SERVICES IN RESEARCH LABORATORIES

WITH SPECIAL REFERENCE TO CHEMICAL RESEARCH

A DISSERTATION
submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF ARCHITECTURE

By

K.N. PATHAK

DEPARTMENT OF ARCHITECTURE
UNIVERSITY OF ROORKEE
ROORKEE (INDIA)
October, 1972

CERTIFICATE

Certified that the dissertation entitled 'Services in Research Laboratories with Special Reference to Chemical Research' which is being submitted by Shri K.N. Pathak in partial fulfilment for the award of the degree of MASTER OF ARCHITECTURE, Department of Architecture, University of Roorkee, Roorkee, India, is a record of the student's own work carried by him under my supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other degree or diploma.

This is further to certify that he has worked for a period of 8 months from 1st January, 1972 to 31st August, 1972 for preparing this dissertation at this University.

ROORKEE
DATED:

(Rattan Kumar)
Professor in Architecture
Department of Architecture
University of Roorkee
Roorkee, India.

A C K N O W L E D G E M E N T

The author wishes to express his sincere gratitude to Professor Rattan Kumar, Professor in Architecture, for his continued encouragement, keen interest and guidance during the preparation of this dissertation.

The author is endebted to Professor G.M. Mandalia, Head of Architecture Department for his valuable suggestions and thoughts that enriched this dissertation.

The author is thankful to those Scientists, Engineers and Architects who cooperated with the author in his survey and other work related to this dissertation, specially Sri G.S. Chakraborty, Reader in Civil Engineering, Jadavpur University, who assisted the author in computer work.

Finally, the author is grateful to all those who helped him in bringing this dissertation to the present form.

ROORKEE (K.N. Pathak)

Dated:

C O N T E N T S

Page No

Page No.

LIST OF ILLUSTRATIONS

PREFACE

A notion often prevails among the architects that standardisation brings sterilisation in creative arts including architecture. This dissertation has been written with an inquisitive mind to analise whether standardisation and optimisation really does any harm and whether these could be done without sterilising the creative faculty of a designer, particularly in areas which ought not and should not be left to intution or chance, such as the services, circulation etc.

Modular planning has become the practise of the day and there is a greater scope of rationalisation as the logical faculty of a designer can enter into the domain of the creative faculty replacing intutive work to a great extent. One of the striking inventions of this century, the electronic-computer has revolutionised the technologies all over the world. Presently, it is being used in a limited way in planning and architecture but a vast field is still open for exploration and implementation. A general study of different works together with this dissertation shows that rationalisation or the use of computer is in no way a deterent to the architect to create new forms, rather it promotes the true synthesis of form and function.

This dissertation is primarily oriented to the rationalisation of Industrial Research Laboratories through optimisation of services but the principles are applicable to the rationalisation of any other project based on modular planning requiring optimisation of services, since the appropreateness of the subject 'Optimisation of Services in Industrial Research Laboratories' is in the overall interest of our Nations progress.

INDUSTRIAL RESEARCH AND THE ARCHITECT

INTRODUCTION

Research activity can be traced back to the dawn of civilisation and will continue till the extinct of human race. The luminnaires like Sorcates, Nuton, Leonardo-da-vinci, Madame curie and many others have dotted the history of research by ages. However a sudden boost in research activities is observed as a world wise phenomenon, only with the advent of rapid industrialisation. The research centres like the Building Research Station, U.K. and such other famous institutions had come up during that period.

In colonial India, the scientific research activities were limited to individual enterprice, in academic institutes and a few devoted and emienent scientists like Sir J.C. Bose, Sir C.V. Raman and such others. At public sector only the institutions like the Indian Statistical Institute, Institute of Science, Bangalore and a few others could be seen. It was only in independent India when the scientific research was promoted by the Government of India, under the Chairmanship of the first Prime Minister, Sri J.L. Nehru. In 1947, under the Council of Scientific and Industrial Research with Dr. S.S. Bhatnagar as its

Director General, thirteen research centres where opened all over India, which multiplied into many sub-centres together with many new centres. Grants on scientific research steadily increased in subsequent years. National expenditure on scientific research steeped up from Rs.10 million in 1947 to Rs.500 millions in 1963-64.[1]

In private sector also reputed institutes have come up such as the 'Tata-Institute of Fundamental Research', Birla Institute', Pilani and similar others.

Inspite of such development in research activities, it is found inadequate in time and space of the vast nation as ours. The expenditure on scientific and industrial research constitutes only 0.3% of our G.N.P. which is admittedly low by International Standards.[2]

Government of India, at present, has given much stress on self-reliance and also recognised the basic needs towards fulfilling its pledge.

In his recent address to the scientists, the Central Minister of Scientific and Industrial Research[3] has express

---

1. Excerpt from the lecture delivered by Dr. Atma Ram in Bose Institute in July, 1964.
2. UNESCO Report on Scientific and Industrial Research-1967
3. Mr.C.Subramanian, the Minister of Scientific and Industri Research had addressed the National Congress of Scientis held in Vigyan Bhawan, New Delhi, on March, 1972.

the Government's desire to boost research activities and give priority towards starting as many research centres as feasible. He has also promised to provide incentive to private sectors to develop indigenous methods and techniques through research laboratories of their own. He has also stated that the Govt. is going to solve the administrative diffiioulties faced by the young scientists towards freedom of work in laboratories.

These refreshing attitudes are going to open the door towards intensive research activities at the national scale. The architects in near future will be required to play their role in uplifting the national economy through laboratory building designs, utilising with utmost efficiency the money spend on the laboratory building by the developing nation.

Rationalisation in Laboratory Planning:

The twentieth century has seen new innovations of phylosophy and style in Architecture and our four runners have created many landmarks with their revolutionary and rational thinking. But today when we compare the achievements in various fields of technology with that in architecture, we find that we have legged behind in shaping our environment as compared to technological advancement. The reason being that where as the technologies have been highly rationalised, the way we shape our environment through Architecture and Planning has remained relatively intutive in nature and it may remain so far all times to come in some of its areas of provision.

To-day, the gadgetry has entered deep into man's day to day life and our living architecture has also been influenced by it to a degree that one is indispensible of the other like the bone and flesh in a living body. It is specially true for the laboratories where sometimes the gadgetry and equipments assume a dominant role and the architecture marely an enclosure to it. In a democratic set up - involving people's wealth, the planning and design in such fields can not be left on intution or the whim of the designer. A rational and systematic approach should be evolved to achieve a highly efficient form and to make the best use of available resources. The following pages are devoted to discuss in details, the need for rationalisation from the very conception of the design.

Scope of the Dissertation:

In the light of present context it is felt appropriate to undertake studies on the various aspects of the planning of Industrial Research Laboratories in a rational way. In the age of technological advancement, the laboratory planning is a highly specialised subject involving numerous divergent informations, too large to be handled by an individual architect, or even small panels of experts. But the contemporary architect should cultivate his capacity to handle rationally the informations and new parameters or threshold supplied to him by the different experts leading towards an optimised solution.

Within limited time and resources available to the author, this dissertation, aims at a systematic approach for optimisation of services in laboratories and as such only a small section out of the various parameters could be incorporated in this study i.e. the 'services within the Laboratory Building'. However, with the same approach and rationality, other variables can also be evaluated as a seperate study if more time and resources are available. The centralised services within the laboratory building under consideration are as follows:

1. Benchservices-Liquids, Compressed air and gas
2. Weather controll - Air conditioning and exhaust
3. Illumination - Natural and Artificial.

The other services pertinent to this class of services are power, telecommunication which need further study.

BUDGET APPORTIONING AT THE PRELIMINARY STAGE:

To the amusement of readers, it is often published in news papers that a building project after completion has cost double its intended budget and the major share of criticism is diverted towards the architect concerned. This happens, no doubt, because of the rising prices as well as the budget made without precise knowledge or made on net requirements and apprehensions.

A large portion of the architects time and energy is wasted in re-doing things on the drawing board, discarding plans and estimates at their advanced stage as the scheme takes a clearer image through working drawings and the descripencies between the sanctioned budget and the actual project costs become evident.

Much of this redundant time and money can be saved if a rational approach is adopted to get a reasonably accurate picture of the budget. It can only be possible if the priliminary sketch design, on which the budget is sanctioned, has been adopted through a high degree of nationalisation. Many alternate proposals should be studied and placed before the client so that in case of exigesis, another alternative scheme could be implemented without undue amputation of the clients requirements or going through a process of sanctioning additional funds, which often occurs due to the rising prices incurred by the time lag between the commissioning of the architect and the slow process through which the scheme is implemented.[1]

Rationalisation of the priliminary sketches can be done on several items such as, the land cost, cost of access, utility cost, circulation, cost of laboratory services, building sketeton, cost of finishes, cost of construction including materials, labour, provision for rising cost in time and space and so on.

Various alternative solutions should be studied for each of the items and overall cost computed to evaluate an optimum solution or a range of solutions within the limits ofthe budget and without undue sacrifice of the work efficiency and aesthetics.

It is impractical for the architect and his team to spend the valuable time and money at investigating numarous alternatives and go on estimating manually the cost of each of them. It can only be possible if he takes the help of a computer which can provide precisely the cost of these alternatives with much less time.

Another interesting matter in adopting computer is that a much more rational approach in designing has to

---

1. The usual steps between the commissioning of the architect and the implementation of the project as follows.

   - Decision on the priliminary design by the administration
   - Financial allocation
   - Release of funds
   - Working drawings and estimates
   - Tender

be taken leading to many quarries and informations which were beyond the normal comprehension of the sketch designer at that stage and which ought to be exposed in due course as the sketch plan is developed further and further towards working drawings.

We all know, the complex contemporary building like a laboratory is an outcome of the synthesis of aesthetics and technology where mechanical and electrical equipments play a vital role. These gadgets are inseparable part of the building form and the aesthetics. However, beautiful and pleasing the building form may be it is going to be marred after the institution of the service lines and add up a considerable amount to the capital cost and running cost of the project unless they are considered during the designing of the building just like the veins in a living body.

Thus a building project needs the co-operation and co-ordination of various experts in different fields. The architect's role, as according to Henry Wright, 'is like a good pannel leader in a radio discussion,' i.e. to co-ordinate the available expertise in different fields of the building project. Large architect's office has such panel of experts either in the form of employee or as consultants, but they come into picture when the building plan has already been done. They either design their respective part on the basis of the given floor plans or have to direct the architect to modify it or change it. Thus it becomes a trial and error project. This could be avoided only if the architect is able to take hèlp of the experts in different fields while he is forming a mental picture of the project, i.e. the initial sketching stage.

Much of hue and cry is often heard about the methods of rationalising construction process by means of 'critical path method', 'Programme Evaluation and Review Techniques' and other sophiticated methods to control the cost of construction of a project through efficient use of materials, man and machine powers, storage on site etc. However, direct labour cost represent only 20% to 25% of the total project cost. Therefore a 10 percent saving in field labour cost results in a 2 to 2.5 percent influence on the total project cost where as rationalising design process which represents 75 to 80 percent of the total project cost, could save a much higher percentage. This shows the need for rationalising during design stages.

Richard Jarrold's views are revealing in this regard, as he says, 'Once the site is selected, the basic plant layout is established and the design basis fixed, the major costs of the project are 'locked-im'. It is during this basic planning period that something can be done about cost'.[1]

---

1. Jarrold, Richard, 'Pharmaceutical Plant in Puerto Rico', <u>Chemical Engineering Progress</u>, (Vol.66, 1970), p.177

A major share of the total budget is consumed by piping and though it is considerably high, the architect tends to over look it till the basic plan has been finalised, and after the basic plan is finalised there is hardly any scope left to optimise the piping circuitry except follow the building plan. A small additional expenditure on piping design to integrate it with the initial sketch plan of the building, may save the client from a huge amount of wastage.

Mr. Pitzer's statement makes it more expicit as he writes, '... the break down of cost of services shows that as compared with the 2 percent of the total project budget absorbed by piping design functions (in laboratories) around 12 percent is spent on procurement of the piping components and a further 10 porcent is utilised in the fabrication and erection at site of the pipe work'.[1]

Apart from direct losses as mentioned above, the indirect losses may also occur such as - delays in the order and delivery period of materials in bulk and hence either delays in the mompletion of the project or to an unsatisfactory man power demand leading to high cost of construction. In many countries pipe work detailing is done by computer to achieve great reduction in cost and design time.

---

1. Pitzer, M.S. 'Pipe Work Delaiting by Computer', Chemical and Process Engineering, (Vol.50,No.10,November, 1969), pp.78-79.

COST CONTROL DURING THE LIFE OF THE BUILDING:

Research laboratories yield indirect benifit to the nation. The extreme cases being an expensive experiment, after a long and tiresome period of persuit has to be abandoned fruitlessly, to a revolutionary achievement in a short duration which is a rare cases, whereas the recurring cost of laboratory services are much higher than in any of the building type.

Public sector can be expected to persue an expensive research project for a long period despite unduly heavy running cost, but in the private sector a small enterprise may not be able to bear such burden and may desert such research project and divert the building to some more remunerative work project. This is specially true if the running costs are unduly higher than the expected.

The layout of building and thereby the service system imparts great influence on running cost of services like the pumps, compressors, fans etc. are subject to work on higher heads due to friction in piping which are either undersized, unduly long or reach the laboratory benches after many turns and bends.

The pipes with larger sizes, though with a higher initial cost, proves to be economical in long run as the lower running cost of services through such pipes, off sets the higher initial cost within a short period.

Apart from the services through pipes, merely the form of the building may become a source of constant expenditure in terms of annual cooling and lighting cost. The total solar radiation absorbed can be minimised by reducing the surface areas that ~~radiation~~ receive maximum solar radiations and increasing them to orientations receiving less solar radiations. The planning which allows inadequate natural light incurs constant expenditure in two ways, one, the cost of lighting and another, the cost of cooling due to additional heat generated by artificial lighting.

Therefore a balance has to be struck between the initial costs and its respective annual running costs for different sizes of piping. The optimum size of pipes and their respective operating cost, thus arrived at, will vary from place to place depending upon the factors like material costs, labour cost, fuel charges (generally electricity), climatic conditions, method of cooling etc. and therefore an optimised design for one place may not be effective for another place.

Mechanical services in laboratories to-day have a life about half of the useful life ofthe building structure.[1]

---

1. Useful life is meant by the period after which the building has to undergo large scale renovation to continue as a research laboratory or it is diverted to some other use, as such it is not the actual life of the building.

This statement is made with full realization that constant improvement in these arts results in fairly rapid obsolescence, and laboratory building can not continue for a longer time to work with obsolete mechanical services to stand in competition with the programme. A review of the extreme modernisation and renovation of laboratory buildings takes place with a radical change in research techniques. Considering financial aspects and time lag in adaptation of such techniques, this period generally falls between 30 to 40 years. The supply of services constantly incur mechanical power leading to recurring operating cost.

Average operating cost of services have been found to vary between 7 to 8 percent of the initial installation cost with a probable low of 5 percent for high priced systems and a high of 10 percent for cheaper installation.[1]

In an extensive supply system like laboratory services the ducts and plumbing cost is about 40 to 50 percent of the total installation cost of services. It is also about 20 to 25 percent of the total cost of the building project as stated earlier.

This shows that the annual running cost of services with respect to the total cost of the building project

---

1. Sevens & Fellows, Air Conditioning (New York: Johnwiley and and Sons, INC., 1958), p.256 and p.289.

including installations etc., varies between 2.5 to 5 percent. This includes power cost, maintenance cost.

These statistics reveal that only the cost of running the services through unoptimised system can balance the total cost of a laboratory project within its useful life. It is too serious an aspect to be overlooked.

An engineer or expert on mechanical services can design a system which will be most economical with respect to the building design furnished to him. But this need not be the lowest possible cost forthe project. There could be other building designs which can produce a still efficient system and which has remained unexplored. Thus optimisation is a process of exploration at the initial planning stage and can not be achieved afterwards. Optimisation of services through building design considering the life of the building may lead to higher initial investment in construction. This point should always be remembered

Therefore, the stress on the long range economy depends on the financial policy adopted by the client. Generally research laboratories are established as long term project but sometimes the clients immediate financing capacity may dictate the architect to look for a lower first cost of services at the expense of higher running cost.

Thus it is a matter to be decided between the client and the architect through meetings and discussions. But such a decision can only be arrived at when the architect can furnish the client with various alternative and concrete proposals regarding initial capital investment versus the corresponding annual operating cost of services.[1]

DESIGN CRITERIA FOR INDUSTRIAL LABORATORY PLANNING:

These conclusions have been drawn at after a general survey of Industrial Laboratories, through site visits and review of books.

Whenever possible the industrial research institute prefer to be detached from the mother plant forthe strong reason that their prime activity i.e. research is lost in industrial operation if attached to the mother plant.

Location:

Most ofthe contemporary research institutions prefer to have a calm and quiet location even if it is a few miles away from their mother plant or mother Institutes. Hence a country or suburban location with large stretch of plot and good landscape is their first choice.

---

1. Present day practise in India, of course, takes account of only the capital investment and recurring costs receive little attention.

The increase in the efficiency of research worker in a calm atmosphere is estimated to offset the increased cost of service installation within a shorter period of years (being detached from their mother plant, all installations, mechanical and other, have to be separately installed).

Distance of a few miles, is not a problem if communication links are there, because the order of physical communication need not be more frequent than daily or weekly (hourly communication dictates the buildings to be in close proximity or linked together).

Planning:

Planning of a project vary according to situation. Some of the factors that guide the planning are as follows.

1. Open type modular planning for flexibility: Research work always goes ahead of the time so the space requirement change faster than other projects.
2. Architectural character ofthe surroundings.[1]
3. Central amenities and services and their distribution system.
4. Nature of research work.
5. Cost - to be discussed separately in detail.

---

1. Not applicable in Indian Conditions.

Growth:

Research buildings are very expensive proposition and the limitation of funds often dictate gradual expansion. Therefore two kinds of expansion need to be provided.

a. Expansion in immediate future, the building is often occupied with minimum possible space and then complete gradually the remaining part - proposed in the plan.

b. Expansion in distant future, provision in plan and site for unforseen expansion in future due to change or addition in requirement and addition of new departments.

Horizontal growth satisfies both the growth patterns and hence it is preferred. Vertical growth is only possible in case of large scale expansion in distant future.

Service Distributions:

In relation to the space module the services often follows the same module to achieve flexibility of tapping the mains from any point according to changing situations.

The services are used generally of two types of spaces:

a. Fixed Spaces

b. For flexible spaces.

Some laboratories require special services and need not be changed. They are placed in close proximity of the mechanical system. Provision of space (like under ground trench, service corridor etc.) for frequent rapairs and changes of the service lines, are appreziated even at an initial higher cost, which is compensated within a short period by gains from the unhampered research work.

Horizontal distribution systems prove to be economical for most research buildings which are generally of low height. Most of the spaces in research building (80 percent to 100 percent) are air-conditioned with varying temperatures and humidity.[1] Hence service systems often guide the planning and layout of building blocks.

Modern trend is to provide individual services as far as practicable which add to the flexibility of the internal arrangements, Unit air-conditioner, cylinder gas, unit hood exhaust are frequently used. Striking a balance between the central and individual services is to be a decisive factor. More the variation in requirements from laboratory to laboratory more efficient is the individual service system.

---

1. The statement is of special significance for chemical, biochemical medical and precision-instrument laboratories.

Module:

Module for laboratories and module for general office building vary. The usual module for a laboratory often proves luxurious for offices and leads to a wastage of space. It is observed that wherever space permitted, the laboratory buildings are peparated from the office buildings to satisfy the variation in their modules.

Modules for laboratories vary from 3 to 4.5 meters (between partition) and from 5 to 7 meters (between external and internal walls).

Width of modules for biological and medical research are on the higher side because of the use of wider benches.

Fire Protection:

Most of the Industrial Research Laboratories, except the physical laboratories, deal with inflamable materials and therefore they are prone towards fire hazards. Special care has to be taken in every step of its design including location. Fire regulations often dictate the selection of site, location of the building proper including the set-backs, selection of building materials and finishes etc. Special care has to be taken for protection of lives and property in case of fire such as the safety egresses from the laboratory proper and fire escape exits from the building. The mechanical means for fire extinguisting like sprinkless, showers, unit-extinguishers; fire alarms, aûtomatic starters and fire fighting equipments are the integrated part of the design of the whole project.

Facilities for medical care in case of injury is also a part of space requirements.

Safty egress fromthe laboratory is a guiding factor in determining the position of the fume hood and the size of the module. With different position of fume hoods and safty egress, the dimensional variations in the module and there by the form of the builing has been dealt with in the IV Chapter.

Structure and Mateŕials:

As compared to the cost of services and equipments in research buildings structural cost is of secondary importance if considered in time scale. For the requirements of flexibility, the internal partitions are non-load bearing and hence R.C. frame with direction of beams related to the service system is the usual structure system employed.[1] R.C.C. is also the least vibrant structure which is essential for most physical laboratories.

---

1. Spandrel beams(along the length of the building) or a corss beam (along the width of building), both structure systems are applicble if a vertical service system is adopted. The spandrel beam system is not applicable to horizontal service system run through the corridor, where as this structural system is applicable to horizental service system run through the laboratory. Ceiling and so on....Split-columns are frequently use for vertical service system where as the horizontal service system requires no such special system.

Partitions are often asbestos cement sandwitched panels, hollow blocks or fire resistant plastic panels, glass partitions etc.

Metal partitions, doors, windows are frequently used. Wood products are sparingly used to avoid chemical and fire hazards and to facilitate water borne cleaning.

For biological and medical research the floor and dado finishes are generally of smooth and water repellent type so that they can be cleaned with water and disinfectant. Terrazzo and glazed tiles are the popular finishes.

Cost Criteria:

Apart from social and philanthropic works most of the industrial research projects are intended to yield economic return to the investment. Thus cost is a guiding factor in designing a project. Some of the factors which guide the economics of the research building are as follows:

1. Proper selection of service distribution system:
   (a) Type of services, individual or central system.
   (b) System of services : horizontal, vertical, exposed, trench type or overhead.
2. Selection of a module : by efficient furniture arrangement the space requirement may differ and thus the volume of the building also vary.
3. Circulation: Proper placing of central utilities, such as stores, photographic, X-rays and other rooms, can

reduce the travel time of workers. Time has a relevance in terms of cost.

4. Structure: provision for horizontal expansion with low height blocks cuts down the structural cost to a great extent, because the money blocked in foundations, strong frames etc. for future vertical growth, is released if horizontal growth is adopted.
5. Cooling load and day light factor: Cooling load is increased due to improper orientation. Illumination load is increased due to low day light factor.

The study reveals that many buildings have added to the cooling load due to improper orientation. Narrow space modules 9' x 24' are often poor in day light factor if partitions are put between them and hence supplementary lighting is require" which add to the recurring consumption of electricity in terms of light and increased cooling load (lights add to heat).

Mechanical Services within Laboratories:

The mechanical services within laboratories may be classified into three catagories as follows:

1. Services related to piped supplies and discharge system.
2. Services related to the controll of climate within the laboratories and ancilliary buildings.

3. Services related to illumination and power supply.

The areas of these services which are related to the planning of the building or can effect each other, have been discussed in the following pages

SERVICES RELATED TO PIPED SUPPLY:

The services related to piped supply have broadly two seperate items as discussed previously.

a) The fixed elements i.e. the supply lines, valves, faucets, pumps etc. which incur a first cost of installation.

b) The recurring element i.e. the mechanical power which enables the materials to be supplied to the user from a central source. This involves the second cost i.e. the recurring cost and it is not a negligible amount to be over looked. Maintenance cost for repairs and controll the operation of machineries is also a recurring cost.

Both these items are inseperable from each other as well as the planning of the building. 'The following are the piped supplies commonly required for an Industrial Laboratory.[1]

---

1. These informations have been reproduced from Coliman, H.S. Laboratory Design, New York: Reinhold Publishing Corporation, 1962, pp 68-72.

Gas for Heating:

Faucet pressure	- 6 inch of water ('25 p.s.i.) (minimum 3 inch)
Faucet discharge	- 14.5 cu.ft. per hour (minimum 8 cu.ft. per hour)
Riser gain	- 0.6 inch per 100 ft. ht.
Contrigugal fan pressure	- 12 inch of water ('5 p.s.i.)
Use factor	- 60 p.c. (or '6)
Material	- Black steel pipes

Compressed Air: (Low Pressure)

Faucet pressure		- 5 p.s.i. to 10 p.s.i.
Faucent discharge		- 1.5 C.Ft. to 3 C.Ft.
Pump pressure		- 15 to 30 p.s.i.
Use factor	Branch	- '66
	Labs	- '3
Material		- G.I. pipe

Steam:

Faucet pressure	- 30 p.s.i. (15 p.s.i. minimum)
Discharge	- 2 to 4 Cft (Dry)
Use factor	- '3
Material	- G.I. pipe (3/4 inch Asbestos wool insulated)

Hot Water:

Faucet pressure	- 3 p.s.i.
Faucet discharge	- 2 gal. per. min.

Pump pressure	- 15 to 25 p.s.i. (For 4 p.c. head loss)
Use factor Branch	- '50
Material	- G.I. pipe (1/4 inch insulation)

Cold Water:

Faucet pressure		- 3 p.s.i.
Faucet discharge		- 2 gal. per min.
Pump pressure		- 15 to 25 p.s.i.
Use factor	Branch	- '8
	Main	- '6
Material		- G.I. pipe

Chilled Water:

Fauoent pressure	- 3 p.s.i.
Faucet discharge	- 2 gal per min.
Pump pressure	- 15 to 25 p.s.i.
Use factor	- '6
Material	- G.I. pipe

Demineralised Water:

Faucet pressure		- 2 p.s.i.
Faucet discharge		- 1 gal per min.
Pump pressure		- 10 to 20 p.s.i.
Use factor	Branch	- '4
	Main	- '3
Material		- Aluminium or Alkethene pipe

AIR-CONDITIONING OF LABORATORIES:

Air-Conditioning of laboratories is an essential part involving annual expenditure and it is dictated by ventillation requirements of the laboratory rather than cooling requirements.

The two purposes of air-conditioning are primarily the ventilation i.e. the need to eliminate or at least dilute the chemical and/or bio-chemical contaminants and secondly to eliminate the heat gains from mechanical equipments, solar effects, artificial lighting and human sources.

Number of air changes that occur in laboratories range as high as 10 per hour. This leads to substantial wastage of treated air. Hence it is desirable to reduce the cooling load to the possible minimum to achieve economy in annual cooling cost.

Heat gains from mechanical equipments and other research activities are constant whereas the heat gains from solar orientation of the building and permanent artificial supplementary lighting are variable and proper design can reduce them to a great extent.

This also needs optimisation for air ducts to impose minimum overall frictional head on the fans and thereby reducing its horsepower, as well as the optimisation for the minimum annual cooling cost combined with the corresponding building construction cost and it can be done by various grouping of laboratory units, office spaces, number of floors and study their impact on cooling load and wastage of supplementary lighting.

SERVICES RELATED TO ILLUMINATION:

Illumination may be natural or artificial.

The window is the source of natural light for working within the laboratory and office. It also provides rest to the eye which gets strained by continuously looking at things within close range and needs a distant view to relax its muscles and nerves. In certain experiments like microscopic and colour tests, natural light is indispensible. The laboratories which have deep bays or an office unit in the front often needs permanent artificial supplementary lighting which consumes power in the following manner. To raise the level of illumination by 20 foot candle in an average 2 man laboratory, approximately 3 wt per sq.ft. power is consumed which means an increase by 10 p.c. of the annual lighting bill.[1]

Togather with the lighting bill it increases the cooling load at the rate of 3413 B.T.U. or about a quarter

1. Excerpt from Hunt William D.Ed. Creative Controll of Building Costs, New York, McGraw Hill, 1967, p.48.

ton. Thus if the whole laboratory building is considered, the increase in the annual cooling load is quite a high percentage. In colder countries therefore the modern concept of heating is based on artificial illumination.[1]

While planning the building it should also be remembered that the natural light is also a source of heat in the form of solar radiation received through the external wall as well as the openings in it specially if it is a western or southern wall.

Therefore, illumination and thermal gain are related and a compromise is to be made or a balance is to be struck to find out the total annual cost of lighting and cooling togather. This study will reveal whether a system with complete natural light or a partially supplementary lighting or a completely artificial lighting system is the most economical one and the planning be done in the like manner.

Apart from the lighting system, another important factor is the quality of light which will decide the type of source i.e. incandescent or fluorescent and whether direct, semi-direct, semi-indirect or indirect source etc. Heat generated is highly influenced by this factor.

The amount of 'PASL'[2] is minimum where all rooms are

---

1. Ibid, p.46
2. Permanent Artificial Supplementary lighting 'PASL' is the lighting which is required to offset the shortage in the level of illumination from the natural source. Thus it is different from the lighting in the night.

facing an external wall and is maximum where the rooms are in the interior with an enclosed corridors on the outer periphery. Hence optimization with respect to illumination is essential.

SUMMARY

Efficiency of a building plan does not only depend on the efficient use of space. Other factors such as the first cost of construction, first cost of services, the running cost of the services and the maintenance cost of the project during thelife of the building etc. are equally important.

Modular planning is a system where mathematics can enter into the domain of the art of building. The product of the two is a rational architecture, a true synthesis of form and function.

CHAPTER II

FORM AND SERVICES

INTRODUCTION

In the previous chapter the need for rationalisation at the priliminary planning stage has been stressed. The services, being one of the major components and the topic of the dissertation, has been brought forth and discussed at length.

This chapter deals with the identification of the major components of the preliminary plan which have their role in the process of rationalisation. It also deals with the collection of informations related to these components which will form the parameters for the optimisation programme of the services later.

COMPONENTS OF FORM IN THE CONTEXT OF SERVICES:

The form is the outcome of proper synthesis of numerous variable and constant elements.

The variables are those elements, the value of which can be changed without changing the physical requirements, where as the constants are those fixed elements that constitute the basic - physical - requirements.

In the case of laboratory planning the constants are the basic requirements of the client such as the number of persons who will be working, the length and width of working surface of the bench per person - hence the number of modules, and the services required.

In the same module the independent variables may be the height, length and width ofthe laboratory proper, the height, length and width of office space, the location of the both with respect to each other i.e. the offices space within lab., office space adjacent to lab., office space in opposite lay or office spaces and labs. grouped seperately. The dependent variably are the lengths of diameters of the circuitry systems, cooling and lighting loads etc.

The number of floors can be another major variable. It may be decided at the first instance whether the building will be a high rise one or a low rise one. If the building is to be a low rise one i.e. upto 3 or 4 storey high then much of the complecacy is reduced. But if more flexibility about height is provided then special consideration of vertical circulation system (persons as well as piped supplies) come into picture. Another important variable is the service system of the piped supplies and or duct supply. There are various service supply systems i.e. horizontal through corridor or labs., vertical through corridor or outer wall, labs., grouped around one or a few service ducts, originating from the roof or from the basement and so on.

If a detailed study is done, it will prove that under certain fixed boundary conditions only one service system is most efficient with respect to the building plan it serves or in other words : under certain environmental restraints a service system can dictate a layout plan for optimum efficiency.

The word 'optimum efficiency' is used to denote the synthesis of various factors that influence efficiency of such as,

Cost Factors:

- Minimum initial cost of the project.
- Minimum running cost of the installations or the services.
- Minimum maintenance cost
- High work efficiency.

COST VARIABLES:

Capital Costs:

The minimum Ist cost of the project does not mean any sacrifice of the quantitative or qualitative aspect of the specification and requirements. It only means the minimum possible ist cost obtainable through proper planning and programming.

A project can be broken down into various items, such as:

i) Location	: Cost of the land
	: Cost of communication.
	: Cost of development (including utilities)
ii) Building work	: Cost of the skeleton
	: Cost of finishes
iii) Services	: Cost of plumbing and duct work and electrification.
	: Cost of equipments to run the piped supplies.

The minimum ist cost will mean the total minimum cost of all the sub-items mentioned above. It may be mentioned here that the minimum cost of any one of the sub-items may not necessarily prove to be the minimum for the others. Therefore, a balance has to be struck where the total ist cost is minimum. Thus the minimum Ist cost will include the sum of Ist cost of sub-items, location, building work and services.

Operating Costs:

The central services supplied to individual benches under certain pressure incurs constant expenditure in terms of mechanical and electrical power to over come the frictional losses, velocity losses and head losses in the pipe and duct circuitry. Lower the loss and more the building is related to the service system, the lower will be the running cost.

The operating cost can be controlled by various means involving the basic three components i.e. the materials used in piping and duct work, the disposition of the circuitry and the form and orientation of the building.

Rationalisation of the costs of plumbing materials and supply mechanism:

The following items are related to the capital cost of the plumbing materials.

- Superior quality of piping and duct materials with low frictional co-efficient (The G.I. pipes have more frictional coefficient than the Alluminium pipes or copper pipes).
- Larger diameter of pipes and ducts than the minimum necessary ones. This also helps in reducing the total frictional loss.

- Sophisticated mechanical devices which have lower power consumption, proove to be cheaper in long run.

The cost of these items have to be rationalised because a point of contraflecture may occur where an additional expenditure on pumbing may not prove to be effective in terms of the return from the saving in the operating cost (refer graph for annual running cost, P. 112).

Rationalisation of Circuitry:

The following items are related to the layout of the circuitry which is dependent on the form of the building. If the building plan is of a spread out or exploded type, there will be longer pipe lines incurring more frictional loss where as if the building is compact and multistoryed, the pipe lines will be shorter but will incur more head loss due to height.

Hence there is again a need to determine the optimum length, height and spread of the building into which a well integrated supply line will have minimum turns and bends and an optimum relation between its horizontal and vertical runs so that the total pressure loss in pipes can be minimised to the possible extent.

ORIENTATION:

Solar Orientation and Cooling Load:

The spaces can be arranged in various ways with respect to sun so that the building absorbs different amount of solar radiation and thereby produce different cooling loads. This phenomenon is comparable to the heat gain of a hollow box kept in the sun in various orientations. The inside air temperatures will be different for different orientations. Larger surface areas of a building facing the north and south and minimum possible surface areas towards the west and east prooves to gain minimum heat from solar radiations. The effect of roof area has been discussed later.

Illumination and Orientation:

The arrangements of the laboratory units andtheir respective office units effect day-light-factor. The natural light in Indian conditions is dependable to a great extent except in the rainy season. The glareless and defused indirect natural light is better than any artificial light. Though, the natural light often needs to be supplemented by permanent artificial supplementary lighting (PASL) for deeper bays but its amount is effected by the admittance of the natural light.

Some laboratories may even work wôll without natural light, perticularly in circumstances where there is a special need for high degree of concentration involving precision work. However keeping in mind that artificial lighting tends to add to the cooling load substantially, as Mr. William Hunt States, 'Large multistorey buildings with high lighting levels require cooling of the interior areas, even at lowest outdoor temperature...'[1]

The total wattage of 'PASL' may be determined for different floor plans by the number of foot candles supplemented and the areas under the influence of 'PASL'.

Here are two examples to reinforce the statements that floor plan and building blocking for the same orientation effect the cooling load and lighting load. However these plans are inefficient in other respects and havebeen mentioned here only as two extreme examples.

A three storey building where the offices and the laboratories are placed opposite each other along the central consider (referscheme 2, P.48) will have the following impacts on lighting and cooling loads.

- Minimum artificial lighting load
- Minimum heat gain from artificial lighting
- Minimum solar heat gain

---

1. Hunt William D. (Ed). Creative Controll of Building Costs New York: McGraw Hill, 1967 p.46. He has further ennumerated interms of initial and annual cost of lighting and cooling for a certain increase in lighting level (refer index for details).

Whereas another building, a single storey development with laboratories grouped around a few vertical service shafts, the offices in single row along each corridor (refer scheme 4-A, P.48) will have the following impacts on the lighting and cooling loads.

- Maximum artificial lighting load
- Maximum heat gain from artificial lighting
- Maximum solar heat gain

These two extreme phenomenon occur because in the previous scheme every room is naturally lighted and has the minimum roof area which is the recipient of maximum solar radiation, where as in the later scheme the laboratories do not get natural light, the east-west exposure is also of high degree as well as the maximum area of the roof as the building is only single storeyed. The highest loads of lighting and cooling may come out to be many times more than the lowest loads (as it will be seen later in the IV chapter).

In between these two extremes there can be tens or even hundreds of alternative schemes which may produce different lighting and cooling loads, and it is unpredictable, which one of the schemes will proove to be most effective in terms of minimum overall running cost.

Maintenance Cost:

Equipments- Maintenance cost of equipments is inversely proportional to the first cost of the equipments i.e. higher is the cost of equipments, more is the sophistication and hence lower is the maintenance cost.

Service lines- the maintenance cost of the service lines depends on their location. The faulty and leaking lines are difficult to locate and create a constant sources of trouble, specially if the service lines are hidden. Where as, if they are exposed, they require careful arrangement and proper location otherwise they may be hazard prone and unaesthetic in appearance. Such systems need frequent attendance. Approachability of the service lines also leads to variations in maintenance cost.

WORK EFFICIENCY

Working efficiency within an Industrial laboratory depends on various factors. Environment imparts its effect on human efficiency. It is a seperate subject by itself. A peaceful and spacious environment sustains the spirit of the research workers, but it has its limitations as well. Too much luxurious environment may follow the law of diminishing return. Despite its abstract aspects, working efficiency depends on physical planning which are of more interest to this topic.

An industrial research personnel spends a considerable amount of his time in putting down his records and writting papers related to his experiments. The experiments being conducted may continue while he is writing and is often taken care of by his assistant.

Under these circumstances his personal office need not be attached to his working space. It can be placed a bit away from his working lab. without hampering his efficiency.

Efficiency is greatly effected by the disruption of services. The system where the service lines serve the floor above often create trouble. While repairing the service lines of the floor or lab. above the work of the floor below is also hampered.

The following check list enumerates the various factors which influence the working efficiency in a lab.

Disruption of Services:

a) Number of average disruption of services per annum

b) Number of laboratories effected by each disruption.

c) Average period of disruption.

d) Total salary per annum ofthe research personels and assistants of the laboratories effected.

Movement factors:

a) Inter-laboratories-circulation in terms of
i) frequency ii) time taken iii) status of persons.

b) Intra-laboratory-circulation: movements of research workers within the laboratory unit, from bench to bench, bench to office etc.

Environmental Factors:

a) Noise level

b) Illumination level

c) Temperature, humidity and ventilation controll.

d) Visual comfort

i) Natural light ii) Natural view iii) Type of views.

(For the relaxation of eyes and mind)

e) Disposition of spaces, colour texture etc.

f) Furniture and Furnishings

Human Factors:

a) Individuals freedom of working

b) Extent of Red-Tape

c) Common and individual facilities.

d) Inter-action and co-relation of different departments and members.

e) Safty of research workers and future gauranttees

f) Just degree of comfort.

g) Temperament of superiors.

h) Working service condition

i) Technical knowledge of the H.O.D. and open mindedness.

INFORMATIONS REQUIRED FOR CORRELATING FORM AND SERVICES:

For correlating form and services in laboratories, it is essential to put equalattention in collecting informations regarding its services and the space requirements. But in usual practice, the architect gives more stress in collecting informations related to space requirements and with a rudimentary knowledge of services he starts his priliminary sketches. The plans, which are of course highly efficient interms of use efficiency of spaces, are given to mechanical, electrical and plumbing engineers for the design of services. Thus a rational design is superimposed on an intuitive design where by a proper synthesis of the two is seldom achieved.

Therefore, if optimisation is aimed at, the detailed informations regarding services are to be collected through a suitable method.

Such informations are supplied by the client or it is collected from the research workers and technical personnel who will actually use the services.

The best method of course, is to prepare a questionnaire, supply it to every member related to the laboratory for reply, collect the questionnaire, scrutinise and screen and then prepare a list of useful informations out of the varying reports available from the questionnaires.

Check List and Questionnaire for Mechanical Components:

The questionnaire should have short and crisp sentences to invite very short replies from the scientists, technical experts and other assistants who handle these services, so that the answers do not consume much of their valuable time and patience.

All the informations may not be expected either from the scientists or the technical personnel. The informations like the pressure of different piped supplies may not be available from the scientist. The technical personnel, or the maintenance Engineer can be useful in this respect. So a close co-operation of all personnel involved in using and handling the services will be required. The partial informations gathered from different persons, will then be compiled, sifted, and processed to bring out the salient and useful information.

The questionnaire for services given in the Appendix has been considered appropriate for collecting informations related to the services under consideration of this dissertation. It has been developed by the author with an eye towards the input data for the computer-programme. Hence only these items have been included in the questionnaire which constitute the impirical formulae used in computer programming.

The actual pressures and discharges of the piped supplied can be easily quantified if the use intensity and the pressure at the faucets are known. Similarly the quality of materials for discharge of waste materials can also be determined if we know the degree of corrossivity, contaminants, and use intensity. The type of size of a hood and the number of hoods are essential to quantify the ventillation requirements where as the heat generated from the running of machines and the type of lamps used for lighting will help in quantifying additional cooling load, keeping in mind these factors the questionnaire has been prepared and tested for its workability[1] and has been modified accordingly. A sample of such a proforma has been given in the appendix for reference.

A detailed questionnaire form may be used for comprehensive study covering other aspects of the laboratory as well. A sample of such a questionnaire has been given in the appendix for further reference.

However, the collection of informations through questionnairs and proforma is only possible for the large establishments or the agencies specialised in the survey work of much nature as they have the resoources to conduct such surveys.

---

1. The workability of the questionnaire has been tested while the author had a chance to exchange his ideas with a few technical personnel and scientists working in the Indian Institute of Experimental Medicines, the premises of which is in close prosinity of the Jadavpur University campus, where the author had stationed himself during an investigation tour related to this dissertation.

The author, within his limited time and resources, found it more convenient to collect the informations and data from the published sources. More over the data, so collected, were sufficient for the hypothetical example cited in the last chapter.

Check List for Rationalising Cost:

Cost components are of great importance and need proper investigations otherwise the whole effort of optimisation related to cost will be futile.

Plumbing cost in the present method of estimation has been devided into two parts:

- The cost of materials
- The cost of labour and erection

The cost of materials include:

- The effective length of pipes and ducts.
- The diameter of the pipes and ducts.
- The length of pipe in wastage (5 percent of effective length).
- The bends, elbo, tee, sockets, connecters etc.
- The valves, bib-cock, faucets, meters etc.
- The insulation and sealing materials etc.

The cost of labour and erection include:

- Tracport cost
- Technical Expertise and supervision

- The wage of the plumber and his helper per day.
- The fabrication time of various joints - say for a 'tee' joint or a 'bend' or a 'socket' (Here fabrication time for a single joint in straight line is called as 'one unit'. Hence a 'tee' connectio is called as 'two units'....)
- The diameter of the pipes and ducts.
- The number of joints per hundred feet length.
- Erection time (depends on the complexity of the job)
- Leakage testing.
- Cleaning and painting and insulating (if any).

Hence the total cost of plumbing installation increases with the number and type of joints within a certain length of the line.

In a modular system where a plumbing system is repeated throughout the building, the cost of materials togather with its fabrication erection cost can be computed per running foot for a certain diameter of the pipe and this can be used as a unit of estimate. For other diameters the cost will vary in direct proportion of the diameter used in the unit cost. The following cost study is revealing in this aspect.

Graphically, costs of materials with respect to its diameter follow a parabolic path with the vertical axis, where as the cost of fabrication and erection follows a parabolic path with the horizontal axis. Combining the two cost components the resultant is a straight line where the increase in the total cost is directly proportional to the increase in the diameter rather than the cross sectional area.

For normal discharge, the minimum diameter of pipes is found to be 1/2 inch and that of the ducts for air supply at the grill and discharge ducts in the foom are found to be 8 inches. The cost per foot of these two materials together with their respective erection cost are found out. These costs are considered as unit costs of pipes and ducts.

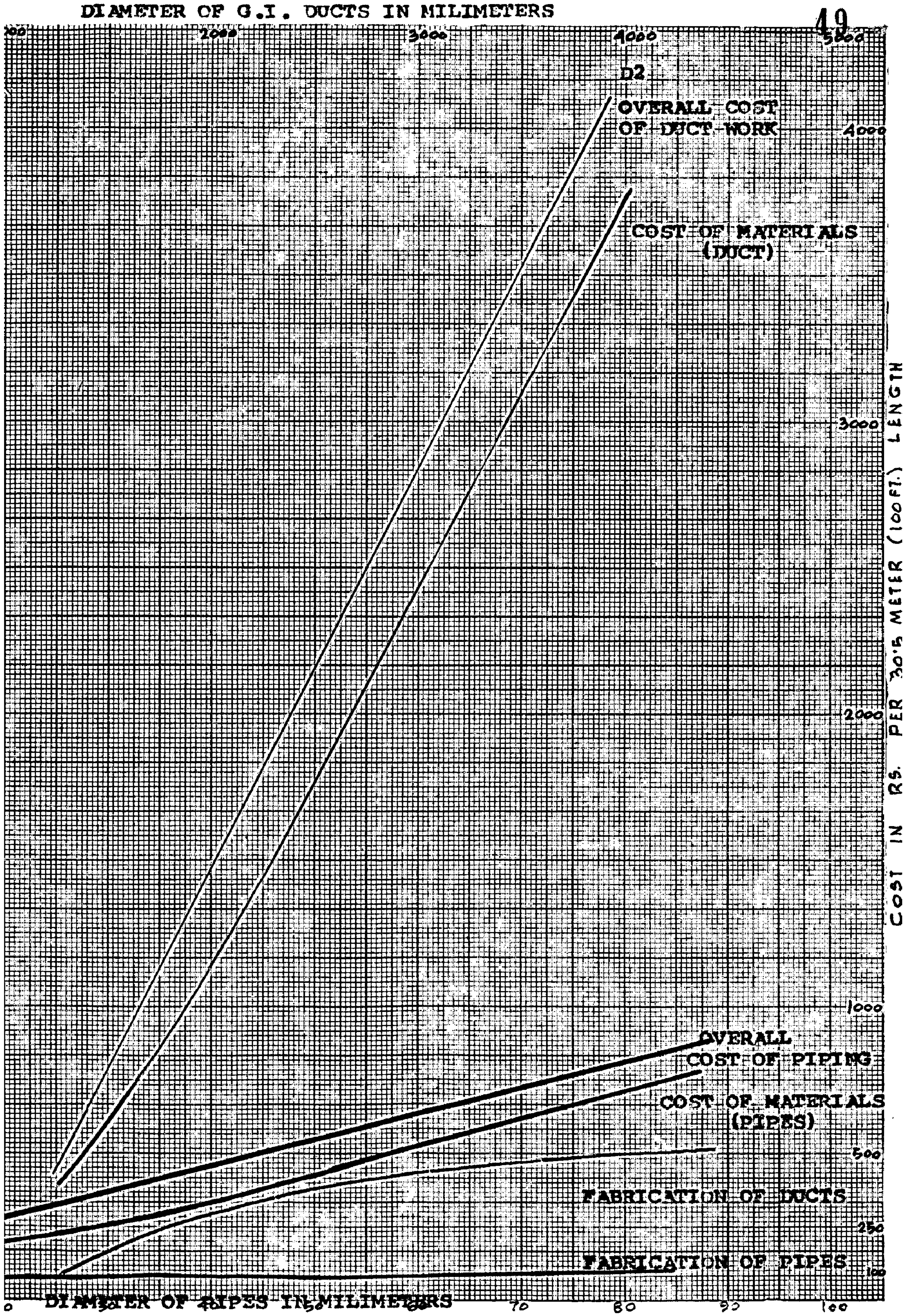
Power cost is related to the running cost. The emphasis on Ist cost or the running cost will vary with the availability and cost of power.

Thus lower is the power cost, more it can be consumed within the stipulated budget and the Ist cost can be further lowered down so that the ultimate cost during the life of the building or the machinery comes down to minimum.

Import of Working Hours:

Running cost of the services depends on how many days per annum the services are run. For different group of services the running days are different.

The plumbing services run for the working days, the ventilation system also runs for the working days. The cooling mechanism runs for the uncomfortable summer season


DIAMETER OF G.I. DUCTS IN MILIMETERS
2000
3000
4000
5000
D2
OVERALL COST OF DUCT WORK
COST OF MATERIALS (DUCT)
4000
3000
2000
1000
500
250
100
COST IN RS. PER 30.5 METER (100 FT.) LENGTH
OVERALL COST OF PIPING
COST OF MATERIALS (PIPES)
FABRICATION OF DUCTS
FABRICATION OF PIPES
DIAMETER OF PIPES IN MILIMETERS
0
70
80
100

called as 'cooling days', the heating mechanism runs for the peak winter months called as 'Heating days' and the power consumption in illuminating during the day is maximum in the rainy season or in case of certain planning, for the whole working days.

Therefore the working days which are annual and the 'cooling' or heating days are seasonal have to be considered seperately. The annuals are the constants where as the seasonals are the variables (from the consideration of varying climatic conditions prevailing all over the country).

Knowing the calander of working, the working hours per week, the number of working days and the unscheduled working hours if any, the total annual running hours for different services can be calculated.

Laboratory Module:

Laboratory module is an outcome of working conditions within a laboratory. These conditions are:

a. Number and status of workers.

b. Continuous length and width of bench surface required for different persons (length of bench required for a scientist is more than his assistant).

c. Position of the scientist's office (the office unit on the external wall needs more depth of the module as the external wall can not be used for placing the cupboards).

d. Safty egress - The position of the safty egress changes the module. The safty hatch system or the common entry and egress require the minimum size of module.

e. Position ofthe hoods - Safty egress beside the hood is unsafe as the hood is the root cause of hazards.

f. Number of floors - A single story building requires least safty egress space and hence lower area of module.

g. Type of partition between modules - A partition above the top of the bench upto the ceiling requires the smallest size of module and has a high repeatitive value.

h. Space of equipments.

i. Space for future expansion

j. The service system.

Serwice Systems:

1. Horizontal through ceiling of corridor serving each bench by puncturing the partition walls on both sides) (Refer Sketch No.1, pp 55-56, p.58).

   a) Dropping to the benches in the same floor.

   b) Rising up through floor to serve the benches in the upper floor.

2. Horizontal through ceiling of the laboratories (Refer sketch No.2, pp 55-56 p.58)

   a) Dropping to the benches in the same floor.

b) Rising through the floor to serve the benches above.

3. Horizontal below the seal of the external windows

a) Serving the benches through floor trench

b) Serving the benches through service strips.

4. Vertical through the partition wall between the laboratories and the corridor (Refer Sketch No.3, p.55 and p.59).

a) One vertical shaft for each bench

b) One vertical shaft for a few benches

5. Vertical through the external wall in the manner similar to -4.

6. Vertical through a few large shafts around which a group of modules consisting of 12 to 16 benches may be arranged. (Refer Sketch No.4, p.55, p.59).

7+ Service corridors sandwitched between two rows of labs. are designed to accomodate services and working space for repairs and maintenance.

8+ Service tunnel under the labs. (generally one floor only) where an underground tunnel accomodates the services as well as a trolly bus for repairs.

\+ These systems are very efficient in maintenance point of view but incur a high initial cost. Advocacy of such systems are justifiable only in countries where annual maintenance cost is very high due to high wage structure of the personnel and labour, thereby a high initial cost is offset very soon by the recurring low maintenance cost.

It is imperative that any of the above mentioned service system has to be integrated with the building planning and a system most rational has to be selected after due consideration of its suitability - physically, economically and aesthetically.

Considering the above factors it is evident that the arrangement of furniture will dictate the size of the module, in consonance with the requirements of service systems.

The common arrangements are:

A. Office on the external wall:

i) One-man lab-one side service benches, another side non-service benches with a central aisle.

ii) Two-man lab. - The same as above with service benches on both sides.

iii) Three-man lab.-Additional island bench with double aisle and two wall benches.

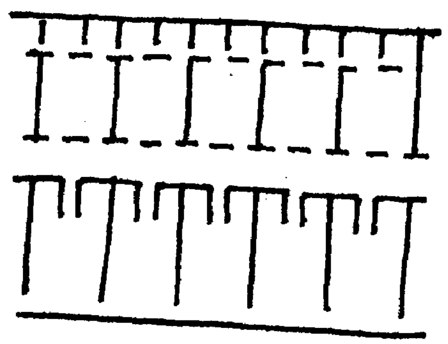
iv) Four-man lab. - Two island benches with double aisle and two wall benches.

In the same manner six or eight men lab can be made by repeating the same module.

B. Office on the sides ofthe same bay: 'U' shape of bench arrangement is possible with safety egress leading to office units. Thus space is saved by utilising the external wall as well.

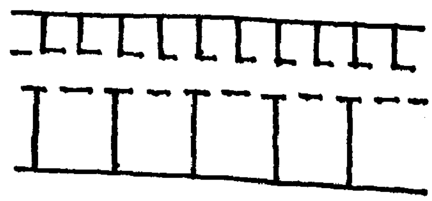
Various arrangements as in 'A' can be done within

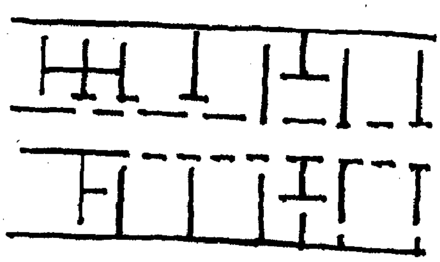
TYPICAL SPACE RELATIONSHIP IN LABORATORIES
(OFFICE AND LABS.)



OFFICE IN THE SAME BAY AS THE LABORATORIES
NO DIRECT ACCESS TO OFFICES
LABS. DEPENDENT ON 'PASL'
SAFTY ESCAPE FROM OFFICE .

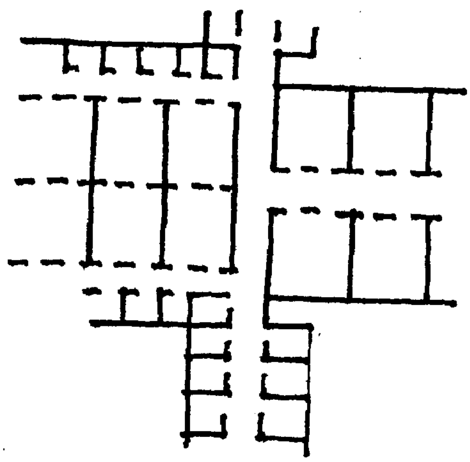
OFFICES AND LABS. IN SEPERATE ROWS ALONG THE CORRIDOR
DIRECT ACCESS TO BOTH. LABS. AND OFFICE GET NATURAL LT.
SAFTY ESCAPE FROM LABORATORIES





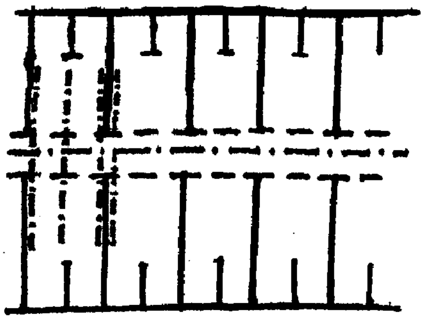
OFFICE ADJACENT TO THE LAB IN THE SAME ROW. A GROUP OF 2 OR 4 OFFICE UNITS.
DIRECT ACCESS TO BOTH
NATURAL LIGHT TO BOTH
SAFTY ESCAPE FROM OFFICE

OFFICES AND LABORATORIES IN DIFFERENT BLOCKS LINKED BY CORRIDORS.
INDEPENDENT ACCESS TO ALL LABS. AND OFFICES. LABS. IN SYSTEM - A, DEPENDENT ON 'PASL'. SAFTY ESCAPE FROM LABS.



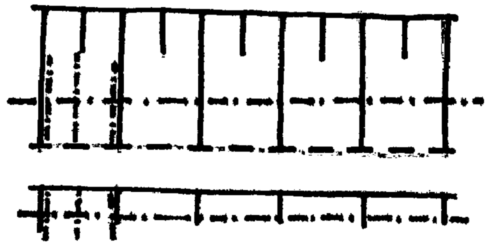
ABBREVIATION: P.A.S.L. (Permanent Artificial Supplementary Lighting)

TYPICAL SERVICE DISTRIBUTION SYSTEMS



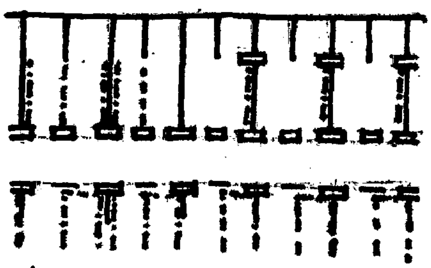
BRANCHES RUN HORIZONTALLY THROUGH THE CORRIDOR CEILING SERVE THE MODULES ON BOTH SIDES OF IT. MAY UP FEED OR DOWN FEED THE BENCHES SERVES ALL LABS. IN ONE FLOOR

BRANCHES RUN HORIZONTALLY THROUGH THE CEILING OF THE LABORATORIES. MAY UP FEED OR DOWN FEED THE BENCHES SERVES ALL LAB.IN ONE FLOOR



(A)

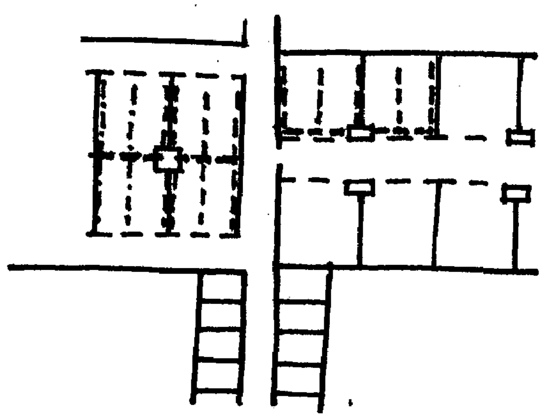
(B)

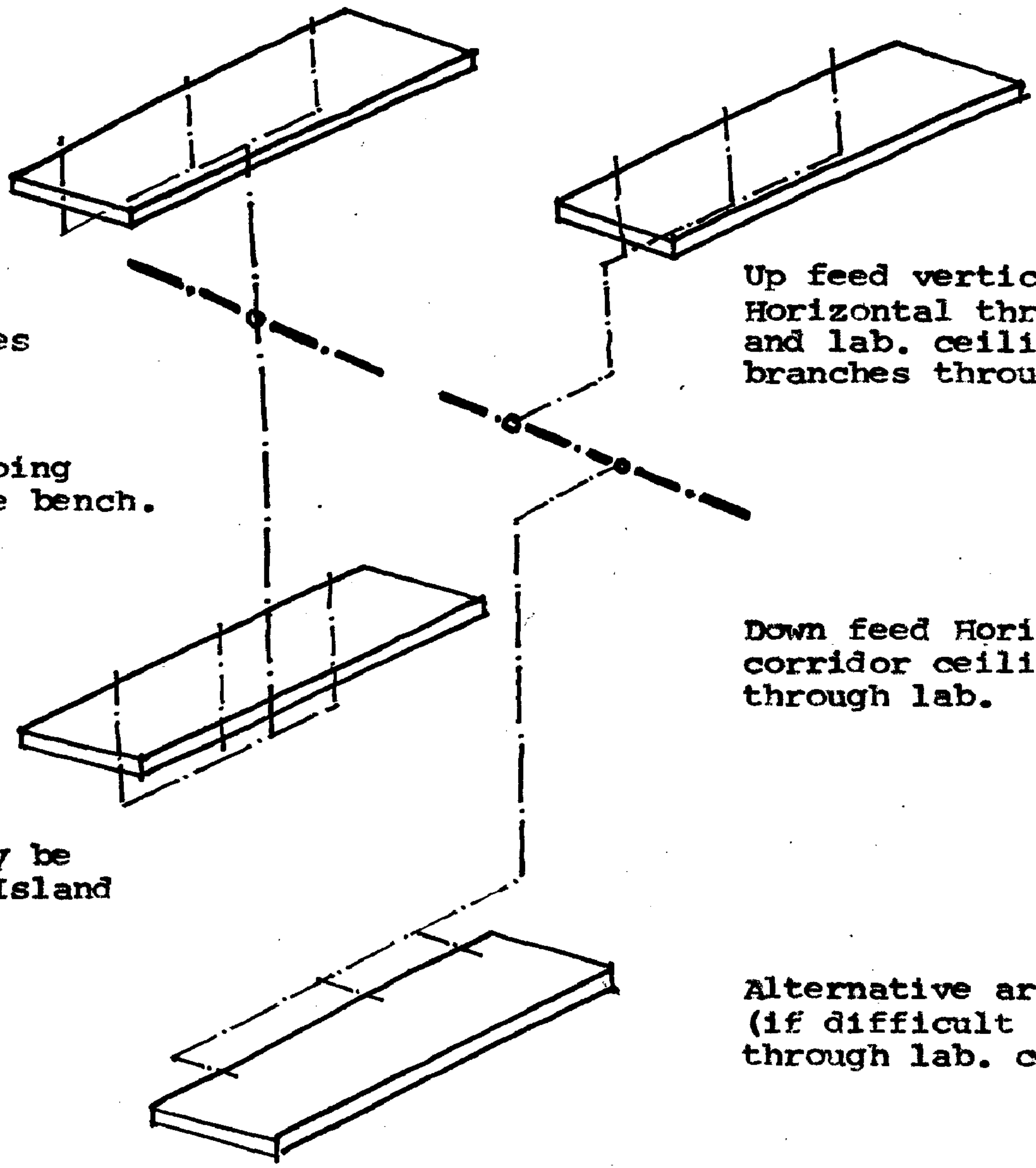


BRANCHES RUN VERTICALLY THROUGH SHAFTS SERVING THE MODULES FOR ALL THE FLOORS ON ONE SIDE ONLY.

SHAFTS MAY BE INTERNAL OR EXTERNAL

BRANCHES RUN VERTICALLY THROUGH A FEW LARGE SHAFTS PLACED CONVINIENTLY AMIDST A GROUP OF LABORATORIES MAY SERVE 2 TO 4 LABS. WITH 3 OR 4 BENCHES EACH.





ng

ches

opping
the bench.

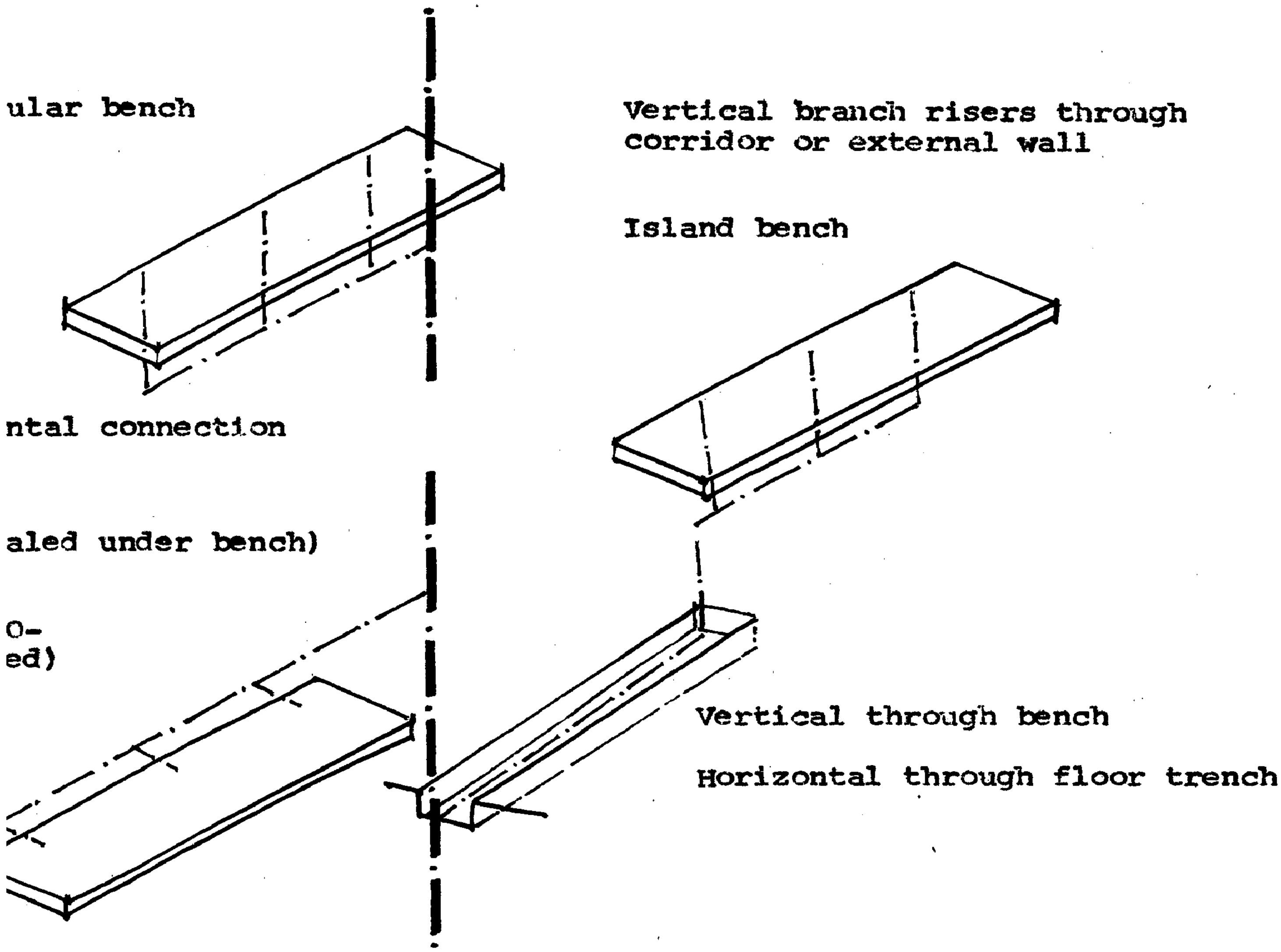
may be
r Island

Up feed vertical within Lab. Horizontal through corridor and lab. ceiling. Service branches through corridor.

Down feed Horizontal through corridor ceiling. Vertical through lab.

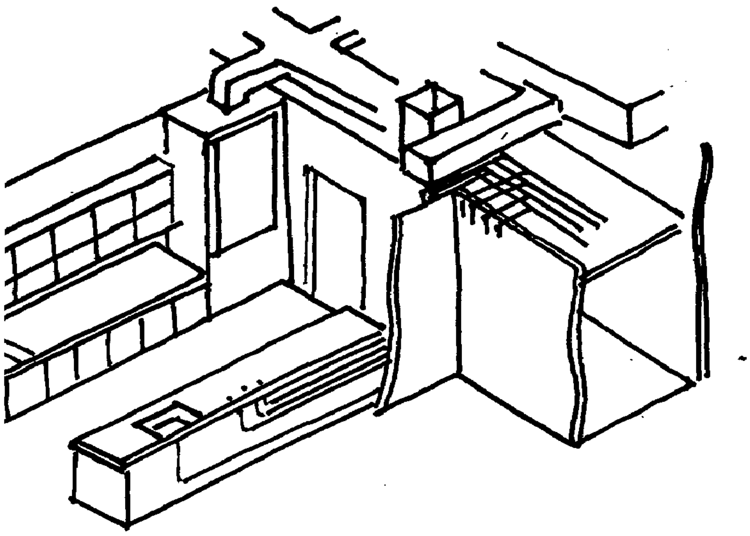
Alternative arrangement (if difficult to continue through lab. ceiling)

Bench connection from the Horizontal distribution system:

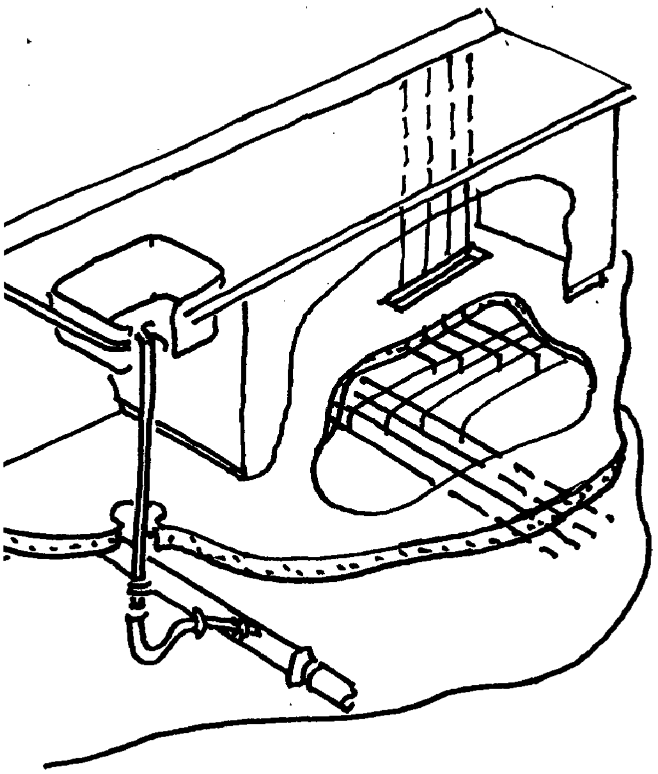


Bench connection from the vertical distribution system:

HORIZONTAL SERVICE SYSTEM

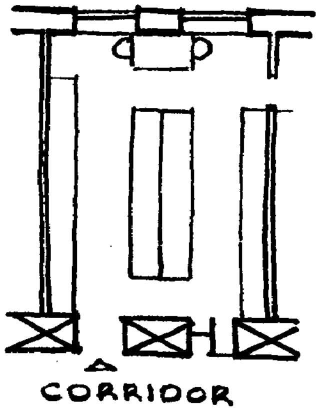


Horizontal service headers run through the Central corridor and serve the benches on both sides
Source: Diamond Alkalico. Research Centre, (OHIO).

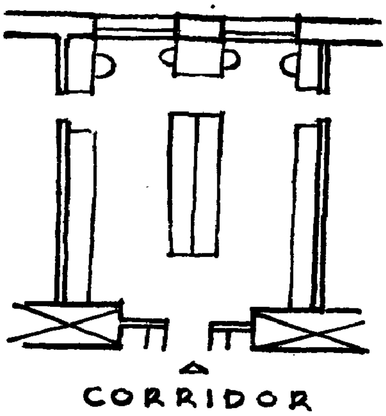


Headers through floors below the benches. Seperate rows of headers for seperate rows of benches
Source: California Research Corporation, (Richmond-Calif.)

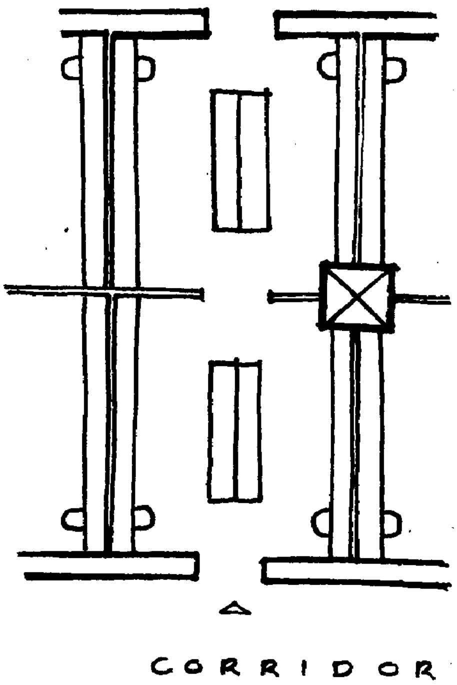
VERTICAL SERVICE SYSTEMS



One shaft for each pairs of benches
Source: Esso Research Centre, (Linden, N.I.)



One shaft for every four benches. Island bench is served through floor trench
Source: DU-Pont Exp.Stn. (Wilmington)



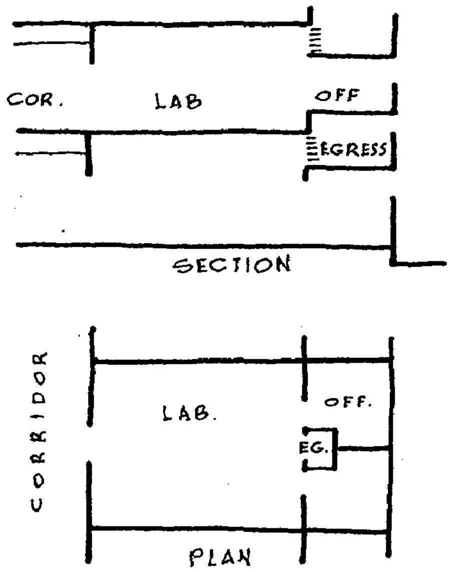
One shaft serves a large number of benches
Thus there are only a few shafts in the whole laboratory building.
Source: Defence Research Centre, (California)

Alternative Arrangement of Safty egress:

The usual arrangement of safty egress is from the adjacent laboratory or the adjacent office. The lacuna of such a system is that one has to depend on the personnel of the adjacent laboratory so that the emergency door opening to other rooms are not bolted or blocked by cabinets or furniture. There is also a chance of misusing the emergency exit. As such, the alternate proposals of safty egresses are given below:

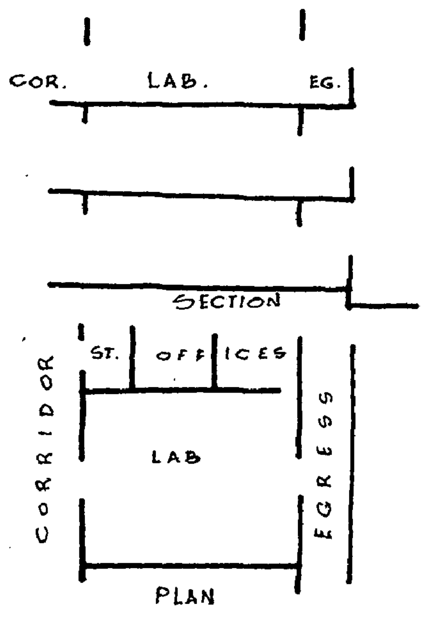
ce cabins on the external wall in same bay:

The office cabins may be ided with 8'-0 inch ht. whereas laboratories with 13'-0 inch ht. his way a corridor can be formed een the office cabins of two rs to be used as an emergency .



ce Cabins in the adjacent bay:

In this case the outer wall ree of any obstruction and the gency exit can be provided ugh a corridor on the external wall.



the form of 'U' shape.

C. Safty egress to outside through the external wall: (single floor) 'L' shape arrangements can be done in such cases.

The sketches of existing laboratories are in support of the various systems mentioned above.

SUMMARY

For rationalising the 'Form' with respect to the services a detailed investigation of various components has to be done and then identify the major components which effect the form and the services. A detailed informations related to these components have to be collected then.

The author feels that the best method to collect these informations is through questionnaires as has been given in the appendix. However for the limitations of time and resources such informations for this dissertation have been collected from published sources.

The informations on components may be classified into independent variables, dependent-variables or constants but all have their ultimate relevence in terms of capital-costs or annual costs of services.

CHAPTER III

QUANTITATIVE DETERMINATION OF INFORMATIONS PERTINENT TO FORM AND SERVICES

INTRODUCTION

After the parameters which effect the form and services have been decided upon, it is essential to quantify them through established empirical formulae, so that they can be translated into a list of data in digital-form to be applied later in computer Programming. Translation of the parameters into a list of alphameric and numeric modes is indespensible because they are the medias through which a man-machine relation is stablished. Alphamerics and numerics are the transition modes of languages which a man and a digital electromic computer both can translate into their own languages respectively.

The following pages, therefore, have been devoted towards depeloping a methodology where by the components of form, and services can be quantified and then co-related into a 'Programme' which ultimately will determine the most meritorious building form with respect to the cost of service. For this purpose a comprehensive list of the parameters, relevent to the programme and which have already been discussed in the previous chapters, have been compiled togather for easy referance while determining the quantities of services, such as the quantities for bench- supplies,cooling,ventillation loads, lighting loads and also the quantities relevent length, width, height of modules etc.

A COMPREHENSIVE LIST OF PARAMETERS:

	Code No.	Description
Service Systems:	1	Horizontal through corridor
	2	Horizontal through labs
	3	Vertical through corridor
	4	Vertical in a group of labs
Floor Plan:	5	Office space within lab.
	6	Office space in the same bay adjacent to laboratory
	7	Office in row on opposite side of corridor
	8	Offices grouped together in separate place
Building Block: (low rise)	.	Single storey
	.	Two Storey
	.	Three Storey
Module:	.	Depth
	.	Width
	.	Height
	.	Width of corridor
Name of Services	a	Cold water
	b	Chilled water (with return pipe)
	c	Hot water (with return pipe).

d Distilled water or demineralised water

e Natural gas

f Compressed air

g Cable duct

h Air conditioning duct

i Vent duct

j Drainage

Sizes of the Service pipes and ducts:

- Maximum length of branch pipe within a module
- Total length of a pipe in a module
- Length of a branch pipe
- Length of the main pipe
- Effective length of pipes
- Total equivallent length of pipe
- Diameter of mains
- Diameter of branches
- Diameter within modules

Materials supplied

- Water, air, gas
- Specific gravity
- Quantity of flow per hour
- Future capacity
- Use factor

Ventillation:

- Type of hood
- Nature of contaminants

Note: Refer Sketches on p.p.

DETERMINATION OF COOLING LOAD:

Knowing the climatic condition of the zone, its Latitude and Longitude, peak summer air temperature materials employed for construction and solid-void proportion of the light admitting wall surfaces with type of glass used, the 'Effective Temperature Differentials (ETD) for different hours can be found out from a solar data book[1] (ETD Charts). The 'Heat Transmission Co-efficients (U) for different materials with different thickness can also be found out from the same book. The glass area ofthe respective wall surfaces can also be calculated which will have different E.T.D. depending upon the type and thickness of glas and shading co-efficiett

From all these data the average E.T.D. during working hours for different walls and roof can be found out for the peak load for which the system has to be designed.

U X E.T.D. will give 'heat transmittance' i.e. BTU/hr/ S.F. of the various surfaces. Now for a certain building form its surface areas can easily be calculated, multiplying which with its respective 'Heat Transmittance' the total solar heat gain from different surfaces can be found out.

Thus the total solar heat gain from a building block (20 ft. X 60 ft. X 100 ft.) will be different from another block (40 ft. X 60 ft. X 50 ft.) though both are of the same volume and may satisfy the space requirements equally.

---

1. American Society of Heating, Refregeration and Air-Conditioning Engineers. ASHRAE Guide and Data Book, 1961 New York: 1961. is widely used for this purpose and also refered by the author.

It will be so beacause of the difference in Heat Transmittance of different surfaces especially the roof surface.

Cooling load:

- Shape of the building block and Sized of fenestrations
- Orientation and Geographical Location.
- Solar protection devices
- Effective Temperature Differential
- Building materials and thicknesses
- Working hours
- Peak summer day temperature
- Amount of Artificial Lighting
- Mechanical Equipments
- Stratafication factor of heat

Permanent Supplementary Artificial Lighting:

- Level of illumination on working surfaces
- Type and system of lighting
- Day light factor
- Use efficiency

Cost Factors:

- Cost of plumbing, materials, labour (only for the lab).
- Cost of running B.H.P. of Pumps and fans, cost of power
- Cost of cooling (per ton)
- Amortization cost
- Cost of lighting

N.B: The length of wiring, no of switch boards, plug points etc. the Toilet block services, and refuge shuter house n been included in the programme as they do not have vital role in capital and running cost.

After the parameters have been listed, the next step is to synthesise the parameters into formulae which will be used later in quantifying the services for optimisati programme.

DETERMINATION OF VENTILLATION STANDARDS:

Supply Air:

Hood is the guiding factor for ventilation of laboratories. The fumes etc. can be safely exhausted without spreading into the room and for doing so a minimum air velocity is required, 'which is about 50 to 70 ft per minute at the face of the hood (An 8 inch dia duct can discharge this air at an inlet pressure = 0.25 inch of water)'[1]

Quantity of air 50 to 70 cu.ft./minute per sq.ft. of hood for common hood = surface.

1/3rd ofthis quantity will be required for the self-purging hood where 2/3rd is supplemented by the outside air.

Therefore the conditioned air wasted through a hood can be calculated if the following are known.

- Type of hood - self purging (say)
- Size of hood per person - 4ft X 4 ft opening.

---

1. Coleman. Laboratory Design. P.47

- No. of hoods in a module - one only.
- Velocity of air - 60 ft. per minute

So the quantity = (4 x 4) X (60) X (1/3)

= 320 C.F.M. per module (4.6 air change per hour).

Other data for (duct size) calculation

- Friction loss permitted = 0.25 inch of water (per 100 ft. length)
- Pressure at the grill = 0.25 inch
- Pressure at the fan = 0.6 inch
- Use factor = 100 p.c.

Exhaust Air

- Quantity per module = 60 x 16 = 960 cu.ft/min.
- Pressure at hood = '25 inch
- Pressure at fan = '5 inch
- Use factor = 40 pc
- Frictional loss = '25 inch (per 100 ft length)
- No of hoods connected to a single exhaust branch.

In a vertical exhaust system this number will be = (No of hoods per module) X (No of floors).

In a horizontal exhaust system this number will be = (No of hoods per module) X (No of modules per floor).

Determination of Lighting Cost:

The Laboratory work need higher level of illumination due to the precision work done there. Artificial illumination should also have closer resemblance to natural light for certain type of works which means using fluoroscent tubes togather with incandescent lamps in certain proportion or use a high class - De-lux fluoroscent tubes in combination with natural light.

Lighting standard for laboratories vary from the standard for office area.

If 'permanent Aritificial Supplementary Lighting is used than these factors should be considered.

- The space for lighting - Laboratory or office
- Area of the same.
- Lighting standards - (Labs - 50 to 80 F.C., Office - 30 to 40 F.C.).
- Existing natural light available in Foot Candles or Lumens per square foot.
- Room ratio, colour of walls, working height.
- Hours of use of the lights - say in general the laboratories operate these lights for 70 percent to 80 percent of the working hours and the offices operate them for the rest i.e. 20 to 30 percent of the working hours.

Find out the average wattage of lights required to achieve the standards of lighting for labs and offices separately.

Eg: If the benches require 70 F.C. and other areas in lab x require 20 F.C. then the average level of lighting

$$= \frac{70 \text{ X area of bench} + 20 \text{ X area of floor}}{\text{Total area of the lab}} \quad (\text{F.C.})$$

Therefore total watt.hr. per annum

= Area of room X watt.per S.F. X Hours of use per annum

and cost of lighting per annum

= Total watt. hr. X Power cost / 1000 (K.Wt.Hr.)

A composit lighting system[1] with semi-direct luminnaires at a standard height above working level (in a room of good proportions and light coloured wall finishes), requires about ·3 watt. hr. S.F. to raise the level of illumination by one foot candle and generates an additional heat of 1.2 B.T.U. per hr.[2]

FORM AND SERVICE CORRELATION

The system evolved for determination of cost of plumbing, duct work and annual expenditure for running piped supplies, cooling, permanent - lighting and amortization cost of the plumbing and duct work, is applicable to modular planning only.

A module with all the dimension, width (W), Depth (D) and Height (H), has to be repeated for the whole laboratory building. A 'Lab-Office' system is then - overlapped with the

---

1. In composit lighting system incandescent and fluorescent lamps are combined in a proportion to produce a closer resemblanc of natural light.

2. These are rudimentary statistics and can not be used for designing a perfect lighting system or installing an air conditioning machine, but can be used readily to arrive at a building form with a good degree of precision, because errors, if any, will be relative in all the forms under consideration.

five service systems as explained earlier. Overlapping of these two systems leads to different dimensions of the module and these dimensions are noted against a code number such as 15, 16, 27, 39 and 49 etc., where 15 will mean overlapping of (1) and (5) where (1,2,3,4) represent a 'Lab-Office' system and (5,6,7,8,9) represent service systems. For further clarification refer proforma on page .

Thus, if there are (4) 'Lab-Office' systems and (5) Service systems, there are (20) possibilities of laboratories with varying dimensions.[1]

The number of modules (AN) being constant, a single sub-system out of these 20 dimensions can be stacked in a single floor, two floors or a number of floors. If the maximum allowable number of flbors are say (10) then each ofthe 20 sub systems can be stacked in 10 different ways i.e. the number of floors. Thus in all there are (200) possibilities of the laboratory building to be designed.

The method to select a design out of the (200) possibilities is to eliminate the misfits.[2]

---

1. There could be many more 'Office-Lab' systems and service systems evolved depending on the ingennity of the architects and engineers concerned, the combinations of which may produce numerous possibilities. However the author has mentioned only a few of the standard arrangments and service system for developing the 'programme'. Addition of other possibilities will only add to the volume of the programme while the working method will remain the same.

2. Cristopher, Alexender a Mathematician-Architect has developed the system of elemination of misfits, for pin-pointing the most desirous combination of variables and constant out of numerous alternatives.

Firstly, by eliminating the misfits due to the site restrictions e.g. a low rise building may not be possible to fit in the site. Secondly, by eliminating the misfits due to constructional difficulties.

After the second sieving the remaining design possibilities are subjected to cost analysis. The cost analysis is done in two terms, firstly, the initial cost of plumbing and duct work and secondly the annual running cost.

Here again, the third sieving of cost misfits starts. The clients dicision regarding the higher first cost in favour of lower annual cost or the vice-versa will guide the third sieving. Say if the client intends to minimise the annual running cost even at the expense of the initial cost then the third sieving will neglect the lower initial costs and concentrate on lower annual costs only.

The third sieve will produce a range of laboratory building plans whose annual running costs are lower.

A plan with lowest annual running cost or lowest first cost can thus be selected. Again it should be borne in mind that the optimised plan so obtained out of this method will not be true for total optimisation, for which the other factors like the cost of the building works have to be considered.

In the fourth sieving the covered area and carpet area will come into picture. The plan with lower covered area may or may not concide with the lower service installation cost or lower annual running cost.

A further investigation may lead to a system by which the cost of the building other than the services can be calculated more accurately than the existing 'per square foot' system.

However in the dimenstration given to the 'Programme' developed in the IV Chapter, the sieving of the fourth order could only be partial because of the lack of resources to develop another 'programme' by which the estimates of the building works could be determined more precisely without indulging to elaborate mannual mensuration work.

As such the plans which palpably appeared to be inefficient in terms of use of spaces, such as the sketch plan No.2 on page 48, have been rej-cted despite its being highly efficient in terms of the services.

The fourth sieving has to be based upon the comparision between the amortisation cost of the building wor the installation cost and the running cost during the life of the building.

In the following pages a check list of variables has b been given, the abbreviated names of which are pertinent to the computer programme developed on emperical formulae. A list of basic empirical formulae has also been given.

CHECK LIST OF VARIABLES AND CONSTANTS:(As used in programmin

FORM:

W	Width of the module in feet
D	Depth of the module in feet
AL	Maximum length of a pipe (from the branch pipe to the bench faucet)
TD	Total length of Duct per module in feet (from branch duct to the supply qrill)
TP	Total length of pipe per module in feet (from branch pipe to the bench faucet)
TE	Total length of Exhaust duct per modulewfeet (from branch exhaust to the hood).
AN	Total number of modules
R	Number of rows of modules along the corridor
K2	Bank interest rate in Rs. per hundred Rs.
W1	Width of a corridor in feet
Area	Area of the lab./office/corridor in S.Ft. (Under the influence of permanent Art. Sup. Lighting)
H	Height of a floor in feet

SERVICES:

FC	Foot Candle requirements of PASL
FM	Multiplying factor to the number of working hours (to get lighting hours).
HW	Annual working hours
HC	Annual cooling hours
CUP	Rate of unit power in Rs. per K.wt.hr.

F	Number of floors (1,2,3.....n)
Q	Quantity of flow from a single faucet or grill (g.p.m. for liquids, c.f.m. for gas and air)
U	Use factor of a branch pipe
U1	Use factor of the main pipe
S	Specific gravity (for liquids - with respect to water as one) (for gases - with respect to air as one)
AK	Constants (multiplyer) used in imperical (to determine the diameter of pipe/duct).
AK1	Constants (multiplyer)used in imperical (to determine the cost of running the pump/fan).
P	Head of liquid/gas/air at the pump/fan (for liquids = feet of water,. for gas/air = inch of water).
E	Head of liquids/gas/air at the faucet/grill (units same as above).
V	Head loss in height (ft per foot, inch per foot)
AK3	Multiplyer to working hours to get running hours of services
CU2	Cost per running foot of 3/4 inch dia G.I. pipes (inclusive of materials and fabrication cost).
CU1	Cost per running foot of 8 inch dia duct (inclussive of materials and fabrication cost).
PLUMB	Total cost of plumbing (piped supplies)
DUCT	Total cost of Duct work (air supply, exhaust)
AMORT	Annual Amortisation cost of PLUMB and DUCT (at a given bank rate per annum)
LIGHT	Annual electricity bill for Permanent Artificial Supplementary Lighting
COOL	Annual cooling cost of the Labs. and Offices
RUN	Total Annual running cost of pumps and fans (to maintain continuous supply ofthe services)

ANUM	Annual liability (in terms of recurring expenditure per year)
AR	Number of modules served by a branch pipe
X	Length of a branch pipe
Y	Number of branch pipes
Y1	Number of branch Ducts
Z	Length of a main pipe or duct
AEL	Effective length of a pipe
Q1	Flow in a branch pipe (liquid or gas)
Q2	Flow in a main pipe (liquid or gas)
PF	Allowable total frictional loss in pipes/ducts
A	Diameter ofthe branch
B	Diameter of the main
A1	Total length times dia. of branch pipes
A2	Total length times dia. of branch ducts
B1	Total length times dia. of the main
C	Total length of supply ducts within the lab. room
C1	-Do- pipes within the lab room
C2	-Do- exhaust duct within the lab. room
ALD	Total cost of supply ducts
ALF	Total cost of exhaust ducts
ALP	Total cost of pipes
CW	Cooling load of walls
CR	Cooling load of roof

Basic Formulae used in Programming

1) Annual Cooling cost = U X A X ETD X AC X CC/12000

2) Annual Permanent Artificial Lighting Cost = W X A X Fc X A X PC

3) Annual Power Consumed = Q2 X P X K1 X '746 X AW/30000 X c

4) Amortising Cost = (PXR) + Depriciation cost of (P) + rate of repayment of (P)

5) $Q = AK\left(\frac{d^5 \times h}{S \times L}\right)^{1/2}$

where: U = Thermal Transmittance

A = Area of the surface under consideration

ETD = AV. Effective Temperature Differencial

AC = Annual Cooling hours

CC = Cooling Cost per ton

w = K. Watt hour per S.F. of flòor area

Fc = Foot Candle shortage

Aw = Annual work hours

Q = Quantity of flow -(Liquid) G.p.m.
- (Gas) c.f.m.

Q2 = Total quantity of flow per hr.

AK = Constant (different for liquids of gas/air)

K1 = Constant

d = Diameter

h = Total permissible frictional loss in pipes.

s = Specific gravity of liquid/gas

L = Effective length of the supply line

c = Pump/mortor efficiency (combined)

P = Capital cost of piping and duct work

R = Bank-rate of Interest on capital

PC = Powor cost per K.Wt.hr.

The abbreviations used here are different from the abbreviation used in 'Computer Programming'.

```
C       PROGRAM FOR OPTIMISATION OF SERVICES
        REAL LIGHT(3)
        DIMENSIONPLUMB(3),DUCT(3),AMORT(3),FIRST(3),COOL(3),    ANUM(3)
        DIMENSION SQ(8),SU(3),SUI(8),SS(8),SAK(8),SAKI(8),
        GSP(8),SE(8),SV(8),SAK3(8),SCU2(8),SCU1(8)
        DO 100 I=I,8
        READ(2,6)SQ(I),SU(I),SU1(I),SS(I),SAK(I),SAK1(I),SP(I),SE(I),SV(
        READ(2,67) SAK3(I),SCU2(I), SCU1(I)
6       FORMAT (9F8.2)
67      FORMAT(3F8.2)
100     CONTINUE
        WRITE(3,101)
101     FORMAT(1H1)
        N=1
1       JJ=1
2       READ(2,33)W,D,AL,TD,TP, TE,AN,R,AK4,W1,AREA,H,FC,FM,HW,HC,CUP
        PASL=0.003*AREA*FC*AN*FM
        CP=PASL*3413.0*0.9
        COSPA=100.*PASL*CUP*HW
        DO 13 J=1,3
        F=J
        PLUM=0.0
        DUC=0.0
        DO21 IJ=1,8
        Q=SQ(IJ)
        U=SU(IJ)
```

```
U1=SU1(IJ)
S=SS(IJ)
AK=SAK(IJ)
AK1=SAK1(IJ)
P=SP(IJ)
E=SE(IJ)
V=SV(IJ)
AK3=SAK3(IJ)
CU2=SCU2(IJ)
CU1=SCU1(IJ)
GO TO (7,8,9,10,11),JJ
AR=AN/F
X=W*AN/(R*F)
Y=F
Y1=Y
Z=H*F
GO TO 12
AR=AN*0.5/F
X=(W*AN/(R*F)+(0.5*D)
Y=2.0*F
Y1=Y
Z=H*F
GO TO 12
AR=F
X=H*F
Y=AN/AR
YI=Y
Z=W*AN/(R*F)
```

```
GO TO 12
AR=2.*F
X=H*F
Y=AN/AR
Y1=0.5*Y
Z=W*AN/(R*F)
GO TO 12
AR=4.*F
X=H*F
Y=AN/AR
Y1=Y
Z(W*(AN/(R*F)-2.))+W1
GO TO 12
AEL=1.5*(X+Z+AL)
Q1=0.5*AR*Q*U
Q2=1.5*AN*Q*U1
PF=P-E-(V*H*F)
A=((Q1/AK)**.4)*((S*AEL/PF)**.2)
B=((Q2/AK)**.4)*((S*AEL/PF)**.2)
A1=A*X*Y
A2=A*X*Y1
B1=B*Z
C=TD*AN
C1=TP*AN
C2=TE*AN
ALD=(A2/8.)+(B1/8.)+C
ALF=(A2/8.)+(B1/8.)+C2
ALP=(A1/.5)*(B1/.5)+C1
PLUM=PLUM+(CU2*ALP)
```

```
DUC=DUC+(CU1*(ALD+ALE))
CONTINUE
AMOR=0.1*(PLUM+DUC)*AK4
CW=((6.4*((D*R)+W1)*H*F)+(10.6*H*F*W*AN/(R*F)))
CR=(11.6*((D*R)+W1)*W*AN/(R*F))
CS=CW+CR
COSCO=(((CP+CS)*HC/120.)*0.9*.746*CUP)
COST=AMOR+COSPA+COSCO
SUM=(PLUM+DUC)
PLUMB(J)=PLUM
DUCT(J)=DUC
AMORT(J)=AMOR
LIGHT(J)=COSPA
COOL(J)=COSCO
FIRST(J)=SUM
ANUM(J)=COST
CONTINUE
WRITE(3,55)(PLUMB(J),J=1,3)
WRITE(3,55)(DUCT  (J),J=1,3)
WRITE(3,44)
WRITE(3,55)(AMORT(J),J=1,3)
WRITE(3,44)
WRITE(3,55)(LIGHT  (J),J=1,3)
WRITE(3,55)(COOL(J),J=1,3)
```

```
WRITE(3,55)(FIRST(J),J=1,3)
WRITE(3,44)
WRITE(3,55)(ANUM(J),J=1,3)
WRITE(3,77)
FORMAT(17F4.1)
FORMAT(3F12.2)
FORMAT(/)
FORMAT(///)
IF(N-4)16,16,17
IF(JJ-5)18,19,19
JJ=JJ+1
GO TO 2
N=N+1
GO TO 1
CALL EXIT
END
```

SUMMARY

For rationalising form and function of laboratory buildings, a systematic approach is required to identify the components which play a vital role in some way or the other towards the cost of the project. The cost may be the first cost or the total cost during the life of the building. Out of the two the total money spent during the life of the building is of more importance.

Therefore, keeping constant the space requirements and working efficiency of its inmates, the various building plans should be subjected to the cost tests as deliberated in the foregoing paragraphs. Within the same boundary conditions of site, height, space requirements, working efficiency of inmates, aesthetics and appearance of the building, future expansion etc. the best project will be the one which can be erected and maintained during its useful life at minimum cost.

For the cost analysis of tens or hundreds of alternative projects, the help of a computer is inevitable. As such the collection of information for input data, formulation of a computer programme and the computer's output information in terms of cost, are the prerequisits of the cost analysis.

Out of these numerous cost data the useful ones are picked up by elemination of the misfits existing in

it. The plans connected with the lowest cost or a range of lower costs may be selected.

CHAPTER IV

PROGRAMME EFFECTUATION: To Optimise Form and Services-- A Hypothetical Example

INTRODUCTION:

It has been felt that a working example at the end will be supplementary for the clarification of the dissertation.

Usually a working example may be a simulation of an existing Research Laboratory or a live project or a hypothetical project.

The author has chosen to refrain from selecting an existing project or a live project and has based his working example on hypothetical data because a critical analysis of such projects based on partial optimisation (optimisation of services only) will not be of any special volue, rather it will misinterpret the existing or the would be building form form within its limited perspective.

CASE STUDY INDUSTRIAL RESEARCH LABORATORY--HYPOTHETICAL
(For P gments, Dyes and Paints)

Location:

A ten acre plot is situated in the outskirts of a metropolis with the ample provision of cheap land, it is desired that the expansion should be horizontal. A low rise building with maximum of 3 floors is suggested to avoid additional costs of frieght and passanger elevators.

The site is connected to utilities such as the high way, underground drain, high tension power line and water supply at low pressure.

Climate: Hot-humid zone in eastern India

Average highest temperature in Summer = 110°F

Average lowest temperature in Winter = 50°F

Average durinal range in Summer = 77°F

Duration of Summer = 7 months

Construction: Conventional - Framed R.C.C. Structure, 10 inch Thk. brick external walls, R.C. roof, lime terracing.

Informations related to space requirements in the laboratory

The laboratory has Research Workers numbering 120. Each module has accomodation of one Senior or Junior

Scientist and one Assistant. The total number of modules required are 60.

Basic requirements of a module:

1). Service benches:

- Each Scientist = 16'-0 X 2'-0 (3'-0 Height)
- Each Assistant = 12'-0 X 2'-0 (3'-0 Height) (including writing space)

2). Storage cabinets = 6'-0 X 2'-0 (3'-0 Height)

3) Writing desk = 4'-0 X 2'-0 (3'-0 Height)

4) Width of aisle,

- Between benches = 6'-0
- Between Island benches and end walls = 4'-0 minimum.

5) Scientist's office = 90 S.F. per person (may be detatched but in close promimity of the lab.).

6) General storage = 24 S.F.

7) Hood with face opening = 4'-0 X 3'-0

8) Corridor width = 10 FT. (8'-0 minimum)

9) Each module should have a 4'-0 wide entry door

10) Safty egress (4'-0 wide) opposit to the entry (may open to the adjasent room - office or laboratory).

11) Permissible minimum floor to ceiling ht. = 10'-0

General services required:

1) Cold water, chilled water, hot water, demineralised water.

2) Compressed air, gas for burner (natural).

3) Supply conditioned air, exhaust through hoods

The partition between rooms should be removable type to add to the flexibility of the room size, so that a single room may be a.ranged in various ways to accomodate own, two, three or four modules as the research programmes may demand from time to time. Artificial lighting should be in closer resemblance to the natural light for colour distinction.

Optimisation Programme for the Laboratory:

Based upon the requirements the laboratory has been designed in four alternative ways as shown in the sketches appearing on pages . There could be many more alternatives depending on the ingenuity of the architect. In this case there are 20 variations in depths, widths, heights, of the modules corresponding to five different service systems adopted. When super imposed with the three floors there are 60 alternative schemes - as shown in the sketches adjoining the cost analysis charts.

The following tables provides a comprehensive list of various data compiled togather for the 20 different variations in design. These data have been fed into the FORTRAN-1130 Computer in the form of - punched cards to run the previous programme. The results have been obtained for 60 (20 x 3) alternatives in term os

-VARIABLES-

		S							
Descriptions	15-7	37-9	38-10	39-11	45-7	46-8	47-9	48-10	49.1
Depth of Module									
Width of Module									
Height of Module									
Maximum Length of a supply line from Branch to Bench									
Total Length of piping within a module									
Total Length of supply duct within a module									
Total Length of an exhaust duct within a module									
Total No. of modules									
No. of floors									
No. of rows of modules									
No. of modules served by a service branch.	AN/F								
Length of a branch feeder	$\frac{H.AN}{R.F}$								
No. of branch pipes	F								
No. of branch ducts	Y								
Length of main feeder	H.F.								
Artificial Lighting load in foot candles									
Area under the influence of artificial lighting									

Mode of Codin,4)
,7,8,9)
7,8,9,10,11).

(F4.1)

D

(Thehediately above it)

s______

Sl. No.	W	D	AL	TD	FC	FM	HW	HC	CUP 1	CUP 2
1.	10.0	32.0	25.0	06.0	50.0	00.9	2500	1900	00.1	0.2
2.		[illegible]	16.0	02.0						
3.		35.0	17.0	09.0						
4.		35.5	16.0							
5.		32.0	40.0	06.0						
6.	15.0	24.0	25.0			00.6				
7.		[illegible]	16.0	02.0						
8.		26.0	17.0	12.0						
9.										
10.		25.0	40.0	06.0	50.0					
11.	10.0	33.0	23.0	08.0						
12.			16.0	12.0						
13.		36.0	17.0	09.0						
14.		36.0	17.0							
15.		35.0	40.0	06.0		00.9				
16.		30.0	45.0	12.0		01.0				
17.			17.0	07.0						
18.		33.0		09.0						
19.		30.0								
20.		31.5		8.0						

PROFORMA FOR COLLECTION OF INFORMATIONS ON INPUT-VARIABLES

								C		O	D		E	S							
Code	Descriptions	15-7	16-8	17-9	18.10	19-11	25-7	26-8	27-9	28-10	29-11	35-7	36-8	37-9	38-10	39-11	45-7	46-8	47-9	48-10	49.11
D	Depth of Module																				
W	Width of Module																				
H	Height of Module																				
AL	Maximum Length of a supply line from Branch to Bench																				
TP	Total Length of piping within a module																				
TD	Total Length of supply duct within a module																				
TE	Total Length of an exhaust duct within a module																				
AN	Total No. of modules																				
F	No. of floors																				
R	No. of rows of modules																				
AR	No. of modules served by a service branch.	AN/F	AN/2F	F	2F	4F	----------Repeat -----														
X	Length of a branch feeder	$\frac{W.AN}{R.F}$	$\frac{W.AN}{R.F}+\frac{D}{2}$	H.F	H.F.	H.F.															
Y	No. of branch pipes	F	2F	$\frac{A.N}{AR}$	$\frac{AN}{AR}$	$\frac{AN}{AR}$															
Y1	No. of branch ducts	Y	Y	Y	Y/2	Y															
Z	Length of main feeder	H.F.	H.F.	$\frac{W.AN}{R.F.}$	$\frac{WAN}{R.F.}$	$\frac{W.AN}{(R.F)-2}+W$															
FC	Artificial Lighting load in foot candles																				
AREA	Area under the influence of artificial lighting																				

Mode of Coding: First Number – First digit denotes Building Form (1,2,3,4)
– Second digit denotes service system (5,6,7,8,9)
Second Number – Statement number in computer Programme (7,8,9,10,11).

(F4.1)

DATA EXTRACTED FROM THE ALTERNATIVE PLANS:

(The data in the blank columns correspond to data immediately above it)

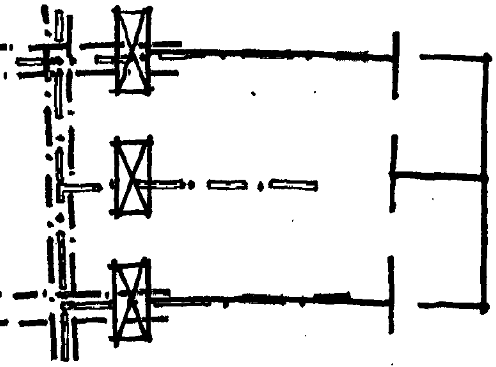
Abreviations are same as per list givenian.page______

Sl. No.	W	D	AL	TD	TP	TE	AN	R	K2	W1	AREA	H	FC	PM	HW	HC	CUP 1	CUP 2
1.	10.0	32.0	25.0	06.0	50.0	11.0	60.0	02.0	0.05	10.0	200	10.0	50.0	00.9	2500	1900	00.1	0.2
2.		[illegible]	16.0	02.0	28.0	05.0						12.0						
3.		35.0	17.0	09.0	16.0	03.0						10.0						
4.		35.5	16.0															
5.		32.0	40.0	06.0	42.0	13.0												
6.	15.0	24.0	25.0		50.0	11.0					130			00.6				
7.		[illegible]	16.0	02.0	28.0	05.0						12.0						
8.		26.0	17.0	12.0	16.0	03.0												
9.												10.0						
10.		25.0	40.0	06.0	40.0	15.0							50.0					
11.	10.0	33.0	23.0	08.0	46.0	11.0		01.0		08.0	100							
12.			16.0	12.0	28.0	05.0						12.0						
13.		36.0	17.0	09.0	16.0	03.0						10.0						
14.		36.0	17.0		20.0	09.0												
15.		35.0	40.0	06.0	40.0	13.0	60.0							00.9				
16.		30.0	45.0	12.0	45.0	05.0		02.0			240	12.0		01.0				
17.			17.0	07.0	34.0	11.0						10.0						
18.		33.0		09.0	16.0	03.0												
19.		30.0								10.0	130							
20.		31.5		8.0	16.0	3.0	60.0				240							

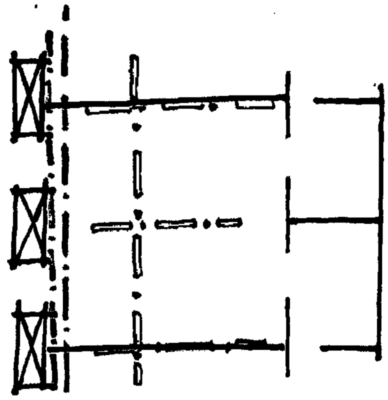
Sl. No.	Itom	C	U	UI	S	AK	AKI
1.	Water Cold	00010.00	00000.60	00000.60	00001.00	00043.00	00023.00
2.	Hot	00004.00	00000.60	00000.40	———	do (as 1)	———
3.	Chilled						
4.	Demineratised	2.00	.40				
5.	Comp. air	00140.00	00000.30	00000.20	00001.00	02340.00	00005.20
6.	Gas	00014.00	00000.60	00000.60	00000.60	02340.00	00005.20
7.	Conditioned air	18000.00	00001.00	00001.00	00001.00	02340.00	00005.20
8.	Exhaust air	60000.00	0.60 (vertical)	0.40 (horizontal)	———	do	———
		P	PE	HL	AK3	CU2	CU1
1.	Water Cold	00025.00	00003.00	00000.43	00000.80	00002.00	00000.00
2.	Hot	———	do	———	00000.60	do (as 1)	———
3.	Chilled						
4.	Distilled						
5.	Comp. air	00230.00	00220.00	00000.00	———	do (as 1)	———
6.	Gas	00007.00	00006.00	00000.01	00000.90	do	(as 1)
7.	Conditioned air	00000.90	00000.25	00000.00	00001.05	00000.00	00005.00
8.	Exhaust air	C0001.00	00000.70	-do-	———	do (as 7)	———

OUTPUT DATA

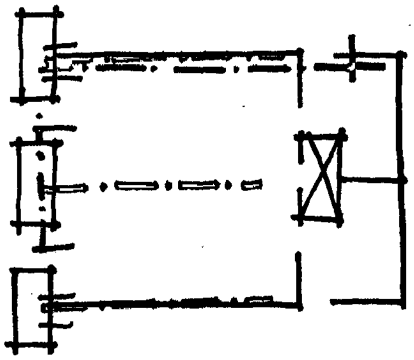
	1 STOREY	2 STOREY	3 STOREY	
1.	36119.34	32160.07	31857.65	PLUMB
	48607.55	38906.35	36112.01	DUCT
	84726.89	71066.43	67969.67	TOTAL
	4236.34	3553.32	3398.48	AMORT
	38879.99	38879.99	38879.99	LIGHT
	8281.94	6973.57	6577.72	COOL
	51398.27	49406.88	48856.20	ANUAL



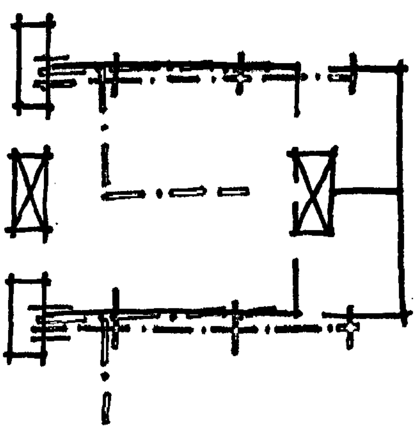
2.	41454.28	35677.51	35413.30
	64427.78	49929.87	45706.25
	105882.06	85607.39	81119.56
	5294.10	4280.36	4055.97
	38879.99	38879.99	38879.99
	8281.94	6973.57	6577.72
	52456.03	50133.92	49513.69



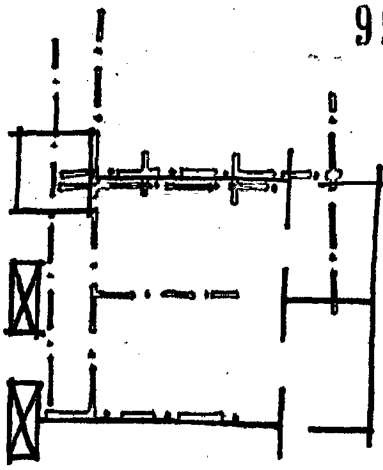
3.	42566.00	32245.83	30761.32
	70203.46	40937.50	33212.96
	112769.46	73183.32	63974.28
	5638.47	3659.16	3198.71
	38879.99	38879.99	38879.99
	8430.31	7004.97	6566.14
	52948.76	49544.12	48644.84



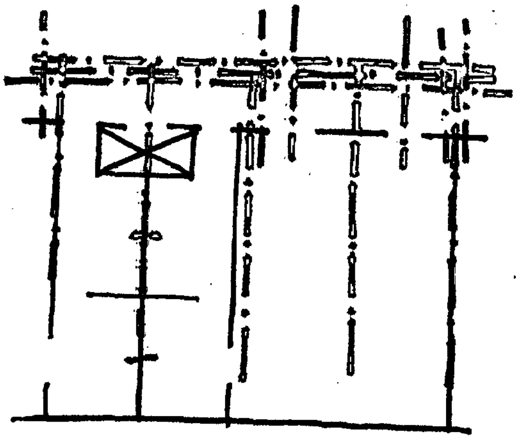
4.	53420.17	42480.51	40346.53
	66826.28	40566.40	36961.46
	120246.45	83046.92	77307.98
	6012.32	4152.34	3865.39
	38879.99	38879.99	38879.99
	8354.96	6965.25	6537.40
	53247.26	49997.59	49282.78



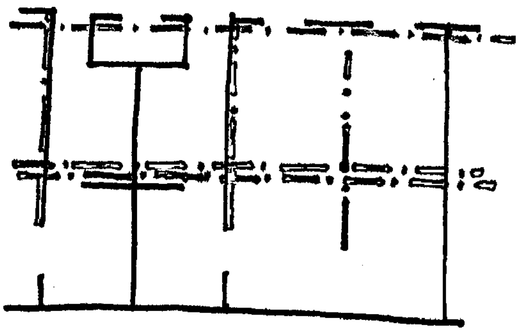
5.	51015.92	39553.53	36762.10
	71876.15	42269.67	34088.96
	122892.07	81823.20	70851.06
	6144.60	4091.15	3542.55
	38879.99	38879.99	38879.99
	8204.26	6885.82	6479.91
	53228.85	49856.97	48902.45



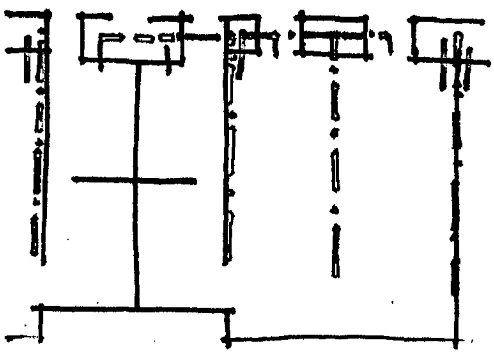
6.	44185.76	37370.17	35565.70
	65947.28	50026.10	44473.31
	110133.03	87396.28	80039.01
	5506.65	4369.81	4001.95
	14039.99	14039.99	14039.99
	5245.54	3833.46	3388.17
	24792.18	22243.27	21430.12



7.	53829.16	44133.29	42541.85
	90470.73	66774.20	58664.17
	144299.90	110907.48	101206.03
	7214.99	5545.37	5060.30
	14039.99	14039.99	14039.99
	5347.31	3943.36	3505.69
	26602.80	23528.73	22605.98

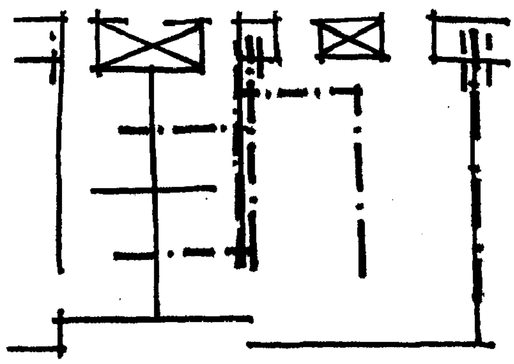


8.	58499.82	42163.36	38968.61
	99820.46	55216.03	42946.80
	158320.28	97379.40	81915.42
	7916.01	4868.96	4095.77
	14039.99	14039.99	14039.99
	5455.42	3942.49	3465.39
	27411.43	22851.46	21601.16



9.

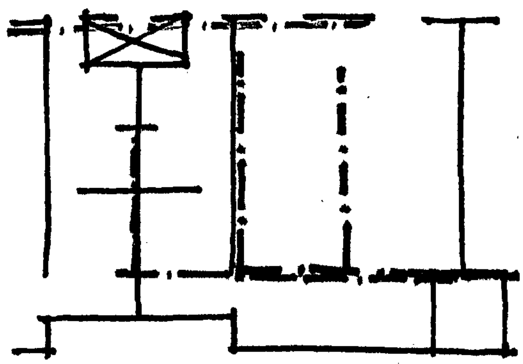
63424.15	47220.20	43584.19
90888.29	51428.62	44031.22
154312.43	98648.82	87615.42
7715.62	4932.44	4380.77
14039.99	14039.99	14039.99
8572.01	7114.57	6655.97
30327.62	26087.00	25076.73
61563.56	44108.70	39585.06



10

10.

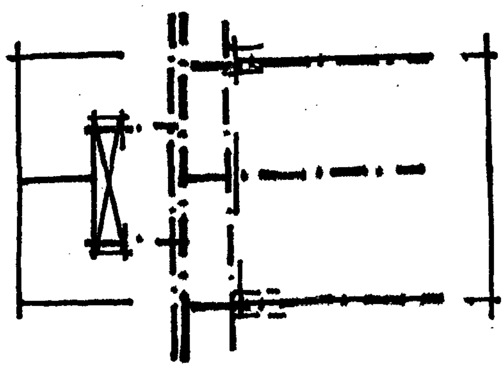
97638.26	52908.00	40280.57
159201.81	97016.70	79865.62
7960.08	4850.83	3993.28
14039.99	14039.99	14039.99
9434.50	7568.55	6980.14
31434.58	26459.38	25013.40



11

11.

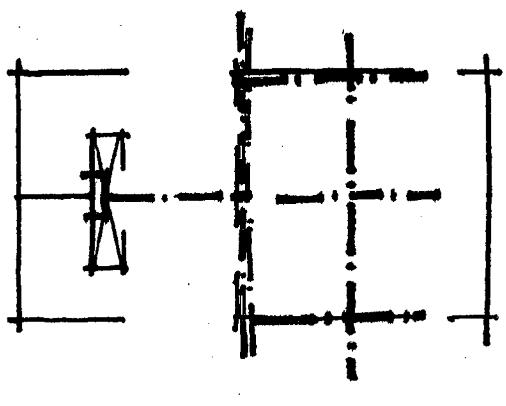
58110.54	47720.31	45473.46
94897.00	69918.50	60882.60
153007.53	117638.79	106356.06
7650.37	5881.93	5317.80
10799.99	10799.99	10799.99
5214.14	3767.03	3306.43
23664.51	20448.97	19424.23



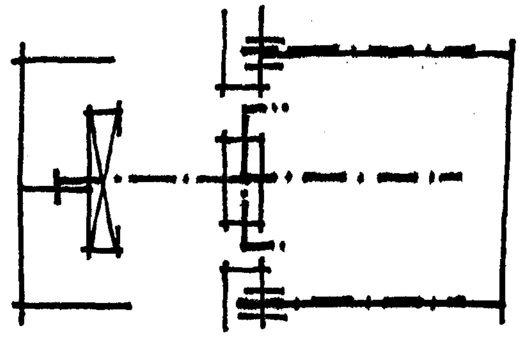
12

12.

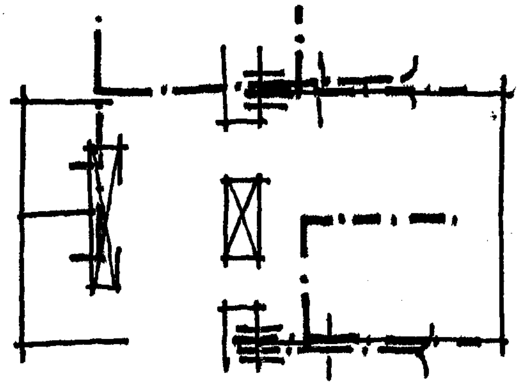
74258.65	58022.24	53305.51
134960.56	96850.76	82683.37
209219.18	154873.00	135988.87
10460.95	7743.64	6799.44
10799.99	10799.99	10799.99
5073.48	3620.93	3154.89
26334.43	22164.57	20754.32



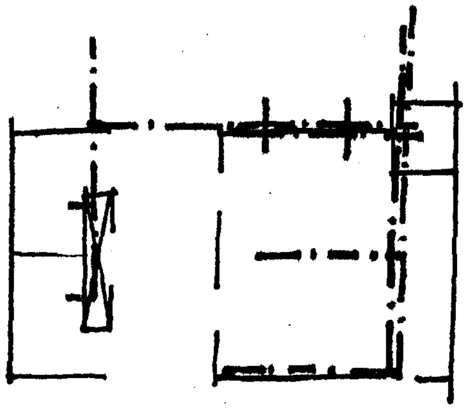
13.	72640.89	46611.39	40662.49
	142502.93	73214.67	53637.31
	215143.81	119826.04	94299.79
	10757.18	5991.30	4714.98
	10799.99	10799.99	10799.99
	5222.82	3697.64	3208.29
	26780.00	20488.93	18723.28



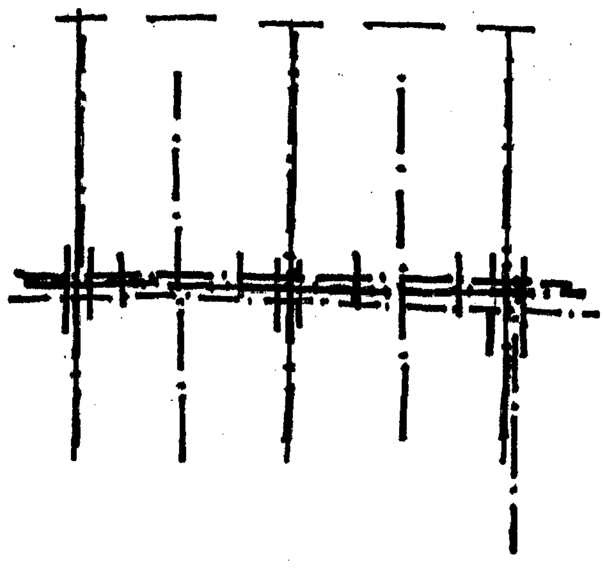
14.	83193.54	56487.14	49853.91
	138667.12	72790.64	57756.91
	221860.65	129277.76	107610.82
	11093.03	6463.88	5380.54
	10799.99	10799.99	10799.99
	5222.82	3697.64	3208.29
	27015.83	20761.51	19388.82



15.	80257.26	53021.82	45712.66
	143323.65	73749.76	53742.55
	223580.90	126771.57	99455.21
	11179.04	6338.57	4972.76
	16199.99	16199.99	16199.99
	5778.80	4326.25	3860.21
	33157.84	26864.82	25032.96



16.	32465.25	28488.18	28170.49
	50892.90	41160.64	38349.03
	83358.15	69648.82	66519.53
	4167.90	3482.44	3325.97
	43199.99	43199.99	43199.99
	8619.33	7417.05	7053.30
	55987.22	54099.47	53579.26

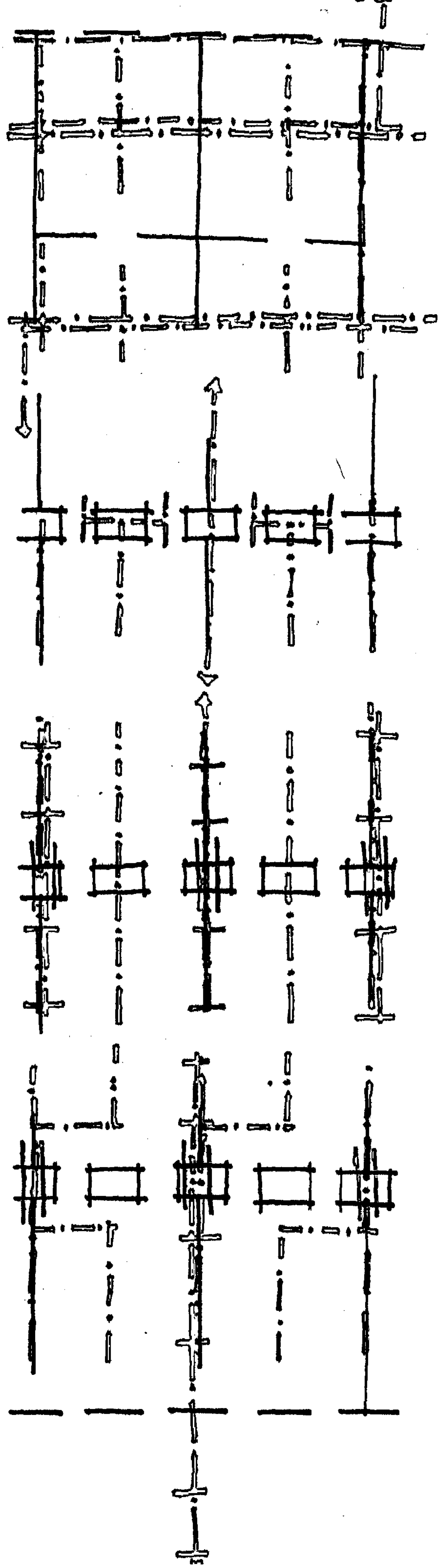


17.	41350.52	35529.35	35217.25
	64209.36	49634.66	45349.79
	105559.89	85164.01	80567.04
	5277.99	4258.20	4028.35
	38879.99	38879.99	38879.99
	8130.70	6893.05	6518.60
	52288.67	50031.24	49426.94

18.	42566.00	32245.83	30761.32
	70203.46	40937.50	33212.96
	112769.46	73183.32	63974.28
	5638.47	3659.16	3198.71
	43199.99	43199.99	43199.99
	8806.19	7469.93	7058.53
	57644.64	54329.09	53457.24

19.	41044.64	31765.21	31440.83
	73791.09	47260.22	32081.75
	114835.74	78425.44	63522.58
	5241.78	3421.27	3076.12
	42159.99	42159.99	42159.99
	9488.78	7470.44	7098.35
	56890.57	53051.71	52334.48

20.	42013.92	30575.55	27782.15
	72198.04	42692.67	34560.73
	114211.96	73263.21	62342.88
	5710.59	3663.41	3117.14
	43199.99	43199.99	43199.99
	8617.82	7370.65	6986.67
	57528.40	54234.04	53303.80



costs in Rupees as follows:

a. First Cost:

1). Cost of plumbing

2). Cost of ducts

b. Annual Cost:

1). Amortisation cost of plumbing and duct

2). Cost of permanent Artificial Supplementary Lighting

3). Cost of cooling

4). Cost of running the pumps and fans

5). Total annual liability for (b.1 to 4).

A few words about programming:

The programming as we know, had entered into the day to day work of every humanbeing but its formulation depends on the work one does and language one follows.

The architects by the virtue of their profession have more aptitude to speak and deal with lines rather than with numbers. This has been a great hinderance to the architects to adopt a digital-elemtronic-computer in design and planning. Unfortunately in our country the sophisticated computer soft-wares like C.R.T. sketching pad and light pen are yet to come where by, to the architect' favour, the man-machine relation is stablished through visual field rather than digits. More over data banks and set programmes are yet to develop.

It is difficult for a practising architect or even a large establishment to maintain its own computer or a programmer but if consulting programmes and computer centres are available in the city, a small amount spent in 'programming' and even a smaller in computer can save the architect and his team from a lot of trouble and wastage of time while doing more justice to the client.

The programme for the academic purpose in this dissertation has been done by the author himself which proved to be time consuming and it is not practicable for a practising architect to programme for the computer. But it has been noted that the architect involved in an optimisation programme and using a computer must have some practical knowledge of computer programming and the language of the computer, otherwise it becomes difficult to transmit his ideas to a professional programmer and becomes a time consuming process.

\+ The working example cited here has been run in the FORTRAN 1130 computer and took 20 minutes time including programme compilation.

Once the alternative plans are ready and such suitable programmes are available from the data bank or the office itself, it is a matter of only one working day to punch the

---

\+ FORTRAN 1130 computer for the academic purpose could be availed at a reduced rate of Rs.150.00 per hour. For commercial purpose it is higher.

input data cards and run the programme and another working day for critical cost analysis of the output data charts.

Therefore, for the benifit of all and like other professionals in different technologies, it is timely for the enterprising architects whether in academic or professional field, to come forward to investigate the potentials of the computer in the field of architecture and valuation, to formulate new programmes and help in developing data banks all over the country.

OBSERVATIONS FROM THE FIRST GROUP OF RESULTS:

The cost of plumbing and duct work togather with the sum of the annual costs of artificial lighting, Cooling and amortisation of plumbing and duct work have been computed for varieus plans and the following observations were made.

1. It is observed that the cost of cooling and the cost of plumbing and duct work, gradually come down with the rise in the building height. In the three-storey building-block these costs are the lowest.

2. The cost of the horizontal and the vertical service systems tend to balance each other with the rise in the number of floors. In most cases the cost of both system are almost same for a three storey building configuration. In a single or double storey configuration, the horizontal service system was more economical.

3. It is observed from the comparative analysis of the costs in the tables that the heighest and the lowest costs are in the ratio of 3:1. In actual figures the heighest annual cost occurs in the range of plans numbered 16-20 and amounts to Rs.53.0 thousand (20th scheme) where as the lowest annual cost occurs in range of plans numbered 11-14 and amounts to Rs. 18.7 thousand per annum (13th scheme). Thus there is an additional burden of 34.3 thousand per annum throughout the life of the building. Within 30 years the loss incured by the client amounts to Rs.8.6 lacks which is approximately equal to the building work at the rate of Rs.40.00 per square foot of floor area.

4. The heighest plumbing cost amounts to Rs.2.2 lacks (scheme No.4-1) and the lowest plumbing cost amounts to Rs.0.6 lacks (scheme No.20-3). The plumbing cost inshheme No.20-3 amounts to Rs.62 thousands whereas in the (scheme No.13-3) At amounts to Rs.94 thousand. It means that even after spending 32 thousand rupees additional on plumbing, the client is benifited in the later scheme (13-3).

5. It is interesting to note that the architect is also benifited economically while rendering his services to the client through optimisation programme. The architects share of additional profit on Rs.32 thousand (additional plumbing cost) at the rate of

4 percent amounts to Rs.1280.00 while the architect has spent Rs.250.00 on optimisation programme.

6. Permanent artificial supplementary lighting is a source of great expenditure and in an extreme case, the heighest lighting bill may be as high as three times the lowest lighting bill.

7. In laboratories, the cost of airconditioning is guided by the constant air supply and exhaust ofthe hoods rather than the cooling cost which constitutes only a small part ofthe total expenditure on airconditioning. However the cooling costs in the extreme cases are in the ration of 3:1.

8. A system where a number of laboratories grouped around a vertical service shaft has no special advantage in reducing plumbing cost over a system with individual vertical shafts for individual bench except the 16-20 group where the number of shafts have been reduced to half and bench connections are of shorter lengths. (In a module where the width (W) is less than the height (H), such grouping could be of more advantage).

9. The range of schemes 11-15 proved to be economical in terms of cooling and lighting but uneconomical in terms of plumbing cost and also the use efficiency of space.

The analysis shows that the blue bordered cost represents the plan for minimum sost of plumbing, the green bordered cost represents minimum for duct, the black bordered cost represents the minimum for the combined plumbing and duct cost in a single supply system and the red bordered cost represents the lowest annual cost.

In the view of building economics the plan representing the lowest annual cost in red bordered is the most economical one. But in case the client's pocket does not permit the corrosponding ocst of plumbing and duct work, the lowest or any other lower plumbing and duct cost may be selected to compromise with the annual cost. Thus there is a wide range of choice to make depending upon the financial disposition ofthe client at the time of undertaking the project.

A further rationalisation of the first cost and the annual cost is to be made by running another short computer programme with varying pump pressure to stablish the optimum cost of the two.

Parameters of the Second Programme:

If the lowest plumbing cost is the criterion of design, the schemes (3-3, 18-3, 19-3 and 20-3) are acceptable.

If the lowest annual lighting and cooling cost (combined) is the criterion than the schemes (8-3, 11-3 to 14-3) are acceptable.

When the combined annual running cost of all the services togather with the amortisation cost of plumbing isthe criterion then none of the plans at this stage is acceptable and needs further reationalisation.

Annual running cost is a function of the Break-Horse-Power of different pumps and fans and the number of hours per annum for which the pumps and the fans operate. For the second stage of optimisation all other factors except the pressure component of B.H.P. are constants. Hence running cost is computed for varying pressures of pumps and fans. The second group of input data for the computer programme were based on either the lowest plumbing cost of the lowest annual cost, and were selected from the output data of the previous group of investigation. The scheme numbers thus selected were 1,3,6,8,13,16,20.

The computer work was done in two stages to reduce the unnecessary running of the computer in redundant work which could be screened out manually. Inthis way the number of operations in the computer could be rdduced to 95 instead of 300.

The second group of results for optimisation of running cost of services are revealing in this respect.

Input data for the Second Programme:

Name of the Service:	Pump/Fan Pressures (P)				
Cold Water	17	18	19	20	21
Hot Water					
Chilled Water					
Demineralised Water					
Gas	5.15	5.25	5.30	5.35	5.40
Compressed air	320	223	225	226	227
Conditioned air	'30	'40	'5	'55	'6
Exhaust air	'4	'5	'6	'65	'7

Note : Other data are same as the previous programme

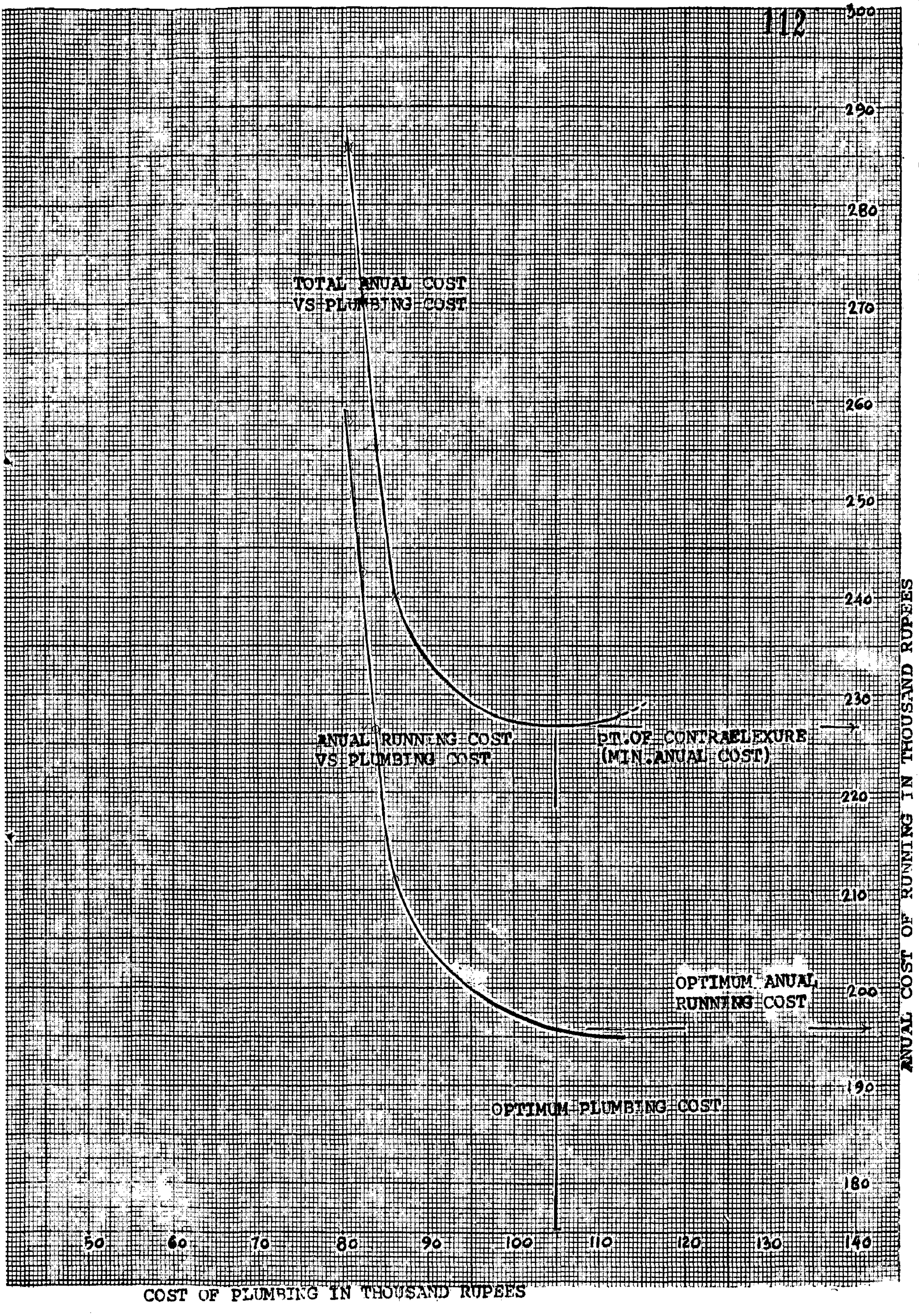
```
C       PROGRAM FOR OPTIMISATION OF SERVICES (II)
        DIMENSION PLUMB (5), DUCT (5), COST (5)?AMONT(5),RUN(5)
        ANNUAL (5)
        DIMENSION SQ(8), SU(8), SU1(8), SS(8), SAK(8),SAKI(8),
        G SP(8), SV(8), SAK3(8), SCU2(8), SCU1(8)
        DIMENSION SP (40)
        DO 100 I=1,8
        READ (2,6) SQ(I), SU(I), SU1(I), SS(I), SAK(I),SAKI(I),
        SE(I), SV(I)
        READ (2,67) SAK3(I), SCU2(I), SCU1(I)
6       FORMAT (8F8.2)
67      FORMAT (3F8.2)
100     CONTINUE
        DO 102 M=1,40
        READ (2,5)SP(M)
5       FORMAT (F6.2)
102     CONTINUE
        WRITE (3,101)
101     FORMAT (1H1)
        JJ=1
1       N=1
2       READ (2,33) W,D.AL,TD,TP,TE,AN,R,AK4,W1,AREA,H,PC,FM,
        HW,HC,CUP
4       READ (2,22) COOL, PLITE
        DO 15 J=1,5
        P=3.0
        PLUM = 0.0
        DUC = 0.0
```

```
      COSPU = 0.0
      DO21 IJ=1,8
      Q=SQ(IJ)
      U=SU(IJ)
      U1=SU1(IJ)
      S=SSI(IJ)
      AK=SAK (IJ)
      AK1=SAK1(IJ)
      E=SE(IJ)
      V=SV(IJ)
      AK3=SAK3(IJ)
      CU2=SCU2(IJ)
      CU1= SCU1(IJ)
      P=SP(N)
      GO TO (7,9,7,9,9,7,11), JJ
7     AR=AN/F
      X=W+AN/(R*F)
      Y=F
      Y1=Y
      Z=H*F
      GO TO 12
9     AR=F
      X=H*F
      Y=(AN/AR)+2
      Y1=Q.5*Y
      Z=W+AN/(R*F)
      GO TO 12
```

```
11      AR=4.*F
        X=H*F
        Y=(AN/AR)
        Y=1Y
        Z=(W*(AN/(R F)-2.))+W1
        GO TO 12
12      AEL=1.5*(X+Z+AL)
        Q1=0.5*AR*Q*U
        Q2=1.3*AN*Q*U1
        PF=P-E-(V*H*F)
        A= ((Q1/AK)**.4) * ((S*AEL/PF)**.2)
        B= ((Q2/AK)** .4)*((S*AEL/PF)**.2)
        A1=A*X*Y
        A2 A*X*Y1
        B1 = B*Z
        C = TD*AN
        C1 = TP*AN
        C2 TE*AN
        ALD = (A2/g.)+(B1/8)+C
        ALF=(A2/8.)+(B1/8.)+C2
        ALP = (A1/.5)+(B1/.5)+C1
        PLUM = PLUM + (CU2*ALP)
        DUC =DUC+ (CU1*(ALD+ALE))
        COSPU=COSPU+ ((Q2*P*AK1*.745*AK3*HW*CUP)/(330.*0.7))
        N=N+1
21      CONTINUE
        AMOR= (((0.05*AK4)+0.1)*(PLUM+DUC))
```

```
      PLUMB(J)=PLUM
      DUCT(J)=DUC
      COST(J)=(PLUM+DUC)
      AMORT(J)=AMOR
      RUN(J)=COSPU
      ANUAL(J)=RUN(J)+AMORT(J)+COOL+PLITE
13    CONTINUE
      WRITE(3,55) (PLUMB(J),J=1,5)
      WRITE(3,55) (DUCT(J), J=1,5)
      WRITE(3,55) (COST(J), J=1,5)
      WRITE(3,44)
      WRITE(3,55) (AMORT(J),J=1,5)
      WRITE(3,55) (RUN(J), J=1,5)
      WRITE(3,55) (ANNUAL(J), J=1,5)
      WRITE(3,77)
33    FORMAT(17F4.1)
55    FORMAT(3F12.2)
44    FORMAT(/)
22    FORMAT(2F8.2)
77    FORMAT(///)
      IF(J)-7) 18,17,17
18    JJ=JJ+1
      GO TO 1
17    CALLEXIT
      END
```

Scheme No.	COST IN RUPEES:							
1.	36559.54	40445.75	40311.11	37579.30	35362.53	34110.06	33299.17	PIPING
	44347.74	41015.57	39043.08	37923.25	37026.52	36282.09	35647.79	DUCT
	80907.28	81461.32	79354.20	75502.54	72389.04	70392.09	68946.96	TOTAL PLUMBI[illegible]
	10922.48	10997.27	10712.81	10192.84	9772.52	9514.36	9306.99	AMORTI-SING
	156733.84	176103.81	195403.87	211069.87	226735.01	242401.81	358067.78	ANNUAL RUNNIN[illegible]
	213119.00	232558.78	251574.37	266720.43	381966.06	297379.12	312972.81	TOTAL ANNUAL
3.	39522.24	37220.43	60327.19	34674.39	33532.14	32730.56	32102.56	
	41480.77	38135.63	36155.45	35031.25	34131.03	33383.64	32746.93	
	81003.01	75356.06	96482.64	69705.64	67662.17	66114.20	64849.50	
	10935.40	10173.06	13025.15	9410.25	9134.52	9005.70	8837.56	
	156738.84	176103.81	195403.87	211069.87	226735.81	242401.81	258067.78	
	213131.93	231734.56	253886.71	265937.81	281328.06	297165.25	311767.93	
6.	44207.50	41929.67	64533.35	39416.08	39291.71	37502.08	36883.23	
	55366.52	50959.14	48350.17	46869.00	45602.90	44698.17	43859.28	
	99574.03	92888.81	112883.53	86285.09	83974.62	82200.25	80742.51	
	13442.49	12539.98	15239.27	11648.48	11336.57	11010.01	11037.12	
	156738.84	176103.81	195403.87	211069.87	226735.81	242401.81	258067.78	
	187609.46	206071.93	228071.28	240146.50	355500.53	270940.00	286533.06	
8.	49643.82	46841.82	75068.26	43740.25	42347.54	41370.40	40604.97	
	53736.24	49370.85	46786.73	45319.66	44144.87	43169.52	42338.63	
	103380.06	96212.67	121854.98	89059.90	86492.42	84539.92	82943.60	
	13956.30	12988.70	16450.42	12023.08	11676.47	11226.99	11147.17	
	156738.84	176103.81	195403.87	211069.87	226735.81	242401.81	258067.78	
	188200.50	206597.87	220359.65	240598.31	255017.65	271134.18	286720.31	
13.	54299.36	50723.73	86877.76	46762.78	44982.49	43733.73	42755.64	
	68396.67	62425.05	58890.13	56883.25	55276.20	53941.98	52805.37	
	122696.03	113148.78	145767.90	103646.03	100258.68	97675.71	95561.01	
	16563.96	15275.08	19678.66	13992.21	13534.92	13283.78	13078.04	
	156738.84	176103.81	195403.87	211069.87	226735.81	242401.81	258067.78	
	187311.06	205387.15	229000.81	239070.34	254279.00	270493.84	285854.12	
16.	32842.81	36704.57	36570.78	33856.15	31653.82	30408.73	29602.94	
	46532.95	43221.75	41261.67	40148.88	39257.78	38517.97	37387.73	
	79375.76	79926.32	77832.45	74005.03	70911.10	68926.70	67490.67	
	10715.72	10790.05	10507.38	9990.67	9572.99	9346.33	9124.53	
	156738.84	176103.81	195403.87	211069.87	226735.81	242401.81	258067.78	
	217707.84	237147.12	256164.53	271313.81	286562.06	301101.43	317695.62	
20.	32952.14	31596.95	45314.23	30095.41	29420.34	28946.85	28576.00	
	41540.60	38716.56	37044.85	36095.78	35335.78	34704.82	34167.29	
	74492.73	70313.51	82359.07	66191.18	64756.12	63651.67	62743.29	
	10056.51	9492.32	11118.47	8935.81	8762.07	8632.58	8437.16	
	156738.84	176103.81	195403.87	211069.87	226735.81	242401.81	258067.78	
	216082.00	235782.78	256709.00	270192.31	285664.56	301271.06	316391.62	


TOTAL ANUAL COST
VS PLUMBING COST
ANUAL RUNNING COST
VS PLUMBING COST
PT.OF CONTRAFLEXURE
(MIN.ANUAL COST)
OPTIMUM ANUAL
RUNNING COST
OPTIMUM PLUMBING COST
300
290
280
270
260
250
240
230
220
210
200
190
180
50
60
70
80
90
100
110
120
130
140
ANUAL COST OF RUNNING IN THOUSAND RUPEES
COST OF PLUMBING IN THOUSAND RUPEES

OBSERVATIONS FROM THE SECOND GROUP OF RESULTS:

1. It is interesting to note that the schemes 6,13 and 8 are in the range of lowest annual cost.
2. The lowest of the three is the scheme number 6 and amounts to Rs.3.28 lacks per annum.

The other schemes (1,3,16,20) produced higher annual cost even though the first cost of plumbing was 40 percent to 50 percent lower than the previous group.

3. This has occured because of the fact that the annual cost also included the annual costs of lighting and cooling apart from the amortising cost of plumbing.
4. The lowest annual cost computed here is sufficient for the purpose of selecting a scheme or plan and can be further refined by testing the lowest running cost of every individual service within the range of pressures obeying the eompirical formula for frictional losses in stream line flow.[1]
5. The cost-benifit analysis shows that a ten p.c. increase in the investment on plumbing is offset by the gain in the annual running cost within a period of 1.5 to 2 years. At very low allowable frictional losses, the results of the cost-benifit data follows the law of diminishing return.

---

1. It is noted here that in the second output data the first two columns of results of plumbing costs are not reliable as the permissible frictional loss in pipes were too low to obey the empirical formula used in computation.

6. It is interesting to note that the range of schemes which proved their merits through retionalisation, seldom caught the eye of even experienced architects.

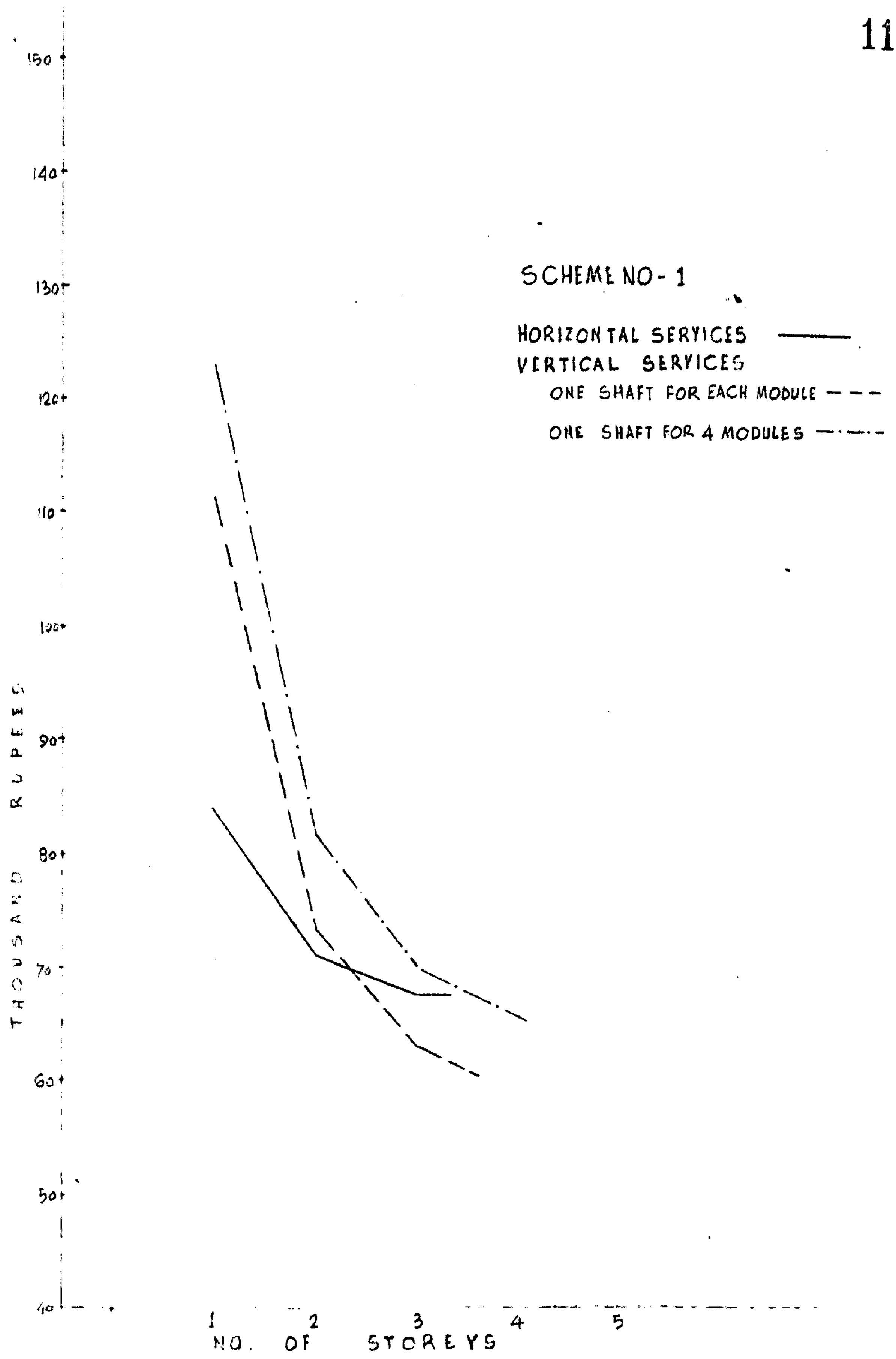
A general survey was conducted to compare the results of rationalisation with those of intutions. For this purpose all the schemes were placed before a number of architects independently to select a scheme, out of the 60 alternatives, which in his opinion would incur the minimum annual cost. The result of the survey revealed that only 5 p.c. could chose the correct form. In most of the cases the forms which incurred the minimum plumbing cost were considered to incur minimum annual cost also.

The nearest appronimation one could strike at was the laboratory plan in two dimensions but in terms of three dimensions i.e. the mumber of floors, non of the intutive results confirmed with the results of rationalisation. The 5 p.c. correct results can not be considered significant and there is a possibility of chance in it.

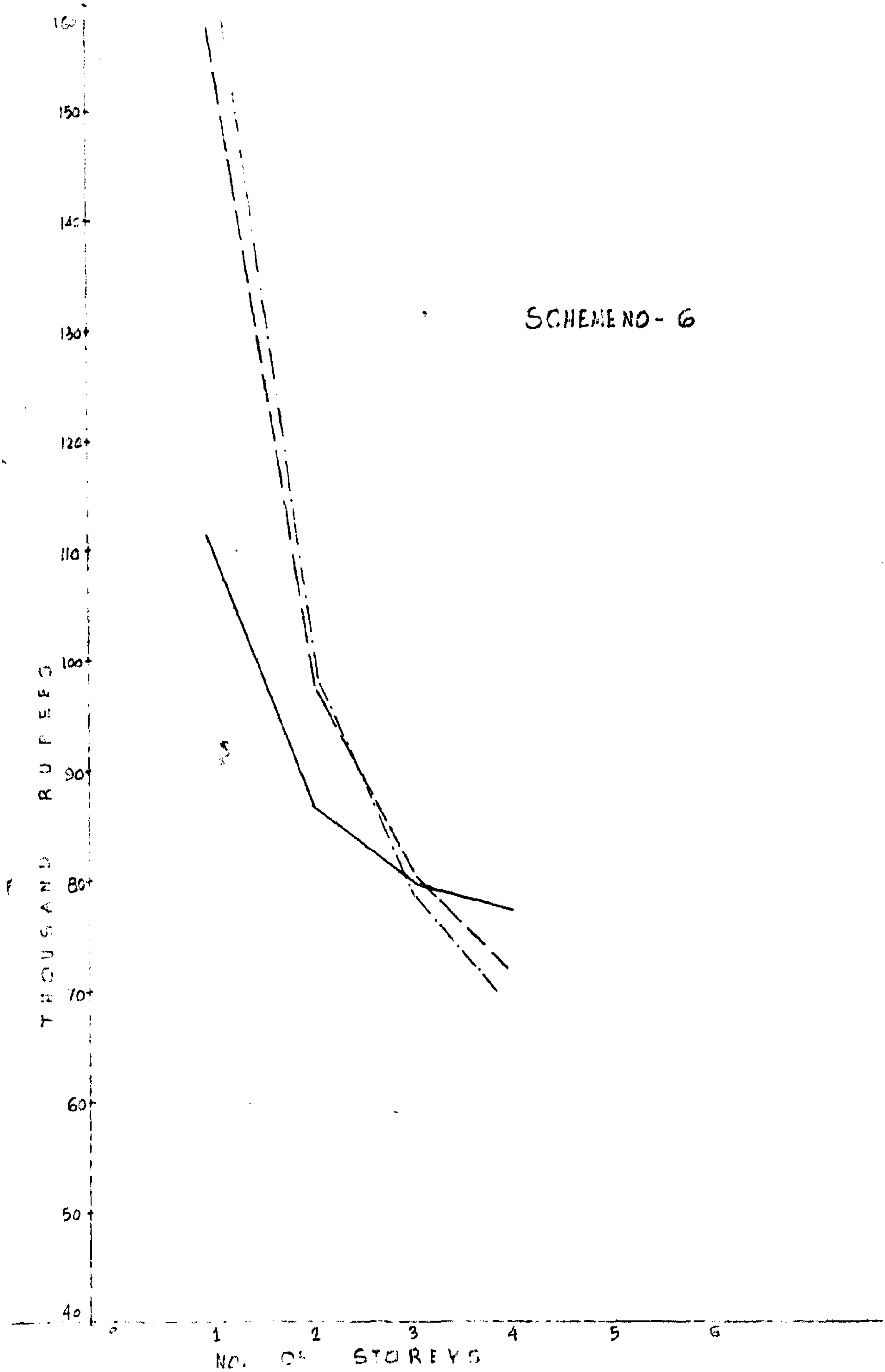
This survey reinforces the need for rationalisation in projects where physical functions are of prime importance.

General Statistics of the Scheme Selected:

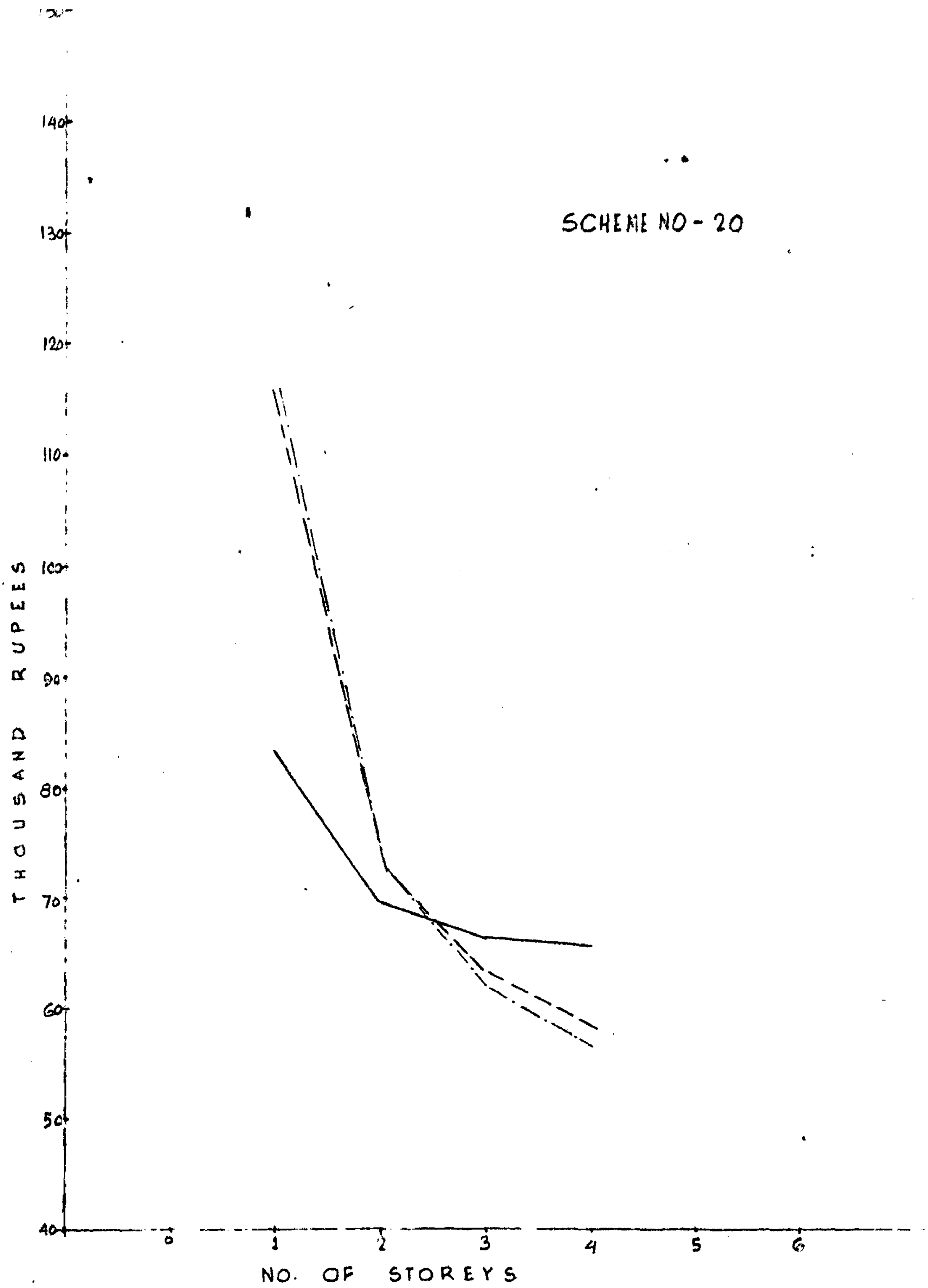
The general statistics of the scheme which proved



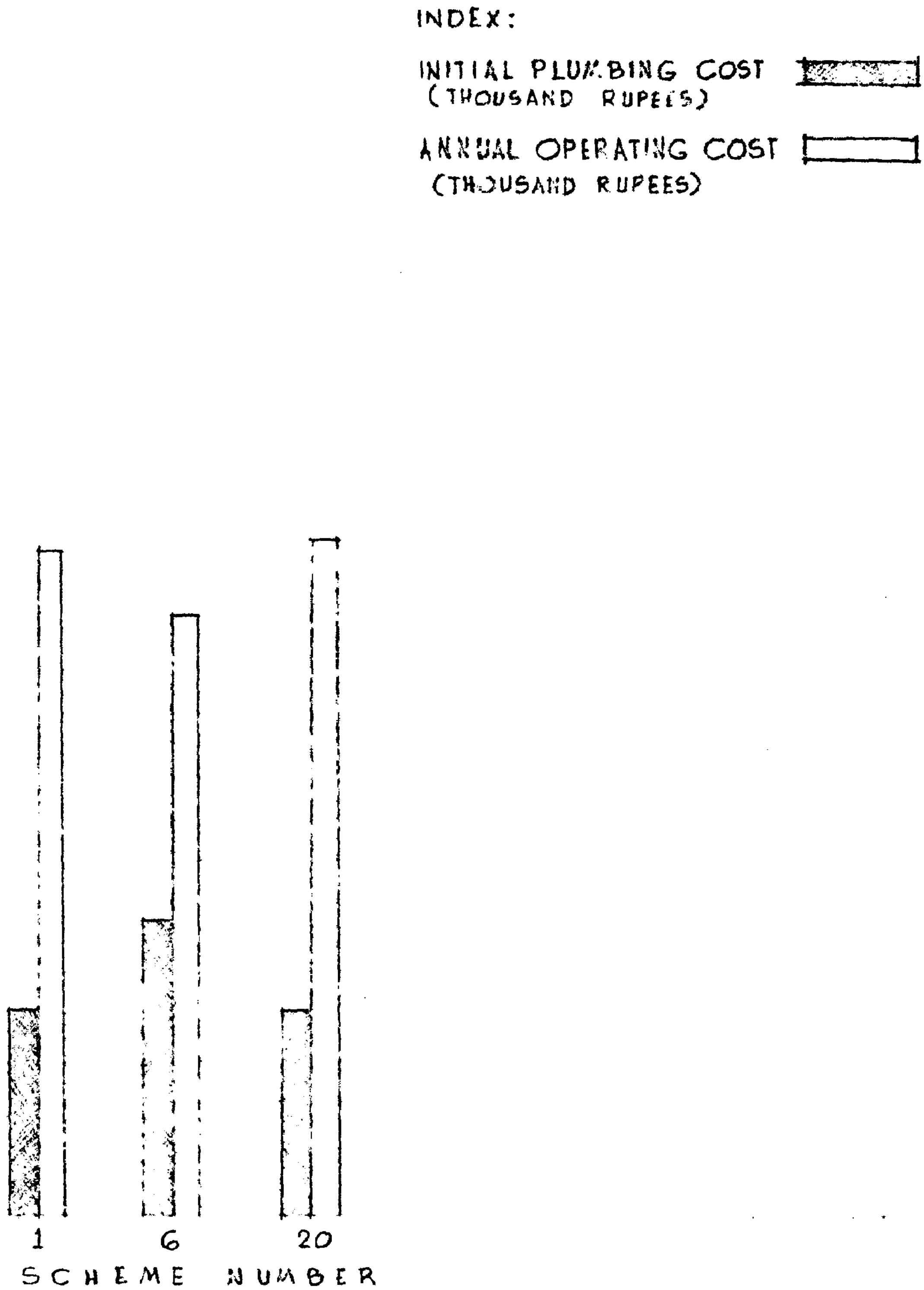
IMPACT OF 'FORM' ON INITIAL COST OF SERVICES



IMPACT OF 'FORM' ON INITIAL COST OF SERVICES



IMPACT OF 'FORM' ON INITIAL COST OF SERVICES



PARITIVE ANALYSIS OF CAPITAL & ANNUAL OPERATING COST OF SERVICES IN LABORATORIES to be the most economical in terms of the annual cost of services has been given below for refering afterwards when the scheme is dealt with in the form of working drawings and details. The code number will fecilitate in locating the scheme in the library of computer programme and data bank when further details on costs and sizes of plumbing material will be required for preparing estimates, calling tenders or placing order forthe supply of materials etc.

Code number - (16-3)

Dimensional Statistics:

- Modules

Laboratory	- 10'-0 x 23'-0 (230 S.F.)
Office	- 8'-0 x 10'-0 (80 S.F.)
Store	- 10 S.F.
Height (floor to floor)	- 12'-0
Safty egress	- to the adjacent laboratory
	- to the adjacent office cabin

- Building Block

Number of floors	- Three
Number of rows perfloor	- Two rows with a central corridor
Total Plinth area	- 25000 S.F.

- Service System

Horizontal branch feeders running through the Central Corridor in every floor.
Bench connections: Up feed system serving the floor above.

- Lighting

  Natural light is available through 30 p.c. glazed north and south walls (all fenestrations shaded)

  Permanent artificial supplementary lighting load - 67 K.wt. hr.

- Peak Cooling load - 30 Tons

Cost Statistics

Plumbing costs	- Rs. 1.12 lacks
Amortising cost	- Rs.15230.00
Annual running cost	- Rs.1.95 lacks
Total annual cost on service	- Rs.2.28 lacks
Total cost of the Building work	- 8.75 lacks at the rate of Rs.35 per S.F

Structural

R.C.C. Frame structure

10 inch Thick external brick walls

4½ Thick R.C.C. roof

4 inch Average lime terracing on roof.

Furniture Arrangement:

The peninsular serviced benches (16 ft long) are perpendicular to the corridor with the position of the hood near the entry door. The central island benches are 12'-0 inch long with one large sink on the corridor and serving both the benches.

The cupboards, drawers, writing table and other non serviced furniture (10'-0 inch long) are placed along the external wall.

The piped supplies from the ceiling of the corridor below are served to the benches through service-ports under the hood. The conditioned air and exhaust air is supplied and extracted from the ducts in the ceiling of the corridor of the same floor.

The scheme mentioned above proved to be meritorious in terms of the services system only. The structural cost and its amortising cost needs to be correlated with the cost of services and form to get the most accurate picture of the scheme. However the variations in the structural cost of the seven schemes, that had been selected for further optimisation, will not be so high an order so as to influence the total annual cost and there by the selection of the scheme.

Concluding Remarks:

It is concluded from this study that the designs based on apprehension and intution often prove to be unrealistic in later stage when it is beyond repairs or repaired after a heavy alteration.

In laboratories, the services play a vital role and an unoptimised scheme may drain out a huge additional amount from the pocket of the client annually than it could usually be expected. This may even balance the cost of the structure itself during its life.

An additional expenditure in plumbing for providing larger capacity pipes and ducts prove to be economical in long run and the additional expenses are offset within a short period through gains in annual cost.

The form so obtained is only a box with the broad dimensions of length depth and height. It is still open to the architects ingenuity to blend this functional form with its environment like any other functional yet aesthetically sound form -- biological or machine.

Apart from the selection of a scheme, this study may prove to be useful to the professional architects in many other ways.

He can detail out the scheme with more confidence. With a knowledge of service system, and sizes of pipes and ducts, the pumctures in the walls and floors, the height of the suspended ceilings and blending of service lines become easier for him.

Services in laboratories consume a major share of the capital investment and needs precise allocation in the budget to be trouble free in the advance stage of designs. The computer results on plumbing costs are fairly reliable in this respect to be adopted during budgeting.

The plumbing and mechanical engineers can proceed with their part of the job without much time lag between the architectural design and plumbing and air conditioning design and load the project i.e. the drawing office work as well as the erection work to be completed in schedule-time.[1]

In calling tenders a precise knowledge of the total cost of plumbing is available before hand. If the circumstances demand, the architect can place orders to the plumbing suppliers for the supply of materials.

Besides the direct benifits of the study, the concept of the synthesis of 'form and services' is applicable from the 'micro' to the 'macro' level of 'form and services'; the 'micro' level being the services in a building and the 'macro' level being the master plan of a city. In between the two extremes there are many levels with many dimensions of form and services.

The application of the concept in the various levels of 'form and services' may save the developing country with crores of rupees.

However, further research on this concept is required and there is a wide field open for it. Within its limitations

1. Lately produced plumbing and a.c. designs demand higher man-power on the site to complete the project in time and thus increase the overall cost of the project or leads to the loss of interest on the capital if not completed timely.

of time and resources this dissertation only provides a glimpse to the subject.

Paul Rudolph has said that 'Form is the outcome of the spirit of the times — economic and sociological conditions.'[1] We are in an age of optimisation where economics plays a vital role. Rationalisation, 'the spirit of the time' can be applied in many facades of architecture of our age such as industrial and commercial architecture, mass housing etc. and ofcourse the monumental or religious architecture and similar others have their own place but the architects in general refrain from experimenting on rationalisation with the fear that rationalisation has sterilising effect on the creative faculty of a designer.

But as Shakespeare said, ' Doubts are traitors and make us lose the good we oft might win, by fearing to attempt.'

---

1. Paul Rudolph, 'The six determinants of Architectural Form', Architectural Record, Oct., 1956.

APPENDIX I

QUESTIONNAIRE FOR SERVICES TO BE CENTRALLY SUPPLIED

Item Plumbing	Name of Service	Required Yes	No	Use Intensity High	Low	Indicate Pressure High	Low	Remarks if any
1. Cold Water								
2. Chilled Water (40°C)								
3. Hot Water								
4. Distilled Water								
5. Demineralised Water								
6. Gas for heating								
7. Compressed Air								
8. Steam								
9. H_2S								
10. Oxygen								
11. Nitrogen								

12. Laboratory Wastes	Corrosivity High.	Medium.	Low	Contanimants High.	Medium	Low

13. Lab. drain for clear water

	Separate from waste Drain Yes	No.	Use Intensity High	Low

Ventilation:

1. No. of persons per hood   Length Ft.   Face Opening S.F.   Duty Heavy Low

2. Type of hood   Glass door   Overhead   Self-purgi

3. Rooms to be specially air-conditioned.

No. and Name of room	size	Tem	Hum.	Air change
1.				
2.				
3.				
4.				

4. Hood in such rooms   Yes.   No.   Duty Heavy Low

5. Machines in room   Yes   No.   Horse Power

Lighting:

1. Type of lamp   Flourescent   Incandescent   Mixed

2. Natural light essential   Yes   No.   Partial

3. Power AC:

220/single phase	Yes	No
3 phase	Yes	No
440 volts DC	Yes	No

APPENDIX II

DESIGN QUESTIONNAIRE FOR SPACE REQUIREMENTS:

1). LABORATORIES:

Module:

a. width of working surface ______ feet ______ inches

b. Desirable maximum continuous length of work surface..................feet.

c. Height of the tallest common laboratory apparatus ....feet................inches.

d. Desirable hood location within the laboratory, near door..............., near window.............,other.........

e. Linear feet of hood permodule................feet.

f. Number of sinks per module, one for..............one for each laboratory.................

g. Minimum door width.........feet.............inches.

h. Number of office type desks for laboratory workers per module.........................

i. Number of kneehole space per module................

j. Length of desk.............feet...........inches.

k. Number of filling cabinet drawers...................

l. Linear feet of shelf space in cased storage cabinets per module.............feet.

m. Coat and/or laboratory apron closets Yes/No.

Safety:

a. Secondary egress from the laboratory...............

b. Safety showers at entrance to each laboratory............. (if in corridor, give separation)..........feet.

c. Eye wash fountain in each laboratory.................

d. Safety blanket storage in each laboratory..............

e. Hand fire extinguisher at entrance to each laboratory.....

(B). OFFICE:

1. Module:

a. Laboratory leader. One per occupany...................
two persons occupany......................, furniture
required per person....................

b. Group leader, One person occupany..................,
two person pcci/amu..
furniture required per person.........................

c. Staff and administrative personnel. One per person
occupany................, two person occupany..............
group occupany...............square feet per person.......
in group office occupany.

d. Executive personnel. Size.........feet by............
feet adjacent secretarial space.............,connecting
labatory.................

(C) PILOT PLANT:

1. Module:

a. Width................feet

b. Height.............feet

c. Depth ....feet

d. Piped services

e. Electrical Services

f. Ventilation. Average exhaust air per module..........
cubic feet per minute, maximum exhaust air per modle
...........cubic feet per minute.

(D). Library............(if required, develop needs by conferenc

(E). Cafeteria..........(if required, develop needs by conference).

(F). Conference Rooms:

1. Maximum number of people.........................
2. Fixed seats...............movable seats............
3. Blackboards............linear feet
4. Project facilities...........................
5. Laboratory demonstration facilities.

(G) SHOPS:

1. Type and area of each

(H). LOCKER ROOMS:

1. Locker size..................................
2. Shower facilities.......................

(I). Auxiliary Space:

1. Lockers. Size of locker.......................
2. Laboratory supply storage. Linear feet of shelf...........
3. Gases under pressure..............., number of types.........
   number of drums................
4. Solvent storage. Linear feet of shelf............,
   number of drums..................
5. Dangerous chemicals. Linar feet of shelf..............
6. General and office supplies. Linear feet of shelf.........
7. Photographic and reproduction space area..................
8. Janitor's and guidard' locker rooms.....................

(J). Number of Employees:

Men Women

1. Total personnel
2. Office personnel (including those in categories (3), (4) and (5) who are located in the offices in addition to having desk space elsewhere).
3. Laboratory personnel
4. Shop personnel
5. Pilot plant personnel
6. Locker rooms Men Women
7. Janitors, guards and maintenance

(K). Space Quantities:

Number of Modules:

1. Laboratories	Laboratories Large	Laboratory Small	Pilot	Office	Eq.ft. lab special
a. Standard	....	....	.....	.....	.....
b. Special	....	....	....	....	.....
2. Offices:					
a. Scientist	....	....	....	....	.....
b. Group leaders	....	....	....	....	.....
c. Assistants Staff	....	....	....	....	.....
d. Executive	....	....	....	....	.....
e. Secretarial	....	....	....	....	.....
f. Small Conference rooms	....	....	....	....	.....

f. Closet for other safety devices on each floor

...............List items to be included................

3. Services:

a. Centrally generated and generally distributed services

1. Piped services. Cold water.........., $40^{o}C$ chilled water...........,hot water............., distilled water............,gas................, high pressure air...........psi, low pressure air.............psi, hydrogen...........,nitrogen ....,oxygen..........,laboratory waste........., clear water drains.............., other.......................

2. Electrical power, 220 single phase and/or 3 phase, 4 wire a.c...............volt amperes per square foot, 440 volts three phase a.c........... volt amperes per square foot, 400 cycles a.c........... volt amperes per square foot, direct current......... volts,..........volt amperes per square foot, ground...........other.......................

3. Hood exhaust. Area of hood opening per module ....square feet, hood face velocity....... per minute, maximum square feet of hood opening in any one module or laboratory........square feet.

b. The Special Services:

1. Special gases,,.........................,

2. Electrical low voltage..........., other..............

3. Special air conditioning. Assuming that the entire building will be air conditioned for comfort, laboratory space requiring special conditions of humidity and temperatures, Number of Modules, Temperature Range Humidity range Internal heat gain-Btu.

BIBLIOGRAPHY

1. ASHRAE Guide and Data Book, 1961. New York: American Society of Heating, Refregeration and Air-Conditioning Engineers, 1961.
2. Babbit, Harold E. Plumbing. New York: McGraw Hill, 1950.
3. Baumeister, T. Ed. Mechamical Engineer's Hand Book. New York
4. Bishop Arica Mice, D. A Study of Coding and Data Co-ordination for the Construction Industry. London: Her Majesty's Stationery Office, 1969.
5. Campion, Devid. Computers in Architectural Design. New York: Elsevier Publishing Co., 1968.
6. Carrier, Wills H. Modern Air Conditioning, Heating and Ventilating. New York : Pitman Pub. Corp. 1950.
7. Coleman, H.S. Laboratory Design. New York: Reinhold Publishing Corp., 1962.
8. Fair, G.R. 'Notes on the Computer as an Aid to the Architects', Architectural Forum, (May, 1966).
9. Harper, NeilG. Ed. Computer Application in Architecture and Engineering. New York: McGraw Hill, 1968.
10. Hunt, William D. Jr. (Ed). Creative Controll of Building Cos New York: McGraw Hill, 1967.
11. Jarrold, Richard. 'Pharmaceutical Plant in Puerto Rico', Chemical Engineering Progress, (Vol.66, 1970).
12. Kinsey, Bertram Y., Sharp, Howard M. Environmental Technologies in Architecture, New Jersy: Prentice Hall, Inc. 1963.

13. Lewis, Harrey F. (Ed). Laboratory Planning (For Chemistry and Chemical Engg.). New York: Reinhold, 1963.

14. McGuinness, William J. Mechanical and Electrical Equipment For Building. New York: Johnwiley, 1971.

15. Munby, Alane E. Laboratories:Their Planning And Fittings London: G. Bell and Sons, 1931.

16. Munroe, W.G. 'Cooling Load Calculation', Arch. Record, (January, 1965).

17. Newman, W.M. 'An experimental Programme for Architectural Design', The Computer Journal, (May, 1966).

18. Nielsen, Louis S. Standard Plumbing Engineering Design New York: McGraw-Hill, 1963.

19. Palmer, R.R. and Rice, W.M. Modern Physics Building New York: Reinhold, 1965.

20. Pitzer, M.S. 'Pipe Work Detailing by Computer', Chemical and Process Engineering (Nov., 1969).

21. Pulver, H.E. Construction Estimates and Costs (Fourth Edition, Chapter, 13), New York: McGraw-Hill Book Co., 1969.

22. Salvadori Mario. (Ed.). Mathematics and in Architecture, New Jersey: Prentice Hall, Inc., 1968.

23. Sevens and Fellows. Air Conditioning, New York: John Wiley and Sons, Inc. 1958.

24. Smith, Herbert L. (Ed.). Buildings for Research. U.S.A: F.W. Dodge Corporation, 1958.

25. Stuart, A.H. (Ed.) Pocket Book The Practical Engineer, London: Oxford University Press, 1949.