITEM NO.	DESCRIPTION OF ITEM	QUANTITY	UNIT	UNIT PRICE	TOTAL UNIT COST
A	**SITE PREPARATION**				
A-1	Site leveling	30,000	S.M	32.50	975,000.00
A-2	Fencing around construction site	1,000	L.M.	423.50	423,500.00
A-3	Construction of entrance road into site	500	L.M.	34.85	17,425.00
A-4	Temporary electrical connection at site	1	Lump Sum	5,000.00	5,000.00
	TOTAL SITE PREPARATION				1,420,925.00
B	**EXCAVATION**				
B-1	Excavation of basement of building	3,750	C.M	24.38	91,425.00
B-2	Excavation of wall footings	234	L.M	15.00	3,510.00
B-3	Excavation of footings for columns	18.4	C.M	35.00	644.00
	TOTAL EXCAVATION				95,579.00

Bidding Methodology

International versus local competitive bidding

International competitive bidding and local competitive bidding are the two methods most commonly used to request prices from bidders for the construction of facilities. The decision to use one form or the other is a function of the project size, the requirements of the lender or donor, and the availability of local companies capable of constructing a project of the size desired.

International competitive bidding procedures are generally used for construction projects costing more than the equivalent of one million US dollars. In internationally bid projects, the invitation to bid is placed in publications of wide international circulation as well as in local newspapers and official gazettes. In allotting time for companies to prepare their bids, consideration must be given to the likely delays in bidders receiving the bidding documents. Additional time should also be allowed for them to request, receive, and coordinate quotations from subcontractors. On all

except the most complex projects involving extensive work on dams, roads, and harbors, 45-60 days between the date of issuance of the invitation to bid and the date of receipt of bids should be sufficient. This is especially true where bills of quantities are furnished as a part of the bidding documents. Use of international competitive bidding procedures may reduce the possibility of collusion on the part of local construction companies. It also should increase the competitive nature of bidding, resulting in lower unit prices and shorter construction time.

Local competitive bidding procedures are used for smaller construction projects or for projects that are so widely dispersed in a country that there is little reason for companies outside the country to become involved in the construction. Normally 30 days between the issuance of the invitation to bid and the date of bid opening is sufficient time for local competitive bidding procedures. Unless the lender or donor has more stringent requirements, the invitation to bid should be advertised in a local newspaper of wide circulation for three days. Advertising a project to be bid using local competitive bidding procedures definitely should not restrict foreign firms from submitting a quotation for constructing the project.

Bills of quantities—unit prices

As pointed out, bills of quantities can form a useful and vital part of the bidding documents. Bills of quantities show the estimated quantity required for every item proposed to be installed as a part of the construction project. To prepare a bid as accurately as possible, every bidder should be able to justify the cost of every item included in the bill of quantities. This means that the bidder not only must indicate the unit cost, but also must be able to justify direct and indirect costs for all components of the project.

Calculation of this breakdown sounds simple. However, the simplicity depends on the material or process being calculated. For example, a simple wall made of concrete blocks could involve the following elements:

- labor to lay the blocks,
- purchase and transportation of blocks to the job site,
- mortar,
- horizontal joint reinforcing,
- plaster finish for both sides of the wall.

Perhaps the most complex part of the cost-estimate breakdown is the cost of labor to construct a single unit of work. A calculation of the direct cost of labor takes into account days lost due to vacations, weekends, national holidays, and religious holidays. Social benefits also must be considered. Easily, the cost of a worker who is on the payroll of an organization can add up to double the salary that the worker actually receives.

Some workers—especially masons—work in teams. There is a master mason and a couple of apprentices or others to assist in the preparation of mortar and to deliver the materials to the master mason. To accurately calculate the labor cost per square meter of wall, the company must have a good idea of the productivity of an individual or team.

The mortar and the plaster shown in the breakdown above seem simple enough to cost until again labor enters the equation. Estimates of labor costs must be added for the preparation of the materials as well as their application. The preparation of the mortar involves the purchase of cement, sand, and water. Labor is again required to transport the mortar and, later, to prepare, transport, and apply the plaster to the wall.

Another important element in a breakdown of costs is the operating cost of equipment. In the example above a mortar mixer is required. The per-hour operating cost of the mixer must be calculated and its per-hour production rate estimated. Also, the life of the equipment must be estimated so that its cost may be amortized. The operating cost of other equipment such as cranes, earth-moving equipment, trucks, and automobiles should be budgeted into every project.

As the simplified example above illustrates, bidders must carefully prepare the details of unit costs and be in a position to justify them to the architect or management during the evaluation of the bids or for future modifications to construction.

Fixed-price versus cost-plus contracts

Construction contracts generally fall into two general classifications: fixed price and cost plus a fee or percentage to cover profit and overhead.

Contracts for fixed prices are signed either for a single lump sum for the entire construction or for a fixed unit price for each item entering the project. In case of a single lump sum for the total construction, each bidder must individually calculate

the amount of material and labor that will enter the project. Bills of quantities are not furnished by the architect as a part of the bidding documents. Any error in calculating the quantity of material is the responsibility of the bidder making the quantity survey. The single lump-sum contract is mainly used in the United States. Other countries, including most developing countries, use a contracting system in which the contract price is based on price quotations for the actual units of work done by the contractor. Either system is acceptable, depending on the customs of the country.

In case of a fixed price for each unit of work entering a project, each bidder is furnished with an estimate of the quantity of work that will be required as reflected in the bills of quantities. Although the total amount of work can vary, the unit prices will remain fixed for the period of the contract (except for increases due to government decrees). The construction company is paid for the actual quantity of work done multiplied by the unit price that was quoted for each item of work. Periodically the architect verifies that the quantity of work billed was actually done.

Cost-plus contracts are based on the actual direct costs of materials and labor plus a fee or percentage to cover the builder's profit and overhead. Here the contractor must produce substantiated bills for all labor and materials employed in the project. These bills are verified by the architect and presented to management on a periodic basis for payment. In using cost-plus contracts, management assumes the risk of cost overruns due to the undeterminable nature of the project scope. Therefore, this form of contract should be limited to very small projects, preferably projects which involve remodeling or similar work where a survey of the quantity of materials or scope of work is impossible to determine in advance. Construction under this type of contract is not subject to price adjustments for inflation since materials are purchased as needed at market prices.

In cost-plus contracts, management should require the contractor to furnish a detailed justification of the percentage or fee being charged for profit and overhead. Also purchase of materials must be accurately controlled to ensure that all materials for the project are purchased at competitive prices and actually enter into the project. To carry out this control, the architect should receive additional payment for performing these extra services for management's protection.

Chapter Nine—Managing Construction

Research institutes should insist on having the person or firm responsible for designing the facility provide construction supervision and monitoring during the full period of construction. It is during this time that careful professional attention to quality and cost control can help to ensure that funds are well spent and that research organizations receive full value for the contracted obligations. Delays in implementation are invariably costly. A well-prepared supervision team should be able to ensure quality construction at a reasonable cost, implemented in a timely manner.

Implementation Acceleration

Projects that move forward toward completion at a steady pace, without delay, are looked upon more favorably than others that drag on for months, sometimes even years, past the proposed completion date. There are innumerable reasons to accelerate a project toward completion, not the least being that the client would like to begin to use the facility as soon as possible. Another excellent reason, and a very important one, is the adverse effect inflation will undoubtedly have on the final construction cost. Other reasons are to make more space available for rapidly expanding

research programs, to provide more modern facilities for research, to coordinate space with equipment due to arrive, and many others, some of which might even be political.

To help accelerate a job to completion the planning team should carry out the following tasks:

- select a competent contractor,
- review the performance history of the proposed contractor,
- investigate the financial stability of the proposed contractor,
- ensure adequate equipment and manpower,
- require a well-designed implementation plan,
- secure early purchase of vital materials,
- store materials at the job site,
- pay for stored materials,
- pay partial billings promptly.

Undoubtedly not all of these will be incorporated into every construction project, but where local conditions permit, as many of these items as possible should be done by management.

Select a competent contractor

In evaluating bids, each company submitting a bona fide bid should be carefully screened as to their overall competence. Although there is no 100 percent guarantee as to a particular company's competence, bid evaluation should never be done on price alone. Be extremely cautious of selecting companies with a reputation for subcontracting major portions of the work. In such cases the contractor becomes just a broker or middle man with no substantial interest in developing a solid reputation in the building industry.

Review the contractor's past performance

The company's performance on past projects should be an important consideration in the evaluation of contractors. This is best done by talking to clients who have used the company. Ask them confidentially how the company performed during the construction period. Were there delays, cost overruns, problems with securing materials or labor, and was the quality of the finished product as good as had been anticipated? In addition to clients, talk to architects, engineers, and even other contractors. Often rumors, even within the same profession, can provide valuable information not to be overlooked.

One good guide to a company's performance on past projects is to check the value of their billings to clients during the middle third of the construction period. It is during this time that the greatest rate of monthly progress should normally be made.

Investigate financial stability

Perhaps the most important factor to be studied in selection of a construction company is its financial stability. Regardless of how well the construction company has performed or what type of guarantee it has provided, if a contracting company declares bankruptcy, implementation will be delayed and completion of the project will be complicated beyond belief.

The financial stability of a company is not only a function of how well it is managed, but it can also be affected by certain restrictions that may be imposed through government decrees or other actions taken to lower the construction inflation rate in a country. Ensure that the selected company has quoted fair and reasonable costs for materials and that it has included adequate costs for labor. Also ensure that an acceptable overhead and profit has been included. Beware of a company that is willing to sign a contract with very low overhead and virtually no profit just to maintain staff continuity until some future date when business might improve.

One final point regarding the financial capability of any company: always demand adequate sureties and guarantees as protection against the possibility of the contractor's financial difficulty or failure to perform according to the terms of the contract.

Ensure adequate equipment and manpower

Construction companies have been known to include in their list of equipment proposed to be used in the construction items of equipment that are not in first-class operating condition. Such equipment is useless and should not be accepted as a part of the contractor's implementation plan.

Much like equipment, personnel are often indicated in project proposals as being key members of the implementation team yet their role in the actual implementation is minimal. In evaluating the manpower proposed to be used, care should be taken to see that sufficient personnel with ade-

quate experience has been specified and that all the indicated manpower will form a part of the actual implementation team.

Require a well-designed implementation plan

To begin a long journey without a map or plan of how to reach your destination would be a mistake. The same applies to construction of every project regardless of its size. Today, with computers forming a part of everyday life, it is inexcusable not to have a detailed plan of just how the project is to be constructed. There are many good computer programs available to assist in the management of manpower and material resources. These programs are capable of describing to the last detail how resources are to interface with the time constraint specified in the contract. Bar graphs (GANTT charts), program evaluation and review technique (PERT), and critical path method (CPM) are all techniques for detailed planning that assure the minimum loss of calendar time. Years back when CPM, PERT, and GANTT charts were prepared without computers, each became a time-consuming chore that often took more time to prepare and maintain than the benefits derived from their use. Such is not the present case.

Management and planners jointly should insist on a detailed plan showing exactly how the contractor intends to manage the project to ensure that the construction is completed in the time frame indicated in the contract. This plan can be prepared using CPM, PERT, GANTT, or any other acceptable format. It must be constantly updated with accurate, meaningful information regarding project status. The work plan includes details of how human and financial resources, purchase of materials, and use of equipment will enter into implementation of the job to ensure completion in a timely manner.

Secure early purchase of vital materials

For some reason there is often a reluctance on the part of contractors to purchase building materials early in the implementation period. Advance purchase of building materials should be a high priority. Bricks, sand, gravel, reinforcing steel, cement, and other items that are normally used during the first few months of construction should be purchased by the contractor immediately after signing the contract. To speed up project implementation, architects and planners should stress the requirement of having adequate materials on the job site within 30 days after signing the contract.

Store materials at the job site

Adequate storage facilities must be made available at the job site as part of the job mobilization. These facilities must keep materials dry, secure from theft, and readily available for use. A storekeeper is normally required to ensure that all materials removed from storage enter into the construction. Sometimes the storage building will have a room attached or located nearby where a night watchman can sleep. Used surplus sea shipping containers make good secure storage buildings.

Pay for stored materials

After urging contractors to secure building materials early in the implementation period and insisting that adequate storage facilities are provided, what incentive is there to encourage contractors to actually purchase the materials? The answer is simple. Prompt payment for materials that are adequately stored and accounted for is the surest way to stimulate the contractor to purchase materials early.

Materials normally account for about 65-70 percent of the cost of a project, labor being the remaining 30-35 percent. It is then easy to see how prompt payment for the full cost of materials that are adequately stored will accelerate implementation. Once materials are installed in the construction, only labor remains to be paid. In contracts where increases in cost are allowed for inflation, these stored materials will not suffer an increase since they will already be paid. Only the labor component will need to be adjusted.

Pay partial billings promptly

The key to stimulating the contractor and encouraging him to purchase materials and to accelerate work is to ensure that all bills are paid promptly. Delayed payments tie up the contractor's operating capital, a condition that most likely was not considered in the original proposal. This is one complaint that often is voiced by construction companies involved in work for the public sector. They say that most government agencies delay payment for work done and, as a result, bid prices must be inflated to cover this delay.

Cumulative Reporting

One of the best ways for management to monitor the progress of implementation is through effective combined reporting by both the contracting company and the supervising architect. These reports normally should reflect both physical and financial progress measured against the schedule of anticipated progress that was prepared at the start of the project. Reports should clearly state the cumulative progress in each of the major divisions of work (excavation, structure, plumbing, electrical, finishes, etc.), rather than stating only the progress that was made during the reporting period. In this way management needs only to examine the last report to find out the complete history of the project from its beginning to the present. Changes and modifications while the work progresses must be clearly identified and described in the reports to management, as these often amount to as much as 15-30 percent of the final project cost.

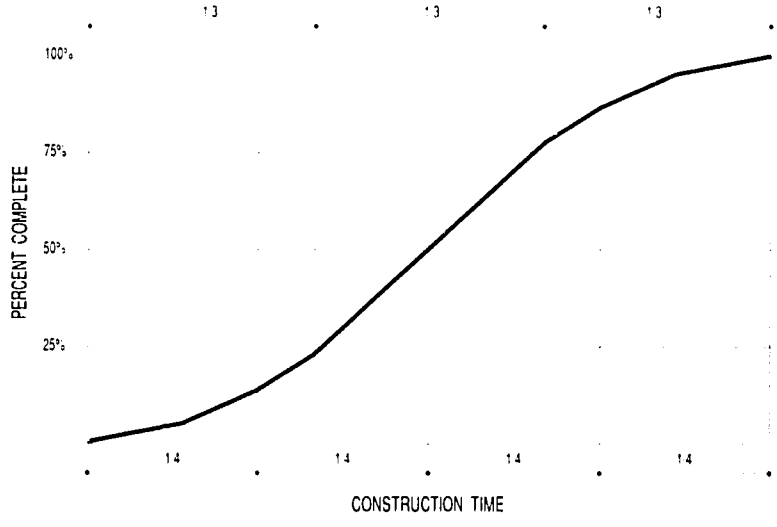
Progress of a normal construction project, consisting primarily of construction of buildings as opposed to highways or power lines, should follow an "S" curve (shown below). Progress usually amounts to about 12-13 percent in the first 25 percent of the construction period. Cumulative progress in the first 75 percent of the construction period should amount to about 88 percent, with 50 percent cumulative progress having been accomplished at the mid-point of the contract time. Progress during the middle one-third of the project time should be lineal. Major variations from these norms should be monitored carefully since they might predict a delay in project completion. Each implementation report to management should include the proposed progress curve and a superimposed curve indicating the actual progress to date. These charts should be supplemented with copies of the proposed PERT (or similar chart) and the actual PERT progress diagram.

Problems and issues arising during construction

During construction, problems and issues arise that only can be resolved with management's intervention. These should be kept to an absolute minimum since management looks to the specialist, the architect, to resolve as many of these issues as possible. It is the architect's obligation to keep management advised of all issues and how they might affect or have affected the overall implementation.

With regard to reporting, issues can be divided into three major categories: past, present, and future. Past issues are those which have been resolved. Only their effect on implementation and project cost needs to be reported. This action is more a record or history of the situation than it is a call for management intervention. Present and future issues, on the other hand, require more detail in their reporting.

Progress of a normal construction project should closely follow a normal "S" curve.



Present and future issues must be clearly identified as soon as they become evident. Reports should contain a clear, concise description of the problem and its likely effect on implementation, whether it be in terms of time or extra cost. The architect in charge of implementation should confer with the contractor and any others who may be involved in or affected by the issue. The architect should then list all possible solutions to the problem with a best estimate of how the implementation might be affected, both in time and money, by each solution. Finally, recommendations should be made as to the action that should be taken to resolve the issue. Management will then be apprised of all problems, their possible solutions, and the action recommended by the architect. With this information, a final decision can be made by management.

Quality Control

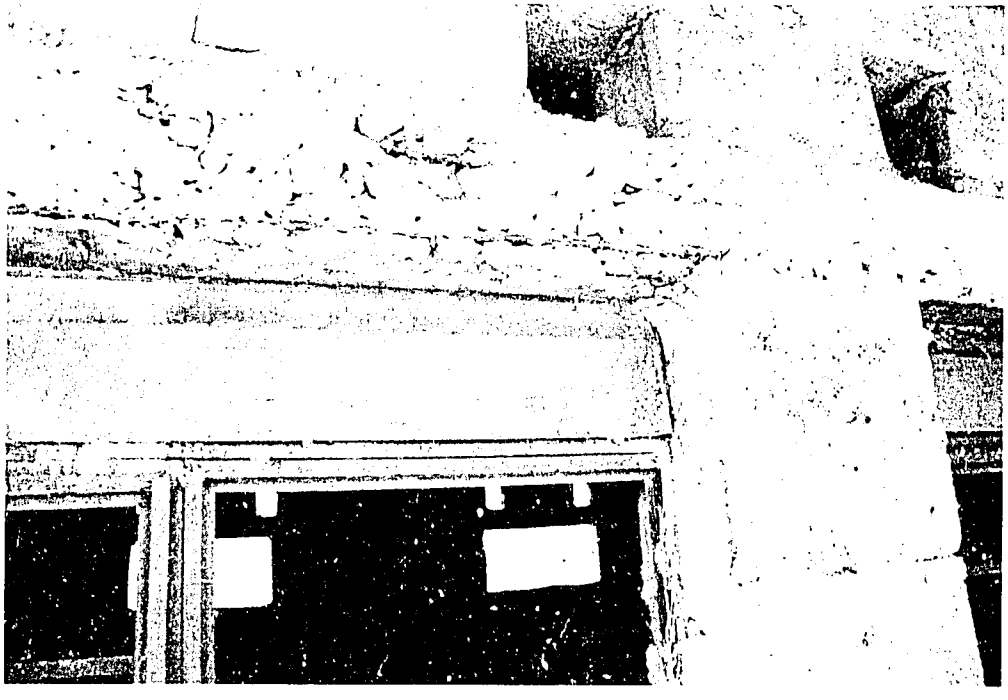
Perhaps the most important facet to be considered during the implementation of a project is that of safeguarding the owner's investment by assuring that quality materials and workmanship are used in construction.

Workmanship

Control of the quality of workmanship is done mainly through supervision. Depending on the size and scope of the project, supervision of a project can require from one to 20 persons or even more in some special cases. Quality of workmanship depends heavily on the geographical location of the project as well as the training received by personnel in each of the construction trades. Projects being constructed in or near large cities generally attract better qualified workers. This is due partly to the higher pay available in cities and also to a more attractive labor market. Rural areas normally retain only a few qualified journeymen who often are employed in the agricultural sector during growing seasons and only seek construction work during off-peak periods. In rural areas extra care must be taken in overseeing the quality of workmanship.

The labor or workmanship used to prepare and install materials is a critical factor that needs almost constant attention at every job site. For example, nearly all projects involve the use of reinforced concrete to some degree. The use of this material requires more supervisory attention than any other material entering the project. Al-

Zambia: Improperly prepared form work allowed slurry to leak and leave this beam in a substandard and weakened condition. Note the exposed reinforcing rods.



though most factories producing reinforcing steel have their own methods of quality control, how and where this material is placed in the column or beam can seriously affect its strength. Similarly, concrete is a mixture of predetermined quantities of stone, sand, cement, and water that produces a certain bearing capacity. Varying the proportions of any one of these materials can easily invalidate the design strength of the final product. Proper curing of the concrete is also important. Curing is the process used to delay the evaporation of moisture from the concrete for the first 28 days after pouring. Concrete that is not properly cured loses a percentage of its design strength, thereby reducing its final load capacity.

It is the responsibility of the architect or engineer in charge of supervision to see that builders conform to the technical specifications and other contract terms. Supervision of construction cannot be effectively managed by the architects making once monthly visits to the work site.

Materials

In most cases, the physical testing of individual materials is not as important as ensuring that materials are properly installed. The quality of materials is usually controlled in the factory where the materials are made. This does not mean, however, that materials such as bricks, steel, and cement cannot or should not be tested if the person in charge has doubts as to their quality. If the testing of materials is required, it should be done by an independent laboratory or in special laboratories approved by government. Almost all materials have minimum standards established by government or by some other quality-control agency and acceptable to the national construction industry.

All materials used in the construction should be equal in quality to those that were described in the technical specifications section of the bidding documents. If necessary, materials should be approved by the proper authority well in advance of their scheduled use. They certainly must be approved before being installed. Delays in selecting materials are frequently causes of delays in implementation. Contractors should decide exactly which materials they intend to use no later than 30 days after being awarded a contract. Many times companies shop around seeking lower prices for materials. Shopping for lower prices after the award of a contract delays timely commencement of work and should be avoided if possible.

How does one know which materials the construction company anticipates furnishing for a

Indonesia: Sufficient construction supervision is especially important in the placement of reinforcing steel.

project? What guarantees that the contractor will not substitute materials once they have been approved?

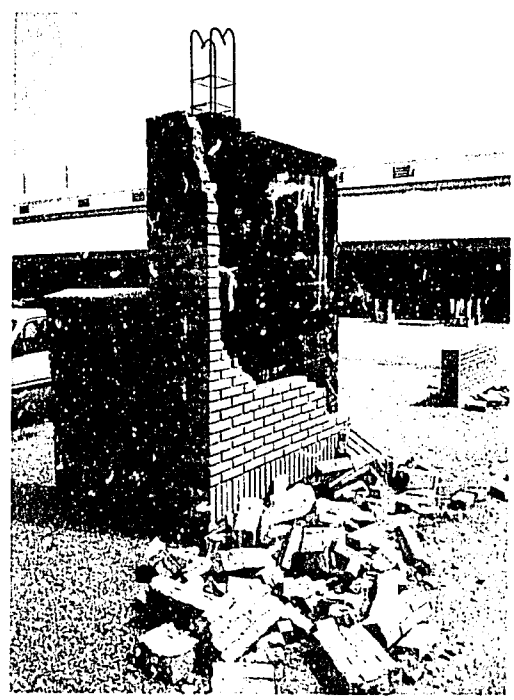
Physical samples of the materials planned to be used should be submitted to the architect for his written approval prior to purchase and delivery to the job site. In some cases samples are not available. In these cases, manufacturers' published technical information in the form of brochures and pamphlets should be submitted to the architect for approval. The materials delivered to the job site can then be checked against the literature that was found acceptable. Samples and printed literature are maintained on file until the project is completed and found acceptable.

In addition to samples of certain materials being furnished for approval it has become almost a standard practice for architects to require the contractor to construct a model wall, column, section of floor, window, or other installation at the job site. In addition to displaying materials that have already been found acceptable, this method of presentation also indicates the quality of workmanship that will be expected for the entire project.

Changes and Modifications to Scope of Work

No matter how well a project is designed or how much detail has gone into planning, changes during construction are inevitable. Changes may be as simple as relocating a door or electrical outlet. Or they may involve a much greater scope. For example, management may decide that a building should be enlarged to accommodate a new program not earlier envisaged. Changes in an average construction project normally amount to 15-30 percent of the original contract price. This percentage excludes increases in price due to government authorizations as a result of inflation.

Changes or modifications in scope are requested through change orders, which describe the work to be done and authorize the contractor to modify the scope and terms of the contract. A request to make changes can be initiated by management, the contractor doing the work, or the architect. This initiation is nothing more than a description of the work desired. If management or the architect is the initiator of the request, the builder is asked for an estimate of cost and how the final completion date of the project will be affected. If the builder is the originator of the request, the cost and time required to complete the work is



Côte d'Ivoire: Sample walls using materials proposed to be included in a project are advantageous. The walls should be maintained as a standard of quality of materials and workmanship until the construction has been completed.

generally included as a part of the request. Remember, the architect as interlocutor should be involved in all phases of project management including preparation and approval of change orders.

Depending on the complexity of the request, the entire process of preparing change orders and formalizing the contract modification can take from a few days to even weeks or months. The motto, "the simpler, the better," in addition to pertaining to the design of the facilities, is certainly applicable in the case of changes or modifications while construction is underway!

Estimating the cost of change orders

It should be firmly pointed out to management that except in one situation no extra work should be commenced by the builder without first determining the cost of such work. Only in situations that can be defined as extraordinary circumstances is it permissible to commence work without first establishing the cost. Extraordinary circumstances cover emergencies that endanger or might endanger the lives of workers, occupants of the facility, or other persons in the vicinity. Also, if a situation arises that might endanger the stability of the facility or of the surrounding facilities, these might also be considered emergencies. In these cases work might be authorized to begin without delay and the cost calculated later.

The cost of modifications to the scope of work is usually calculated using one of two standard methods: bills of quantities or market prices.

When the original contracts were signed using bills of quantities, modification costs are easy to calculate. In this case, the builder is paid agreed unit prices for the actual quantity of work performed. The same process can be used to estimate the cost of modifications if the materials involved in the modification are the same as those anticipated in the original contract. However, should the materials or the installation process vary from those originally quoted, the contractor must prepare another quotation using fair market prices of materials plus charges for labor, profit, and overhead.

If the original contract was signed for a single lump-sum amount, there is normally no base from which the costs of the modification can be estimated. In this case the contractor should prepare a detailed cost estimate for the modification using fair market prices of materials and a reasonable amount for labor, profit, and overhead. A lump-sum amount for the modification should be quoted.

In addition to these two standard methods for estimating costs, three alternative methods are sometimes used: competitive bidding, work by administration, and authorization to perform the work on a cost-plus basis. None of these are recommended under normal circumstances.

Competitive bidding, whereby other companies are allowed to provide quotations for the modification or extra work, should be approached with extreme caution. There is always the risk that the main contractor will not be the lowest nor the most convenient bidder. In that case there is the likelihood of having two or more companies working in the same project area. Conflict is sure to arise.

Work performed by administration, whereby the supervising architect takes on the task of subcontracting the various divisions of work to be performed, is even more involved and more complex than competitive bidding. Here, in addition to working at the same project site as the prime contractor, other trades must be organized and managed by the architect. Payrolls also must be maintained. The extra time involved in the management of the project and the conflicts that are likely to arise in the course of the work make this indeed a very poor alternative.

Work done on a cost-plus basis is the most attractive of these three alternatives. Here the prime contractor maintains receipts for all materials and labor and presents these to the architect for verification. Once approved, the contractor's previously agreed-upon percentage or fee is added for profit and overhead. Although additional work is involved in verification of materials and labor, there is no conflict between labor forces since all labor is that of the prime contractor. In emergency situations especially and in the absence of bills of quantities or fair market pricing as described above, a cost-plus method is considered the most appropriate means of performing extra work.

Delays and extension of construction time

Major construction projects are almost never completed within the time agreed upon and specified in the contract. Although the terms of the contract may clearly permit penalties to be imposed against the contractor for delays, some delays may be justifiable, thereby negating the penalty clause.

Probably four of the most common causes for delays in project implementation are increases or changes in project scope, inclement weather, delays in receiving materials, and failure of subcontractors to perform in a timely manner. The first two may be adequate justification for an extension of time without penalty provided they are adequately substantiated. Control of the latter two, however, should be within the full authority of the prime contractor. Delays as a result of either or both should subject the contractor to sanctions.

Each construction contract should make provision for delays as a result of force majeure—conditions that are beyond anyone's control. This category includes earthquakes, floods, storm damage, civil strife, and similar occurrences. It is impossible to predict or counteract the delays caused by force majeure. Therefore, when the delay is clearly attributable to force majeure, construction companies are not penalized.

It should be noted that the imposition of sanctions against contractors is never easy. In developing countries less than one-half of the projects suffering delays have had penalties imposed against the prime contractor.

A daily journal containing a log of the weather, number of workers, material deliveries, and orders and observations of the architect and the contractor should be kept at the job site. The journal should be signed by representatives of the architect and the contractor at the end of each day. In this way there is a permanent record of events during the entire period of construction.

Payments to Contractors

Construction companies should receive periodic payments as work progresses. They should not be expected to finance construction costs themselves. The law of many countries authorizes and may even require that construction companies receive an advance before work is begun. This amount can vary from 20-30 percent of the value of the total contract. Advances, when given, should always be adequately guaranteed by some form of acceptable surety.

Advances should be given only with the stipulation that they will be used to purchase materials or to secure the subcontracts that are needed to start the work. Prior to being given the advance, contractors should be required to present to the architect for his approval a list of materials (indicating both quantity and cost) that they propose to purchase with the advance. Otherwise there is the risk that the funds will never be used in the project for which they are intended. Note that the amount given as an advance could easily be equal to the contractor's profit and perhaps even a portion of his overhead.

Construction companies periodically present bills for materials and labor that have been incorporated into the project. Normally such bills are prepared on a monthly basis for work done up to the last day of the previous month. Depending on the type of contract, billings are based either on a measurement of the individual components such as walls and floors (bill of quantities type contracts) or on an estimate of the percentage of the total contract amount performed during the billing period (lump-sum contracts). Bills for additional work that has been approved through change orders are paid separately from normal billings or are incorporated in regular billings as an amount that increases or decreases the original contract amount.

Final payment to the contractor, totaling 100 percent of the contract amount plus any approved modifications, is due when all the contract conditions have been fulfilled. One of the conditions for final payment should be that the owner is satisfied that all bills for the materials and labor incorporated into the work have been paid. This condition varies depending on the country. In most developing countries such a requirement is not yet routine since laws do not permit suppliers and subcontractors to place a lien against the completed facility. Suppliers in these countries cannot legally recover an item that has been installed but not paid for. This system is likely to change in time. Although not now a requirement, it is strongly recommended that a release be required from all materials suppliers as well as subcontractors before final payment is made to the prime contractor.

Amortization and retention

As a further guarantee of satisfactory performance, it is good practice to withhold a portion of each payment made to the contractor. Many times management feels that this places undue financial strain on the builder. However, the strain on the builder is nothing compared to the strain that will

be put on management if the builder declares bankruptcy or abandons the project.

It is likely that during construction there will be times when the builder will beg and plead with management to make advance payments against what is owed in the overall contract. If there could be one word of warning to management regarding advance payments for work not completed it would be, **"Pay only for work done—never make advance payments except against 100 percent guarantee."** There is nearly always a wide gap between promises and performance.

Even if a builder furnishes an irrevocable guarantee of satisfactory performance on a project, it is wise to withhold an additional amount from each of the partial payments made as the work progresses. This amount should be in the range of five to 10 percent of each payment. As soon as the construction has advanced about 50 percent and if the builder is performing satisfactorily, one-half of the amount retained sometimes can be released to the builder. After this point only half of the original amount should be retained from each payment (2.5 to 5.0 percent).

In cases where an advance was made to a contractor to start construction, provision should be included in the contract whereby management can amortize the advance. Although the advance may be guaranteed, it still is dangerous to release these monies without a specified plan to recover them at some point before the final payment is made to the contractor.

There are two scenarios to recover advances that have been used with excellent results. The first involves giving an advance and not paying the contractor for materials delivered and satisfactorily stored at the job site. In this case the advance should be amortized over the life of the contract. Care should be taken to see that the entire advance is progressively recovered prior to completion of the project. The second scenario assumes that an advance has been given and also that payment is being made to the contractor for building materials satisfactorily stored at the job site. In this case, management should withhold an amount from each payment to the contractor to ensure total amortization of the advance by the time the project is 50 percent complete. The advantage of having received an advance and also being paid for stored materials warrants an earlier amortization of the advance.

On projects where either of these methods of amortization have been used, reputable contractors have not appeared to have had financial difficulty. Only when companies were already in financial difficulty did either of these systems cause problems. In these cases management certainly needed to thoroughly protect their investment by ensuring that the builder did not receive payment before doing the work.

Government cost increases during implementation

Construction contracts in most developing countries have some provision whereby the original unit prices can be increased or decreased in line with variations in government-approved increases or decreases in the market cost of labor and certain basic materials such as cement, reinforcing steel, structural steel, petroleum products, and wood. Each country probably has its own adjustment formula. The one shown below is a very simple example that was taken from an agreement between the World Bank and Mexico (Cuernavaca Agreement). The formula shows how a contract base price can be altered as the project progresses. Other models are available that function on similar principles of equitable payment for authorized increases in certain construction materials and labor. Short-duration construction projects—usually those of 12 months or less—do not normally make provision for price adjustments.

$$AF = (A)\frac{EF}{EI} + (B)\frac{LF}{LI} + (C)\frac{MF}{MI} + \ldots + (N)\frac{IF}{II} - 100$$

Key to terms in adjustment formula:

AF = percent cost (A)djustment for the period being analyzed

$A, B, C, \ldots, N$ = percent influence that each of the basic components of the project has on the total project

- A = machinery and construction equipment
- B = labor
- C = materials
- N = input "X"
- $A + B + C + \ldots + N = 100$

EI, EF = indices of machinery and construction (E)quipment applicable to the contract date and the date of adjustment, respectively

LI, LF = indices of (L)abor applicable to the contract date and the date of adjust-

ment, respectively

MI, MF = indices of construction (M)aterials applicable to the contract date and the date of adjustment, respectively

II, IF = indices of (I)nputs "X" applicable to the contract date and the date of adjustment, respectively

Variables $A, B, C, \ldots, N$ are determined by each bidder and included in the break of costs that is submitted with the bid. Indices shown in the adjustment formula are usually determined by one of the central government agencies or one of the professional organizations associated with the construction industry. These indices normally reflect an average market value of such items available within the country.

This formula is periodically applied to adjust the cost of the work remaining to be done at a specific point in time. Work already done is not subject to any price adjustment. With this in mind, it can be easily seen how an advance to the contractor specifically for the purchase of materials and their delivery to the job site can save the owner substantial cost increases on that portion of the work.

Guarantees and Sureties

Normally, over the life of a project four types of guarantees are required: bid guarantees, performance guarantees, guarantees for any advances that the contractor receives, and maintenance guarantees. Some of these have already been mentioned; however, due to their importance it is worthwhile to mention them again in more detail. Again, bidding documents should clearly describe the types of guarantees and sureties that will be required and their limits. In lieu of bonds, guarantees, or sureties, a certified check or cash equal to the stipulated amount of the bond is normally acceptable.

Bonding in developing countries usually ties up the financial resources of the contractor since projects are usually guaranteed by local banks. Surety levels that are set too high, while protecting a project better, can easily cause financial hardships for the builder. Management, on the other hand, must set the limits high enough to provide adequate protection against potential financial losses.

Standard types of guarantees

First, to guarantee that the bidders will sign a contract for the amount of their proposal, a bid bond is required. The amount of the bid bond varies depending on the country, two to five percent being the normal acceptable range. The period of validity of a bid bond should be equal to the period of validity of the bid plus 30 days. This period can be extended by mutual agreement of the bidder and management. As soon as a contract has been signed the bid bond is released.

At the signing of the contract, a performance bond is furnished by the builder. This bond is to ensure that the project will be completed, either by the contractor or by the entity issuing the bond, at no additional cost to the institute. The amount most developing countries require for a performance bond is usually extremely low and therefore cannot fully provide the necessary protection. It is recommended that the performance bond be for an amount equal to no less than 20 percent of the contract amount with a period of validity equal to the full implementation period. Even a 20 percent bond will not afford complete protection in all cases, but coupled with other guarantees and methods of facilitating implementation, it will be better than what is now required in some countries.

It is not uncommon to find that local customs, and even legal requirements, stipulate that contractors be given an advance to begin construction. This advance varies from 10-30 percent of the total contract price and is usually secured with a bond guaranteeing that the contractor will repay these monies within a designated period. The guarantee or bond that the contractor furnishes management at the time of receiving the advance should be for the total amount of the advance.

Additional guarantees

Since the value of performance guarantees is relatively modest and frequently does not fully protect the institute against financial loss, it is highly advisable that management seek some additional type of guarantee. One guarantee that has been used very effectively is the equipment of the contractor. All the contractor's equipment entering the construction site should remain on the site unless specific permission is given by the architect for it to be removed. The value of this equipment then becomes a type of supplemental guarantee to ensure the performance of the contractor. If a contractor has financial problems and it becomes

obvious that it will be impossible for him to complete the construction, legal action can be taken to dispose of the equipment and to use the funds to complete the construction.

Along these same lines, contractors have been known to deliver construction materials to one job site, then to transfer them to another site. All material entering the job site should remain there and, paid for or not, should be considered a part of the project. Only in isolated cases should the architect give permission to remove materials not destined to be incorporated into the project but stored on the site.

Maintenance period

It is customary in many countries to require a maintenance guarantee from the contractor. Such a guarantee goes into effect as soon as the project is complete and is found acceptable by the architect and management. A maintenance period is specified during which the contractor guarantees materials and workmanship to be free of defects. Usually this period is one year from the provisional acceptance of the completed project.

In addition to the normal maintenance guarantee or surety that the contractor provides, it is also advisable to withhold a portion of the contractor's final payment. Usually a combined total retention and guarantee equal to around five percent of the value of the project is sufficient. These monies plus the guarantee are used to make repairs and to correct defects occurring during the guarantee period. It is recommended that no less than one-half of the total guarantee be in the form of cash retained from the amount paid to the contractor—the balance can be in the form of an irrevocable guarantee issued by a bank or insurance company.

The Need for "As Built" Drawings

Many small components go into the final assembly of a facility for agricultural research. Once installed, most of these components are covered with plaster, ceiling tiles, finished flooring, and a myriad of other finishes. Electric wiring, plumbing and drainage piping, and other installations that were so visible during construction are no longer in view once the buildings are completed. However, to know the exact location and the size of utilities is important for architects, planners, and the institute's maintenance department.

One part of the contract for the construction of facilities should specify that the builder will prepare "as built" drawings for all buildings. These drawings indicate the exact locations of walls, electrical outlets and feeder lines, plumbing and drainage lines, and any other information that would be useful for future renovations and maintenance. These drawings should be well detailed and normally are prepared as the building is being erected. Photographs should be included to more clearly indicate the exact location of most of the utilities. A list of materials, their manufacturers and trade names, as well as their sizes, colors, and textures is also included. Final payment should not be made to the contractor until reproducible copies of the as built drawings are turned over to management.

Chapter Ten—Estimating Project Costs

Requirements of International Agencies

Since the construction of facilities for agricultural research ia developing countries will most likely involve international funds, it is appropriate to include a few words related to the project costing and financing required by most international agencies.

The costing of a project in the early planning stages is at best only a rough estimate of the total final cost. Estimates must be restudied and updated periodically until the time that a loan or grant is received for the work. Available market pricing data are used for updating estimates. Once a commitment for funding is made by an agency, the estimate of cost usually is thought of by the institute as that project's "budget" rather than as a realistic cost estimate. To prevent this "budget" from becoming a major constraint, the final cost estimate must include all factors affecting the cost of construction, such as inflation, devaluation of local currencies, delays in project implementation, and similar problems that would affect the rate of disbursement of the funds.

Unit Costs and Phasing

Cost estimates for construction should be based on the cost of each unit of the building being proposed multiplied by the area to be constructed. The "unit cost per square meter" normally is used in these measurements. Roads, power lines, utilities, fencing, and similar items are usually estimated on a cost per lineal unit. Fairly standard unit costs for buildings and other utilities are readily available in most countries or might be easily obtained from similar projects in the area. Architects and builders are also excellent information sources regarding construction costing.

Unit costs for buildings often vary considerably from country to country and from region to region within the same country. Price differences between regions are often as high as 25-30 percent. The cost of construction also varies depending on the quality of materials and workmanship of the buildings being planned and on the phasing of construction.

The index approach to costing

With so many variables, the best method found so far for making preliminary estimates of construction costs on a worldwide basis is one that uses an index factor for various types of buildings excluding purchase of land. The base cost index of 100 is assumed to be the cost per square meter of a modest residence or office in an area readily accessible to a medium-sized city. It is assumed that at least 80-90 percent of the construction materials are locally available. Using the index approach, the table on the following page relates the costs of some of the components of agricultural research facilities to the cost of a modest residence or office in a similar geographical area. Projects in rural areas are likely to be as much as 10-25 percent more expensive than projects in urban locations. Again, the unit cost depends on the availability of materials, transport conditions, and other factors such as weather and labor availability.

The indices are used to arrive at an estimate of the base unit costs of construction. To estimate the effect of phasing on the final cost, management must carefully plan the probable dates of bidding, signing the contract, commencing construction, and completing the project. Contingencies and the effects of inflation are then estimated as accurately as possible.

Cost Comparisons Using the Index Method

Name of Facility	Cost Index
Scientists' offices	100
Administration offices	100
Auditorium/multipurpose room	110
Library	110
Scientific laboratories	150
Warehouses/storage	80
Garages	80
Open sheds	60
Seed drying yards	20
Plastic houses	75
Glasshouses—cooled	160
Glasshouses—cooled/heated	190
Screenhouses	65
Kitchen	150
Cafeteria	110
Executive housing	115
Senior staff housing	110
Junior staff housing	100
Trainee housing	90
Labor housing	70
Enclosed animal buildings	90
Enclosed animal buildings—wire divisions	120
Enclosed animal buildings—slatted floor	130
Animal sheds	70
Animal sheds—wire divisons	100
Animal sheds—slatted floor	110

The table shows the cost of some of the components of agricultural research facilities compared with the cost of a modest residence or office in a similar geographic area. The cost index of such a residence or office is 100.

Contingencies

Regardless of how accurately one feels that a project size has been determined, differences will invariably occur. For example, it is easy to decide that a scientist will need 12-15 square meters of space or that about 20 km of electrical distribution line will be required to service an institute. In reality, however, the amount of space or distribution line actually needed will be more or less than these preliminary calculations. In normal projects, a physical contingency factor of 10 percent should be added to the cost estimate. In projects where planning details are sketchy, 15-18 percent should be added to cover physical contingencies.

Price contingencies must also be calculated to cover the effect of inflation on the final project cost. Some lender and donor agencies add a single percentage to the base cost estimate. As is shown later in this section, this practice is dangerous, as it can lead to shortfalls in financing or a severe underestimate of project cost.

Most internationally financed agricultural research projects estimate the project implementation period to be six to eight years. The construction portion, however, usually is accomplished in the first four to five years. To show how using a single percentage for price contingencies may produce erroneous results, examine the following hypothetical example.

A construction project with a base cost equal to US $1.25 million is planned for a developing country where the local annual rate of inflation is

estimated at an average 23.5 percent uniformly over a six-year project period. The foreign exchange component is estimated at about 25 percent of the full project cost. The annual foreign inflation rate averages 6.5 percent. Construction is planned to occur during the first five years of the project.

Price contingencies are calculated separately for local and foreign components. To determine the effect of annual inflation on the overall cost of a project, one must take into account delays between project preparation, appraisal, and project start-up as well as the length of time for construction to be completed. For the purpose of this exercise it is assumed that the cost estimate had been updated to the start-up date and, therefore, no additional inflation factors were required.

In calculating price contingencies, it is assumed that expenses are to be incurred continuously over the year. Expenses at the end of the year incur a higher rate of inflation than those incurred during the first part of the year. To adjust for variations in inflation during the year, only 50 percent of the inflation rate for the year is used plus 100 percent for all preceding years.

To arrive at the foreign inflation weight for Year$_n$ the following formula is used:

$$(1+FY_1)(1+FY_2)(1+FY_3) \ . \ . \ . \ (1+FY_n/2) = FY_n$$

FY_1 = foreign inflation rate for (Y)ear one
FY_2 = foreign inflation rate for (Y)ear two
FY_3 = foreign inflation rate for (Y)ear three
FY_n = foreign inflation rate for (Y)ear "n"

Calculation of the inflation weight for the foreign exchange component in the third year of this project is as follows:

$$(1+FY_1)(1+FY_2)(1+FY_3/2) = FY_3$$

Similar calculations are used to determine the inflation weight for the local LY_n component of the project.

Finally, to determine the phased project cost, the above weights are multiplied by the project base cost including physical contingencies. For the hypothetical example introduced on page 122, calculations are illustrated on pages 123 and 124.

Calculation of physical contingencies

Project base cost	1,250,000
10% physical contingencies	125,000
Subtotal	1,375,000

Calculation of foreign inflation weights

Year 1	(1+0.065/2)	1.033
Year 2	(1+0.065)(1+0.065/2)	1.100
Year 3	(1+0.065)(1+0.065)(1+0.065/2)	1.172
Year 4	(1+0.065)(1+0.065)(1+0.065)(1+0.065/2)	1.248
Year 5	(1+0.065)(1+0.065)(1+0.065)(1+0.065)(1+0.065/2)	1.329

Calculation of local inflation weights

Year 1	(1+0.235/2)	1.118
Year 2	(1+0.235)(1+0.235/2)	1.381
Year 3	(1+0.235)(1+0.235)(1+0.235/2)	1.705
Year 4	(1+0.235)(1+0.235)(1+0.235)(1+0.235/2)	2.106
Year 5	(1+0.235)(1+0.235)(1+0.235)(1+0.235)(1+0.235/2)	2.601

Calculation of phased base cost plus physical contingencies

Year # (% Phasing)	Local (75%)	Foreign (25%)	Total
Year 1 (10%)	103,125	34,375	137,500
Year 2 (25%)	257,813	85,937	343,750
Year 3 (35%)	360,937	120,313	481,250
Year 4 (25%)	257,813	85,937	343,750
Year 5 (5%)	51,563	17,187	68,750
Total (100%)	**1,031,251**	**343,749**	**1,375,000**

Phased project cost including physical and price contingencies

Local Component

	Base	Inflation	Total
Year 1	103,125	12,169	115,294
Year 2	257,813	98,227	356,040
Year 3	360,937	254,461	615,398
Year 4	257,813	285,141	542,954
Year 5	51,563	82,552	134,115
Total	**1,031,251**	**732,550**	**1,763,801**

Foreign Component

	Base	Inflation	Total
Year 1	34,375	1,134	35,509
Year 2	85,937	8,594	91,531
Year 3	120,313	20,694	141,007
Year 4	85,937	21,312	107,249
Year 5	17,187	5,655	22,842
Total	**343,749**	**57,389**	**401,138**

Total project cost including all contingencies

	Base	Inflation	Total
Year 1	137,500	13,303	150,803
Year 2	343,750	106,821	450,571
Year 3	481,250	275,155	756,405
Year 4	343,750	306,453	650,203
Year 5	68,750	88,207	156,957
Total	**1,375,000**	**789,939**	**2,164,939**

As can be seen, inflation can easily amount to a substantial part of the total project cost. Inflation costs are normally included as an integral part of the financing for construction In the case presented here, inflation on the local component amounts to 71.0 percent of the base cost and 16.7 percent on the foreign component. For the overall project, physical contingencies and inflation amount to 57.5 percent of the total project cost. Many projects are hesitant to include such a large amount when the inflation factor is expressed as a single percentage. As a rule, when a single figure is included in preliminary cost estimates, no more than 25-30 percent of the total base cost is used. For many projects this has left significant shortfalls which must be compensated for by increases in counterpart funding or by a decrease in project scope.

Financing Plan

Every project should have some proposed plan of how it will be financed. If funds are not available and they are being sought, a proposed financing plan serves as a target. If funds have already been made available, in all probability a financing plan has been agreed upon by the agencies involved.

The preparation of a proposed financing plan usually does not involve the management of the research institute. This task is usually performed by higher government officials, normally in planning or treasury. The "magic" percentage of project financing, 50 percent by the borrower and 50 percent by the lender, is a general target that has been used by most countries for many years. The exception to this figure is countries that receive donor funding or those in line for "soft" loans with long grace periods and a 40- to 50-year payback period. In these cases, each situation is judged on its own merits.

One word of caution—in preparing a project cost estimate do not mix project cost with project financing. As simple as it may sound, this is a common error. Prepare the schedule of physical requirements, estimate the cost taking into consideration all the contingencies, phase the project, and make an estimate of the local and foreign cost components, **then** tie the financing to these estimates. If the project must be reduced in scope to fit the financing, make the cuts.

Disbursement plan

Disbursement plans are important both to local government and to the donor or lender. The estimated disbursement plan is a schedule of how the funds are anticipated to be made available to the project as work progresses. The phased estimate of cost, if carefully prepared, can be a rough guide to how the construction funds should be disbursed. This disbursement, however, is by the institute to the contractor. Other disbursement plans guide the donor or lender as to when the recipient country proposes to draw on the funds that have been committed. Frequently there can be a lapse of two to three months between the date bills are submitted by the contractor and the date that reimbursement is requested from a donor or lender. In exceptional cases, six to 10 months have elapsed. But these cases are rare. Institutes should ensure that bills are paid promptly and that reimbursement is requested without delay.

In planning a disbursement schedule, advances and special accounts authorized by donors or lenders must be taken into consideration as well as any normal delays between the date contractors are paid and the date reimbursement is requested. On the following page is a typical disbursement schedule for the aforementioned hypothetical project. Notice that disbursements have been calculated on a quarterly schedule. This is not to say that only quarterly disbursements should be made. They may be made as often as needed, but should not be in amounts so small as to cause undue clerical work on the part of the donor or lender.

Sample disbursement schedule

		Disbursement	Cumulative
Year 1			
	1st Quarter		
	2nd Quarter	32,500	32,500
	3rd Quarter	43,300	75,800
	4th Quarter	54,100	129,900
Year 2			
	1st Quarter	75,800	205,700
	2nd Quarter	75,800	281,500
	3rd Quarter	140,700	422,200
	4th Quarter	140,700	562,900
Year 3			
	1st Quarter	162,400	725,300
	2nd Quarter	173,200	898,500
	3rd Quarter	184,000	1,082,500
	4th Quarter	184,000	1,266,500
Year 4			
	1st Quarter	173,200	1,439,700
	2nd Quarter	162,400	1,602,100
	3rd Quarter	140,700	1,742,800
	4th Quarter	140,700	1,883,500
Year 5			
	1st Quarter	75,800	1,959,300
	2nd Quarter	75,800	2,035,100
	3rd Quarter	54,100	2,089,200
	4th Quarter	43,300	2,132,500
Year 6			
	1st Quarter	32,500	2,165,000

A FINAL WORD

These guidelines have covered a wide range of issues concerning the planning, design, and construction of buildings for agricultural research. Information has been presented on what should be done to design more functional buildings, to avoid costly mistakes in the actual construction phase, to reduce operating costs, and to increase the useful life of facilities through proper maintenance. These are all important considerations in times of fiscal restraint. In this sense, the guidelines should contribute to enhancing the sustainability of agricultural research institutions.

The information gathered here is the result of pooled experience from numerous agricultural research institutes, and all the participating institutions are again thanked for their assistance. If the guidelines are used extensively by those in national agricultural research organizations, ISNAR will have achieved its prime objective. For managers, administrators, scientists, and many others these guidelines can serve as a starting point in their search for creative solutions to the problems of providing appropriate research facilities and for the continued sharing of such experience.

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