ARCHITECTURAL DESIGN OF ROOFING SYSTEMS IN INDUSTRIAL BUILDINGS

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF ARCHITECTURE

By

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CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **ARCHITECTURAL DESIGN OF ROOFING SYSTEMS IN INDUSTRIAL BUILDINGS** in partial fulfilment of the requirement for the award of the degree of **MASTER OF ARCHITECTURE** submitted in the DEPARTMENT OF ARCHITECTURE AND PLANNING of the University, is an authentic record of my own work carried out during a period from 25th July 1992 to 10th Feb. 1993 under the supervision of Dr.(Mrs.) S. Sahu and **Ms. Rita Ahuja.**

The matter embodied in this thesis has not been submitted by me for the award of any other degree.

(SANJAY BHARGAVA)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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CHAPTER 1

INTRODUCTION

1.1. ROLE OF ARCHITECTS IN THE FIELD OF INDUSTRIAL BUILDINGS

Industrial Architecture the world over has come a long way since the advent of Industrial revolution. The modern industrial system which today permeates our whole life is almost 200 yearS old, although the "factory system" originated about 400 or 500 years ago in England.

In recent years, industrial building construction has undergone fundamental changes. Not only have the functional conditions and technical possibilities changed - smoking chimneys and old fashioned north-light sheds of bricks are also a thing of the past. In India, however till as recently as a decade and a half ago,factory design still fell into the realm of what could be best called "functionalism". For a long time architects were seen as unnecessary, even unsuitable for factory design, especially in India where, for some reason factories, along with roads and bridges, had long been considered as being within the realm of "engineering design". Although the engineers had forced the architects to the path he must eventually follow, but it has been a difficult task. The architect felt that this art was being discreted by the engineers passion for structure and its relation to purpose and as a result he continually sought to abandon the field of industrial development.

But, now there is a growing recognition of the fact that architecture and aesthetics need not be confined to the planning and execution of buildings alone. They can play a useful role in the design and construction of bridges, fly over, industrial structures, marine and aviation structures, landscaping along highway etc. Architects need to be trained in various aspects of engineering because advances in building construction technology have resulted in a vast array of new materials and increasing complex techniques of design and construction. Although there were engineers with as developed a sensibility of aesthetic as any one else, they were more often the exception than the rule. The ~~result : factories and industrial structure that often functioned~~ well but were generally dismal to look at.

Good factory design involves the right balance between form and function. A factory has to meet the functional requirements of both the client commissioning the project, as well as the workers using the designed space for perhaps a good part of his life.

Many architects are still imbued in notion that industrial plants are either "industrial buildings" pure and simple where the appearance is of little relevance, or are of "subordinate character and therefore hardly worthy of architectural effort. Such a notion, dating back to the 19th century, its not only nonsensical but even dangerous It is dangerous because even by their very size, modern industrial plants have a considerable influence on their environment. This also represent a major task in the professional training of architects.

Structure/envelop has a vital bearing on the shape of an industrial building. In words of Ludwig Hilbersheimer "There is a freedom to choose the structure but once chosen, there is freedom only within its limitation. To discover these limitations and to develop the structure accordingly in the requisite of any architectural work".

All these factors emphasize the need for careful planning of building design and providing an economical structural system which would be functionally feasible, provide better working and aesthetic conditions.

1.2 PURPOSE AIM AND OBJECTIVES OF THE STUDY :

The main purpose of the dissertation is to contribute in a small way to the ongoing research in the field of Industrial buildings, specifically finding solution to the problems associated with the roofing system.

The other objectives are :

1. To formulate a system for adopting type of roofing system which will ~~will~~ be functionally feasible, generate economy, provide better aesthetics and working condition in different class of industrial buildings.
2. To formulate a system for selecting different roofing options for covering different spans in Industrial buildings.
3. To evaluate and analyse impact of outer envelop on internal environment of a industrial building i.e. effect of form and structure on function and internal environment of a industrial building.

1.3 Scope of Study

The design of industrial buildings was considered to be beneath the dignity of the architect unless they were marked by a facade of masonry or brick work. As a result the architect received no formal training nor experience to fit him the task and the initiative was passed to the Engineers. Now, for the past few years changes have taken place, the architect once given free hand they never looked back.

There is probably no sphere of industrial buildings which the architect has a greater task to perform than in the design and construction of fabric.

The scope of this study is :

1. To present all the information on the architectural design of roofing systems in industrial building. At present this vital information is scattered through numbers of technical periodicals, research reports and text books etc.

2. It will provide guidelines to practicing architects, working on industrial buildings, projects, helping them in selecting a roofing system, during architecture design process.

3. It will also stimulate research in field of industrial building.

1.4 LIMITATIONS

The study is limited to :

i) Architectural design of industrial building with special reference to roofing system.

ii) The data will be collected from the secondary sources, books, journals, research reports through persons working in the field of industrial buildings.

1.5 Methodology

The methodology is divided into three main steps :

Step 1 - Study of Existing trends

Step 2 - Analytical Study

Step 3 - Guidelines/Inferences

1. - Studying the available literature, earlier research studies, papers, seminar reports, articles in different journals and collecting information on industrial buildings with special reference to roofing systems.

2. Analysing and identifying problems associated with roofing systems in industrial buildings through case studies.

3. Suggesting guidelines based on inferencesfor formulating a system that shall be helpful in choosing/selecting roofing system during design process of industrial buildings.

1.6. DEFINITIONS OF INDUSTRY AND ARCHITECTURE

INDUSTRY - The industry, which is a simple or complex relationship of input, process and output, where labour, machine, material and energy are combined together to produce an economic product [1]. It is a technical and specialized field of Mechanical

Engineering, mainly but coordination with the economist, the business manager, the planners and the architect is always beneficial and necessary.

ARCHITECTURE - In the same way architecture is aimed at creating special environment for mankind. It is an art or science of building, structure or distinctive style of building, exerts on ideological and emotional influence by specific forms of its structure and character of spatial organization, that is by means of architectural images[2].

These definitions accept the relationship between industrial function and human convenience as their esteemed common goal for its design on the site. Therefore, the team of experts as policy maker, for any industrial design should include the planner and also the architect. They will ensure the physical planning and space utilization, without causing immediate, or future, danger to human environment.

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1. Murther, R. "Practical Plant Layout", McGraw Hill Book Co. New York, 1965, Chapter 1.
2. Rimsha, A., "Town Planning in Hot Climates", Mir Publisher, Moscow, 1975, pp 275.

2
LITERATURE REVIEW

CHAPTER - 2

LITERAURE REVIEW

2.1 INTRODUCTION

Before proceding to formulate guidelines for adoption of industrial roof, it is essential to go for an extensive literature survey. The analysis of these informations facilitates to form a base for further study. This chapter of the study presents a general overview as well as the abstract of extensive literature survey. The literature survey is specially directed to the existing trends of practice of roofing systems and their classifications.

2.2 DEVELOPMENT OF INDUSTRIAL BUILDINGS

The modern industrial system which today permeates our whole life is almost 200 year old.

The early buildings were of load bearing brick work or masonry with timber roofs and very wide window openings.

1740 - Method of making steel by Huntsman, led to the advent of industrial revolution.

1750 - Use of iron in machinery.

1750-1800 - Source of power changed from manual to steam. Grave evils followed the advent of steam powered factory, which marked a most radical change. The desire of the factory owner to economise meant low ceilings.

- Windows space was reduced to a minimum.
- Ventilation was nonexistent .
- Lighting totally inadequate .

1802 - A bill was introduced in British Parliament to improve condition of factories, i.e. all walls and ceilings of factories were to be whitewashed twice yearly, and windows areas must be adequate for ventilation.

1800-1825 Earliest use of cast iron in buildings. Timber warehouse roofs extremely liable to catch fire and destroy the whole building, e.g. 1802 - A Granary burn down by fire in Paris. In 1811 it was rebuilt by an Architect and Engineer working in collaboration, starting a trend which has now been widely accepted all over world.

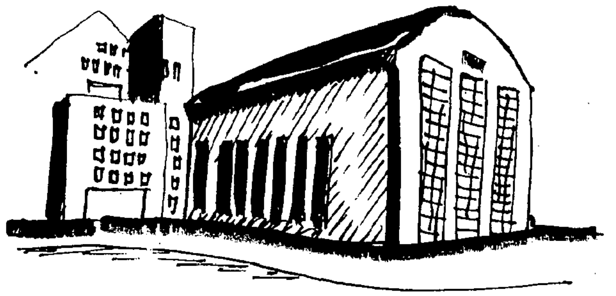
Two types of industrial buildings were prominent :

(i) Merely erecting a shed of neatest and most basic type

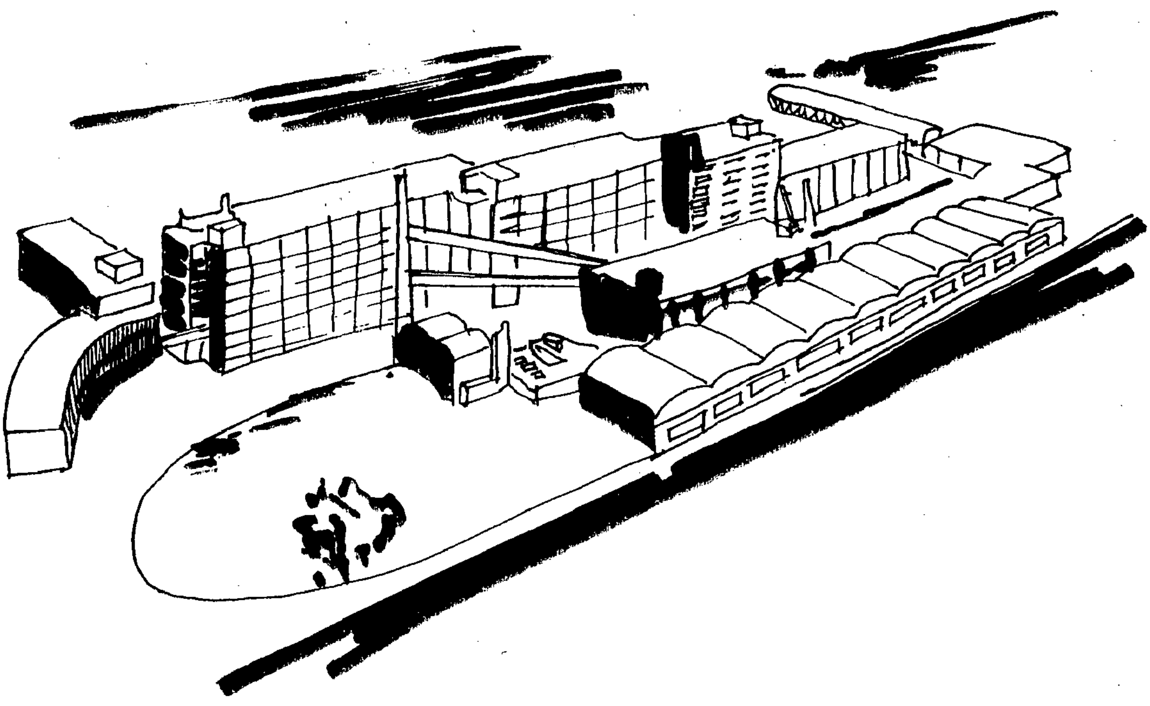
(ii) Cloaking the building behind a classical facade, Architect was reduced to an exterior decorator. Many industrialists still consider this as the only contribution, the architect can make.

1845 - Zosgraves, a Paris iron founder produced the first wrought iron joist to be rolled. This produced a far reaching effect on industrial design.

Wooden attic of factory 1800, Gt. Britain.



Behren's assembly shop 1911-12, Germany



Van Nelle factory, Netherland
a finest example of prewar factory

source - pp. 5, 8, 10 Munce J.F. 'Industrial Architecture'. ILIFFE BOOKS Ltd. London - 1960

Fig 1. Development of Industrial Buildings.

S.B 1992-93

1871-72 - First true skeleton building was erected (industrial building). The chocolate works at Noisiel - Sur - Marne, built by Jules Saulnier.

1890-1900 - Hennebique, a French Engineer evolved a new form of reinforced concrete but due to high rate of skilled labour, the contracting industry found them impractical. An American Engineer, Ransome developed a simpler form of reinforcement, a twisted square iron rods. It was effective and economical.

1900-1915-Peter Behren, a German Architect, made a positive contribution to industrial architecture in particular and modern architecture in general. His turbine factory in the Huttenstrasse, built in 1909, was a huge-framed structure, with masonry enclosed corners and glass infilling giving a tremendous feeling of space. His buildings were very monumental in scale and classical in feelings. Two other German Architects Hans Poelzig and Walter Gropius made significant contribution to the development of the factory design.

1920-30- The slump and depression made a profound effect upon the whole industry, the most significant being on the sociological and technical side. The architect was forced to consider not only the fabric of building, of the buildings, but also the process taking place in it, and well being, health and moral of the workers.

1927 - Van Nelle Factory, Rotterdam, which still stands today in undiminished quality

2.3 FUNCTIONAL DESIGN REQUIREMENTS FOR INDUSTRIAL BUILDINGS*

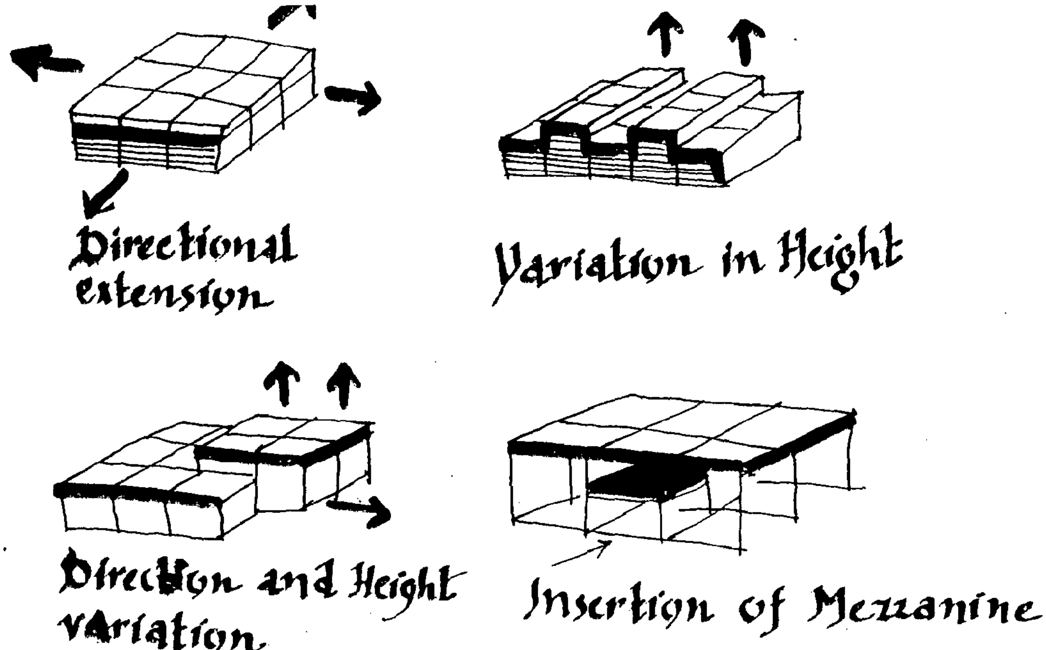
"Functional Design" - The purpose of an industrial building is to facilitate production. It should house the manufacturing equipments in such a manner as to enable that equipment to function efficiently. To this and the general scheme is all important and should provide :

1. Straight Line Production - Various departments for successive operation located to effect a simple and direct production flow. So that transportation and handling of materials will be cut to a minimum. There should be no crossing or retracing of the production line with con-sequent congestion.

2. Flexibility - A departmental layout sufficiently elastic to permit rearrangement in accordance with changes in production methods. Or expansion of departments or production expansion without disorganizing the existing scheme.

3. Generous column spacing - Interior columns spaces as far apart as economically possible to allow for free location of machines and cause the least interference with the transportation of materials.

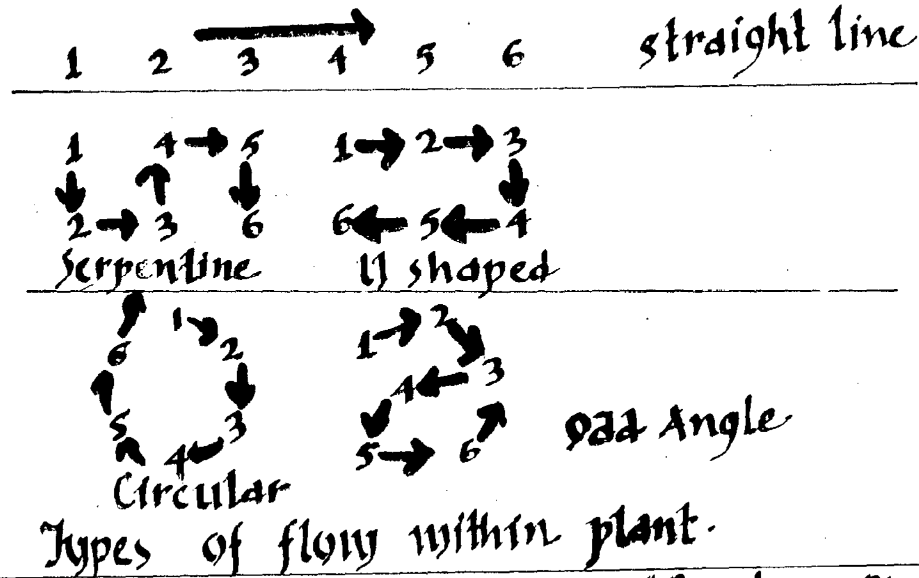
4. Suitable floors and ceilings - Clear ceiling heights adequate for the work performed, and floors strong enough to meet all loading requirements.



"Concept of flexibility and Multiplicity of Industrial Building."

* source - pp10, Grube O.W. "Industrial building & Factory" The Architectural press, london. 1971

Fig 2 Functional Requirements of Industrial Buildings.



Types of flow within plant.

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* Source - pp 195, Murther R., "Practical Plant layout" Mcgraw Hill Book Inc, New York, 1955.

5. Properly located utilities - Elevators, Stairs, Locker and Toilet rooms located where they best serve the purpose and do not interfere with the flow of production.

6. Good lighting - Adequate natural and artificial illumination, properly distributed and of sufficient intensity for the tasks performed. Absence of disturbing glare.

7. Adequate ventilation - Air movements sufficient for human needs, and special equipment to meet any problem created by the manufacturing process.

8. Low first and upkeep costs : Economics resulting from skilled design and the efficient use of materials, reducing both initial costs and maintenance expense to the minimum.*

2.4.0 Classification of Industries :

There are various methods of classification of industries according to the purpose it is called for. Therefore, an attempt has been made to classify the industries to suit to architectural design from the various types of classification.

The most general classification of industry is done as per the service characteristics of the basic industrial product. It may be as: (a) Basic industry, (b) Service industry, (c) consumer goods industry. The other mothod of classification of the industries be based on process involved in it, such as: (a) Extractive industries, (b) Process industries, (c) Oil and fats

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Source : * Grubè, O., Industrial Buildings and Factories, Architectual Press, London, 1971, pp 14.

based industries, (d) Forest based industries, etc. The other method of classification of industry is on the basis of employment potentials such as (a) labour intensive, (b) machine intensive. The basis for classification of industries may be as capital intensive or labour intensive also.

The above classification may hold good for collection of statistical data and for industrial census.

In order to assess the physical criteria for the planning and designing of industries following type of classification of industries, is advantageous: (a) It is based on production capacity, (b) load handling capacity, (c) nature of process involved in it like, (i) continuous or (ii) interruptable*, (d) consumption of power, i.e. i) large scale, (ii) small scale, (iii) cottage industries. (e) Accessibility requirement, (f) type of industrial waste discharged, (g) obnioxious characteristics, (h) hygienic requrements, (i) pollution qualities and its harmful effects on surrounding, and (j) statutory status given to industries on account of human safety and risk involved in it, and lastly as (i) Mill or Factory, where the process and product are linked together with envelop for classification of industries.

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* Grant I.W. and Grant, El., 'Hand Book of Industrial Engineering and Management', Prentice Hall of India (P) Ltd., New Delhi, 1969, Chapter 1.

2.5 GENERAL REQUIREMENTS FOR SELECTION OF ROOFING SYSTEMS

The most suitable structural form are those which satisfy following requirements.

1. Speed of Erection

Preferable systems are those which are prefabricated at the factory e.g. steel triangulated frames, portal frames either steel or precast concrete, they are economical initially, lighter and are less affected by foundations settlements than other alternatives.

2 Enclosure Free of Obstructions

The requirements are usually met by stressed strain structure such as

a) A two curved shells - the dome and hyperbolic paraboloid single clear spans of up to 200 ft, attained with R.C.C.

b) A single curved shell - 100 ft - presented edge beams. Others alternatives are (a) Arch ribs with cladding. (b) A space frame structure (e.g. Fuller's dome) with light weight cladding.

3. Adequate - Daylight

The requirement is met by

a) Saw-tooth roofs

b) North light cylindrical shell

c) North light steel roof

d) Conoidal shells

4. Low Maintenance

Concrete structures generally do not requires much maintencance, internally or externally, if adequate provision is made for good expansion joints and firm foundations.

5. Provision Made For Heavy Fixtures

If fixtures like cranes service ducts, pipes are to be installed, provision should be made in original design for such fixture, steel frames are suitable.

6. Flexibility in Use

The multispan, single storeys steel or concrete structures is most suitable, both functionally and economically, because it permits zonings of production areas and storage, facilitates even day lighting and allows intermediate columns to serve as anchorages for sub-division.

7. Ease of Future Extension

Framed buildings allow easies union of existing and proposed new structures.

8. Specialised Production

A fully economical structure may be achived efficiently meeting all the process requirements. Such factories generally have a good appearance and require low maintenance, especially if the material of construction has been selected to suit the type of production, e.g. light weight concrete with good thermal characteristics for a factory manufacturing pharmaceuticals and other high quality chemicals, or laminated timber arches for a dyeworks.

2.6 ROOFIING OPTIONS - A CLASSIFICATION BASED ON CHOICE OF MATERIAL AND STRUCTURAL FORM

1) STEEL
2) R.C.C.
3) PREFABRICATION
4) COMPOSITE
5) TIMBER

2.6.1 STEEL :

Various types of arrangements of structural members may be used to support the external cladd ing and other loads.

(1) STEEL BEAMS - For light and normal building roof loads, beam memberscan span upto certain dimensions beyond that they will be deeper and heavier. For large columns free spaces for operational purposes, they are unsuitable.

SUITABLE SPAN - 6 TO 8 M

(2) TRUSSES - The logical choice for relatively light loads and large spans are the trusses. Trusses, therefore, can be considered as a stage in the evolution of structures from beams and girders, for large span. A truss is a longitudinal structure which carries superimposed loads to the support.

The truss is a jointed frame or structure which is designed to sustain inclined, vertical, or horizontal loads, occurring at or between its points of support, and which has the following characteristics :

a) Straight members

b) Members connected at their intersections by means of frictionless pin or hinges.

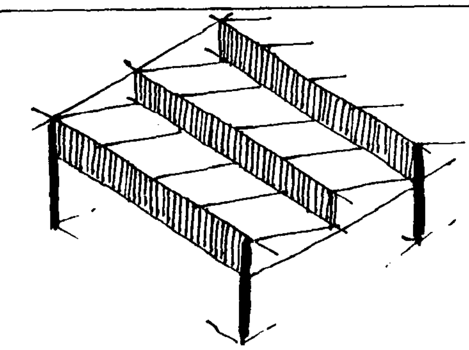
c) Members so arranged that the truss is loaded only at the joints.

The traingle is the basic geometric figure in a truss because the triangle is the only geometric figure which cannot be changed in shape without changing the length of one or more of its sides.

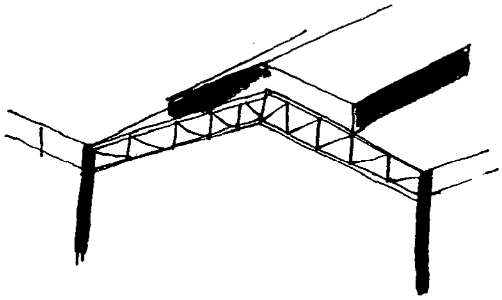
COMMON TYPES OF TRUSSES :

In buildings the trusses are most commonly used is for the support of roof of long clear span.

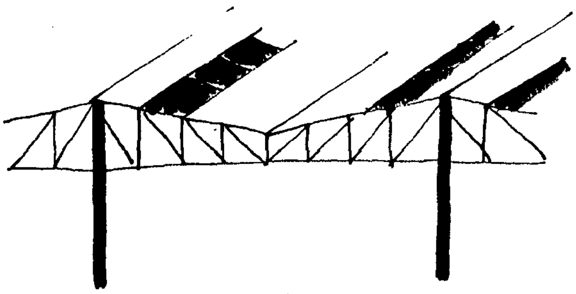
The trusses as shown in figure 4 (PRATT, HOWE, and FINK) are common types of trusses used for roofs of moderate span when a sloping or pitched roof is wanted. The Howe truss is best suited to timber construction but some times built with steel, although when constructed of this material, it is less economical than the PRATT TRUSS or the FINK TRUSS. The PRATT TRUSS is limited to moderate spans because of the wasteful use of material resulting when the vertical members become long. The FINK TRUSS may be used for span of greater length if the roof does not require support at close intervals. When the spans are long and roof must be supported at shorter intervals, the FINK TRUSS may be modified and used in the forms as shown in figures (FAN FINK, WARREN). The compound find may be "fanned" i.e. its web system modified to that used for the truss in FAN FINK, resulting in a truss suitable for fairly long span with the roof supported at relatively short



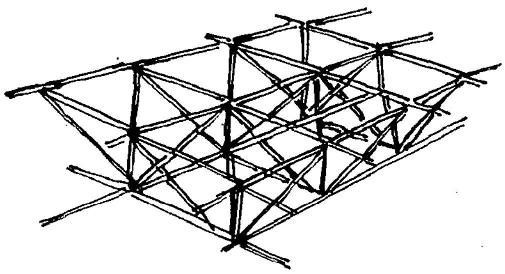
NORTH LIGHT ROOF



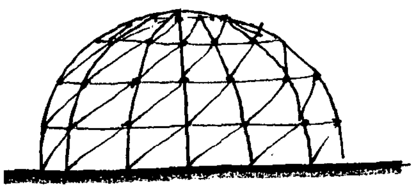
TUBULAR STEEL TRUSS WITH MONITOR



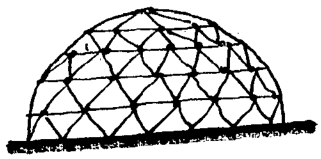
UMBRELLA TYPE TUBULAR STEEL TRUSS.



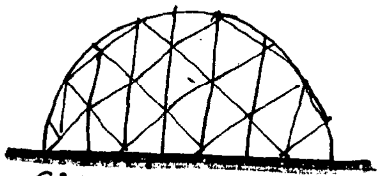
TYPICAL SPACE FRAME.



SCHWEDLER TRUSSED DOME



THE ZEISS-DYWIDAG TRUSSED DOME



GEODESIC DOME - BUCKMINISTER FULLER

Fig 3. ROOF TYPE - STEEL.

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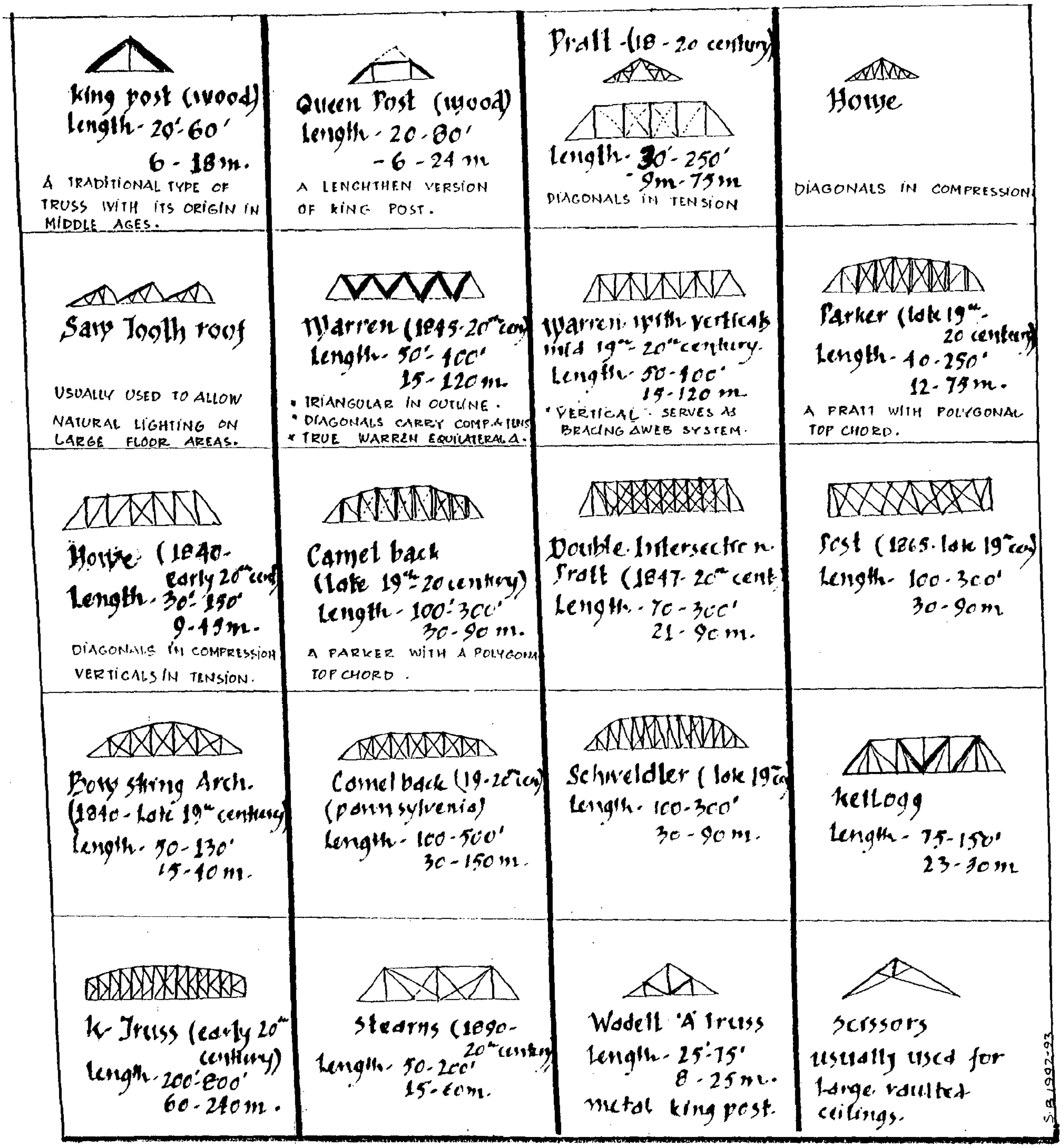

Fig 4. Trusses (cremonas diagram)

* source - p.p 384, Fig 11. Melarangro M. "Simplified Truss Design", Van Nostrand Comp., New York, 1981

intervals. All these trusses may be built with the bottom chord arched upward or cambered, resulting in a cambered pratt. When a flat roof or one which is nearly flat is suitable a WARREN TRUSS may by used. The PRATT and HOWE trusses are also used for flat roof trusses. The SAW TOOTH trusses are especially useful for building in which relatively close spacing of columns is not objectionable and in which uniform lighting is important, such as textile mills.

ADVANTAGES OF TRUSS :

Sheeting is fastened to purlins, and if incorporated continuous strip glazing gives a good sky light factor. The system may comprise single or multispan construction; foundation settlement is negligible due to light weight of structure.

DISADVANTAGES OF TRUSS :

Perodical painting of columns, trusses and purlins is necessary. In multi span construction, there is much interrupted floor space. The depth or construction tends to become excessive, particularly in long spans. As with steel structure generally the construction is not fire proof.

3. GIRDER AND PURLINS :

i) PURLINS :

The purlins supports roof covering and are themselves supported on roof trusses. The span of the purlin is equal to the spacing of the trusses. Purlins are flexural members and are subjected to vertical loads due to dead and live load and so loads, normal to roof covering due to wind pressures. Purlins, thus are subjected to biaxial bending the purlins are usually made of channel section or angle iron.

ii) ROOF GIRDER:

This is of different types of frames as per lighting and space requirement. Generally sections are used rolled steel. This spans from column to column at eaves level and is paralled to gable end.

iii) WIND GIRDER :

Which is provided at the eaves level spanning from column to column, generally comprising open web box section perpendicular to the trusses.

iv) CRANE GIRDER :

The function of the crane girder is to support the rails on which the travelling cranes moves. These are subjected to vertical loads from cranes, horizontal lateral loads due to surge of the crane, that is, the effect of acceleration and braking of the loaded crab and swinging of the suspended load in the transverse direction and longitudinal force due to acceleration and braking of the crane as a whole.

The crane girder spans from column to column usually having no lateral support at intermediate points excepting when a walkway is formed at the top level of the girder which restrains the girder from lateral bending. Thus under normal circumstances, the crane girder must be designed as laterally unsupported beam

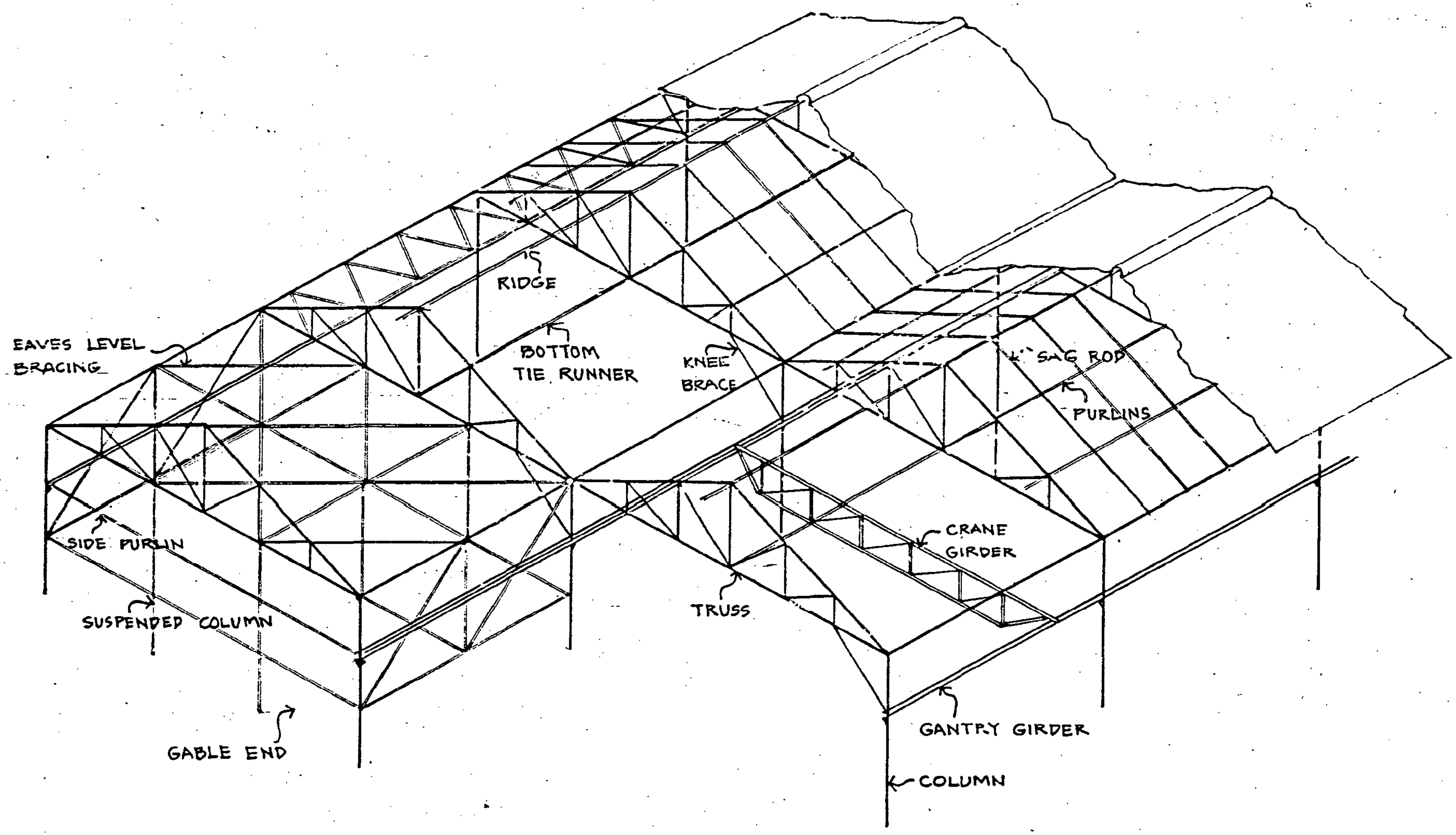

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Fig 5 : INDUSTRIAL SHED

carrying vertical and horizontal load at the level of the top flange. Apparently a girder with havier and wider compression flange is required. Welded box girders offer maximum service performance in longerspans.

4. SAW -TOOTH ROOF (NORTH LIGHT ROOF)

Roof consist of parallel chord trusses, which may continuous over columns, with secondary transverse triangulated truss or frames spanning between. Purlins spanning secondary trusses are to take sheeting only.

Span 20-150 ft

Economical - 40 ft.

ADVANTAGES

1. Structure is of light weight construction 7.5 lb/ft
2. Speedly erected
3. Parts prefabricated, transported to site in convenient size
4. Direct sunlight cannot enter interior
5. Suspension of services easy.

DISADVANTAGES

1. Painting of steel work
2. Water-proofing of gutters is periodically necessary.
3. Require regular maintenance
4. Poor thermal insulation
5. Extra cost of thermal insulation

5. STEEL PORTAL FRAME

In a steel portal frame system, the load collecting beam, or truss, becomes rigidly interconnected to the supporting columns.

Maximum span - 250'

The structure is factory made, each frame may be transported in two or three sections. The daylight factor is same as for a triangulated truss and is greatest at mid span. The design of this frame, according to the plastic theory, saves upto 25% of steel required by design according to elastic theory.

ADVANTAGES

1. Large, unobstructed floor space
2. Medium weight frame can be speedly erected with proper machines.
3. To meet technical requirements, the form or shape of the load collecting beam can be varied.

DISADVANTAGES

1. Wide spans frames require the erection of comparatively heavy unit, owing to the structural depth of members.
2. Paintiing and other maintenance is necessary.

6. TUBULAR STRUCTURES

With the use of tubular steel, structure upto 100 ft spans are economical (generally based on 3'4" module, with spans in multiple of 10 ft. Self weight is less than 2 lb per square ft.

(a) TUBULAR STEEL TRUSS WITH MONITOR

ADVANTAGES

1. Faster erection
2. Light weight
3. Most economical
4. Easy suspension of services
5. Good daylight

DISADVANTAGES

1. Poor insulation
2. Needs regular maintenance
3. Leakage from gutter

(b) UMBRELLA TYPE TUBULAR STEEL TRUSS

ADVANTAGES	DISADVANTAGES
1. Faster erection	1. Skylight give rise to glare
2. Easy suspension of services	
3. Economical	2. Ununiform light distribution
4. Light weight	

7. TRIDIMENSIONAL TRUSSING

(a) NON PLANAR TRUSS

A non planar truss that lies on a cylinderical surface whose cross-section is an arc of a circle with a central angle of 90 . Acting like a barrel shell, the truss carries metal skin of zinc sheeting, e.g. roof structure of the production hall of the Institutoo Tecnico de Constructiccion y del Cemen to, Constillares, in Spain Engineer : Eduardo Torrojo.

(b) SPACE FRAME

Space frames are also a form of tridimensional truss system which has gained an important position on the list of modern structural alternatives in recent years.

The geometry of space frame is characterised by two features.

(i) A space frame is an assembly of two parallel plane grids, equal or not, connected by diagonal web members.

(ii) A space frame is an assembly of modular tridimensional units formed by the edges of a tetrahedron, a square pyramid, or other polyhedra.

The space frame is much more efficient than truss. Depth required for space frame - 1/20 to 1/30 of span. Depth required by a series of parallel trusses - 1/10 of span to carry same load.

(C) DOMICAL SPACE FRAME

Domical space frame are also a tridimensional trussed structures consisting of hinged rectilinear members, which are the edges of triangles or other regular polygons obtained by subdividing a spherical dome. The domical space frame is a polyhedron inscribed with in the sphere. The choosen pattern in which the sphere is subdivided determines the type of dome. Famous type includes

- Schwedler doome
- Zeiss - Dywidag dome
- Geodesic dome by R.B. Fuller.

2.6.2 REINFORCED CONCRETE STRUCTURES

R.C. construction can be precast or cast in situ.

ADVANTAGES

1. Require lesser maintenance
2. Good day light possibilities
3. Withstand fire better or better fire-resistant.
4. Provides better thermal insulation
5. Aesthetically, concrete structure offer wider scope for architects in terms of shapes and form.

DISADVANTAGES

1. Slow erection
2. Difficulties in suspending services like ducts, pipes etc.
3. In case of future expansion the expansion joint creates problem.
4. Difficult to dismantle
5. Acoustically difficult to treat

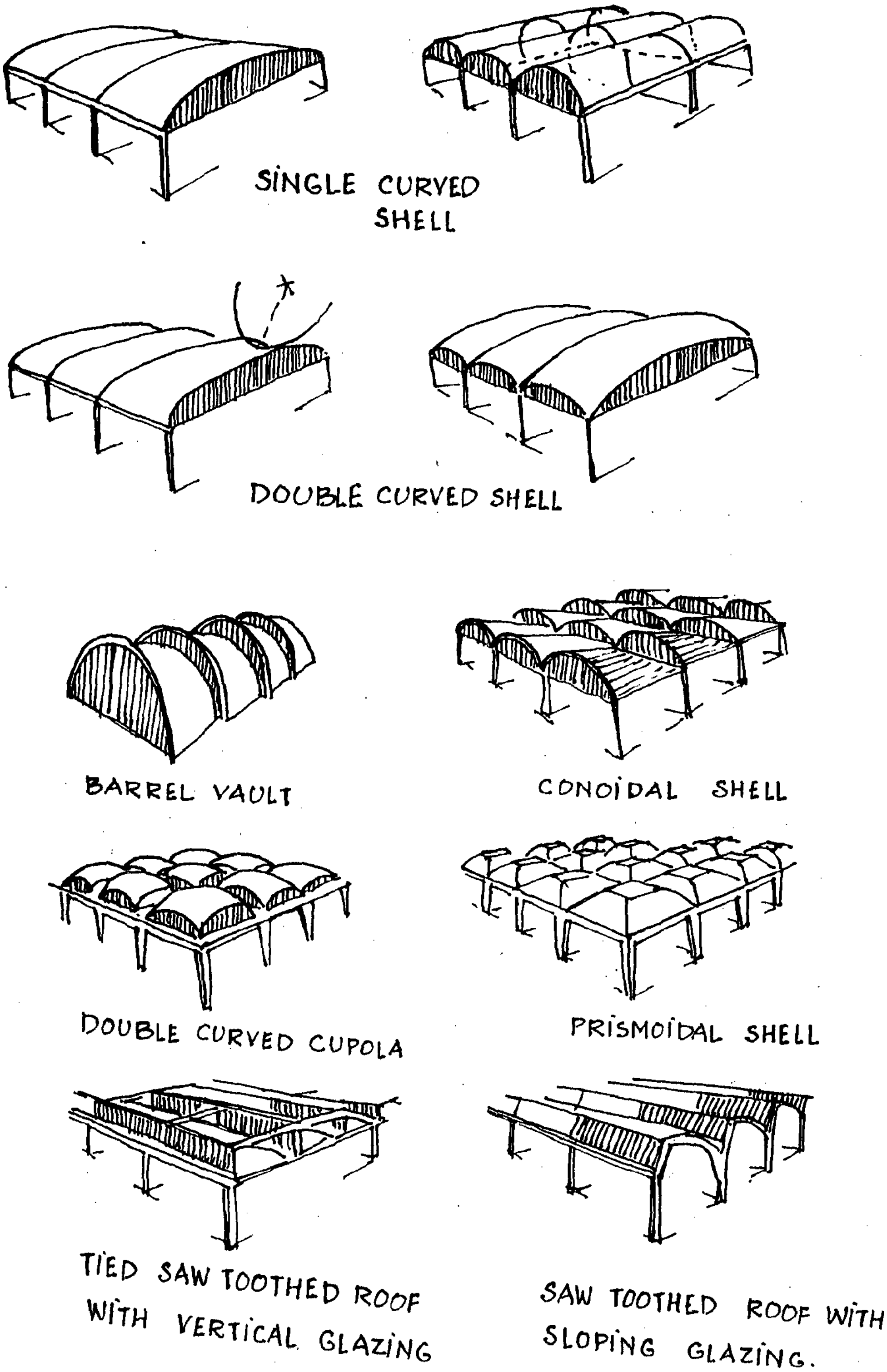


Fig 5: CONCRETE SHELL STRUCTURE ROOF.

* SOURCE - PP. 88. Munce. J.A. "Industrial Architecture." iliffe books Ltd. London. 1960.

S.B 1992-93.

1. North light shell roof

Suitable for single storey industrial buildings, consist essentially of an inclined folded slab, generally bent to the arc of a circle, spanning between end frames, with glazing between adjacent slabs.

Span - 40 to 60 ft.

greater span is affected by prestressing valley beams.

Span - Cord ratio (economical) - 3:2

Loads supported on end (and intermediate stiffening beams, frames or ribs.

ADVANTAGES

1. Good daylight
2. Lesser maintenance
3. Good drainage
4. Efficient use of material

DISADVANTAGES

1. Uneconomical unless light units are built
2. Suspension of services difficult
3. Slow erection
4. Creates acoustical problems.

2. CONOID ROOF

A conoid is a saw-tooth roof where the supporting valley beam or glazed arch are curved longitudinally and concrete shell spans between top and bottom chords of adjacent glazing surfaces.

SPAN 7.5 - 20 m

ADVANTAGES

1. Long single span
2. Utilizes the structural properties of shell concrete with relative efficiency
3. Low in weight

DISADVANTAGES

1. Necessity of subsidiary framework to support essential services
2. Acoustical problems.

3. FOLDED SLAB ROOF :

A folded slab roof is a stressed skin roof consisting of a finite number of plane slabs laid to profile. It can be of any desired shape. The folded slab requires only inexpensive flat shuttering and lends itself to use on site. Errection is easy for all form of folded slab construction and maintenance cost are low, particularly in saw tooth form.

SPAN - UP TO 70 FT economical. Thickness slightly greater than curved shell.

4. LONG BARREL CYLINDRICAL SHELL ROOF :

Cylindrical shell roof consist of reinforced concrete slab curved to the arc of the circle and spanning longitudinally between spandrel end frames. Supports consists of valley and edge beams, with end (intermediate) transverse rib supported at ends only or at intermediate points.

ADVANTAGES :

(1) Upto 200 ft. wide uninterrupted floor space is possible.

(2) Shell roof approach maximum efficiency by the use of reinforced concrete and have the normal advantage of this material-low maintenance cost, clean appearance, fire resistance, and

(3) ability to accomodate ducts and services with in the structures.

DISADVANTAGES :

(1) Such construction is uneconomical unless repetition can be effected that is the formwork must be used 4-6 times, as it is a major cost factor.

5. HYPERBOLIC : PARABOLOID OR SADDLE ROOF :

Basically, the hyperbolic paraboloid is a double curved or warped shell, the surface of which is generated by straight lines. Span upto 200 ft. with a thickness 2-1/2 in. have been attained. Support is on end frames only. End frames are glazed, gable or clear story lighting.

ADVANTAGES :

(1) The saddle roof utilizes efficiently the structural properties of concrete and is exceptionally resistant to buckling.

(2) An infinite number of shapes and variations of form may be achieved.

(3) No expensive curved shuttering is required.

(4) In addition to low material and maintenance cost, the system also offers the other advantages normal too concrete; such as good appearance and fire resistance.

DISADVANTAGES :

(1) The difficulty of representation on paper and of mathematical analysis even for the membrane stresses presents problems.

6. DOME ROOF :

Dome is a surface of revolution in concrete contained within a tension ring, usually at eaves level. Variation of the form comprise any polygonal plan where support is thorough stiffening of frames and column.

The crossection may be elliptical, circular, or of some other shape dictated by aesthetic requirement. Concrete construction is always on site, span are upto 200 ft.

ADVANTAGES include economical use of material and large, uninterrupted floor space. The initial cost is high owing to expensive frame work shuttering. The difficulty of placing the concrete is another disadvantage.

2.6.3 PRECAST CONCRETE :

This consists of precast members siteconnected by bolted scarf-type joints located more or less at the points of contraflexure; thus the frame has all the advantage of structural continuity, added to those of ease and speed of erection.

Precasting of concrete elements, either in a factory or on site is an enormous advantage when there is a good deal of repetition. The cost of the mould per casting is dependent on the number of uses from the mould. This has led to standard frames being promoted with the use of steel moulds have a very long life.

Transport of heavy and awkwardly shaped elements can increase the cost of the structure, so it often happens that a "factory on site" is sent up if conditions justify this.

Precast concrete curved roof :

This is a composite construction consisting of curved precast prestressed beams and purlins and normal precast reinforced columns.

2.6.4 TIMBER :

Light structure are eminently suited for small buildings, and timber is being increasingly used for structural purpose, besides cladding by the department of timber research association has made a close study of the way in which timber can be used in factory roofs, and has given guidance both on the degree of thermal insulation achieved by the combination of timber and other material, and on the steps necessary to prevent additional fire hazard.

A common requirement for a factory roof is that of providing as little obstruction on the covered area for the minimum cost. One example is the use of rigid frame construction for a portal frame.

Timber shell roof is simple geometric shapes can be made to suit the particular requirement of a building. The choice is governed by the general outline of the area to be covered, the number and position of support, the amount of roof lighting etc.

The maintenance of timber exposed to the weather is of tremendous importance, the five basic types of exterior treatment for wood: preservatives, water repellents, stains, clear varnish and paints.

2.6.5 COMPOSITE MATERIAL CONSTRUCTION :

Although composite action design have been used in Europe for many years, they have only recently been used for building work in Great Britain, although the method has been widely adopted for bridge work in this country and is practically universal for plate girder or beam bridges with reinforced concrete decks.

There are a number of ways in which a composite beam can be constructed. The steel beam, simply supported at its ends can carry the shuttering and concrete during the construction period. In this case the construction loads are carried solely by the steel beam and the super load and weight of finishes applied after the concrete has set and attained the requisite strength, will be carried by the composite section.

Alternatively, the beam supporting the concrete and shuttering can be continuously propped during construction so that it does not deflect, thus remaining unstressed. In this case after the concrete has attained the requisite strength, the prop are removed, after which both dead and superimposed loads are carried by the composite section. For all practical purposes the beam may be assumed to be continuously propped if it has three supports equally spaced between the ends.

From the point of view of strength of member, the second method is the more advantageous but against this must be set ease of construction in the first case, which leaves the floor below entirely clear of props.

2.7 MATERIALS FOR INDUSTRIAL ROOF CLADDING :

The cladding of roof materials have one or more of the following functions :

1. To keep the rain out (weatherproofing materials)
2. To provide a surface for the weather proofing material which will support the imposed loads (decking materials)
3. To provide a thermal insulating layer (insulating material)
4. To provide a suitable internal surface (surfacing material)
5. To transmit light (glazing materials)

6. Require minimal maintenence
7. Prevent direct ingress of light
8. Prevent entry of birds and insects

The choice of material for given situation will depend upon.

1. The efficiency with which it performss its function
2. Its durability and hence potential maintenance liability
3. Its cost
4. Its appearance

A whole range of new products and techniques has been developed in recent years for the solution of basic problem of cladding.

1. Asbestos-Cement Cladding :

Most commonly used. Though it is banned from production in most part of world, as it is hazardous from health point of view.

Finding an economically competitive alternatives to cement asbestos, will be a real contribution towards improving the quality of the working.

2. Aluminium sheeting.

- Light in load
- easy to replace if damaged in structural settlement
- Give contrasting texture and colour

3. Plastic Panels

Plastic panels are mostly of corrugated glass fibre met, impregnated with a resin. The great disadvantage in that it is not fire prof.

4. Precast Concrete Panels

- Economical and time saving

5. PVC sheets

Acrylic, polyester resin with invisible fibre glass reinforcement. It refracts light and reflect light it allows 90% light to enter, reducing day light bills considerably.

6. Polycarbonate Compact Sheets

- light weight
- No need of heavy supporting structure

7. Galvanised Sheet Roof

- durable
- crackproof
- leakproof
- light weight and economical
- health hazard free

3
ARCHITECTURAL DESIGN PARAMETERS
FOR ROOFING SYSTEMS IN INDUSTRIAL BUILDINGS

CHAPTER - 3

3.0 ARCHITECTURAL DESIGN PARAMETERS FOR ROOFING SYSTEMS IN INDUSTRIAL BUILDINGS

Roofing in industrial building in meant to protect production line from sun, wind, rain to keep off dust and dirt. Roofs also serve as a source for lighting and ventilation. It also serves as a structural support for number of essential services of the factory. Modern materials and methods of design offer a range of types of roofing systems that can be adopted for any industrial building. Initially cost will often be decisive in making the choice, but maintenance cost characteristics relevant to production layout, ventilation, lighting, noise control, fire resistance, orientation and Aesthetics often tends to control the design.

3.1.0 LIGHTING

Lighting affects internal working condition due to various fenestrations provided in building envelop. A good lighting of work space can be achieved by.

(1) Day lighting

(2) Artificial lighting, or

(3) Combination of 1 and 2

There are five aims in industrial lightings.

1) To provide sufficient light of the right quality and colour to enable the various visual tasks to be carried out efficiently and effectively.

2) To create a general visual atmosphere suited to the buildings- in industry this will usually mean a cheerful and stimulating atmosphere.

3) To eliminate, as far as possible, sources of excessive visual distraction which may divert attention away from task, and to avoid glare (direct and reflected) which tend to interfere with the work.

4) To provide sufficient quantity of light, in lux or daylight factor (DF) as recommended.

5) To provide suitable vistas that are visually restful, so that the eye may relax during rest pauses and minimise overstain.

The values of illumination given below are based on difficulty of seeing the various tasks in factories and offices.*

a)	Most difficult seeing tasks, such as extra fine assembly, precision grading, extra fine finishing	10,000 Lux
b)	Very difficult seeing tasks, such as fine assembly, high speed work, fine finishing	1000 Lux
c)	Difficult and critical seeing tasks, such as ordinary bench work and assembly, machine shop work, finishing of medium and fine parts, office work	500 Lux
d)	Ordinary seeing tasks such as automatic machine operations, rough grading, continuous processes, packing and shipping	300 Lux

*Source: pp 3, Handbook of Functional Requirements of Industrial buildings.; ISI, New Delhi, 1986.

e) Casual seeing task, such as stairways, wash rooms and other surface areas, active storages — 100 Lux

f) Rough seeing tasks, such as corridors, passages, inactive storages — 50 Lux

3.1.1 CHARACTERISTICS OF GOOD LIGH. TING :

The following characteristics with regard to the quality are to be given due consideration for planning the lighting for the task or tasks in view.

(i) Glare :

Glare is caused due to an uneven distribution of light sources or due to excessive contrast or abrupt changes in brightness in space and time or by seeing light sources or sun directly or after reflection from polished surfaces. An example of glare source in daylighting is the view of the bright sky through a window or a skylight specially when the surrounding wall or ceiling is dark of weakly illuminated. This kind of direct glare can be minimised either by shielding the open sky from direct sight by means of louvers, external hoods or deep reveals or by cross-lighting the surrounding to a comparable level. Other direct sources of glare can be screened by providing either louvers or reflectors. Local lighting at the work bench or machines should have opaque reflectors. Indirect glare can be avoided by carefully positioning the light souces in relation to glare surfaces and line of vision or by painting objects in matte.

(ii) Uniformity of Distribution :

It is usually desirable to provide reasonably uniform general illumination over the entire work area. A gradual transition of brightness with diversity ratio of not less than 0.7 from one area to the other within the field of vision not only ensures reasonable uniformity but also minimises glare. Maximum and minimum illumination at any point should not be more than one-sixth above or below the average level in the area. Maximum spacing to mounting height ratios are generally specified for different types of luminaires for attaining reasonable uniformity. In daylighting design also, the uniformity of illumination distribution over the work area could be achieved by suitable positioning of windows and glazings and by increasing the internal reflected component of daylight factor. However, the uniformity of workplace illumination is not so critical in the daylighting design as in the artificial lighting.

(iii) Brightness Contrast :

The brightness of an object depends upon the amount of light flux incident and proportion of that light reflected or transmitted in the direction of the eye. Proper brightness ratio or brightness contrast between adjacent surfaces is an important requirement of good lighting. Excessive brightness ratios, even though not severe enough to cause glare, may be seriously detrimental to lighting quality. Generally the task should be brighter than both the immediate background and general surroundings; as an example, workplace should be brighter than the working table and floor area. Where the illumination levels are above 300 lux, the ratio of average brightness between the task, immediate background and general surroundings may be 10:3:1. Since the illumination for the task and the immediate background are usually much the same, desirable ratio could be achieved by choosing a finish for the background having lower reflection factor. The following brightness ratios are recommended for industrial areas :

Ratio	Location
3:1	Between task and immediate background.
10:1	Between task and more remote (general) surroundings.
20:1	Between luminaire and surface adjacent to them.
40:1	Anywhere within the environment of the work.

(iv) Direction of Lighting and Diffusion :

The light gest diffused when it flows from various random directions. It is measured in terms of the absence of sharp shadows. The degree of diffusion desirable for a task depends upon the type of work to be performed. For instance, for preventing specular reflections, such as in viewing polished metal surface in a machine shop, a highly diffused light is essential. The appearance of a three-dimensional object on the other hand is affected by the directional component of light. By appropriate use of directional lighting and control of the size and positioning of the light sources, solid shape of the component

*Windows in exterior walls should be toned down by painting or otherwise.

parts of some tasks and details of surface texture or polish can be enhanced or suppresssed-a facility particularly of importance in the lighting of many inspection processes.

(v) Colour and Colour Rendering

The efficiency of performance of visual tasks is independent of colour of light or of the object, provided the brightness and the brightness contrast remain the same. However, there are psychological effects of colour in lighting, namely, the feeling of coolness, depression and distance for green and blue colours, and the feeling of warmth, stimulation and nearness for red, orange any yellow colours.

(vi) Strosboscopic Effect and Flicker From Discharge Lamps :

When discharge lamps are operating on alternating current, their light output varies with each cycle and this produces certain effects known as flicker. It can cause annoyance. Flickering also occurs due to half-way rectification in fluorescent tubular lamps and causes strosboscopic effect whereby rotating machinery or other objects appear to slow down in speed and this may lead to acidents. The combination of light from lamps on two electrical circuits, one lagging and the other leading in phase, reduces the effects arising out of cyclic variation of light output. Similarly, strosboscopic effect can be eliminated in fluorescent fittings by employing special circuits, and in the case of high pressure mercury vapour (HPMV) lamps, by installing lamps on three-phase power sysstem so that the light emitted by the lamps overlaps. The flicker in fluoresscent lamps in most noticeable at the ends and these should be shielded from the direct view.

(vii) Colour Dynamics :

As has already been pointed out, the eye sees an object by the light it reflects and distinguishes its details chiefly by colour contrasts. A good white paint reflects 80 per cent or more of the light; a good black paint reflects only a small percentage of light; a dirty grim-faced wall in a factory may absorb 90 per cent or even more of the light it receives; dark dirty machinery may be nearly as bad. If the place is cleaned-up and the walls are painted or colour washed with pleasing light tone having moderate reflecting qualities and the machine parts are painted to given a moderate contrast with walls and the work, the viewing of tasks can be greatly improved without increasing the light intensity. Only when clean-up and painting is done, can it be determine whether any further benefit could be derived by increasing the illumination level.

Since the white paints are distracting and do not afford much contrast, the walls should not be painted white. The ceilings can be white or nearly so when they are out of line of vision. The machine parts that constitute the background for the task should also be of soft hue without high reflection qualities. In determining the choice, the colour of the material being worked should be taken into account. For key parts of machines, such as guards or control levers, a colour that stands out should be chosen. Yellow orange or yellow green has maximum visibility ranking even higher than the conventional red in this respect. The following surface reflectances may be used for selecting finishes for walls and other surfaces to achieve the desired brightness and colour relationship for industrial areas :

Surface	Colour Finish	Reflectance, Percentage
Ceiling	White	72-80
Upper walls	Light green or light buff	50-55
Lower walls & machinery	Dark green or dark buff	25-35
Immediate background	Medium green of medium buff	35
Floor	Blend with above	25

(viii) Aritificial Light and Health

Recent studies have shown that long hours of the day and night under artificial light causes many biological and other health problems. Excessive exposure to ultra-violet radiation can cause skin cancer. Unshielded fluorescent lights may be increasing by five per cent the weekly dose of ultra violet radiation, many office and factory workers are receiving. For sensitive persons, added dose could already be causing cancer. Even more disturbing factor is that the potent unnatural wavelengths of fluorescent light can cause genetic mutation, cancer and death in the cells of many living things, including man, at a significantly high rate.

As is already known, fluorescent lamp gives off or 'fluorescences' when a coating of phosphors inside the tube is hit by ultraviolet light. These lamps can be made to give off virtually any colour or mix of colours by blending different phosphors . But early developers of fluorescent light drew on scientific findings that the human eye is most sensitive to yellow-green light and designed their lamp to most strongly to those colours the standard 'cool white' fluorescent light in use today.

One of the steps to minimize the biological hazards of fluorescent lighting in factories and other places of work is to use broad-spectrum lamp instead of the narrowspectrum 'cool white' lamps in common use. Light stress could be reduced by mixing fluorescent and incandescent light in workskylight and windows to bring in sunlight.

3.1.2 DAYLIGHTING :

As a rule, daylighting is preferable to artifical lighting as it is potential natural source of light which meets all the requirements of good lighting. Therefore, when a factory is to be built, the shape of the building is usually planned on the basis of daylighting. It is only very rarely that factory space will be planned with view to obtaining the most favourable artificial lighting. Except in factories having multiple shifts, the buildings will be used during more hours per day be natural lighting than by artifical illumination. One may, therefore, safely base the layout of the factory buildi ngs on natural daylighting, because artificial lighting can be easily manipulated to suit the different circumstances.

The prime source of light for daylighting is the sun. The availability of daylight outdoor in the plains in this country is quite high throughout the year. The light received by the earth from the sun consists of two parts, namely, direct solar illumination (direct sunlight being excluded) and sky radiation. The latter is nearly constant through the major portion of the day, while the sunlight (direct solar illumination) can be as much as four times the skylight. The wide variation and the chances that incidence of direct sunlight over moving machinery in factory floors during certain hours of the day can cause undesirable visual fatigue and may become a source of danger, necessitates its exclusion in the planning of apertures for daylighting. Therefore, for the purpose of daylighting design direct solar illumination is not considered and only sky radiation is taken as contributing to the illumination of the factory interiors during the day.

3.1.3 Daylight Factor :

Since the brightness of the sky is constantly changing, it follows that the light inside a building must change, and therefore, it is not practical to estimate the efficiency of a system of fenestration of a building in absolute units such as lux. The visual appreciation of the increase in the magnitude of the light is damped by overall increase in adaptation level, and the ultimate criterion of efficient illumination is its effect on the observer. In a building the eye of the observer automatically tends to make a comparison with the brightness in his working environment and the brightness of the part of the sky visible through the windows or skylights; in other words, he judges good daylighting less by a sense of actual intensity than by one of proportion. Therefore, daylight at a point indoors is usually measured, as in fact appraised, as a ratio of the total illumination which would be received at the same moment out-of-doors from an unobstructed view of the clear design sky (excluding direct sunlight). This ratio is called daylight factor, and is expressed as a percentage. Thus, the daylight factor of 1 per cent at a point inside a building would signify the illumination of 1 per cent of that which would be obtained if the whole of the hemisphere of the sky were contributing light. Since exterior design illumination for clear design sky is taken as 8 000 lux, the daylight factor is, therefore, a percentage of 8 000 lux. To get daylight factors from lux values of illumination levels for various industrial tasks and locations divide values by 80. As an example, if an illumination level required at a point inside a building is, say, 300 lux, the daylight factor required would be 300/80 = 3.75, that is, 3.75 per cent of the illumination obtained outdoor from unobstructed sky, direct sunlight being excluded.

Daylight reaching an indoor reference point comprises the light from the following sources :

a) The direct sky visible from the point (excluding direct sun),

b) External surfaces reflecting light directly to the point, and

c) Internal surfaces reflecting and interreflecting light to the point.

Each of the three components, when expressed as a ratio or a percentage of the simulataneous external design sky illumination on the horizontal plane, are respectively called the sky component (SC), the external reflected component (ERC) and the internal reflected component (IRG) of the daylight factor. Therefore, total daylight factor (DF) is the sum of the sky component (SC), the external reflected component (ERG), or

DF = SG + ERG + IRG

As a conservative estimate, only the sky component is taken into consideration for the purpose of designing fenestrations of the factory buildings. However, other components are also important from the point of view of reducing glare and ensuring brightness contrasts between the objects and the suroundings, and these should be taken into consideration for the quality of the lighting required in the interiors.

3.1.4 Daylight Fenestration :

For the purpose of daylight fenestration, the factory buildings may be grouped into three types; buildings with skylight, buildings with closed ceilings (as in multistoreyed buildings), and high-bay large span structures.

A Buildings with Skylight :

Where skylight is utilised, it is, as already mentioned, done in a way to avoid the effect of direct sunlight. Direct sunlight should be screened as far as possible. The alternative is to make use of diffusing materials of low transmittance for glazing those areas where the possiblity of direct sunlight is high. The glazed areas are generally oriented away from the sunny side; thus in the northern hemisphere they face north. In this way a natural lighting is obtained of a diffused quality and with less variation of colour than is inherent in direct sunlight. Most factories emplोy north light as the principle source of daylighting. This is achieved by roofs of single-pitched truss of the saw-tooth type, where the glazing is oriented in north only. These keep off direct mid-day sun in latitudes north of 23^{o}. It is useful to know the period of the day over which direct sunlight enters such fenestration. Indiscriminate use of north lights in places located south of 23^{o} latitude should be avoided. In South India the use of northlighting is highly questionable unless some special forms of diffusing glasses are also used to cut off direct entry of sumlight. The seqnd method of fenestration by skylight is when double-pitched (gabled roof) trusses are used so that glazing may be distributed on one or both pitches. One more method which is not so common in India is where the roof glazing is arranged in opposite vertical strips in a system known as 'Monitor' roofing.

i) **Saw-tooth (north-light) fenestration :**

a) Two types of northlighting are illusrated in Fig. Fig. with inclined glazing and Fig.7 with vertical glazing, each having glass area 20 per cent of floor area. The lighting curves show troughs and valleys, but in case of inclined glazing, the curve is more even, level of illumination varying between 10 and 7 per cent daylight factor whereas it varies between 9 and 6 per cent daylight factor in case of vertical glazing. The variation may not be objectionable if, in practice, the work benches run in the same direction as the glazing, but if they are set in the opposite direction, the variation would be more noticeable. Shadows caused at working plane by machiness can be minimised by providing openings on the side walls and/or by use of light-coloured finish for ceiling surface. The uniformity of illumination on the working place in the north-ligh factory building depends on the width of the bay (distance between the north-light openings), slope of the roof and the reflectance of the ceiling. By adjusting the slope of the roof and the width of the bay, shadows on the working plane can be avoided. When the length of a bay in a north-light factory building exceeds its width by five time may be considered as infinitely low for the purpose of daylighting.

b) Precomputed values of working plane illumination due to different fenestrations inside 2-bay, 4-bay, 6-bay and

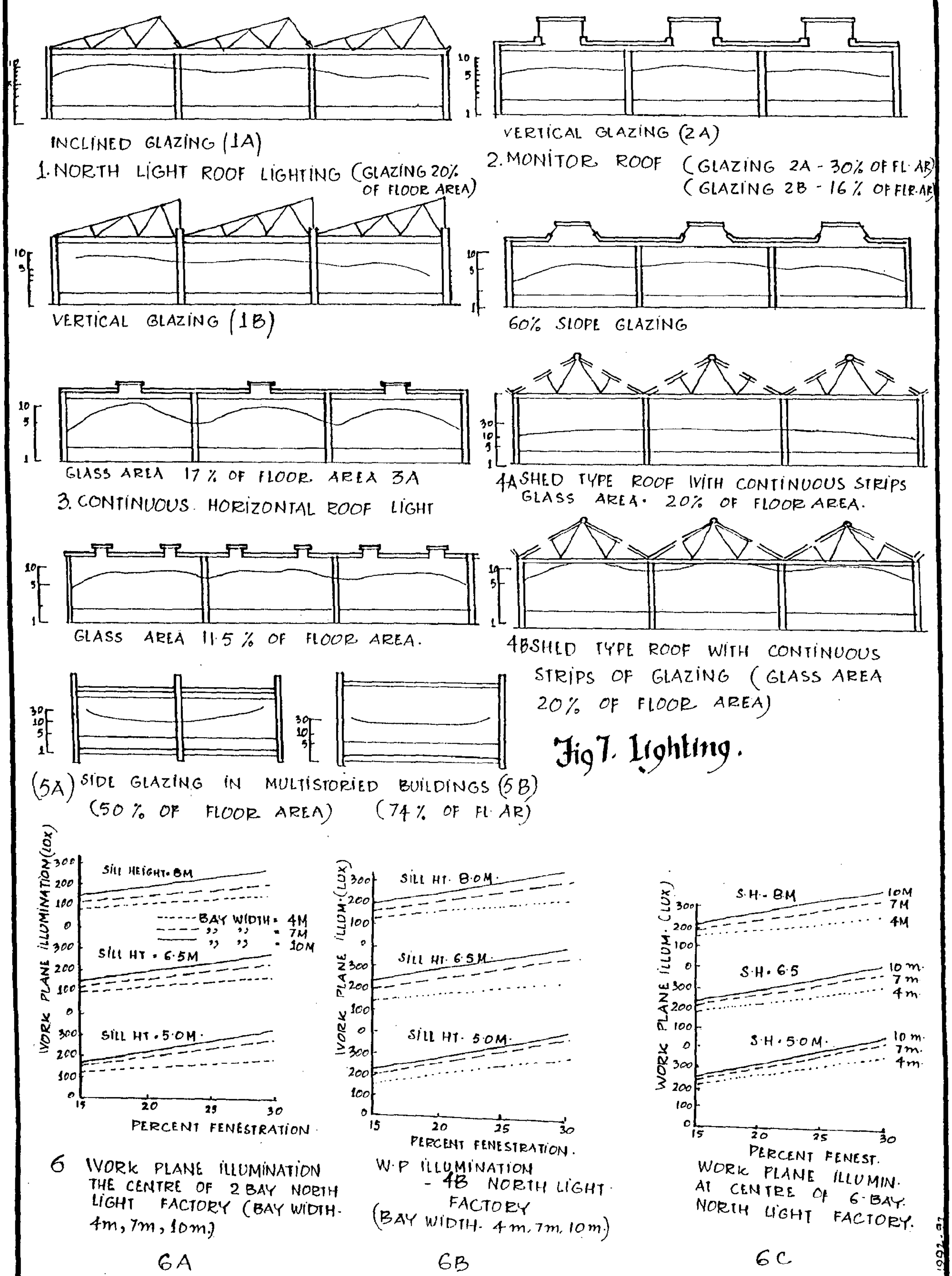


Fig 7. Lighting.

* Source 1-6 · PP· 15-20, HANDBOOK OF FUNCTIONAL REQUIREMENTS OF INDUSTRIAL BUILDINGS, ISI, NEWDELHI· 1986

8-bay factory buildings with northlight (saw-tooth) roofs are given in Fig.   for sill heights 5,5 and 8 m and bay width 4,7 and 10 m. Reflectances of ceiling, walls, floor, roof and outside ground have been assumed as 0.5, 0.5, 0.3, 0.25 and 0.25 respectively. 0.5 represents an off-white finish and 0.3-0.25 a dull finish. Allowance has been made for glass transmitance, reduction due to dust collection under good maintenance condition, glass area to gross window area ratio and obstructions due to beams and trusses. Poor maintenance under dirty conditions reduces the working plane illumination by a factor of 0.7 corrections factors due to changes in interior finish from off-white ceiling and walls to white ceilings and walls or dark ceilings and walls.

ii) Monitor roof fenestration :

a) In America the monitor roofs seem to have largely taken the place of northlight or saw-tooth roofs. The use of monitor roof is not very common in this country since the monitor openings also let in considerable quantities of direct sunlight which may be objectionable. However, the system has certain commendable features. For example, glass cleaning is straight for ward, not involving special gantry equipment, and if opening lights can be suitable arranged, the inside face of the glass may also be cleaned from the outside. Because the glass is vertical, the periods between cleaning can probably be longer.

b) General level of illumination of monitor roof is low compared with other systems considered. This may be seen by the illumination distribution curve in Fig. where a vertical glazing of 30 per cent of the floor area hardly gives between 7 and 6 per cent daylight factor, compared with 9 and 6 per cent for north-light roof with 20 per cent glazing. Figure however, shows that when the monitor roof glazing is sloping at 60° to the horizntal, the level of illumination goes up and, even with only 16 per cent area of glazing, is between 7 and 5 per cent daylight factor, though with this type of sloping monitor, the distribution is not so even. The monitor roof will give satisfactor results only if a succession of vertical glazings is used and then, over a large area, a very uniform distribution of light will result. Using of miniature louvers in conjunction with the glazing apertures with the louvers tilted by 45° to the horizontal may tend to send the light flux from the openings towards the ceiling of the monitor which in turn will diffusely illuminate the working plane. The ultimate working plane illumination will depend on the louver dimensions, spacing, reflectances, the interior surface finishes as well as the availability of daylight outdoors. The width of the monitor has also critical effect upon the influx distribution and, within limits, the monitor should in most cases be quite narrow. The glazed areas are then brought nearer to the areas between the monitors, so increasing the illumination in the region. Care should also be taken to avoid obstructing the daylight by roof overhangs or projecting gutters. These may seriously diminish the light immediately beneath the monitor. If it is desired to reduce the more marked effects of sunshine penetration, monitor lighting should be laid out on a north-south axis. A good proportion of high angle hot noon sun will then be excluded, and further, early morning, late afternoon and winter sunshine coming at a flat angle will mostly be prevented from hitting the working plane.

(iii) Double-pitch inclined roof or horizontal roof fenestration

a) In either of these types of openings direct sun-lignt will be incident on the fenestrations for part or most of the daytime. This type of construction is employed when some direct incursion of daylight is permissible or uniformity of lighting is not critical as in the case of large warehouses. The value of the total illumination to sun and skylight may be taken as 10 000 lux, To effectively diffuse this illumination in the interior the use of diffusing glass or transluscent materials of known transmission factors is recommended. The final available illumination on the working plane is calculable by the use of methods employed in artificial lighting tehniques. If the area and location of glazed openings are known, the point-to-point method is suitable. If the illumination required is given, the lumen method is preferable.

b) The transmission properties of materials vary and available illumination is much reduced due to dust collective and on the state of maintenance; with plastic materials there is also considerable loss of lighting due to weathering. The average window maintenance factors for glass as a fraction of clean glass transmittance are given in Table

TABLE* AVERAGE WIINDOW MAINTENANCE FACTORS FOR GLASS

BUILDING	Office in Clean Location	Factory in Dirty Location			
WINDOW	Vertical	Vertical	30^{o} from Vertical	$60^{o}$from Vertical	Hori-zontal
Average over 6 months	0.83	0.71	.65	0.58	0.54
Value at the end of 3 months	0.82	0.69	0.	0.54	0.50
Value at the end of 6 months	0.73	0.55	0.4	0.39	0.34

TABLE* TRANSMISSION COEFFICIENT FOR GLASS AND OTHER GLAZING MATERIALS

MATERIAL	TRANSMISSION COEFFICIENT
Transparent window glass	0.80 to 0.85
Patterned glass	0.70 to 0.85
wired finish glass	0.60 to 0.80
Sand blasted glass	0.65 to 0.80
Clear acrylic plastic	0.80 to 0.85
Clean rigid PVC	0.70 to 0.80
Wired rigid PVC	0.70 to 0.75
Corrugated glassfibre reinforced sheet	0.55 to 0.80

*Source ; Handbook of Functional Requirement of Industrial buildings; ISI, New Delhi 1986 pp. 19, Table 5, Table 6.

c) The distribution curves of daylight factors for continuous horizontal roof lights with diffused glazing are shown in Fig.7 and Figure shows deep troughs and valleys with values of illumination varying between 10 and 5 per cent daylight factor for glazing area 17 per cent of the floor area, whereas Fig. with 2 rooflights per bay, gives more uniform distribution, percent daylight factor for glazing area of 11.5 percent of the floor area. Figure shows double-pitch roof with continuous strips of glazing, two openings on each pitch. This type of roof also gives a little more even distribution with the values of illumination with the values of illumination varying between 12 and 10 percent daylight factor for glass area 20 percent of the floor area. With one opening on each pitch as in Fig. , the variation is much greater, between 15 and 10 percent daylight factor for the same glass area.

B. Buildings with Closed Ceilings

For factory buildings with closed ceiling as in multi-storeyed buildings side glazing is the only answer for daylighting. The daylighting at any point inside the building is treated in the same manner as in a roof. In working areas with closed ceiling, the width is adopted to be so large that the windows in the walls are proportionately to low to provide sufficient natural lighting in the centre of the room. At a depth of twice the window height, the horizontal illumination amounts to no more than 10 percent of that near the window and beyond a depth of about 8 m only reflected component of daylight can reach, and therefore, in many situations artifical lighting has to be employed during day time as well to supplement day-lighting.

Unilateral lighting from side openings will in general be unsatisfactory if the effective width of the room is more that twice the height of the opening. Opening on two opposite sides will give greater uniformity of internal daylight illumination specially when the room is 8 m or more across. Crosslighting with openings on adjacent walls will tend to increase the diffused lighting within the factory shed. Openings should be provided with louvers, baffles or other shading devices to exclude, as far as possible, direct sunlight into the building.

The distribution curve of daylight factors for side-glazings on opposite walls in buildings with closed ceilings (multi-storeyed buildings) is parabola. As shown in Fig. , the parabola has a variation in illumination levels between 25 and 15 percent daylight factor for glazing 50 percent of the floor area, and as in Fig.7 , between 30 and 20 percent daylight factor for glazing of 74 percent of the floor area.

Generally with side lighting, while taller openings give greater penetration, broader openings give better distribution. Broader openings may also be equally or more efficient provided their sills are raised by 30 to 60 cm above the working plane. However, it is to be noted that this raising of the sill level is likely to reduce ventilation at work level. Therefore, while designing side openings for ventilation also, a compromise may be made by providing the sill height about 15 cm below the average head level of workers, so that the incoming air stream is passed over the workers.

In this type of construction it is less the daylighting than the tasks that are the determining factors. Situations may also arise where total exclusion of daylight may offer the only optimal solution to lighting design of industrial areas. Considerations such as heat loads due to sunlight, and of the areas or special requirements of production processes and the cost of air-conditioning the area may be the deciding factors, and the solution may lie in providing artificial illumination from the ceiling designing purely on the needs of the nature of work and layout.

C. High-bay Large Span Structures

So far, the fenestrating of only the more common forms of factory builidings has been considered. Some attention should be directed to the daylighting of the kind of factories where provision of a large and unobstructed floor space is essential and smoother production flow and greater flexibility, in which the process is likely to be changed at some future date, is needed. The floor-to-roof height of such structures is high enough to provide clearance for the big jobs like assembly of aircraft, or accommodate overhead cranes, or to allow the fumes and steam from the processes to be carried off. In such factories it is usually possible to provide sufficient daylighting which would enter through the windows in the relatively high walls. Glass strips in the roof, when artifical lighting is required, would usually be installed a high as possible in the roof structure so as to allow unobstructed manipulation with cranes and assembly jobs. Due to high mounting of light sources the horizontal illumination is much more than the vertical illumination. When in particular cases, a high level of illumination in the vertical plane is required, a portion of the light sources are also mounted half-way between floor and roof against the walls or the wall columns. These are to be carefully screened to secure unobstructed view of the working space.

Where the spans are very large, the requirements of daylighting may impose limitations of a free choice of possible structures, or, conversely, the structural arrangement which is to be used may limit the method of fenestrating. In the case of shell concrete constructions, which is eminently suitable for covering extensive areas, the thin skin of reinforced concrete is structural and may not be pierced with impunity. In cases of dome-like structures with single large spans, the tendency should be to distribute the glazing in comparatively small individual areas rather than in large single panels which would break the structural continuity of the system. Alternatively, if the shell is formed in the vault, the glass may be arranged in more or less continuous narrow strips which follow the roof curve. In both cases the daylight distribution can be very even and intensities as high as 10 percent daylight factor. In case of structures with more than one span, the shell may be designed as a series of balanced cantilevers in either direction of each span, in which case a wide strip of glass running continuously down the crown of the vault is provided. In this type of structure also, with series of such roofs the daylight distribution of the order of 15 percent daylight factor in the middle of each bay with sloping of the curve to a value around 10 percent between the bays can be expected at the working plane.

3.1.5 ARTIFICIAL LIGHTING

Artificial lighting may be provided to obtain the recommended illumination levels or general levels of lighting at the working plane when daylighting is not available or is inadequate, in the latter case to supplement daylighting.

i) Permanent Supplementary Lighting

In work areas in which daylighting alone will not be adequate as , for instance, in deep multi-storyed buildings, a permanent supplementary artificial lighting installation (PSALI) is provided. This sytem used in conjunction with daylighting ensures lighting which is more or less uniform througout the day and is conducive to better efficiency and output. Specially where depths greater than say 12 m in buildings with ceiling heights of 3 m are encountered, such a system of artificial lighting becomes a necessity. The requirement of supplementary artificial lighting increases with the increase in availability of daylight. The design requires a careful analysis of the spacing of artificial light sources and no general solutions are, therefore, available. This system can also be integrated with artificial lighting for the night only by suitable compromise in the illumination levels desired.

ii) Quality

Artifical lighting may also be required to be provided as local lighting when visual task may demand higher levels of illumination than are possible by general lighting. It must be designed to satisfy both quantity and quality for the industrial tasks in view. As already pointed out, quality relates to colour diffusion, direction (where important)), direct and reflected glare and other factors that affect the degree of comfort for the workers. Quality is also influenced considerably by visual environment or surrounding area within the field of view.

iii) Layout

While planning artifical lighting, the layout of the light fittings has to be related to the layout of the working area so as to obtain the most favourable lighting effect for comfortable working.

Types of Light Sources - There are mainly three types of light sources for industry :

a) Incandescent (tungsten filament) lamps;

b) High pressure mercury vapour (HPMV) lamps, sometimes blended with correction to improve colour; and

c) Fluorescent tubular lamps.

TABLE*

	Range W	Lumen Efficiency Lm/W	Rated Life, hours	Advantages	Disadvantages
	1	2	3	4	5
Incandescent	100 to 1500	10 to 22	1 000	Low installation cost instant start, simplified maintenance	Low lamp efficiency, short life, more energy cost
Mercury vapour	400 to 3 000	40 to 60	4 000 to 6 000	High lamp efficiency long life good system efficiency	High installation cost, colour deficiency, do not start at brightness, no immediate restart

	1	2	3	4	5
Fluore- scent Prehea- start	20 to 100	50 to 65	7 500	High lamp efficiency low surface brigntness long life	High install- ation cost, low system efficiency in high narrow areas
Instant start	40 to 75	60 to 65	6 000	minimum shadows	

*pp. 23, Handbook on Functional requierments of Industrial Building ISI, New Delhi 1986.

3.1.6 ARTIFICIAL LIGHT ING

ADVANTAGE	DISADVANTAGES
1. Manufacture and maintenence of roof structure and drainage become considerable simpler. There is no heat gain through glass panes	1. Long hours of the day and night under artificial light causes many biological and other health problems Excessive exposure to ultra-violet radiation cause skin cancer
2. Artifical lighting has a constant quality independent of the time of day and is much healthier, especially where high output levels are rquired shift work can take place under constant lighting condition	

3. The structural and Functional limitations to changes in space utilisation are minimal	3. Day lighting is preferable to artificial lighting as it is a potential natural source of light which meets all the requirements of good lighting.

3.1.7 Modern Trends :-

1. In recent years a number of special types of glass such as thermolux- one way reflecting and strongly tinted glass-have come into market, by which the possible disadvantages of direct sunlight can be greatly reduced.
2. There are number of ingenious roof designs where structure and lighting are integrated in a way which is reminiscent of the well lit stations of the last century.
3. In Europe a new mode of admitting daylight has been developed for smaller buildings in the form of the toplight dome. The insertion of such domes into the roof structure makes little difference compared with a fully enclosed flat roof.

Although these arrangements can be said to continue the tradition of natural lighting, the advance of fully enclosed factory buildings with artificial lighting must be regarded as a significant trend in modern industrial building construction. Apart from the lighting and economic advatages referred to at the outset, new planning possibilities are created in that the roofs can be utilised for the storage of light weight goods, for staff welfare purposes, car-parks etc. possibilities which may well become interesting in metro-politan cities where land is increasing at premium.

3.2.0 VENTILATION

In a hot country like India, special attention should be given to the requirments of ventilation in the design and layout of factory buildings so as to maintain such thermal environments as are conducive to the efficiency and well being of workers. This aspect is of particular importance in the case of factories, as in addition to the heat transmitted into the buildings from the sun, heat is added within the building as a result of manufacturing processes carried on in factories. When the temperatures inside the factory buildings are raised due to this excessive heat gain and the workers are required to perform heavy jobs manually, they not only suffer discomfort and heat stress, but their efficiency is also likely to be adversely affected. Observations in many industries have shown that workers output undergoes a seasonal variations; it is generally highest in winter, lowest in summer and at an intermediate level between the two in spring and autumn. In summer, when thermal environments in factories are worsened, an adequate supply of fresh air by ventilation from outdoors into the factory buildings will help in relieving discomfort and distress. Ventilation is also required to remove dusts, gases, fumes and other contaminants from certain processes carried on in the factory buildings.

3.2.1 AMOUNT OF VENTILATION REQUIRED

Ventilation has, therefore, three main functions to perform-bringing down the temperature inside the building closer to that outside, distributing the air satisfactorily throughout the building interiors and maintaining an adequate air movement at places of work. Although every case has to be studied according to the conditions prevailing, the amount of ventilation (the quantity of air in cubimetres per minute) is governed chiefly by the size of the building space and its usage, duration and type of occupancy and the nature of the activities, total amount of sensible heat gained from sun through walls, roof windows, and other openings, and that generated from equipment, processes, lights and occupants and temperature conditions desired to be maintained inside the building space at the working level in relation to those of outside air, and is given by the formula :

The quantity of air in m^3/min

$$= \frac{0.0496 \times \text{sensible heat gained in watts}}{\text{Temperature rise in } ^{\circ}\text{C in relation to to outdoor temperature}}$$

Temperature rise refers mainly to the difference between the air temperature at the outlet (roof exit) and at the inlet openings for outdoor air. As very little data exist on allowable temperature rise values for supply of outside air in summer months, the values given in Table related to industrial buildings may be used for general guidance.

TABLE ALLOWABLE TEMPERATURE RISE VALUES

HEIGHT OF OUTLET OPENINGS, m	TEMPERATURE RISE °C
6	3 to 4.5
9	4.5 to 6.5
12	6.5 to 11

NOTE 1 - The conditions are limited to light or medium heavy manufacturing process, freedom from rediant heat and inlet openings not more than 3 to 4.5 m above floor level.

NOTE 2 - At the working zone between floor level and 1.5 m above floor level, the recommended maximum allowable temperature rise for air is 2 to 3° C above the air temperature at the inlet openings.

General ventilation in a building can be provided either by natural means or by artificial (mechanical) means. Efforts should be made to design industrial buildings from the point of view of natural ventilation keeping in veiw the industrial processes carried on therein, particularly the location of the heat producing equipment and processes. Only when natural ventilation fails to provide adequate thermal and environments that mechanical means of ventilation may be employed. Sometimes, certain operations require removal of heat and other contaminatents before general ventilation is provided for the whole building. This may be kept in view in designing buildings for either natural ventilation or mechanical ventilation or both.

3.2.2 NATURAL VENTILATION

Forces which operate to induce natural ventilation in a building are due to :

a) Pressure exerted by the wind outside, that is wind action. This causes the outside air to enter the building, pass over the working area and then leave on other side of the building.

b) temperature difference of the air within and without the building, that is, thermal head. This causes warm air to move upwards by convection (stack action or chimney effect) where from it leaves the building through the openings in or near the roof and is replaced by comparatively cool air entering the building at lower levels through windows or louvers.

A Roofed Ventilation -

Cross ventilation by provision of windows and wall ventilators is suitable only for narraw factory buildings in which openings are provided at least on two opposite sides open to ouside. When the buildings are wide as is the case in most of the single-storyed factory buildings, good results can often be achieved by provision of roofed ventilation. Roofed ventilation can be designed either from the point of view of stack action for removal from floor level to roof, of smoke, fumes and other contaminants liberated during heat producing processes or for wind action to provide roof-to-floor ventilation when the manufacturing processes do not contribute appreciably to the heat of the environment. In the latter case, the cross ventilation, to make use of the high pressure on the windward side of the building and the reduced pressure on the leeward side to effect sufficient floor of air through the building.

Three types of buildings with roofs commonly used in factories will be considered from the point view of natural ventilation :

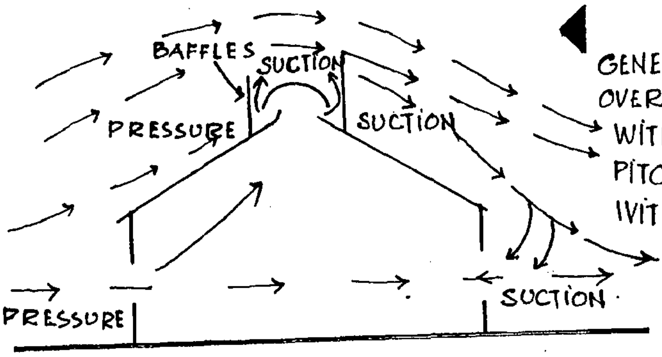
a) Double-pitched roofed building with a continuous ridge in the middle of each bay,

b) Saw-tooth (north-light) roofed building, and

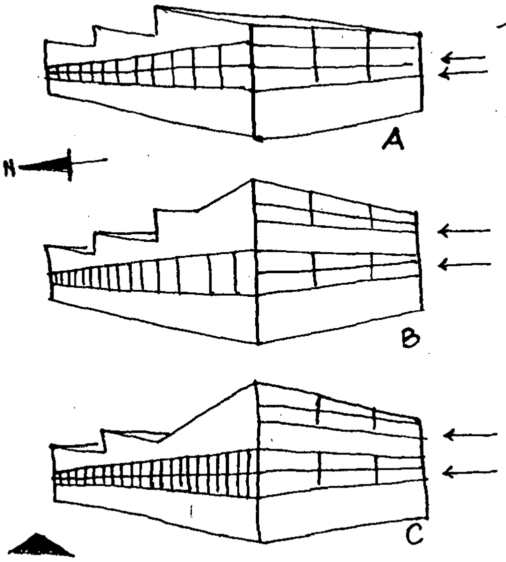
c) 'Monitor' roofed building with louvers or other openings in each monitor.

Double-pitched roofed Building :

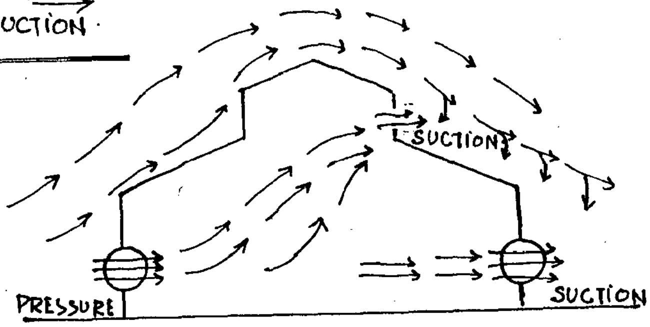
a) No sunction will be induced due to wind action in this type of building if the ridge has openings on both sides as the wind would pass through one side of the ridge to the other without any effect in the lower portion of the building. This type of roof is employed only if there is sufficient stack action inside the building and is effective for the removal of substantial and concentrated heat over open-hearth furnaces, soaking pits and glass furnances. However, when the ridge is provided with longitudinal baffles on both sides , these baffles act as wind jump over the ridge, and the attendant suction between the baffles will result in an upward movement of air from inside the building. Its capacity will increase with wind velocity. These types of stream lines ventilators are most suitable for highbay buildings and warehouses. On some of these buildings, instead of continuous ridge ventilators, cowl type ventilators or what is known as



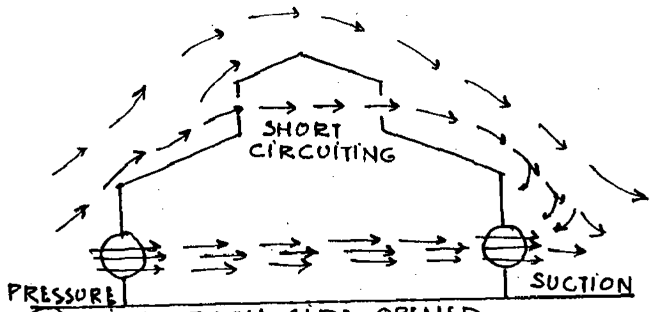
GENERAL PATTERN OF THE AIRFLOW OVER AND THROUGH A BUILDING WITH CONTINUOUS OPEN RIDGE PITCHED-ROOF WITH RIDGES FITTED WITH LONGITUDNAL BAFFLES.



SUGGESTED ARRANGEMENTS FOR IMPROVING AIR MOVEMENTS INDUCED BY WINDS CONTRARY TO THE DIRECTION OF NORTH LIGHT ROOF.

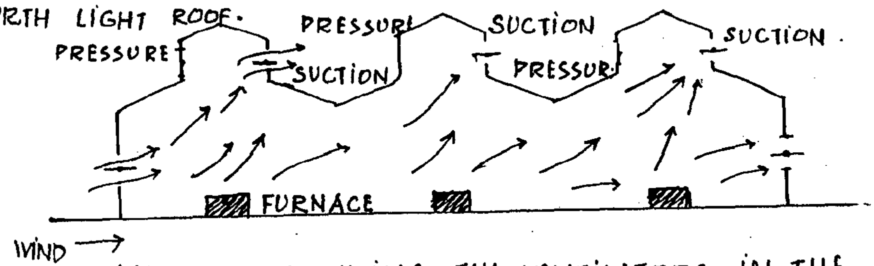


(A) WITH SIDE MONITOR CLOSED



(B) WITH BOTH SIDE OPENED
GENERAL PATTERN OF WIND FLOW THROUGH A BUILDING WITH SINGLE MONITOR

Fig8. Ventilation.



METHOD OF USING THE VENTILATORS IN THE ROOF LIGHTS IN A BUILDING WITH REPETITIVE MONITORS.

SB 1992-93

* source P.P 39-43. HANDBOOK OF FUNCTIONAL REQUIREMENTS OF INDUSTRIAL BUILDING ISI, NEWDELHI, 1986.

'Robertson' ventilators. The circular wind band around each ventilator causes a wind jump resulting in an upward movement of air from within the building. The performance of roof-cowl ventilators depends on the difference between the temperature of the air inside and that outside, on the height of these ventilators above the air intake, on the velocity of the wind outside and on the cross sectional area of the ventilator, and is given by empirical equation :

$$Q = A\ [8.0 \sqrt{H(t_1 - t_o)} + 5.82\ V]$$

where

Q is rate of air flow in m^3/min

A is cross sectional area in m^2

H is the height above inlets in m, t_1 and t_o are temperature inside at inlet level and outside in ^oC, and

V is the wind velocity in km/h.

b) Any number of continuous ventilators could be provided not along the ridge but from valley to the ridge on each bay of the roof approximately over the sources of heat and smoke to remove large volumes of air, thus providing infinitely greater free area for ventilation than would otherwise be possible with ventilator along the ridge only. To ensure high level of performance it is essential that the height of the ventilators is sufficient say 10 m or more, above the low intakes, and the exit temperature is about 10^oC above the prevailing outdoor temperature.

Saw-toothed (north-light) roofed building -

The pattern of airflow produced in this type of building by wind forces is fairly complex, and varies with the proportions of the ridges, size and plan of the building itself and the direction of the wind, that is, whether it blows with, against or along the saw-teeth or obliquely. The inherent difficulty with this type of roof is that wind from north often creates down draughts into the building. To create upward draughts for the removal of heat, smoke and fumes, a suitable modification in the shape of the saw-teeth is necessary so that wind blowing over the roof creates wind jump and causes an upward flow of air from the building and thus assists the flow due to thermal head of the building. In localities where southerly winds predominate in summer, the design of the north-light roofs does not permit to utilise the winds for ventilation, and this deficiency can be compensated at least in part by increasing the ventilation openings in the southern walls. The penetration of direct rays of the sun from the so uth can be prevented conveniently by over-hanges or adjustable louvers or openings incorporating opaque materials or heat absorbing glass. When the wind blows from the east or the west, the provision or omission of the openings in the north-light roofs does not appear to be important. In such cases it is desirable to provide large areas of ventilation openings in the east and west walls of the buildings in localities where winds blows frequently from these directions.

Monitor-roofed building :

In a narrow building with single monitor, if the openings on the monitor on windward side are kept closed and those on leeward side opened, an upward draught of air from within the building would be induced. If, however, openings on both sides of the monitor are opened, short-circuiting will take pla ce through them and no draught would be induced. Hence there should be an arrangement for closing and opening of the monitor ventilators. For buildings with repetitive monitors in the roof, same pressure zones and suction zones would be created if one side of each monitor is closed and the other kept open. Such an arrangement is of particular advantage when there is considerable release of heat or smoke directly under each monitor. However, it is difficult in actual practice to control adjustable openings to suit the direction of prevailing winds, and if there are no sources of heat and smoke, as is usual in factories with this type of roofs, the openings may be provided only at the windward end and leeward end of the building if advantage is to be taken of the winds blowing across the monitor roofed building to produce air movement at the working level. In intermediate bays, it may be preferable to use small adjustable openings which may allow stagnant hot air accumulating near the roof, particularly during the periods of calm, to escape.

Amount of Air

By Wind Action :

Rate of air flow by wind action when openings are provided both on the windward and leeward sides of the building is given by the expression :

$$Q = 16.7\ KAV$$

where

Q is the rate of air flow, in m^3/min,

K is the coefficient of effectiveness,

A is free area of inlet openings (windward or leeward side) in m^3, and

V is the wind velocity in km/h.

The coefficient of effectiveness K depend upon the direction of wind relative to the openings. It varies from 0.5 to 0.6 for wind blowing perpendicular to the openings and from 0.25 to 0.35 for wind blowing obliquely at 45^{o} to the openings.

3.2.3 MECHANICAL VENTILATION :

Ventilation by natural means is not always practicable nor adequate enough to provide thermal environments in factory buildings which could prevent bodily discomfort of workers or which could be tolerated without injury to their health. Sometimes, work places cannot be provided with ventilating openings due to their situation with respect to adjoining buildings, or due to processes carried on in them. In case of large buildings, because of their configuration, natural means may fail to provide adequate ventilation. In such situations, mechanical means of ventilation should be resorted to. In providing mechanical ventilation, proper consideration should be given to the size and configuration of the building, the arrangement of inlet openings in relation to outlet openings, location and disposition of fans, air grilles and ductwork, if any, with due regard to manufacturing processes carried on. Mechanical ventilation may be either (a) by exhaust whereby air is removed from a building by a fan while fresh air is introduced from windows and other openings, or (b) by positive ventilation whereby air is supplied by means of a fan or blower from out-side, or (c) by combination of both exhaust and positive ventilation. In case of positive ventilation, it is possible, where necessary, to cool the air before being brought into the building either by way of evaporative cooling or by air-conditioning.

Mechanical Roof Ventilators :

Cowl type roof ventilators described earlier under 'Natural Ventilation' can be equipped with fan barrel and motor thus permitting gravity operation or motorised high capacity, at will. Two types of roof ventilators are available:

a) the vertical discharge or foundry-type, and

b) the low-hood type.

In case of saw-toothed (north-light) roofs, when these motor-driven roof ventilators are running to exhaust, the openings in the north-light within their area of influences should be closed, or the purpose would be defeated by 'short-circulating'. In case of flatroofed or minitor-roofed buildings, combined positive and exhaust ventilation can be provided by roof ventilators, with alternate air inlet and exhaust adjacent to one another without the effect of 'short-circuiting'. Exhaust fan will exert very little influence beyond a velocity contour of about 15 m/min, which is just a short distance from the fan. The supply air, owing partly to forced ventilation and partly to negative pressure caused by exhaust, will stream into the space below in a straight line until its momentum is spent or it runs into an obstruction. Although the supply and exhaust ventilators are adjacent, there will be no short-circuiting of air between them if the throw of the supply air is sufficient to reach the working level, but there will be, if the throw is much less than that.

3.2.4 AIR-CONDITIONING

When the manufacturing process requires a controlled temperature and humidity and these cannot be obtained by ventilation or evaporative cooling, air-conditioning may be resorted to. When refrigeration is employed to obtain desired temperature and humidity, it may be necessary to recirculate a part of the inside air after getting it mixed with fresh air to save on refrigeration. The fresh air should be drawn from areas where the air is not likely to be polluted or vitiated by any harmful dusts, fumes, gases, etc, given off into the working atmosphere from nearby exhaust ducts or chimney; and to make it free from any organic matter, the air should be efficiently filtered before it is supplied.

As far as possible, central air-conditioning system with ductwork may be employed, but where the requirements of air-conditioning are not high and are for a part of the building or processes, that part of the building may be partitioned and air-conditioned by means of window type or packaged type air-conditioning system with or without ductwork.

3.3.0 NOISE CONTROL :

Noise is often defined as unwanted sound. The degree of 'unwantedness' is however a physiological and psychological question and may range from moderate annoyance to various degrees of permanent hearing loss and, will furthermore be rated to differently by different observers. It is generally recognised that the overall efficiency of human beings is considerably higher when they are less irritated or annoyed by the surroundings. Also a certain degree of quietness is desirable quality in itself. Control of noise is therefore important from all points of view, as it affects the very efficiency of man.

High noise levels are prevalent in industrial buildings. The amount of noise depends on the type of machines installed and industrial operations carried on and also the way the power is applied and transmitted. The harmful effects of excessive noise have been well recognised and it has been shown that such noise produces physiological and psychological effects on industrial workers, for example, annoyance, fatigue and loss of hearing.

3.3.1 SOURCES OF INDUSTRIAL NOISE

These can be classified into following groups:

1. IMPACT:

Noise caused by the impact is the most intense and widespread of all industrial noises. It is normally coupled with resonant response of the structural members connected to the impacting surface.

2. FRICTION:

Most of the noise due to friction is produced in such processes as sawing, grinding and sanding. Friction also occurs at the cutting edge on lathes and badly lubricated bearings. It is very unpleasant in character.

3. RECIPROCATION:

Where a machine vibrates or reciprocates, the moving surface will radiate noise directly.

4. AIR TURBULENCE:

Noise may be generated by rapid variation in air pressure caused by turbulence from high velocity air, steam or gases. (for example exhaust noise)

5. OTHER NOISES:

In addition, there are other noises as well such as whining noise from turbines, humming noise from transformers, noise of driving belts as they pass over joints at the drums of driving shaft, noise of pressure pumps in action etc.

3.3.2 Subjective and Harmful Effects of Noise

Excessive noise is harmful to the factory workers in following ways.

i) Annoyance resulting in lack of concentration due to distraction, (ii) Inducement of fatigue may lead to accidents and to decreased output. This is especially so where the job demands mental concentration and vigilance. (iii) Interference with speech communication level (SIL) results making difficult the intelligible communication even at a distance of 1 M from the source (Generally above 55 dB). In areas where the SIL is above 70 dB, even the raised voice communication becomes very difficult and troublesome, (iv) Industrial deafness, at first only temporary (Temporary threshold shift TTS) but gradually becoming permanent (Permanent Threshold Shift PTS). It is found that where an octave band level of continuous noise between frequencies 150-9600 c/s exceeds 85 dB the risk of damage to hearing exists. <u>The time of exposure to such noise is very important.</u>, (v) Noise of operation if rythematic is less distracting, (vi) Noise levels above 75 dB result in contraction of blood veins leading to heart trouble, (vii) Psychosomatic diseases originating from noise action may include outbursts of rheumatism, gynaecological complications and mild neurosis. (viii) High noise levels tend to excite the nerve system and upset the normal temperament, create weakness of muscles and may lead to lever diseases and ulcers.

Range of Noise Levels in some industries*

Industry	SPL in dB (mean levels)
Machine tools	- 85
Leather Industry	- 88
Heavy electricals	- 90
Rail coach	- 90
Sugar	95 dB
Printing and publishing	87
Small fabrication	93
Textiles	95
Automobile	92
Heavy Engg.	95
Primary metals	97
Air craft	93
Pottery works	89

PROCESSES

Manual Hammering - small	90-98 dB
- big	115-120
Drop forge	98-115
Riveting	95-115
Cooking	112-122
Chipping	108-116
Shearing	103 to 108
Small Punch and forming	95 to 100

Pneumatic jotter	105-110
Short blasting	100-105
Wood plaining	105-110
Aircraft Engine test-Propeller -jet	 110-128 115-135
Jaw crusher	90-95

* CBRI, Building Digest 33, Industrial Noise, Part II

3.3.3 METHODS OF NOISE REDUCTION :

The level of ambient noise in a factory area can be reduced by following methods, based on the source, path and the receiver, i) Location and layout, ii) Noise reduction at source, and (iii) Acoustical Treatment.

Noisy processes can be located or may be enclosed and separated by walls from the main functions. This will generally segregate the noisy processes from the quieter ones and the sonic pollution of the entire factory could be prevented.

(ii) Noise Reduction at Source :

(a) Selection of Machinery :

This is beyond control of an architect, however, choice would largely depend on manufacturer's advice.

(b) Reducing noises from potential sources :

(c) The Machinery, specially the vibrating type, (i.e. pumps, compressors sieves) should be laid on 'isolators' which may be of resilient materials like steel in the form of springs, rubber, cork and felt. However the exact material related to vibrations can be decided by a mechanical engineer. However, the 'machinery foundation' should be separated from the main floor wherever possible. This helps in preventing the transmission of vibrations to the main floor and structure.

(d) Acoustical Treatment : This can be achived by

i) Enclosures, or barriers,

ii) Acoustical treatment of walls and ceilings,

iii) Suspended sound absorbers,

iv) Appropriate openings near the machinery,

v) Ear defending equipment.

Air borne noise generated by the machine may be reduced by placing the machine in an enclosure or behind a barrier.

3.4.0 ORIENTATION :

By orientation in industrial context, we mean, a facing and locating of factories in such a manner so as to obtain maximum advantage from natural agencies like sun, wind, temperature, i.e. minimum and maximum solar heat gains during summer and winter respectively, wind-movement indoors etc. With proper orientation, the conditions indoors would be more comfortable naturally and expenses on mechanical devices for physical comfort will be reduced.

3.4.1 Factors affecting orientation

From the point of view of orientation, solar heat gain is the primary consideration but other factors like the direction of prevalent breeze, the amount and direction of rainfall and the site conditions cannot be overlooked. Factors that need consideration are as follows :

3.4.2 THE ROOF AND ORIENTATION :

In tropical climate and particularly in industries the roof with its large surface poses a major problem of heat gain, through the fenestration and roof lighting and the roofing material itself. Fenestration should be adequately protected from the direct entry of sun. This is not possible if skylighting system is resorted to. Fenestration can be protected with diffusing glasses, overhanging eaves or miniature louvres. For minimising heat gains through this roof glazing, a proper orientation would necessitate its facing to north or south sides.

Thermal performance of a roof depends on its shape, reflective and emissive properties of roofing material, thermal properties and total area of exposed surface. In general light coloured materials are preferable to dark ones. The shapes like, hyperbolic parabola, folded plate, conoids, have inbuilt advantage of retaining parts of its surface under shade and as such the heat gain will be less. Moreover they offer larger surface in terms of area than flat roofs and this reduces the per unit area solar radiation over them. The radiation exchange is directly proportional to the effective surface area over which radiation is distributed. Concrete roofs relatively are better in thermal performance than A.C. sheets or aluminium sheets. For thermal comfort, the roof should ensure lower internal surface temperatures to minimise the radiant heat lead to the occupants.

The factory act stipulates a clear internal height of 14'-0" with r.c. roofs and 20'-0" with trussed roofs without insulation and a minimum gap of 4 in. air space between insulation and sheets.

This difference in height does play some part in directing the airflow from the openings towards the floor because of higher air prossure on one face of the building. The wind velocity $V \alpha \sqrt{P_1-P_2}$ and as such the bigger the P_1 due to larger heights and surface, the greater will be the V. ~~However for thermal comfort~~ the extra height does not contribute significantly. In a project sponsored by A.C.C. (India) Ltd. and the Fibre Glass Pilkington India and the studies conducted in recent years by C.B.R.I. on the insulation of A.C. sheet roofs of factory buildings with height of 20'-0" and 16'-0" have shown that no significant difference in the indoor air temperature inspite of a height difference.

The overall thermal performance index (TPI) is defined as the relative rating of the different building components by taking overall climatic data, thermophysical properties of building sections and indoor air temperature variations and the T.P.I. values for different roofs has been tabulated to help in the final choice of roofing material.

TABLE NO.

Sl. No.	Roof Section	Treatment External	Treatment Internal	T.P.I	Range of T.P.I.	Performance
1.	10.00 cm.r.c. slab	Tarfelt	1.5.c plaster	225	175 225	Very poor
2.	10.00 cm + 5.00 cm mud phuska	5.00 cm brick tile	1.5c. plaster	122	75 125	Fan
3.	10.00 cm + 5.00 cm Thermocole	Tarfelt	1.5c. plaster	64	75	Good
4.	10.00 cm + 10.00cm foam conc.	Tarfelt	1.5c. plaster	66	75	Good
5.	10.00 cm + 5.00 cm foam conc.	Tarfelt	1.5c. plaster	81	75 125	Fair
6.	10.00 cm + 2.5 cm Thermocole	Tarfelt	1.5c. plaster	86	75 125	Fair
7.	Aluminium sheets with 2.5 cm thermocole	Tarfelt	Insulation fibre board	90	-do-	Fair
8.	A.C. sheet + 2.5 cm thermocole	-do-	-do-	85	-do-	Fair
9.	"+2.5 cm mineral wool	-do-	-do-	86	-do-	Fair + Sound absorbant
10.	Aluminium + sheets	-do-	-do-	84	-do-	Fair + Sound absorbant

3.5.0 ECONOMY

Roof Type and the cost Consideration

The overall cost of a roof depends upon a number of factors, and it should be seen vis-a-vis the advantage offered by a structure. The cheapest structure need not always be the choice if advantage are missing.

Shell roofs are competitive for areas over 800 sft. provided atleast eight units are built to reuse the shuttering.

Tubular steel work in roofs weighs less than 3 lbs/sft. and results in the greatest economy by way of reduced weight of steel.

From the daylighting point of view lantern light should be prefered to skylighting to ensure a uniform lighting indoors.

For having some idea as to the cost of various roofs enlisted, an estimate was made based on the cost of material, quantity and labour and tabulated. It includes only the trusses and roofing materials, slabs and beams (for concrete roofs) and does not include columns or foundations. This would vary from place to place, and every year and as such gives idea of relative costs of different roof types.

COST FACTOR OF SOME ROOFS 15 M X 15 M GRID

R.C.C STRUCTURE	COST STRUCTURE
a) NORTH LIGHT SHELL	.81
b) CONOIDAL SHELL	.75
c) BARREL SHELL	1.00
d) WAFFLE FLOOR SLAB	.75
STEEL	

3) If water main pressure is inadequate for fire fighting, storage towers or tank must be provided.

4) If steel beams and columns are used they must be protected.

5) Extra precautions must be taken in siting hazardous operations, in shielding them from other plant areas, and in minimizing the fire risk within the hazardous area itself.

3.7.0 STRUCTURAL STABILITY :

The following which effects the structural stability :

1) Stability of independent section

2) Stability of entire system

3) Stability against lateral loaods

4) Machine foundation (vibration)

In addition to strength and stiffness, the stability of any structure is a vital design requirement. The importance of the problem of structural stability in Industrial structures further magnified by their large heights, presence of heavy machinery loads vibrations etc.

The two significant lateral loading conditions arise from the action of wind and seismic forces. The action of seismic forces becomes predominant generally only when there are heavy loads located at heights, as in the case of multi-storeyed structures in steel R.C.C. As the seismic condition is not considered significant for Industrial sheds in general, the effect of WIND is only being discussed in detail in this report.

MULTI SPAN ROOF :

In multi span roofs in which the spans, height and slopes are approximately equal and where the windward span gives shelter to the suceeding spans, the spans being adjacent, the following external pressure may be taken in making the general stability - calculation and in design of the framework.

a) On the windward slope on the windward span and the leeward span the pressure appropriate to the slope.

b) On the other roof slopes, account need be taken of only the effect of wind drag.

DESIGN ELEMENTS TOO RESIST WIND PRESSURE :

In framed structure it may be obtained by bracing members, rigidity of the joints or by infilling the frame with shear resistance panel. A few of system can be categorised as :

i) Braced steel skeleton : Here column joined with diagonal web members from vertical trusses which resist wind loads and provide rigidity to the skeleton thus minimising lateral deflections.

ii) Wall and slab porta l : In this system closely spaced exterior columns, corridor walls and floor slabs work together to resist wind moment. The reinforced concrete frame depends upon portal action for its rigidity.

iii) Continuous steel frame : In this bracing of full one bay is done due to its stability of structure. This is done at every after 4 or 5 bays.

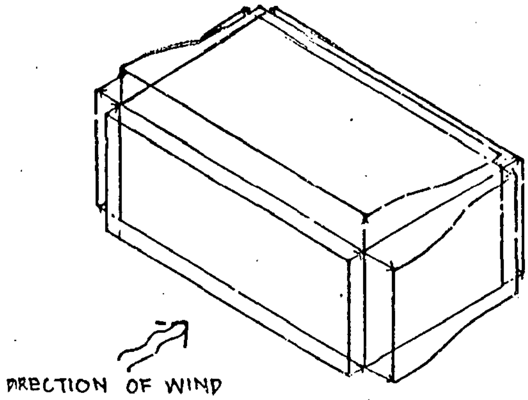
SIMPLE FACTORY STRUCTURES

In the design of simple factory structure individual components of the structure have to be designed to withstand the effects of wind pressures, in addition to overcoming the problems of instability of the overall structure. Thus, the problem begins with holding down the sheeting to purlins, the purlins to the trusses, the trusses to the columns, all the way down from the foundations to the supporting earth.

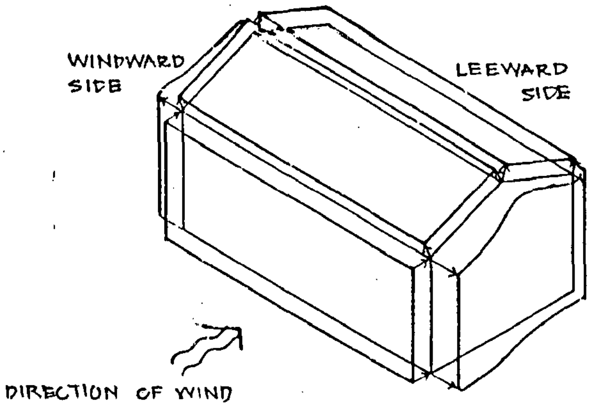
Owing to the presence of low dead loads at roof level, the roof members are subjected to uplift forces owing to the attack by wind. Hence the purlins and truss members should be designed for this coondition, whereby reversibility of design stress conditions (due to dead and live loads) is liable to occur. Similarly, the columns and foundations should be designed to posses adequate factor of safety against overturning.

For the condition, of wind acting along the ridge of the sheds, the trusses should be adequately braced at eaves level and compression chord level at regular intervals to ensure a three-dimensional behaviour of the entire structure. If this is not ensured, each portal frame is liable to collapse in the manner of failure of a pack of cards', Finally, the gable ends should be designed to take the blast of the wind locally.

For the condition of wind acting perpendicular to the ridge of the sheds, each portal frame tend to behave independently and must possess adequate rigidity. Although, it is normally difficult to achieve a monolithic joint between truss/girder and

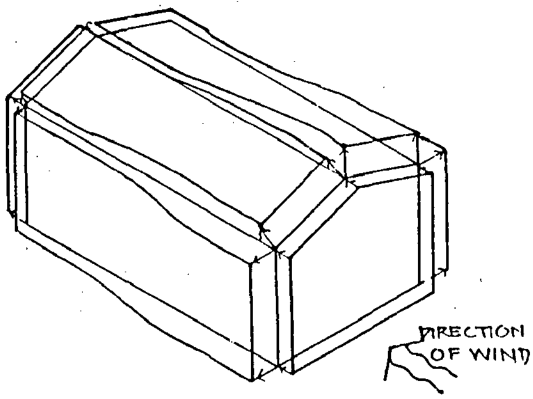


FLAT ROOF



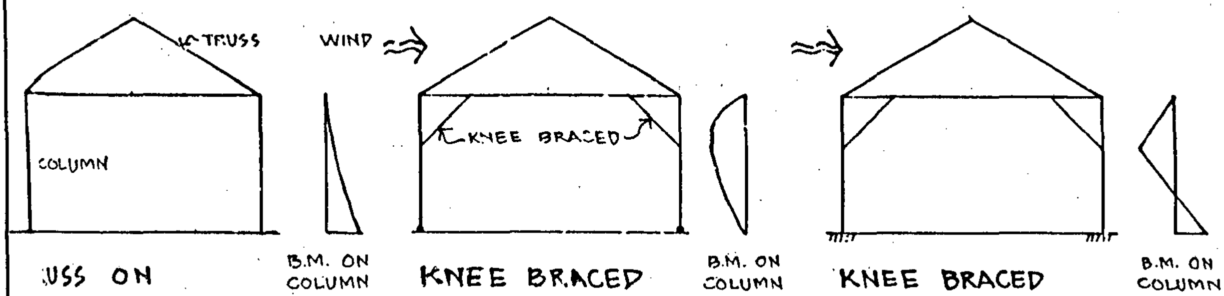
SLOPING ROOF

WINDWARD ROOF SURFACE IS SUBJECT TO PRESSURE IF WINDWARD SLOPE OF ROOF IS MORE THAN 30°, AND SUBJECT TO SUCTION IF SLOPE IS LESS



SLOPING ROOF

WIND PRESSURE AND SUCTION ON BUILDING



USS ON LUMN

KNEE BRACED TRUSS HINGED COLUMN

KNEE BRACED TRUSS FIXED COLUMN

Fig 9 : Structural Stability.

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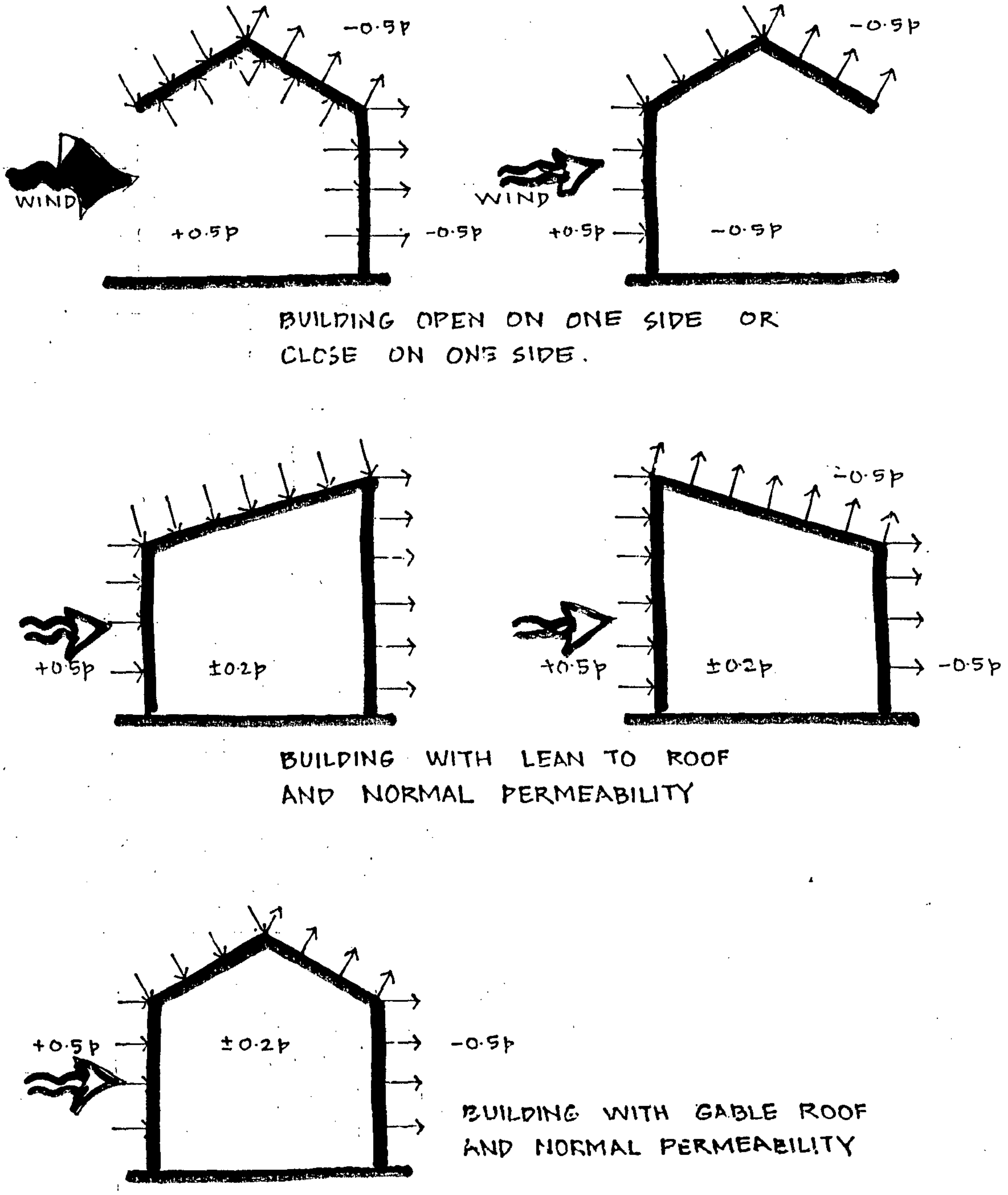


Fig 10 : Structural Stability.

S.B 1992-93

column, semi-rigid joints may be effectively detailed. 'Kneebraces' are often provided for this purpose. "Wind girders" are sometimes provided at the eaves level, spanning from column to colummn, generally comprising open-web box sections. This behave as horizontal beams taking wind loads. In addition for very tall sheds, intermediate auxiliary girders may be provided in random with the gantry girders at the crane level.

3.7.2 MACHINE FOOUNDATION :

Several kinds of machine foundation exist but the design concept for all of them are the same. The fundamental aspect is basically resolve a problem of vibration. If the presence of vibration is not taken care of at the design stage it is liable to cause failure of the structure locally and affect neighbouring machinery.

A problem of vibration isolation of machinery is often encountered requiring complete from neighbouring machinery isolation. This is achieved by the use of springs and neoprene pads at the base a vertical layer of sand filling surrounded by a brick partition wall isolates the foundation on all sides.

A proper design should overcome the following problems :

i) Problem over coming resonance

ii) Bearing pressure of soil.

iii) Amplitude within tolerable limits.

Resonance is a critical condition whereby the operating frequency of the machinery coincides with one of the natural frequencies of the foundation system. The structural designer may vary the latter by altering the size of the foundation, or by providing springs in order to ensure that the natural frequencies are at least 20% well above or below the operating frequency of machine.

4

EFFECT OF FORM AND STRUCTURE ON INDUSTRIAL BUILT ENVIRONMENT

CHAPTER - 4

EFFECT OF FORM AND STRUCTURE ON INDUSTRIAL BOILT ENVIRONMENT

Structure is not an end in itself but is the result of the integration of all the requirements to be met by a building. There is a freedom to choose a structure but once choosen, there is freedom only within its limitions. These can be no architecture without technology to translate architectural concepts into physical reality. Technology has always influenced building forms and architects of every age have desired inspiration from the technical mastery, of material. Forms born of the union of art and technology, with features derived from modern techniques of construction, then come structural form.

This chapter deals with relation of span and structure form and structure the analysis of effect of roof form in the industrial environment. In an industrial environment, where the gigantic machines dominate the surrounding, can there be a very human approach to solve?

4.1 SPAN AND STRUCTURE

Several factors, functional and aesthetical, have a bearing on the problem on providing the most appropriate structural framing and roof for a factory building at the minimum overall cost consistent with the fulfilment of all requirements. The choice is not easy and has to be based on a number of considerations.

4.1.1 Relevant Considerations for Industrial Buildings

These may be broadly divided under five categories :

a) Structural considerations,

b) Materials of construction,

c) Services,

d) Aesthetics,

e) Future expansion.

The broad divisions could be further subdivided as follows :

a) Structural Considerations

i) Spacing for internal columns governed by process, machinery and equipment.

ii) Clear internal height.

iii) Speed of erection.

iv) Possibility of dismantling and reerection.

v) Cost/sqm or sft.

vi) Overall weight of foundations.

b) Materials of Constructions

i) Special requirements of a process.

ii) Nature of process.

iii) Desired floor and wall finishes.

vi) Base of maintenance.

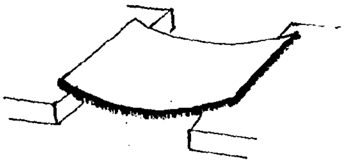
v) Thermal insulation.

vi) Fire resistance.

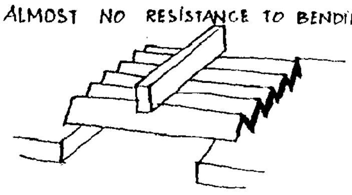
c) Services

i) Suspension of services like ducts, pipes, fans, sliplines. light -fittings.

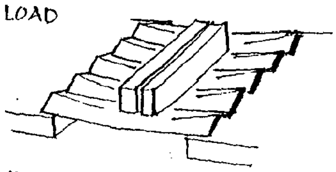
Ⓐ A PAPER MODEL OF A FOLDED PLATE.



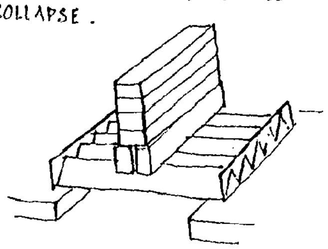
1 A FLAT SHEET OF PAPER HAS ALMOST NO RESISTANCE TO BENDING.



2. FOLDED IT CAN SUPPORT A CERTAIN LOAD



3. IF OVER. LOADED, THE FOLD COLLAPSE.

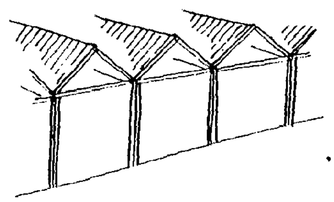


4. DIAPHRAMS, GLUED TO EACH OTHER END, STIFFEN THE FOLDS AND INCREASE THEIR CARRYING CAPACITY.

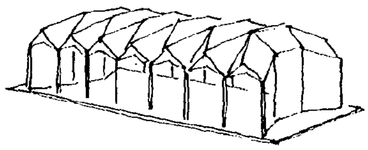
* Source Fig 128, 130, 142. BORTON. T.E. "STRUCTURE AND FORM IN MODERN ARCHITECTURE. CROSBY LOCKWOOD & SON LTD, LONDON, 1961.

Fig 11. Span and Structure. Folded plate.

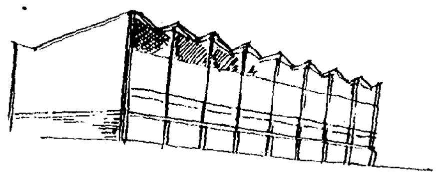
FOLDED PLATES DERIVES THEIR STRENGTH FROM THE STIFFNESS OF THE FOLDS. THE ELEMENTARY SLABS ARE STRESSED IN TENSION, COMPRESSION AND SHEAR IN THEIR OWN PLANE AND IN BENDING IN A DIRECTION AT RIGHT ANGLE TO THIS PLANE.



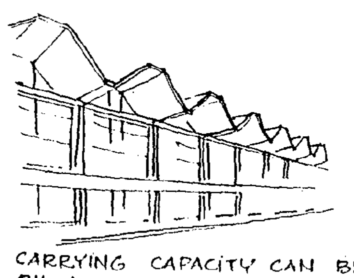
1. TIE MEMBER BETWEEN SUPPORT.



2. ARROWHEAD STIFFNERS SUPPORTED AT THE LOW POINT.



3. ARROWHEAD STIFFNER SUPPORTED HEIGHEST POINT.



4. CARRYING CAPACITY CAN BE INCREASED BY INTRODUCING HORIZONTAL SLABS AT RIDGES.

Ⓑ VARIOUS FORMS OF FOLDED PLATE

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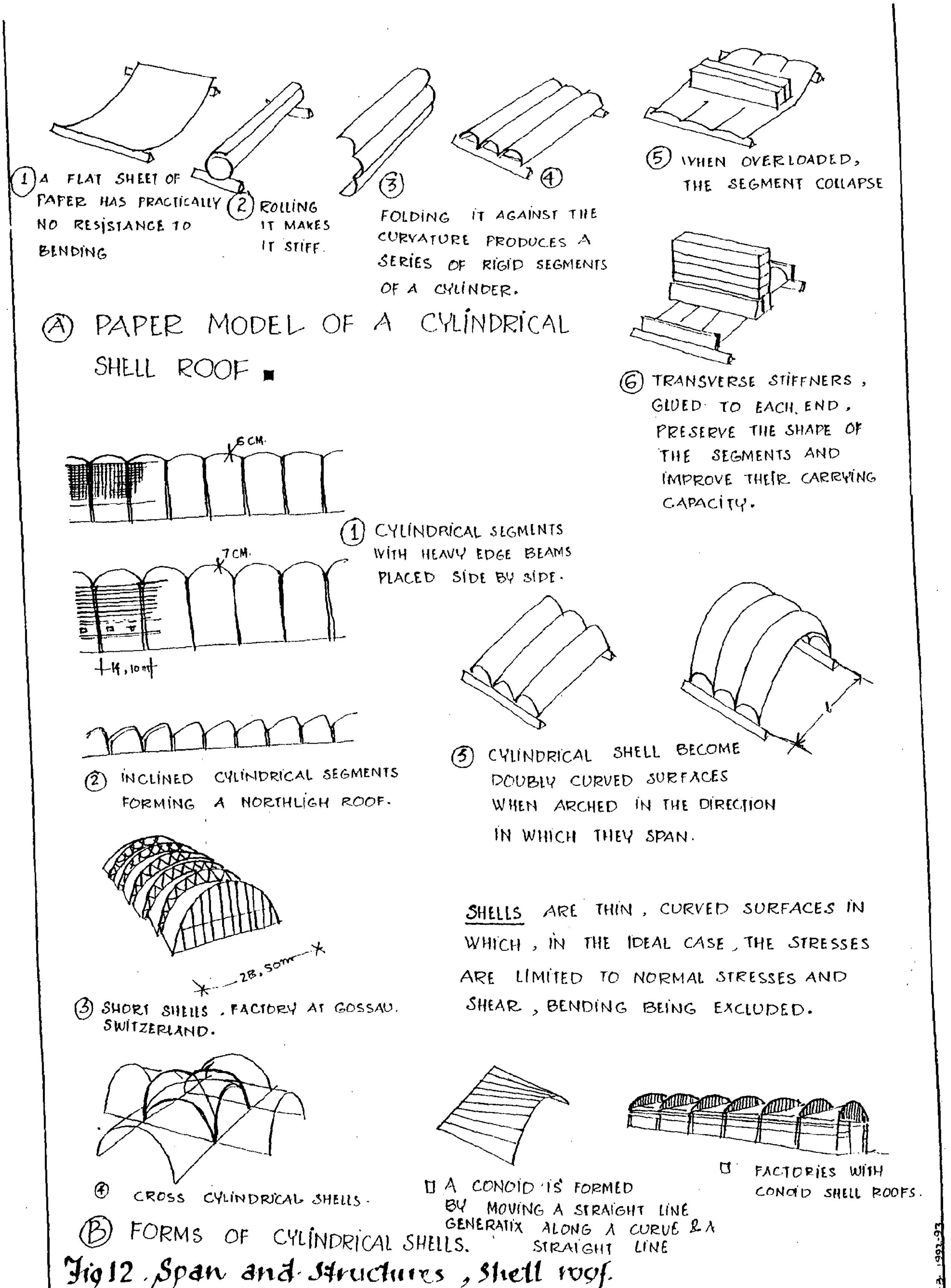
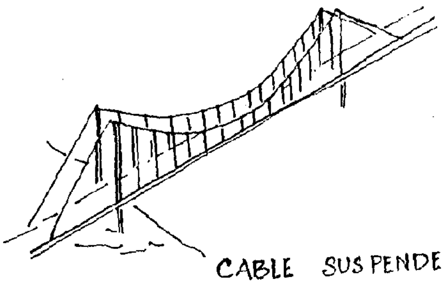
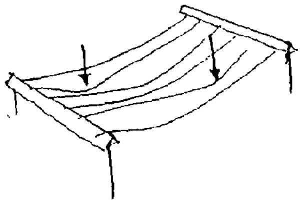


Fig 12. Span and Structures, Shell roof.

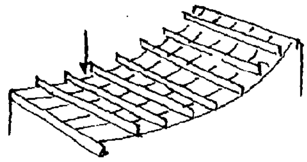
* Source Fig-143,146,152, 159,174. Borton T.E., "STRUCTURE AND FORM IN MODERN ARCHITECTURE. CROSBY LOCKWOOD & SON LTD. LONDON, 1961.



CABLE SUSPENDED ROOF.



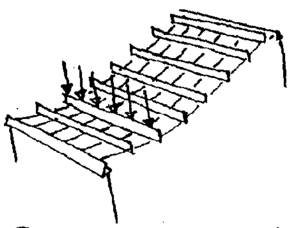
(A) UNDER LOAD EACH CABLE DEFORMS INDEPENDENTLY.



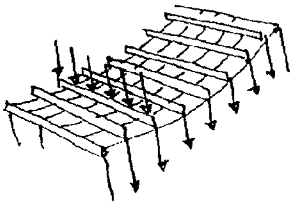
(B) IN ORDER TO MAKE A[I] THE CABLES ACT TOGETI TRANSVERSE STIFFNERS MUST BE INTRODUCED.

1 SIMPLE SUSPENDED CABLE ROOFS.

SUSPENDED ROOFS A FORMED OF CABLES, STEEL NETS, FABRIC, OR THIN SHEETS. THE ARE STRESSED EXCL IN TENSION.

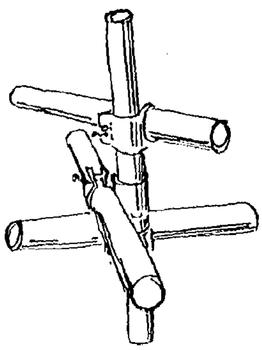


(C) UNDER ASYMMETRICAL LOADING THE STRUCTURE WILL BE UNSTABLE, EVEN IF STIFFNERS ARE EMPLOYED.

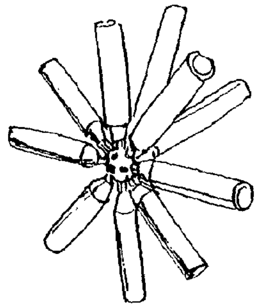


(D) COMPLETE STABILITY CAN ONLY BE ENSURED BY TYING DOWN THE ENDS OF THE TRANSVERSE STIFFNERS.

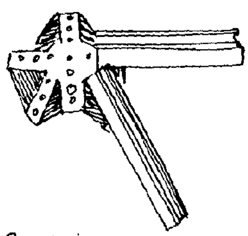
2. SPACE FRAME ARE COMPOSED OF LARGE NUMBERS OF INDIVIDUAL MEMBERS. THESE MEMBERS ARE STRESSED AXIALLY, THAT IS EITHER IN TENSION OR COMPRESSION. THEY ARE BRACED AGAINST EACH OTHER IN A THREE DIMENSIONAL SYSTEM.



1. MANNESMANN SYSTEM.
- TUBES CAN BE CONNECTED AT ANY ANGLE. IT IS POSSIBLE TO USE ANY NUMBER OF TUBES AT ANY LENGTH.



2. MERO SYSTEM.
- UP TO 18 TUBES CAN BE CONNECTED AT ANY JOINT.



3. UNISTRUT SYSTEM.

Fig 13. Span and Structure, Cable and Space Frames.

ii) Protruding chimney through roofs.

iii) Daylight considerations.

iv) General ventilation.

v) Roof drainage.

vi) Materials handlings - Introduction of industrial trucks.

d) Aesthetics

i) External shape of roof.

ii) Appearance from within.

e) Future Expansion

i) Ease of addition or extension,

ii) Problem of expansion joints.

4.1.2 Steel and Concrete Structures a comparative Study

In Indian context, the industrial structures are limited mainly to the two materials namely steel and concrete. It is worthwhile therefore to study the merits and demerits in respect of these principal materials used for industrial buildings. In table every point enumerated, is assigned a value out of ten, to give its relative merit or demerit over other material. This system of value assignment helps to make the final choice easier and faster.

TABLE NO.

Sl. No.	Reinforced Concrete Structure	Value Assigned of ten for each point	Steel Structure	Value Assigned out of ten for each point
1.	Slow erection (excepting prefabricated construction)	3	Faster erection	8
2.	Difficulties of suspending services like ducts, pipes, ~~slip lines etc.~~	3	Ease of suspending service	10
3.	In case of future expansion the expansion joints create problems.	6	Expansion joints pose no problem in case of future expansion	10
4.	Requires lesser maintenance	8	A regular maintenance by way of painting is necessary	5
5.	No possibility of dismantling unless a specially designed profabricated type.	2	Could be dismantled and reerected	8
6.	Chimney cannot protrude through roof at any point without a specially designed opening	3	Chimneys can be allowed to protrude at any point on the roof	10
7.	Satisfies requirements of process	10	Satisfies requirements of process	10
8.	Good daylight possibilities	10	Good daylight possibilities	10
9.	Wt/sqm of roof and supporting structure is more, bigger foundations and consequent greater cost	6	Wt/sqm of roof and supporting is lesser, relatively lighter foundations and consequent saving on costs	8

10.	Withstand fire better	8	Relatively weaker against fire resistance	4
11.	Acoustically shells are difficult to treat	6	Lesser acoustical problems	8
12.	Roof shapes help general ventilation	8	Roof shapes help general ventilation	8
13.	Possibilities of flat as well as ridge, shall, N.L. roofs.	10	Possibilities of flat roof are almost absent in present Indian context, other shapes include NL, ridge roofs etc.	6
14.	Provides better thermal insulation	6	Poor in thermal insulation	3
15.	Flat roofs provide lesser surface area for promoting convection and rediation heat losses.	6	Sloping roofs greater surfaces area for promoting convection and radiation heat losses.	8
16.	Aesthetically, concrete structures offer wider scope for architects, in terms of shapes forms.	8	Lesser scope for architects in terms of forms or shapes.	4
	Total value assigned	103/160		120/160

It can be seem from above, that for industrial buildings the steel structures offer obvious advantages over the reinforced concrete structures.

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* Chatre. A.L. : Ceramic Industry with spl ref. to porrety works, U.O.R., Roorkee, pp. 173-174. Table 31.

4.2 RELATIONSHIP BETWEEN ROOF FORM AND INTERNAL ENVIRONMENT

Most machnies and equipment will react to condition of temperature, humidity and cleaness and these condition, if they are unsuitable, affect the efficiency and accuracy with which the machine operate. A machine is however is entirely unaffected by the colour, shape or aesthetics qualities of its surroundings. While a human being is greatly affected by these considerations.

Basically a industrial building is a shell to protect and run a process. But the process needs workers who are increasingly demanding better conditions. Good management practice now has its constituents as the provision of pleasant and efficient working conditions. One of the essntial is to provide a working environment which is optimal for both work and satisfaction. It is created by space with in the building, its envelop and the equipment, the process and the people concerned. The main constituents for the physical environment are as follows :

1) Dust free and hygenic atmosphere
2) Noise control and reduction
3) Lighting (daylight and artificial)
4) Colour
5) Safety
6) Smoke and fire
7) Pollution
8) Ecological Balance

Roof form had an impact on environment as it affect & control lighting, ventilation, dust control, thermal and noise control. So during design stage of factory selection of roof form for different industrial process, it is essential to consider all the requirement which effect internal environment.

4.3 RELATIONSHIP BETWEEN ROOF FORM AND FUNCTIONAL REQUIREMENTS

Decision of selection of roof form depends upon various factors. While the single span roofs without intermediate supports are the best as they offer flexibility for process layout, these aspects should be viewed in following perspective.

1) Size of the biggest machinery or equipment.

2) Any particular process requiring maximum space including circulation space.

3) In absence of intermediate supports, problem of suspending services like duct, slip lines, pipes etc.

4) Comparative cost of a single span roof vis-a-vis the roof with intermediate supports of columns or stanchions.

Production process it may be linear, circular or horse shoe shaped alignment strictly aligned production process are mainly encountered in paper mills, glass factories, rolled steel mills.

6) Lighting and Ventilation requirements.

7) Aesthetics

Basically roofing forms are derived from functional requirement of any factory but if the clients requirement in a factory of its own identity then a roofing option can be selected based on its visual quality. From economy point of view the best option will be, selecting a roofing option based on functional requirement and then aesthetically treating it.

TABLE

CENERALLY RECOMMENDED CEILING HEIGHTS (IN FEET)

TYPE OF PRODUCTION	WITHOUT OVERHEAD INSTALLATION*	WITH OVERHEAD INSTALLATION**
SMALL PRODUCT ASSEMBLY ON BENCHES	9 - 14	10-18
LARGE PRODUCT ASSEMBLY ON FLOORS	MAX. HEIGHT OF PRODUCT + 75%	MAX. HEIGHT OF PRODUCT + 125%
SMALL PRODUCT FORMING	HEIGHT OF MACH-INERY + 100%	HEIGHT OF MACHINERY + 150%
LARGE PRODUCT FORMING	HEIGHT OF MACH-INERY + 125%	HEIGHT OF MACHINERY +125%

* OTHER THAN LIGHTING AND SPRINKLER

** AIR DUCTS, UNIT HEATERS, CONVEYORS ETC.

4.4 HUMAN NEEDS IN INDUSTRIAL ENVIRONMENT

The humanising of working environment and the working conditions in a factory must be given priority and it is in this area that the architect can make the greatest use of his particular talents.

As maximum industrial works are repetitive and those engaged in these works requires great concentration find their efficiency drops after a time and they need a charge. Working condition which are more human can play on important role in increasing the productivity.

A well designed working environment includes not only suitable lighting, heating and ventilation and comfort standards but also the tangible and intangible amenities which can convert discontent and boredom into interest and a sense of participation i.e.

1) Break Area : In order to provide the change of atmosphere which is necessary at regular intervals throughout the working day.

2) Land Scaping : Garden courtyard i.e. to bring nature closer, to make environment more habitable.

3) By placing the services in floor and ceiling ducts, complete freedom of layout is provided for working floors.

5

ANALYSIS OF INDUSTRIAL ROOF FORMS THROUGH SELECTED CASE STUDIES

CHAPTER 5

ANALYSIS OF INDUSTRIAL ROOF FORMS THROUGH SELECTED CASE STUDIES

This chapter deals with the analysis of different type of roof forms used in different industrial buildings. The basis of analysis is worked out. Different roof types are adopted through selected case studies and they are analysis.

5.1 BASIS OF ANALYSIS

The selection of industrial roof form depends upon number of factors i.e.

1. Aesthetics and visual quality
2. Size or span
3. Form
4. Internal environment and functional requirements
5. Physical comfort
6. Lighting
7. Ventilation
8. Height to span ratio
9. Orientation
10. Flexibility
11. Fire protection
12. Economy

5.1.1 Aesthetics and visual quality

- Urban setting
- Physical appearance

- The characteristic of building forms, signs, landscape, route pattern, finishes
- Building and back ground

5.1.2 Size or span

- Small - up to 50'
- Medium - 50 to 100'
- Large span - 100' to 300'
- Very large - more than 300'

5.1.3 FORM -

The physical form of building structure

i.e. Planar or Space Structure

Planar ——→ trusses, north light, etc.

Space Structure ——→ Shell roof, dome, folded plate etc.

5.1.4 Internal Environment and Functional Requirements

Internal environment Physical and Psycological Aspect

- Dust free and hygenic atmosphere
- Noise neductition
- Sufficient light and ventiltion
- Pollution free environment

5.1.5 Physical Comfort

- Controlled or uncontrolled condition
- Thermal condition
- Acoustical treatment

5.1.6 LIGHTING

- Natural lighting
- Artificial lighting
- Combination of two

5.1.7 Ventilation

- Natural
- Mechanical
- Air conditioned

5.1.8 Height to span ratio

- Process requirement
- Choosen roofing form
- Scale and proportion

5.1.9 Orientation

- Natural lighting
- Ventilation (Cross or Roofed)
- Thermal condition
- Landscape treatment

5.1.10 Flexibility

- Future expansion
- Future requirements
- Change in use

5.1.11 Fire protection

- Fire resistance
- Treatment

5.1.12 Ecomomy

- Roof type and its material
- Form work
- Maintenance

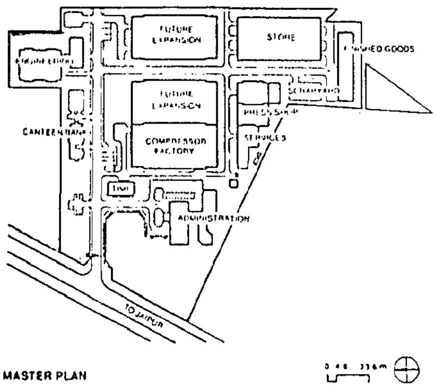
5.2 CASE STUDY AND ANAYSIS

Case studies are selected on the basis of their roof form. The case study are

CASE STUDY No.	ROOF TYPE	CASE STUDY
1.	NORTH LIGHT TRUSS	CARRIER AIRCON, GURGAON
2.	SPACE FRAME TRUSS	SPECTOM ENGG. VADODARA
3.	PRECAST R.C. ROOF	CHLORIDE INDIA LTD. HALDIA
4.	R.C. SHELL ROOF	AMMONIA PERCOLATE PLANT, COCHIN
5.	VAULTED R.C. ROOF	STENCIL TROUSER FACTOR, NOIDA
6.	HYPERBOLIC PARABOLOID SHELL ROOF	PUNJSTAR STANDARD ELECTRONICS JAPAN
7.	DOME ROOF	TYRE RETREADING FACTORY, JABALPUR
8.	FOLDED PLATE ROOF	TEXTILE FACTORY, MARIYAMA
9.	SADDLE ROOF	GLASS FACTORY, AMBERG GERMANY
10.	STEEL CABLES	PAPER FACTORY, WANITUA, ITALY
11.	LANTERN ROOF	WHOLE SALE BAKERY, BERGEN, NORWAY,

ROOF TYPE - NORTH LIGHT TRUSS

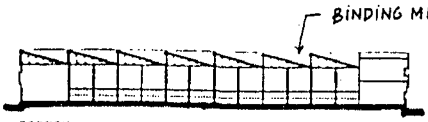
CASE STUDY 1 . CARRIER AIRCON GURGAON



MASTER PLAN

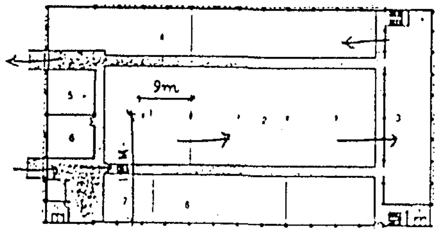
ARCHITECT - M.M. KATIRA.

INTRODUCTION - A joint venture with Carrier Corporation, U.S.A., carrier aircorn manufactures - window and split unit airconditioners. Located on a 4.8 hectare site fronting N.H 7



SECTION

STRUCTURE - The factory is an R.C column construction designed in modular bays of 16m x 9m roofed over with aluminium sheets, in the form of north light truss.



MAIN FACTORY

GROUND FLOOR

1 STORES
2 MACHINE SHOP
3 ASSEMBLY
4 FINISHED GOODS
5 INCOMING MATERIAL
6 TESTING
7 TOOL ROOM
8 BRAZING WELDING
9 TOILET

AESTHETIC - The end binding members of North light truss of main compressor factory gives the building its own identity and not look like yet another factory.

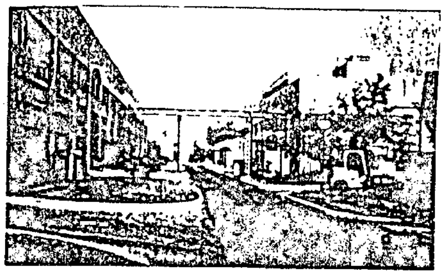
Other related buildings in the complex are load bearing structure of lesser height with gable roof to distinguish them from the main factory.

The low profile of the complex sets out and combine with the landscape lawns to give it more humanising look.

The low profile of complex set within landscape lawns

The main compressor plant with the HRD office to the right.

The roof creating silhoutte an interesting



Binding element of Northlight truss concealing the triangulated tuss form.

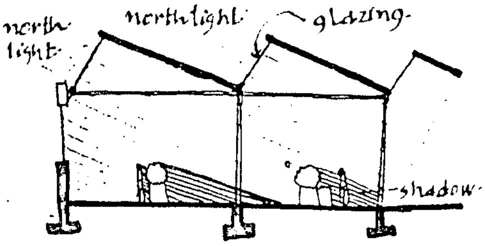
<u>FORM</u> - The overall triangulated form is concealed by binding end member. The factory establishes its own identity not look like yet another factory.

<u>INTERNAL ENVIRONMENT</u> - Use of ample natural light, dust free atmosphere.

PHYSICAL COMFORT - Controlled environment. use of A.C.

<u>Polarity</u> - Unidirectional structure less polar.

<u>Flexibility</u> - Flexible internal divisions.
- Future expansion in both direction.



The diagram shows the effect of north light in any factory either the mechanics cast a shadow on his work or machine casts a shadow.

NORTH LIGHT TRUSS

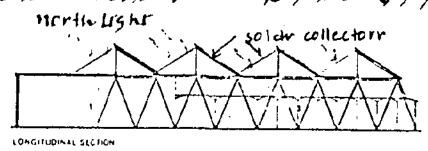
<u>ADVANTAGES</u>

1 Good daylight
2 Faster erection
3. Suspension of services easy.

<u>DISADVANTAGES</u>

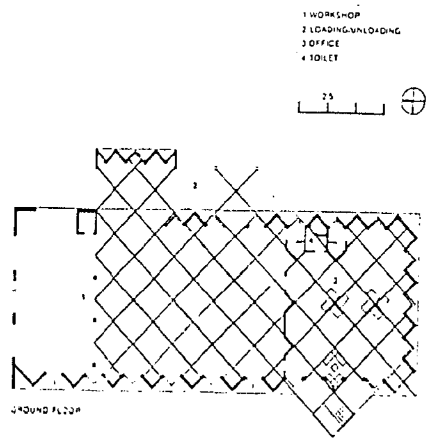
1. Requires regular maintenance.
2. Poor thermal insulation.
3. leakage from gutters.
4 Effect of shadow of machine or mechanics on wor

ROOF TYPE - SPACE FRAME ROOF
CASE STUDY - SPECTOM ENGINEERING



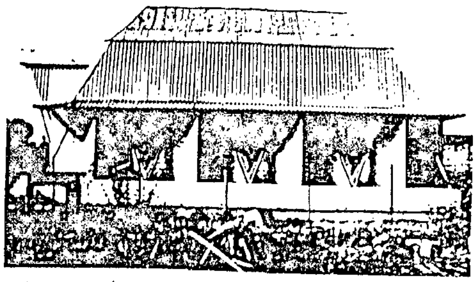
ARCHITECTS - P.S. Rajan, Panna Rajan

MANUFACTURE - Standard components of space frame truss.



STRUCTURE - Span - 36.5 m.
Truss depth - 4.2 m.

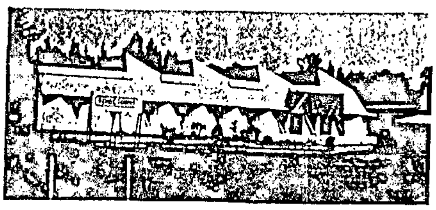
1 The inter truss space is used effectively for storage, office use and factory.
2. Truss resting on plinth



South side of roof used for solar collector panels.

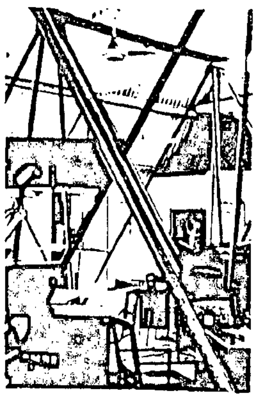
AESTHETICS - External appearance as of a normal factory.
The truss resting on plinth break up interior space, creates confusion.

FORM - The outer form of roof is fully exploited, as solar collector on south side, and north light window.



Roof line gives an impression of factory ——

INTERNAL ENVIRONMENT - Criss crossing of truss creates confusion, though the space is fully exploited for functional use.



Internal environment
• Space functionally utilised.
- Criss crossing of truss adds confusion.

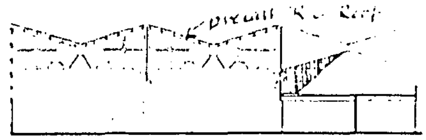
PHYSICAL COMFORT - Natural light and ventilation

FLEXIBILITY - Easily expandable structure.
Less internal flexibility.

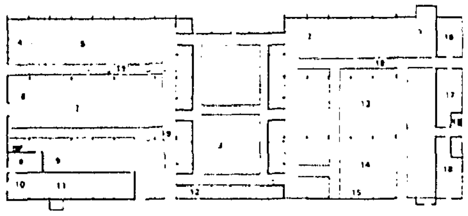
Polarity - Polar structure.

ROOF TYPE - PRECAST R·C ROOF

CASE STUDY - CHLORIDE INDIA LTD. HALDIA.



CROSS SECTION



MAIN FACTORY GROUND FLOOR

ARCHITECT - P. Mitra.

INTRODUCTION - The plant produces package power technogy. (batteries).

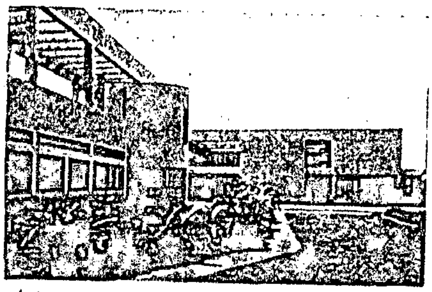
STRUCTURE AND MATERIAL.

Due to high salinity and acid fumes in air, steelwork gets rapidly corroded. To avoid this all buildings are R·C structure with R·C roof truss. and purlins.

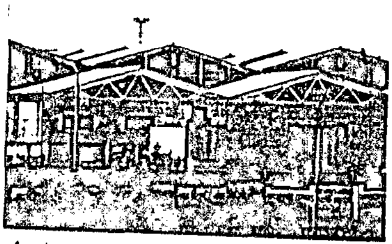
AESTHETIC AND FORM - The main feature is highly articulated roof form of R·C truss with north light. The roof is visible from a distance and creates an interesting silhouette.

Polarity - non polar

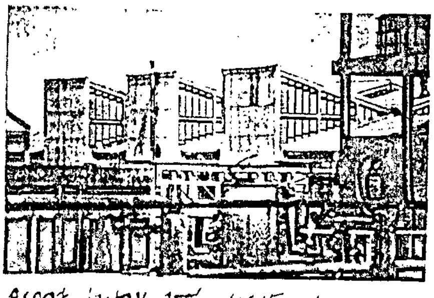
Flexibility - Internal flexibility possible



Administrative complex with pergola defining the entrance



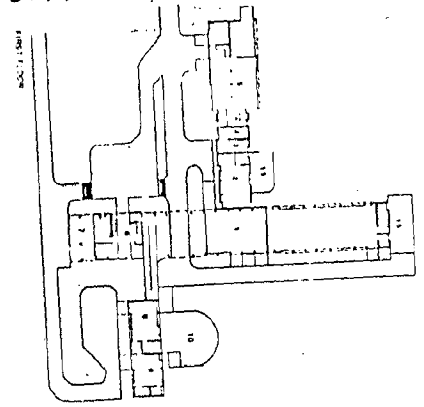
Articulated roof form of export factory.



Export factory roof creates an impression from a distance creates an interesting silhoutte.

ROOF TYPE- R·C SHELL ROOF

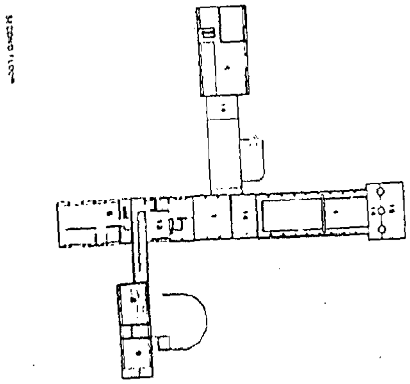
CASE STUDY- AMMONIA PERCOLATE PLANT, Cochin.



ARCHITECT- S·D Sharma.

INTRODUCTION- The factory is located at cochin which has a sultry and humid climate. manufacturer of ammonia.

STRUCTURE- An interesting feature of & AESTHETICS- architectural design is R·C shells on optimum grid. Shells on top of each building unify the overall composition of building with contoured site.

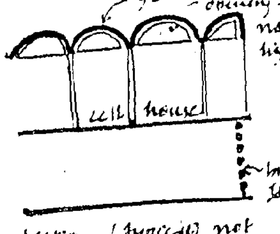


INTERNAL ENVIRONMENT- Natural light enters factory at the end of shell.

Cross-ventilated.

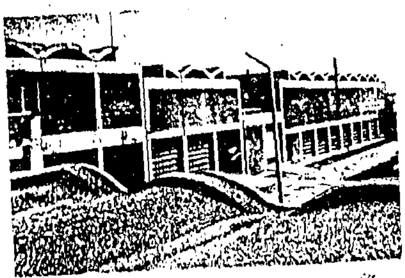
• Non polar structure

• less flexibility.



Section (typical) not to scale.

The building is in traditional architectural style of cochin.
- Exposed brick work.
- Use of Jalis.
- Cross ventilated to suit sultry and humid climate.



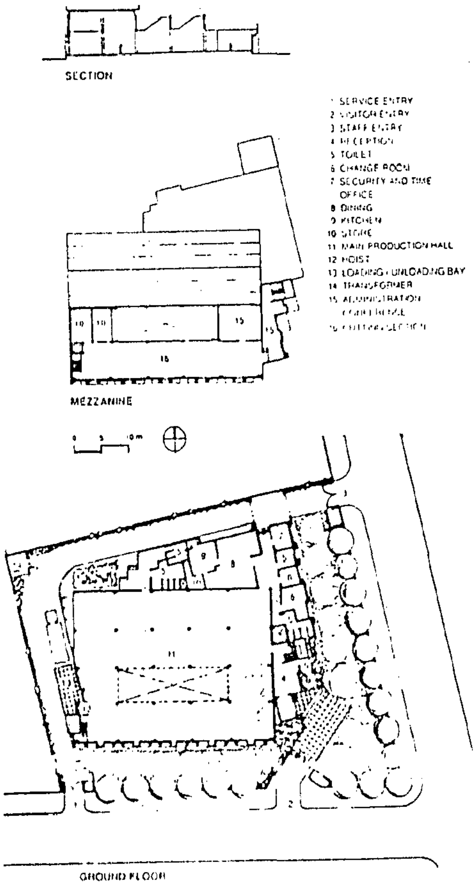
The shell roof combines well with ...

The roof line gives an interesting silhouette.

ROOF TYPE - VAULTED SHELL ROOF

CASE STUDY - STENCIL TROUSER FACTORY NOIDA, U.P

ARCHITECT - Mohit Gujral.



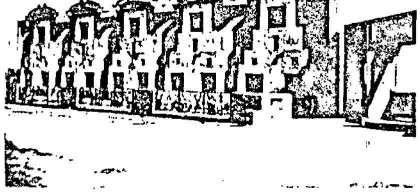
INTRODUCTION - The factory manufactures the readymade housery. The site is skewed at 12°.

Orientation had played a strong role in design and development of facades.

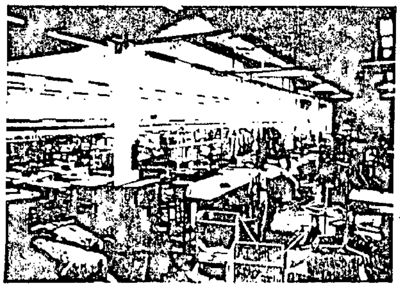
STRUCTURE - The saw tooth aesthetic of north lit factory was investigated. Finally the structure choosen was a series of gentle vaults over mezzanine combining with L-section form of north light roofing.

INTERNAL ENVIRONMENT - Use of daylight.

Non-polar but flexible.

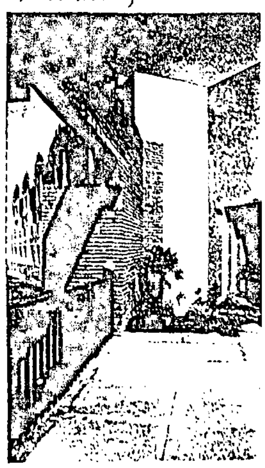


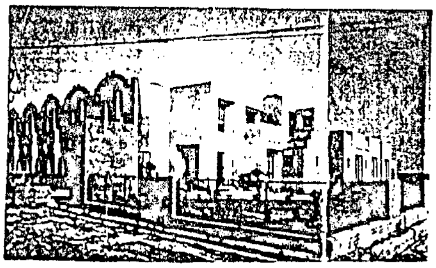
Gentle vault roof and deep recessed windows gives the factory its distinct charater



Inside the main hall - The entire hall is imbued with indirect glare free light.

Gentle vaults gives an interesting silhouette.



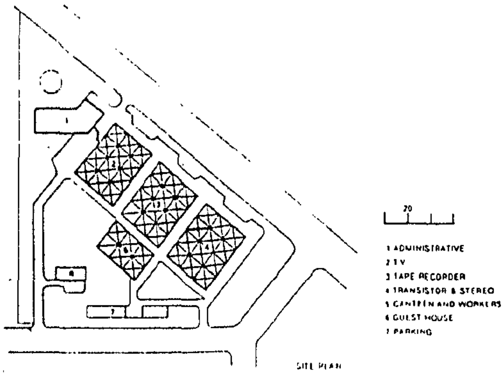


A specific language identify the stencil factory.

The length of factory showing north light well knit interior.

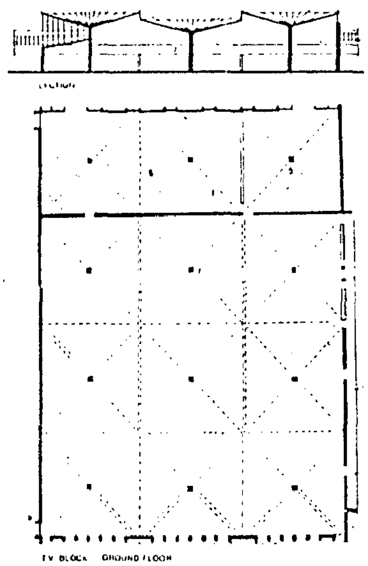
ROOF TYPE - HYPERBOLIC PARABOLOID.

CASE STUDY - PUNJSTAR STANDARD ELECTRONICS, Mohali



ARCHITECT - H. S Kohli, S.K Saini.

INTRODUCTION - The factory manufacture T.V, Transistors, tape-recorders. Located on a main Chandigarh-Ludhiana highway. The architects were called upon a design a functional structure which would catch the eye and provide much needed publicity.



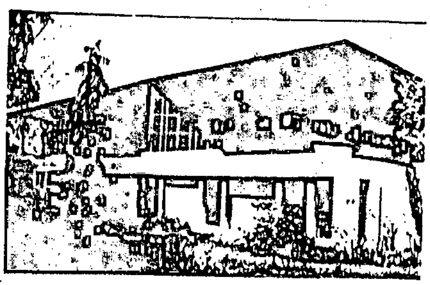
STRUCTURE - The use of a repetitive hyperbolic paraboloid shell with a central support on a 12.2m x 12.2m module. The R.C shell roof is 7.62 cm using minimum of steel.

AESTHETIC AND FORM - The overall roofing form create a powerful visual impact even from a distance. The large projecting platforms at top gives a floating effect.

The projecting roof slab gives an impression of floating structure.

INTERNAL ENVIRONMENT - Well lit and airy space created by varying ht of pattern roof shells. Bright and cheerful internal environment.

PHYSICAL ENVIRONMENT - Noise and dust free environment created by planting shrub and tree.

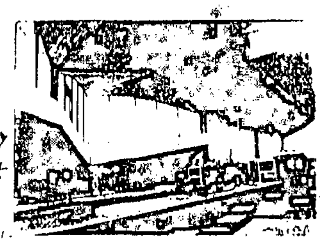


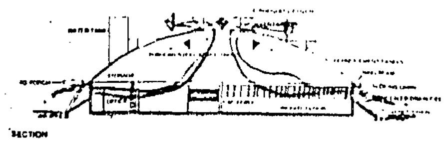
Powerful visual impact from distance.

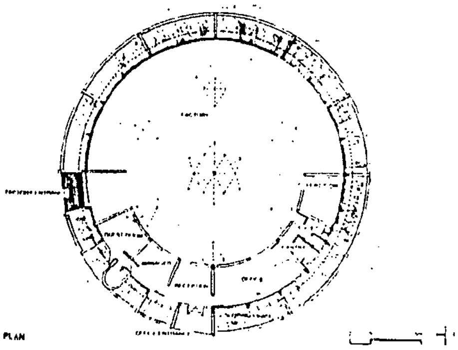
POLAR STRUCTURE.

FLEXIBLE STRUCTURE.

Well lit interior → environment roof creates [illegible]







Plan.

ROOF TYPE - DOME ROOF (R.C.C)

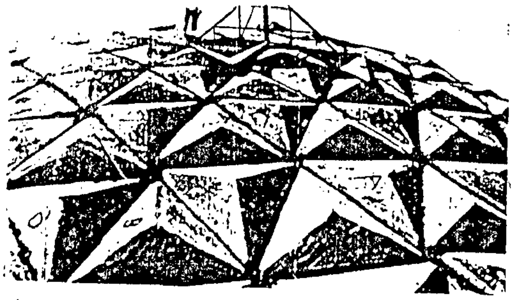
CASE STUDY - TYRE RETREDING FACTORY. JABALPUR.

ARCHITECT - A. K DHOPE.

INTRODUCTION- THIS IS FIRST TIME A SPHERICAL BRACED DOME HAS BEEN USED TO BUILD A FACTORY IN INDIA.

STRUCTURE - 25 . SPAN , 5M RISE.

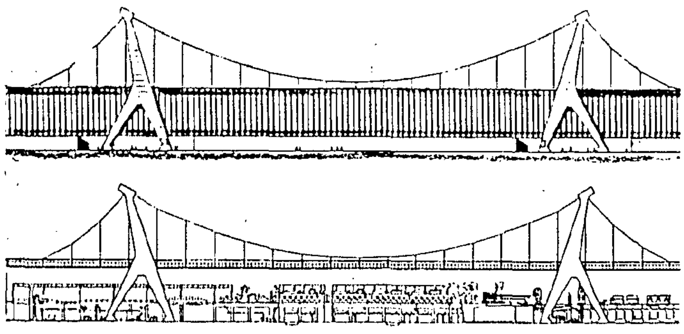
R.C.C RING BEAM FORM THE BASE. CLADDIN WITH PREFABRICATED PANELS.



Prefab. Panels - 40 mm thick ferrocement panels.

VENTILATION- FIBREGLASS PANEL AT TOP TO ENSURE ROOFED VENTILATION GLAZINGS ALSO ENSURE AMPLE NATU-RAL LIGHT.

ROOF TYPE - CABLE ROOF

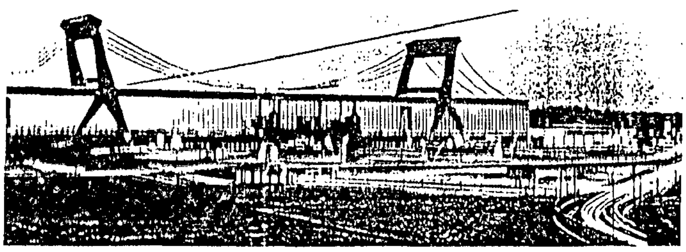


Cable suspended roof.

CASE STUDY- PAPER FACTORY. MANTUA . ITALY.

INTRODUCTION- FACTORY JUSTIFY REQUIREMENT OF PREPARATION OF PULP- LONG AND NARROW PRODUCTION LINES.

STRUCTURE- SUSPENDED CABLE ROO



* Greater span possible
* Flexible and adjust for loading
* Uneconomical for span less than 100'
* Difficult to get standard fittings.

* Well lighted interior
* narrow production process.
* linear production process.

ROOF TYPE- FOILDED PLATE

CASE STUDY- TEXTILE FACTORY. MORIYAMA JAPAN.

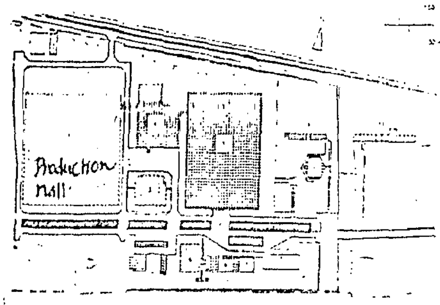
INTRODUCTION- THE DESIGN OF NEW PRODUCTION HALL WAS INFLUENCED BY NEW PRODUCTION METHODS.

STRUCTURE- LARGE COLUMN FREE AREA.

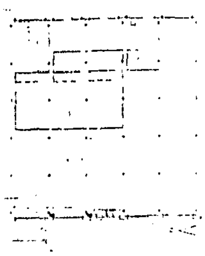
COLUMN SPACING- 18m X 19.8m.

ROOF- PARTIALLY GLAZED HOUSES SERVICES MAINS. THIS ROOF CAN BE DISMANTELED.

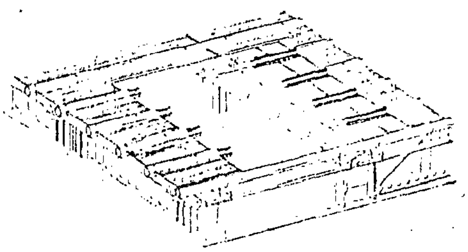
FLEXIBILITY- FLEXIBLE SPACE, LARGE COLUMN FREE AREA.



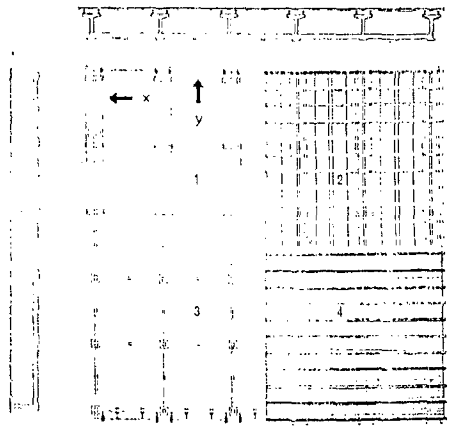
Plan.



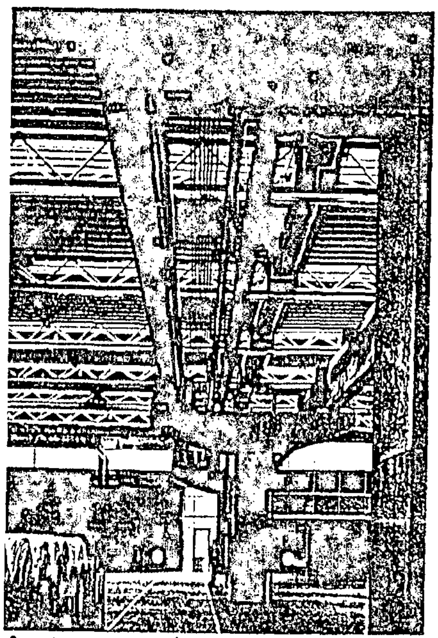
Plan of new hall.



Isometric view.



CONSTRUCTION SCHEME.
SECTION VIEWED FROM BELOW.



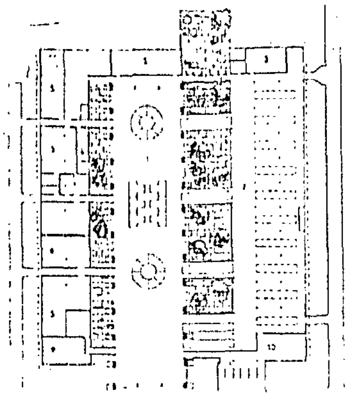
Interior- Light through skylight

View - LENGTH- 100 M.

ROOF TYPE- SADDLE ROOF

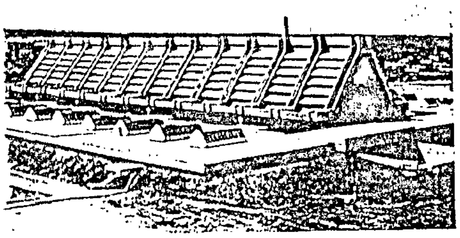
CASE STUDY - GLASS FACTORY, AMBERG, BAVARIA GERMANY.

ARCHITECT- WALTER GROPIUS.

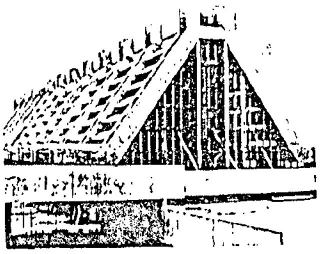


Plan

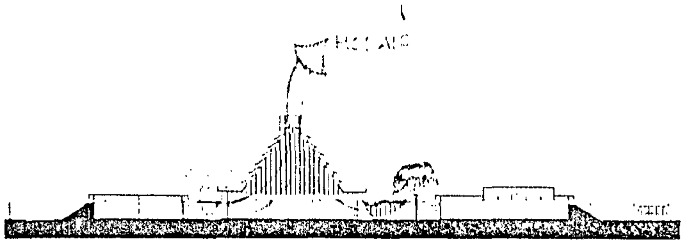
INTRODUCTION- THE plant is dominated by the 20m high saddle Roof of the central section which houses the glass ovens. The unorthodox shape was choosen in an attempt to create tolerable condition through natural conditions only.



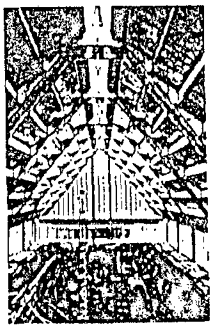
View of factory.



Photograph showing cross-section detail.

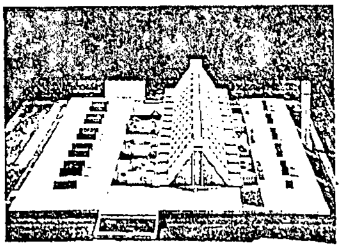


Section- The vertical glass shutters in the side walls below the saddle roof can be fully opened so that fresh air can enter from the courtyard on either side. The hot air is evacuated at the heighest point of the building.



Side walls with shutters for proper cross-ventilation.

Internal Environment- Lighting is even and glare free. Gables fully glazed.



The whole factory is dominated by saddle roof of 20m height.

ROOF TYPE - LANTERN ROOF

CASE STUDY - WHOLESALE BAKERY, BERGE NORWAY.

ARCHITECT - GEORGE GREVE AND GEIR-GRUNG, OSLO.

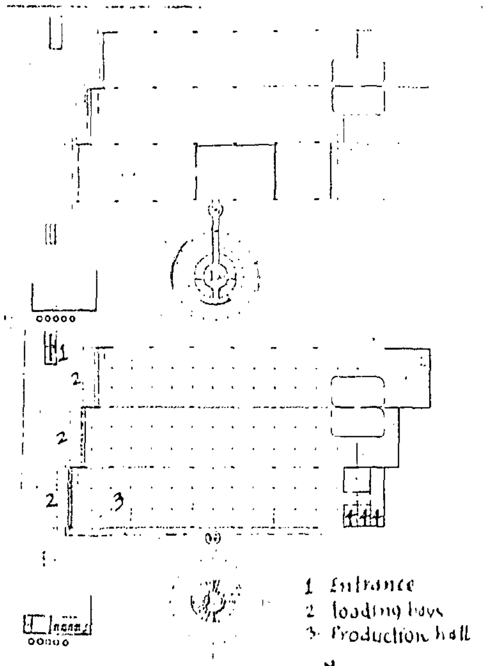
INTRODUCTION - DESIGN OF WHOLESALE BAKERY IS BASED ON A PROGRAMME WHICH HAD BEEN WORKED OUT BY CLIENTS AND ARCHITECT.

STRUCTURE - R.C.C FRAMEWORK.

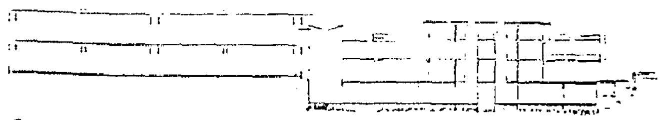
FLEXIBILITY. POSSIBLE EXTENSION.

INTERNAL ENVIRONMENT

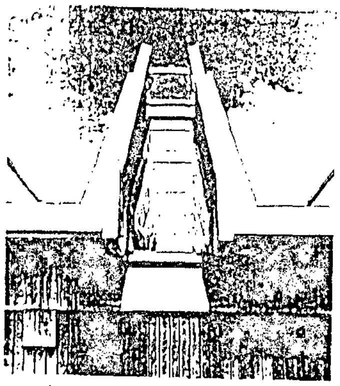
-IDEAL WORKING ENVIRONMENT.

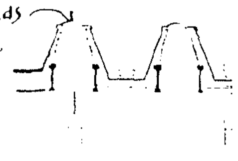


Plan

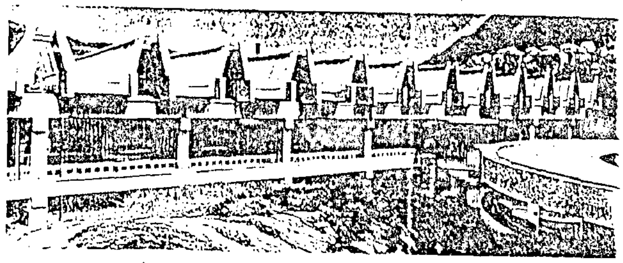


Cross section.





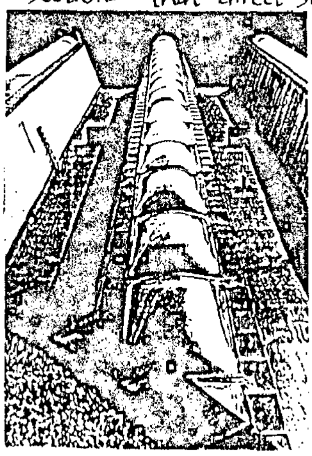
Cross Section of roof Structure.

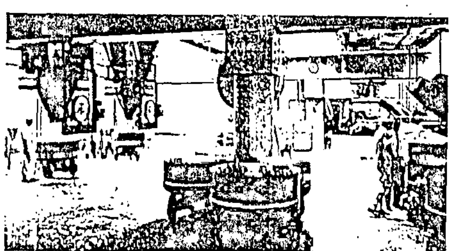


View of building fascade.

Details of roof.

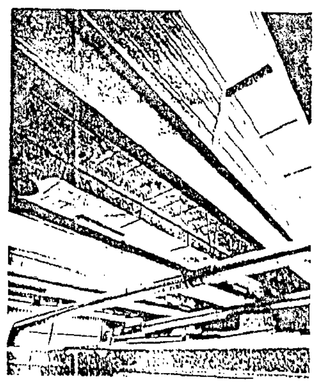
* roof light has narrow cross section that direct sun light entry prevented.





Wide Column spacing - flexibility.

Services ducts under roo



6
GUIDELINES FOR ROOFING OPTIONS

CHAPTER 6

GUIDE LINES ROOFING OPTIONS

Thise chapter deals with the formulation of guidelines for better adoption of industrial roofing options. This will be done through generalisation of different spans used in the industrial buildings.

Different creteria for selection of roof is worked out. A comparative guideline also formulated for selection of a particular roof type.

6.1 Generalisation of different roofing option based on span. Presented in tabular form, it gives minimum, maximum, economy limit of different spans.

6.2 COMPARATIVE ANALYSIS OF ROOF FORMS.

A comparative guideline is formulated for the selection of roof form depending upon requirement and analysis of various factors.

6.3 FORMULATION OF GUIDELINES :

Different roof forms are formulated in tabular form. It gives choice of roofs for different class of industrial buildings.

NO. 25

6.1 ROOFING OPTIONS BASED ON SPAN

ROOF TYPE	SPAN (meters)		REMARKS
	MINI.	MAX.	
1. STEEL BEAM ROLLED SECTION (L,T,C,Z,I)		S < 8M	6 to 8M. Ratio $\frac{Depth}{SPAN}$ R = 1/20
2. TRUSSES	6	120M	R - 1/10
3. TRIANGULAR TRUSS	9	45M	12-18 M - Economic
4. SAW TOOTH	6	45M	
5. STEEL PORTAL FRAME		S < 75M	
6. TUBULAR STEEL SPACE FRAME	10	250M	R - 1/20
7. CONCRETE SHELL ROOFS			L - Length B - S - Span
8. NORTH LIGHT	12	60	L:B 3:2
9. SINGLE CURVED	20	30	L:B < 1 L = 10 - 15 M B = 20 - 30 M
10 CYLINDRICAL	7.5	15	L:B > 1 L - 15 - 40 M B - 7.5 - 15 M
11. HYPERBOLOID		S ≤ 100	L:B 1:10 L ≤ 10 M B ≤ 100 M.
12. PARABOLOID		S ≤ 100	L ≤ 10 M B ≤ 100 M.
13. SERRATED BARREL		S ≤ 35	L ≤ 15 M S ≤ 35 M.
14. CONOID	7.5	20	L - 7.5 - 12.5 M S - 7.5 - 20 M

ROOF TYPE	Aesthetics					FORM					Internal Envir					Physical Comfort					Flexibility					Fire Protection					Maintenance Factor					Total
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	/35
1 Northlight Truss				✓					✓				✓						✓				✓						✓						✓	27
2. Space frame			✓					✓					✓					✓				✓						✓						✓		21
3. Precast R.C roof			✓						✓				✓						✓				✓				✓					✓				21
4. R.C shell roof			✓					✓					✓					✓						✓			✓						✓			21
5. Vaulted R.C roof		✓					✓					✓					✓						✓				✓							✓		17
6 Hyperbolic Paraboloid		✓					✓					✓					✓					✓					✓						✓			15
7. Dome Roof	✓					✓						✓					✓						✓					✓						✓		16
8 Folded Plate			✓						✓				✓					✓				✓						✓					✓			
9 Steel Cable		✓					✓					✓						✓					✓					✓						✓		19
10 Saddle Roof		✓					✓					✓					✓						✓					✓					✓			15
11 Lantern Roof		✓					✓					✓					✓					✓						✓						✓		17

Rating
1 - Excellent
2 - very good
3 - good
4 - fair
5 - Total.

6.2 COMPARATIVE ANALYSIS OF ROOF FORMS

No.24 6.3 FORMULATION OF GUIDELINES.

MATERIAL	ROOF	INDUSTRIES
1. STEEL	North Light	-Heavy assembly shops, textile carpet factories, garments, ancilleries, turbine halls.
	Steel Portal Frame	-Air craft hangers, large scale industries.
	Space Frame	-Industrial exhibition spaces large spaces.
2. CONCRETE	North Light Shell	-Assembly shops -Research stations -Research Lab.
	Hyperboloid	-Electronics, light industries watch factories.
	Folded Plate	-Textile factory, process indu-tries.
	Cable	-Paper factory.
	Dome Roof	-Research labs, Nuclear reactor
	Saddle Roof	-Glass, Foundries.
3. TIMBER	Truss	-Dye work.
4. GLASS & PVC	Lantern	-Light weight industries.
5. PRECAST CONCRETE	Trusses	-Chemicals and fertilizers industries

7

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Being step children of the 19th century, civil engineering and industrial building construction have a common history. Both had to develop and to assert themselves in the shadow of eclecticist decoration, both were only able to come into their own at the beginning of this century - for instance in the building of peter Behrens. Apart from its rational character, industrial building construction is fascinating because of its dimension involved.

Today, industrial building construction is in danger of becoming degraded by indolent designers so as to become a kind of "packaged architecture".

The role of the architects in the design of the industrial environment is defined perhaps by three trends in contemporary industrial culture in the country.

1. From commercial point of view, aesthetic sense and good sense entering in to the industrial field, as clients tries to project impressive image.

Here the Architect role is confined to his popular image as an agent who can confer status by suitable 'packaging of building products'.

2. Growing trend is a part of industrial management. Firms which integrate engineering and building management with architectural design find greater favour with industry. The

role of Architects as technologists - manager is greatly valued if they can meet the bill.

3. There is a growing acceptance in the industrial world to humanise the work place. There are also signs of an understanding of the validity of environmental protection and conservation of natural resources. i.e. restructuring the balance between man and machine and between nature and industrial development.

This dissertation, endeavour to focus attention on the many problems confronting the architects in the design of industrial buildings in general and to roofing systems in particular.

The working environment has become as important as the production process to acheive overall operational efficiency. Why can't the working in factories be made more enjoyable with a clean, well lit, ventilated, colourful and acoustically satisfactory interior with an enclosure that satisfies the thermal and structural requirements ?

7.1 CONCLUSIONS

Based on the studies presented in this dissertation, the following conclusions are made -

1. The architects with certain personalized studies, is the only specialist capable for providing appropriate envelop for industrial buildings. He is the best coordinator of various specialists and their services.
2. The architecture of indsustrial building should be vivid enough and enhance the landscape without aesthetic pollution.

3. Industrial buildings should not upset the ecological balance.

4. Industrial building though 'functional' in nature should also be employee-friendly, creating a relaxed and informal workplace and pleasant environment.

5. Natural light should be adequately used from point of view of energy conservation and economy but direct sunlight should not be allowed.

6. Integrating functions of administration unit and employees facility etc with the production unit breaks the monotony and dominance of production hall.

7. A significant area of industrial design is integrating industrial environment with landscape, humanising the environment of workplace.

8. The totality of industrial environment should be safe guarded while designing industrial buildings of large size.

7.2 RECOMMENDATIONS

These are divided into following broad categories.

7.2.1 Physical Planning

7.2.2 Psychological aspect and the indoor environment.

7.2.3 Fabric and envelop

7.2.4 Visual and Aesthetic control through roof forms.

7.2.1 Physical Planning

1. The requirement of industrial process of product to be manufacture, requirement of machinery, environment (controlled or uncotrolled) functional requirements should be considered while dealing with project of industrial building.

2. Integration of functions of administration with that of production hall helps in breaking monotony and dominance of the production hall.

3. The nature and site potential, character should be respected while planning and designing large scale industrial projects.

4. Special requirements of industrial projects should be given due considerations while desiging.e.g. spacial, machine-height of ceiling, clear span, spacing, lighting etc.

5. Larger walls should face North or South to minimise solar heat gains during summer and western walls should be insulated and used for storage etc.

6. Roof glazing should face north or south so as to avoid direct sunlight and give adequate diffused natural light.

7. External surfaces of roofs and walls should be light coloured to minimise heat gain.

7.2.2 Psychological Aspect and the Indoor Environment.

1. Noisy area should be seperated from quiet zone.

2. There should be more reliance on daylight and to get the required DF indoor. Glazing area should be in relation to floor area.

3. Recommeded illumination level for different type of industrial building is given in Appendix.

4. Overall lighting system should be based on combination of natural and artificial light.

5. Colour schemes should be based on cool colours such as green or blue with predominance of light coloured surfaces.

6. Preference should be given to pastel shades over glossy and bright colours to minimise the glare.

7. Walls near ceiling should be white for uniform distribution of light.

7.2.3 FABRIC OR ENVELOP

1. A column spacing of 15m x 15m is recommended as representative of economy, a reasonable degree of flexibility and minimum obstruction to process or machinery.

2. Tubular steel structure i.e space frames should be preferred to heavy steel trusses.

3. Roofs should have thermal insulation to minimise heat transmission indoors.

7.3 VISUAL AND AESTHETIC CONTROL THROUGH OF ROOF FORMS:

For years industrial buildings have been considered purely functional, with little or no considerations for aesthetic. visual suggestion are given to control aesthetic of assembly line.

The suggestions will prove useful in planning of new factories or in improvement of existing one.

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APPENDICES

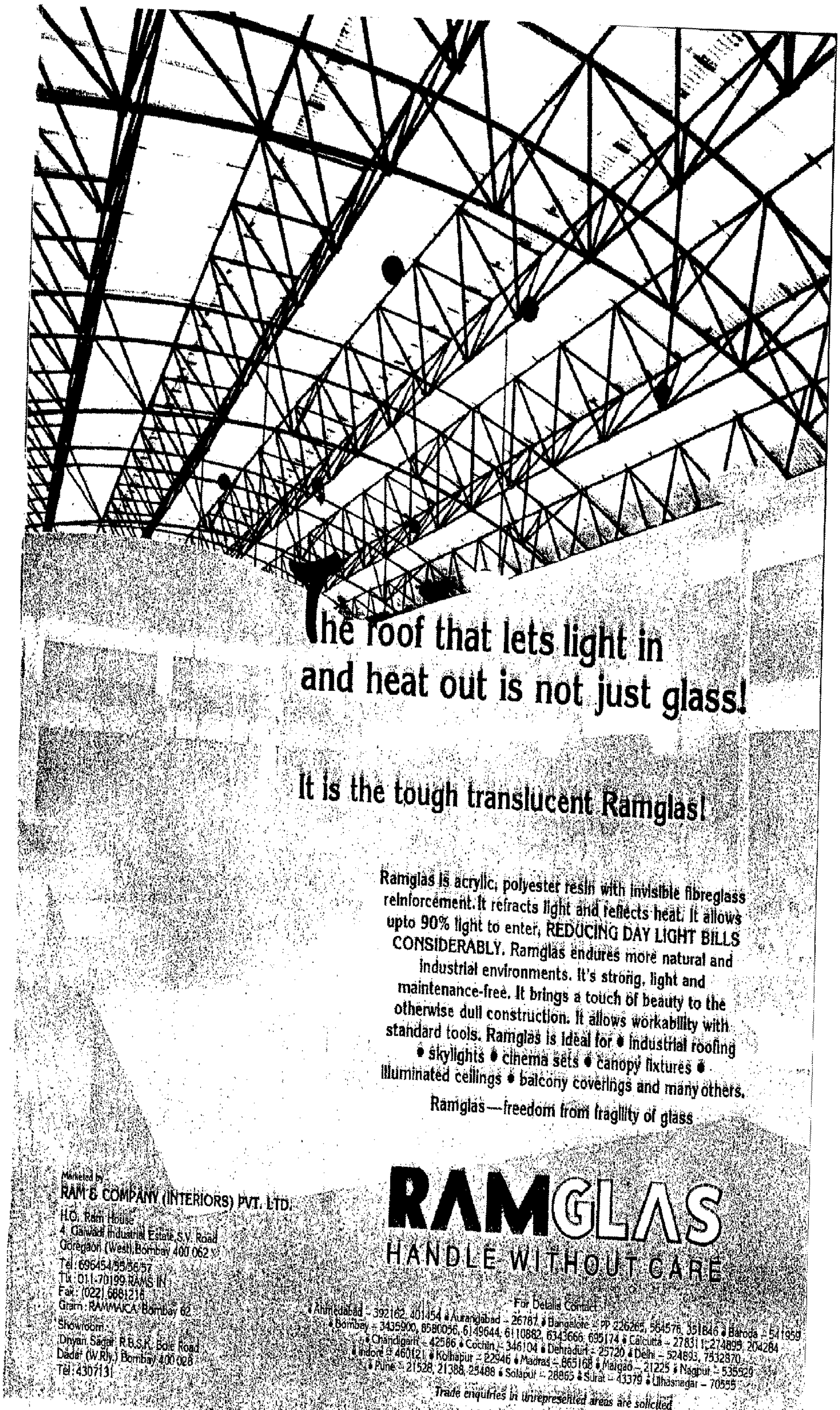
APPENDIX A

RECOMMENDED VALUES OF ILLUMINATION.

SL.NO.	INDUSTRIAL BUILDING & PROCESSES	AVERAGE ILLUMINATION (LUX)
1.	GENERAL FACTORY AREA	
	a) Canteen	150
	b) Entrances, Corridors Stairs	100
	c) Cloak Rooms	100
2.	AIRCRAFT FACTORY	
	a) Production	450
	b) Assembly	300
3.	ASSEMBELY SHOPS ROUGH TO VERY FINE	150-1500
4.	BAKERIES	150
5.	BOILER HOUSE	100
6.	SHOE FACTORIES	1000
7.	BREWERIES AND DISTILLERIES	150
8.	CARPET FACTORIES	300
9.	CHEMICAL WORKS	150
10.	CLOTHING FACTORIES	450
11.	DYE WORK	700
12.	ELECTRIC GENERATION PLANT	
	a) Turbine Hall	200
	b) Control Room	200-300
13.	FLOUR MILLS	150
14.	FOUNDRIES	150-300
15.	WATCH MAKING	700-3000
16.	PRINTING WORK	200-450
17.	TEXTILE MILLS	150-700

Source PP. 6-8 "HANDBOOK ON FUNCTIONAL REQUIREMENTS OF INDUSTRIAL BUILDINGS, ISI, NEW DELHI, 1986.

Product Information



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