One day National Workshop on National Building Code of India 2016:

Glass and Glazing Aspects

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ABOUT THE ORGANIZERS

BUREAU OF INDIAN STANDARDS

Bureau of Indian Standards (BIS) is the National Standard Body of India established under the BIS Act,1986 for the harmonious development of the activities of standardization, marking and quality certification of goods and for matters connected therewith or incidental thereto. A new Bureau of Indian Standards Act, 2016 which was notified on 22nd March 2016, has been brought into force with effect from 12th October 2017, that reinforces the activities of BIS in respect to standardization and certification of goods, article, process, system and service. BIS has been providing traceability and tangibility benefits to the national economy in a number of ways- providing safe reliable quality goods; minimizing health hazards to consumers; promoting exports and imports substitute; control over proliferation of varieties, etc through standardization, certification and testing. Keeping in view, the interest of consumers as well as the industry, BIS is involved in various activities as given below.

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- Compulsory Registration Scheme
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- Foreign Manufacturers Certification Scheme
- Laboratory Recognition Scheme
- Training Services (National & International)
- Sale of Indian Standards
- Promotional Activities
- Hall Marking Scheme
- Laboratory Services
- Information Services

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GSI is a not for profit, independent, inclusive organization working on Testing and Certification of Building Envelopes and its materials for High Performance in the areas of Energy, Safety, Structural Integrity, Acoustics, Fire Resistance and others. GSI is a collaborative initiative involving various stakeholders from the Indian Building Envelope Industry including Manufacturers, Processors, Fabricators and Installers, Builders, Designers, Consultants, Policy Formulation Bodies, special bodies from the Government of India, Educational Institutions, Research Bodies, Architects, Interior Designers, Industry experts, International organizations and other stakeholders.

GSI in collaboration with its respective Academic Partners has established three "first of its kind state-of-the-art testing facilities" in India at IIT Madras, Chennai, CSIR – CGCRI, Kolkata and CEPT University, Ahmedabad for research and testing of Architectural Glazing and its associated materials for 'Safety and Structural' and 'Energy' Performance.

GSI has supported and is involved in various Technical Committees of Bureau of Indian Standards (BIS) and Bureau of Energy Efficiency (BEE) in building the codes and regulations for the use of Architectural Glass and Glazing Products in Indian Buildings.

For more details please visit www.glazingsociety.com

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Indian Institute of Technology Madras (IITM) was established in 1959 by the Government of India as an institute of national importance. The activities of the Institute in various fields of Technology and Science are carried out in 16 academic departments and several advanced interdisciplinary Research Academic Centres. The Institute offers undergraduate and post - graduate programmes leading to the

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IITM has been ranked No.1 among Engineering Institutions in the India Rankings for three consecutive years – 2016, 2017 and 2018. The Institute was also ranked as the No.2 in the category of Overall Institutions in 2017 and 2018 Rankings, released by the National Institutional Ranking Framework, Ministry of Human Resources Development, Govt. of India.

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1. NATIONAL BUILDING CODE OF INDIA 2016: ENSURING SAFE AND SUSTAINABLE BUILDING CONSTRUCTION USING GLASS

Sanjay Pant[1] & S Arun Kumar[2]

1.1 INTRODUCTION AND HISTORICAL BACKGROUND OF NATIONAL BUILDING CODE

Construction programs are interwoven in a large measure in all sectors of development, be it housing, transport, industry, irrigation, power, agriculture, education or health. Construction, both public and private, accounts for about fifty percent of the total outlay of the planned expenditure in the country. Half of the total money spent on construction activities is spent on buildings for residential, industrial, commercial, administrative, educational, medical, municipal and entertainment uses. It is estimated that about half of the total outlay on buildings is on housing. It is imperative that for such a large national investment, optimum returns are assured and wastage in construction is avoided.

Soon after the Third Plan, the Planning Commission decided that the whole gamut of operations involved in construction, such as administrative, organizational, financial and technical aspects, be studied in depth. For this study, a Panel of Experts was appointed in 1965 by the Planning Commission and its recommendations are found in the 'Report on Economies in Construction Costs' published in 1968.

These studies led to conclusion that one of the important steps towards achieving economy is through the formulation of a unified building code at the national level, which would rationalize and unify building codes and byelaws of various departments and local bodies, respectively and which would reflect the latest trends in building construction activity. For this, it was recommended that a National Building Code be prepared to unify the building regulations throughout the country for use by government departments, municipal bodies and other construction agencies. The then Indian Standards Institution (now Bureau of Indian Standards) was entrusted by the Planning Commission with the preparation of the National Building Code. For fulfilling this task, a Guiding Committee for the preparation of the Code was set up by the Civil Engineering Division Council of the Indian Standards Institution in 1967. This Committee, in turn, set up 18 specialist panels to prepare the various parts of the Code. The Guiding Committee and its panels were constituted with architects; civil engineers; materials experts; structural, construction, electrical, illumination, air conditioning, acoustics and public health engineers; and town planners. These experts were drawn from the Central and State Governments, local bodies, professional institutions and private agencies. The first version of the Code was published in 1970. After the National Building Code of India was published in 1970, a vigorous implementation drive was launched by the Indian Standards Institution to propagate the contents and use of the Code among all concerned in the field of planning, designing and construction activities.

Since the publication of the 1970 version of the National Building Code of India, a large number of comments and useful suggestions for modifications and additions to different parts and sections of the Code were received as a result of use of the Code by all concerned, and revision work of building byelaws of some States. Based on the comments and suggestions received, the National Building Code of India 1970 was revised in 1983.

Some of the important changes in 1983 version included: addition of development control rules, requirements for greenbelts and landscaping including norms for plantation of shrubs and trees, special requirements for low income housing; fire safety regulations for high rise buildings; revision of structural design section based on new and revised codes, such as Concrete Codes, Earthquake Code, Masonry Code; addition of outside design conditions for important cities in the country, requirements relating to noise and vibration, air filter, automatic control, energy conservation for air conditioning; and guidance on the design of water supply system for multi-storeyed buildings. Thereafter three major amendments were issued to the Code, two in 1987 and the third in 1997. Considering a series of further developments in the field of building construction, including the lessons learnt in the aftermath of

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number of natural calamities like devastating earthquakes and super cyclones witnessed by the country, the National Building Code of India was revised in 2005. Some of the important changes in 2005 version included: incorporation of a new Part 0 ‘Integrated approach – Prerequisite for applying provisions of the Code’ emphasizing on multi-disciplinary team approach for successfully accomplishing building/development project; addition of new chapters on structural design using bamboo, mixed/composite construction and landscaping; incorporation/modification of number of provisions relating to reform in administrative aspects, also detailing therein provisions to ensure structural sufficiency of buildings; incorporation of planning norms and requirements for hilly areas and rural habitat planning, apart from detailed planning norms for large number of amenities; categorization of fire safety aspects distinctly into fire prevention, life safety and fire protection; assigning importance to the aspects like energy conservation and sustainable development in various parts and sections through appropriate design, usage and practices with regard to building materials, construction technologies and building and plumbing services giving due consideration to renewable resources like bamboo and practices like rain water harvesting; incorporation of the revised Earthquake Code for due implementation of the provisions thereof in applicable seismic zones of the country, by the Authorities.

Two amendments were thereafter issued to the Code in 2015, first to include a new chapter relating to sustainability namely, Part 11 ‘Approach to Sustainability’, and the second to modify/include certain provisions in Part 4 'Fire and Life Safety'.

1.2 NEED FOR CURRENT REVISION AND MAJOR MODIFICATIONS INCORPORATED IN THE CODE

Due to large scale changes in the building construction activities, such as change in nature of occupancies with prevalence of high rises and mixed occupancies, greater dependence and complicated nature of building services, development of new/innovative construction materials and technologies, greater need for preservation of environment and recognition of need for planned management of existing buildings and built environment, there has been a paradigm shift in building construction scenario. Considering these, a Project for comprehensive revision of the Code was taken up under the aegis of the National Building Code Sectional Committee, CED 46 of BIS and its 22 expert Panels; involving around 1000 experts. As a culmination of the Project, the revised Code has been brought out in 2016 as National Building Code of India 2016 reflecting the state-of-the-art and contemporary applicable international practices. The salient features of this latest revision of the Code are:

1) Detailed provision for streamlining the approval process in respect of different agencies in the form of an integrated approval process through single window approach thereby avoiding separate clearances from various authorities, with a view to ensuring ease of doing business in built environment sector.
2) Progressive computerization of approval process, for enabling online submission of plans, drawings and other details, and sanction thereof.
3) Updated mechanism of ensuring certification of structural safety of buildings by the competent professional and peer review of design of buildings.
4) Defining the roles and responsibilities of all professionals and contractors involved in a building construction project.
5) Comprehensive planning norms for minimum amenities to be provided in a city/town.
6) Detailed provisions relating to requirements for accessibility in buildings and built environment for persons with disabilities and the elderly.
7) Planning and development norms, such as, Transferable Development Rights (TDR) and Accommodation Reservation (AR).
8) Provisions for underground or multi-storeyed parking as also mechanized parking of vehicles.
9) Norms for solar energy utilization.
10) Requirements for buildings on podium for ensuring fire and life safety in such buildings.
11) Fire and life safety in modern complex buildings including the high rises, glazed buildings, atria, commercial kitchen, car parking facilities, and metro trainways and metro stations.
12) Updated structural design provisions for wind and seismic loads, imposed load due to helipad, and blast loads, for safe design and construction of buildings with due focus on ductile detailing.

13) Latest research and development inputs and provisions on concrete, steel and masonry buildings with a view to ensuring disaster resilient buildings.
14) Assessment of liquefaction potential of a site and ground improvement techniques for maximum utilization of land resources including at seismically vulnerable sites.
15) Updated provisions on engineered use of bamboo in housing and other building construction.
16) Promotion of use of agricultural and industrial wastes including construction and demolition wastes in building construction without compromising the quality and safety.
17) Inclusion of provisions on self-compacting concrete, high performance concrete and steel fibre reinforced concrete.
18) Updated provisions on prefabricated construction technique for speedier construction.
19) New chapter on structural use of glass in buildings.
20) New and alternative building materials, and technologies for building construction such as, reinforced masonry, confined masonry building construction and masonry wall construction using rat-trap bond.
21) Construction project management guidelines for timely completion of building projects within the budgeted cost with desired quality.
22) Habitat and other welfare requirements for workers at construction site.
23) Inclusion of modern lighting techniques such as LED and induction light and their energy consumption.
24) New provisions on compact substations and updated provisions on installation of energy meters.
25) Comprehensive provisions relating to lightning protection of buildings.
26) Provisions on aviation obstacle lights; electric vehicle charging and car park management.
27) Protection of human beings from electrical hazards and against fire in the building due to leakage current.
28) Use of refrigerants for air conditioning addressing zero ozone depletion potential (ODP) and ultra-low global warming potential (GWP).
29) Inclusion of new and energy efficient options of air conditioning, heating and mechanical ventilation, such as variable refrigerant flow system, inverter technology, district cooling system, hybrid central plant using chilled beams, radiant floor components, and geo-thermal cooling and heating.
30) Thrust on envelope optimization using energy modelling, day lighting simulation, solar shade analysis and wind modelling software to optimize the air conditioning load.
31) Air conditioning, heating, and ventilation (HVAC) provisions considering adaptive thermal comfort conditions for energy efficiency.
32) Provisions pertaining to metro trainways and metro stations with respect to fire and life safety; and air conditioning, heating and ventilation for metro stations.
33) HVAC requirements for data centres and healthcare facilities; refrigeration for cold stores; efficient strategies for winter heating using reverse cycle operation, solar heating systems, ground source heat pump and electric heat pump; and modern system of mechanical ventilation for industries, commercial kitchen and underground car parking.
34) Updated provisions on building automation system to include the latest practices for web-based monitoring and control of performance parameters.
35) High speed lifts for tall buildings.
36) New chapter on escalators and moving walks for comfortable and safe movement of people.
37) New chapter on information and communication enabled installations in buildings.
38) Updated provisions on water supply, drainage and sanitation for modern high rise buildings and complexes.
39) Provisions relating to swimming pools covering hygiene and safety.
40) Updated provisions on rainwater harvesting.
41) New chapter on solid waste management covering various solid waste management systems within the building and building complexes.
42) Updated provisions on piped gas supply in houses, and in hospitals for medical purposes.
43) Promoting quality of outdoor built environment through updated provisions on landscape planning, design and development.

44) Promoting sustainability in buildings and built environment in tandem with relevant sustainable development goals.
45) New chapter on asset and facility management to cover provisions relating to management of building assets and associated services, also covering responsibilities of occupants for maintenance of facilities, such as structures, equipment and exterior property.

1.3 ACTUAL COVERAGE

The National Building Code of India lays down a set of minimum provisions designed to achieve orderly, safe and sustainable building construction and development; and *inter alia* covers the following important aspects:

i) ***Integrated approach through multi-disciplinary team work*** to obtain maximum benefits in terms of quality, timely completion and cost effectiveness by utilizing appropriate knowledge and experience of qualified professionals right from the conceptualization through construction and completion stages of a building project and indeed during the entire life cycle;

ii) ***Administrative provisions*** which pertain to the efficiency and effective application of the Code defining powers, duties and responsibilities of those concerned;

iii) ***Development control rules and general building requirements*** including such aspects as subdivision and layout rules, land use classifications, open spaces in and around buildings, area and height limitations, means of access, parking spaces, requirements of various parts of buildings, etc.

iv) ***Fire and life safety requirements*** related to the occupancy and use of buildings; Stipulations with regard to use of ***accepted and new building materials*** from consideration of safety, performance, compatibility, durability and economy;

v) ***Design and construction practices*** for structures as a whole using various materials like reinforced and prestressed concrete, structural steel, timber, bamboo, masonry, glass, etc, and guidelines for design of prefabricated structures and mixed/composite constructions, duly taking into account the various loads, forces and effects including due to natural calamities like earthquake;

vi) Guidelines for ***construction project management*** and measures to ensure ***safety of workers and public*** during construction including habitat and other welfare requirements for workers at construction site;

vii) Provisions for ***safe and efficient design of various building services,*** such as lighting, ventilation, electrical and allied installations, air conditioning, heating, lift, escalator and moving walk installations, acoustics systems, and information and communication enabled installations;

j) Provisions with regard to the requirements of ***water supply, drainage and sanitation including solid waste management*** and the design of water supply and drainage system in buildings, and safety requirements for **the *installation of gas supply*;**

k) Requirements regarding ***landscape planning, design and development, signs and outdoor display structures*** with a view to promoting safety and quality of outdoor built environment;

m) Guidelines relating to ***sustainable planning, design, construction, operation and maintenance of buildings and built environment***; and

n) Provisions for ***asset and facility management*** in buildings.
This information is brought out in 13 Parts, details of which are given below:

PART 0	INTEGRATED APPROACH – PREREQUISITE FOR APPLYING PROVISIONS OF THE CODE
PART 1	DEFINITIONS
PART 2	ADMINISTRATION
PART 3	DEVELOPMENT CONTROL RULES AND GENERAL BUILDING REQUIREMENTS
PART 4	FIRE AND LIFE SAFETY
PART 5	BUILDING MATERIALS
PART 6	STRUCTURAL DESIGN
Section 1	Loads, Forces and Effects
Section 2	Soils and Foundations
Section 3	Timber and Bamboo
3A	Timber
3B	Bamboo
Section 4	Masonry
Section 5	Concrete
5A	Plain and Reinforced Concrete
5B	Prestressed Concrete
Section 6	Steel
Section 7	Prefabrication, Systems Building and Mixed/Composite Construction
7A	Prefabricated Concrete
7B	Systems Building and Mixed/Composite Construction
Section 8	Glass and Glazing
PART 7	CONSTRUCTION MANAGEMENT, PRACTICES AND SAFETY
PART 8	BUILDING SERVICES
Section 1	Lighting and Natural Ventilation
Section 2	Electrical and Allied Installations
Section 3	Air conditioning, Heating and Mechanical Ventilation
Section 4	Acoustics, Sound Insulation and Noise Control
Section 5	Installation of Lifts, Escalators and Moving Walks
5A	Lifts
5B	Escalators and Moving Walks
Section 6	Information and Communication Enabled Installations
PART 9	PLUMBING SERVICES (INCLUDING SOLID WASTE MANAGEMENT)
Section 1	Water Supply
Section 2	Drainage and Sanitation
Section 3	Solid Waste Management
Section 4	Gas Supply
PART 10	LANDSCAPE DEVELOPMENT, SIGNS AND OUTDOOR DISPLAY STRUCTURES
Section 1	Landscape Planning, Design and Development
Section 2	Signs and Outdoor Display Structures
PART 11	APPROACH TO SUSTAINABILITY
PART 12	ASSET AND FACILITY MANAGEMENT

1.4 THE BUILDING CODE PROVISIONS ON GLASS AND GLAZING

1.4.1 Coverage

Part 6 / Sec 8 of the Code deals with selection and application of glass in buildings; provisions related to effect of glazing on energy, light and solar aspects; structural design of glass with respect to wind loading and seismic loading; manifestation of glass and safety with respect to human impact; and brief provision of glazing system. The provisions can also be suitably utilized for installation of alternative sheeting materials like plastic glazing sheets and polycarbonate sheets.

1.4.2 Application and Selection Methodology

Selection of glass, its location, shape, size, cost, constraints, security, thermal effects, are the major factors to be considered by the professional. *See* Fig. A suggesting typical flowchart of steps required. Properties of various types of glass such as annealed glass, laminated glass, toughened glass, heat strengthened glass, reflective glass, insulating glass unit and wired glass; and the associated glazing materials such as structural sealant, gaskets, preformed tapes and setting/location blocks, etc have been included to enable proper selection suiting the requirements. Quality requirement of glass as per the available Indian Standard specifications such as IS 14900 (float glass), IS 2553 (Part 1) [safety glass], IS 2835 (sheet glass), IS 5437 (wired glass), IS 16982 (heat strengthened glass); have been included.

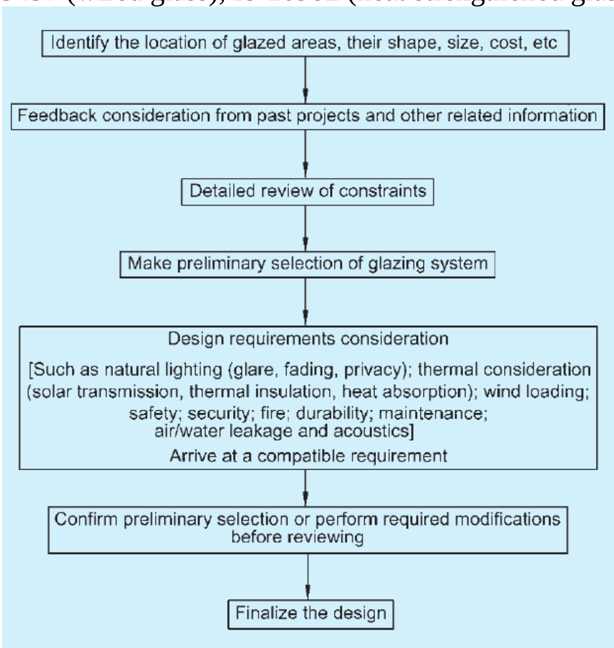


Fig A Typical Flowchart Indicating Selection Methodology of Glass

1.4.3 Energy, Light and Solar Aspects

The characteristics such as transmitted light, reflected light, solar heat gain, energy loss (heat/cold), thermal safety, glare, fading, diffusion, etc due to presence of glass have been elaborated so as to achieve proper aesthetic and functional requirements of buildings while using glass. The role of solar control glass towards achieving required energy transmittance, low emissivity coatings that improve thermal insulation, double glazed units with appropriate air/gas filing for enhanced thermal performance, etc are included to enable the designer in making right choice. In line with the international standards, the provisions on optical requirements and those related to light reflectance, solar energy transmittance, U-Value, etc have been dealt with in detail.

1.4.4 Structural Design and Safety Requirements

Determination of the right size and thickness of glass which can withstand the lateral wind pressure has been dealt with in detail with coherence to the provisions of IS 875 (Part 3). Features such as maximum permitted glass panel area, maximum span aspect ratio, factor of safety of material (glass), support conditions (two sided/four sided) have also been included with a view to ensuring safe design of glass components. The effects of seismic forces on the design have also been covered; and respective modification factors included for various non-structural elements which have been classified as sensitive to either acceleration or deformation. Checks with respect to relative displacement at two different heights on a building for non-structural glazing components ensure compatibility in design. Detailed tables relating to design wind pressure and nominal thickness for various types of glass have been included to arrive at maximum area of glass panes. Serviceability checks with respect to deflection limits guide a professional so as to ensure that the safe design also caters to performance requirements. With respect to fire safety, five different glass types have been suggested for use with necessary conformity requirement as enumerated under Part 4 'Fire and Life Safety' of the Code.

1.4.5 Human Impact Safety

Credible likely forms of human impact on glass, protection measures that minimize the likelihood of cutting/piercing due to breaking of glass have also been covered. Safety glass (toughened or laminated) and quality requirements has been suggested for use in various critical locations which has been identified based on height of sill protection in a floor and height of fall of glass from building. Also, critical locations (see Fig. B) where human impact on glass walls/doors has been indicated in the Code, along with suitable precautions (such as manifestation) to overcome them.

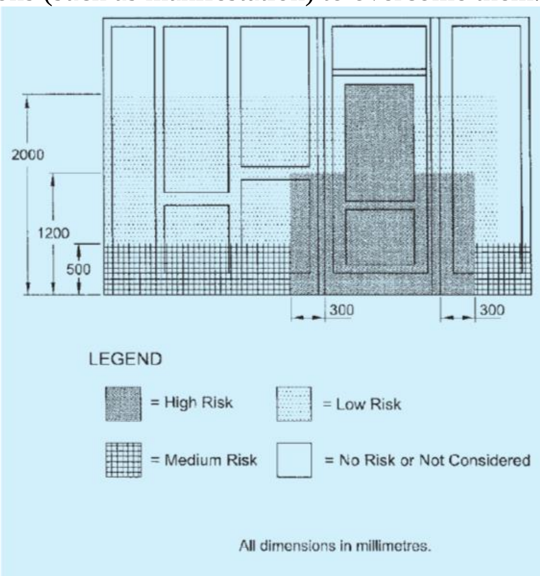


Fig B Typical Critical Locations Indicating Risk Due to Human Impact.

1.4.6 Glazing System

Selection and design of glazing system based on performance criteria, design parameters, structural framing materials (aluminium, stainless steel, UPVC, timber-their finish), and anchorages that secure the glazing assembly, have been included in detail. Provisions related to fabrication, transportation, installation (including tolerance), sealants, etc, of elements of glazing system; testing (laboratory and on-site); and maintenance of glazing system also have been detailed towards proper functioning of glazing in buildings.

1.5 The Building Code Provisions Towards Ensuring Fire & Life Safety

1.5.1 Philosophy

Part 4 of NBC 2016 deals with safety from fire. It specifies the demarcation of fire zones, restrictions on construction of buildings in each fire zone, classification of buildings based on occupancy, types of building construction according to fire resistance of the structural and non-structural components and other restrictions and requirements necessary to minimize danger to life from fire, smoke, fumes or panic before the buildings can be evacuated. The Code recognizes that safety of life is more than a matter of means of egress and accordingly deals with various matters which are considered essential to the safety of life. The Code therefore covers provisions relating to means of egress covering various components thereof namely exit access, exit and exit discharge. It also covers provisions relating to fire protection of buildings through portable and fixed firefighting installations.

Fire protection techniques have to be based on the fire behaviour characteristics of different materials and structural elements of buildings. The activities pursued by the occupants of buildings must also be taken into consideration for assessing the extent of hazards, and method should then be devised by which the hazards could be minimized. An indefinite combination of variables is involved in the phenomenon of fire, all of which cannot be quantified. The requirements of NBC 2016 should, therefore be coupled with sound engineering design so as to ensure fire safe design of buildings. Depending upon the type and complexities in a building, qualified and trained fire protection engineers should be associated with the planning of buildings, so that adequate fire and life safety measures could be incorporated in the building design right from the beginning.

Absolute safety from fire is not attainable in practice. The objective of Part 4 is to specify measures that will provide that degree of safety from fire which can be reasonably achieved. NBC 2016 endeavours to avoid requirements that might involve unreasonable hardships or unnecessary inconvenience or interference with normal use and occupancy of buildings but insists upon compliance with minimum standards of fire safety necessary for building occupants and users. For ensuring compliance of fire protection equipment/installations to the laid down quality requirements, it is desirable to use such equipment/installation duly certified under the BIS Certification Marks Scheme. NBC 2016 provides guidelines for minimizing chances of occurrence of fire through passive fire protection measures and does not intend to cover all aspects of general fire prevention including sources of ignition. Nor does the Code cover the prevention of accidental personal injuries during the course of normal occupancy of buildings.

Part 4 while recognizing that panic in a building on fire may be uncontrollable, deals with the potential panic hazard through measures designed to prevent the development of panic. Experience indicates that panic seldom develops even in the presence of potential danger, so long as occupants of buildings are moving towards exits which they can see within a reasonable distance and with no obstruction or undue congestion in the path of travel. However, any uncertainty as to the location or adequacy of means of egress, the presence of smoke or fumes and the stoppage of travel towards the exit, such as may occur when one person stumbles and falls on stairs, may be conducive to panic. Danger from panic is greater when a large number of people are trapped in a confined area particularly when people are not adequately guided towards egress and safety notifications are not implemented or practiced. Consideration towards announcements and annunciations needs to be given to guide the occupants to safe egress routes and to control panic during situation of distress.

1.5.2 Revision of Part 4 in NBC 2016

In the last (2005) version of the Code, apart from other changes made, the text was divided into the following broad clauses:

a) **Fire prevention:** Covering aspects of fire prevention pertaining to design and construction of buildings on passive fire protection measures, also describing the various types of building materials and their fire rating;
b) **Life safety***:* Covering life safety provisions in the event of fire and similar emergencies, also addressing construction and occupancy features that are necessary to minimize danger to life from fire, smoke, fumes or panic;
c) **Fire protection**: Covering the significant appurtenances and their related components and guidelines for selecting the correct type of equipment and installation meant for fire protection of the building, depending upon the classification and type of the building.

In this current revision of 2016, the following significant changes have been made:

***General*:**

1) The scope of application of provisions of this Part of the Code for different occupancies has been clarified.
2) Definitions of various new terms have been included and definitions of some of the existing terms have been updated based on latest developments and use.

***Fire Prevention*:**

3) Based on the experience in the use of the provisions of the Code in relation to various occupancies and subdivision classification under various building occupancy types, the same has been reviewed and updated. Also, mixed occupancy and minor occupancy have been further clarified.
4) Table 1 on fire resistance ratings of structural and non-structural elements has been updated.
5) The provisions relating to fire separating walls, fire separating floors and fire partitions have been detailed.
6) Provisions of fire safety requirements of services shafts have been rationalized and updated.
7) A separate comprehensive clause on electrical power supply distribution for fire and life safety systems has been provided.

8) Detailed clauses on air conditioning systems towards safety and smoke control integration have been provided.
9) Glass façade requirements have been detailed towards fire protection and smoke exhaust aspects.
10) A separate comprehensive clause on Fire Command Centre (FCC) has been introduced covering various requirements.

***Life Safety*:**

11) The components of means of egress have been comprehensively brought out covering specific aspects relating to exit access, exit and exit discharge. The relationship of occupant load exit width requirements and travel distances have also been duly detailed enabling efficient planning for enhanced life safety provisions. The Table on capacity factors has been modified based on aspect of width per person approach used globally.
12) Requirement for displaying the occupancy load for assembly buildings and call centres, has been included.
13) The concept of firefighting shaft for safe and efficient use by the fire fighters to access the floor on fire and also allow egress/evacuation of the occupants with simultaneous use of refuge area used as staging of the occupants, have been well integrated, including in the Annex for high rise buildings.
14) Aspects of compartmentation with fire barrier and its passive fire safety requirements have been detailed for respective occupancies.
15) Pressurization of exits and smoke extraction requirements for respective areas including car parking have been updated with an approach towards selecting alternative means therefor.
16) The clause on gas supply has been comprehensively updated.
17) The clause on fire detection and alarm system has been completely reviewed and updated as per the latest practices.

***Fire Protection*:**

18) The table on minimum requirements for firefighting installations (erstwhile Table 23 and now Table 7) has been comprehensively updated.
19) Detailed provisions have been included on fire water storage, fire pump room, sprinkler system and various alternative fire suppression systems**.**

Additional Occupancy-wise Requirements

20) The table on minimum requirements for firefighting installations (erstwhile Table 23 and now Table 7) has been comprehensively updated.
21) Concept of progressive evacuation in case of hospital buildings has been included in detail to ensure life safety of the inmates.
22) Provisions relating to requirement of refuge area have been updated including for D-6 occupancy and introduced for apartment buildings of height 60 m and above.
23) Separate provisions on atrium have been included in Annex F.
24) Detailed separate provisions have been included on commercial kitchens in Annex G.
25) Detailed separate provisions have been included on car parking facilities in Annex H

Applicability

The applicability of the provisions of Part 4 of the Code has been explicitly specified, which extends to:

- a) all high rise buildings; and
- b) special buildings, those are,

1) hotel, educational, institutional, business, mercantile, industrial, storage, hazardous and mixed occupancies, where any of these buildings have floor area more than 500 m^2 on any one or more floors;
2) educational buildings having height 9 m and above;
3) institutional buildings having height 9 m and above;
4) all assembly buildings;
5) buildings, having area more than 300 m^2 of incidental assembly occupancy on any floor;
6) buildings with two basements or more, or with one basement of area more than 500 m^2.

unless otherwise mentioned specifically in the provisions. Parties to agreement and the building owner may also decide to apply provision of this Part 4 to buildings other than those indicated above.

Terminology

In this revision of Part 4, clarity in the understanding of various issues and provisions has been sought to be improved and made unambiguous through insertion of series of new definitions as well as updating the existing ones. Some of the important definitions worth highlighting are as follows:

- Exit — That unobstructed component of means of egress which is between the exit access and the exit discharge or public way. Exit components include exterior exit doors at the level of exit discharge, interior exit stairways, exit passageways, exterior exit stairways and exterior exit ramps (*see* Fig. C).
- Exit Access — That portion of a means of egress that leads to an exit (for example, doorways, staircase lobby, ramps, *Veranda*, corridor or passageway leading to an exit) (*see* Fig. C)
- Exit Access Corridor — A corridor in exit access which may not necessary have the requirement of exits being met.
- Exit Discharge — The component of a means of egress between the termination of an exit and a public way (*see* Fig. C).

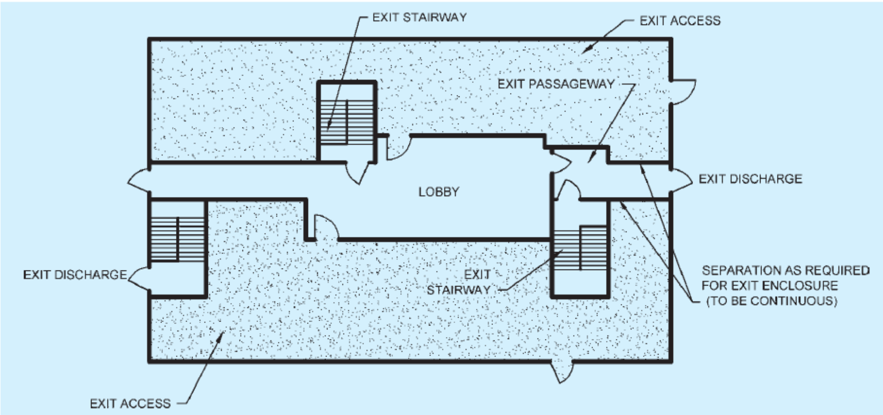


Fig C Exit, Exit Access and Exit Discharge

- Fire Door and Fire Door Assembly — Any combination of fire door, frame, hardware and other accessories that together provide a specific fire resistant rating to the opening in terms of its stability, integrity and insulation properties, when installed in the openings in fire separation walls. Fire door is a component of fire door assembly.

NOTES

1 Wherever reference has been made to fire door or fire check door in this Part, the same shall be construed as fire door assembly.

2 Fire doors in exits shall have fire rating as required in this Part to meet the requirement of integrity and stability; and the insulation criteria shall be 20 min.

3 Fire doors in exits shall be provided with smoke seal.

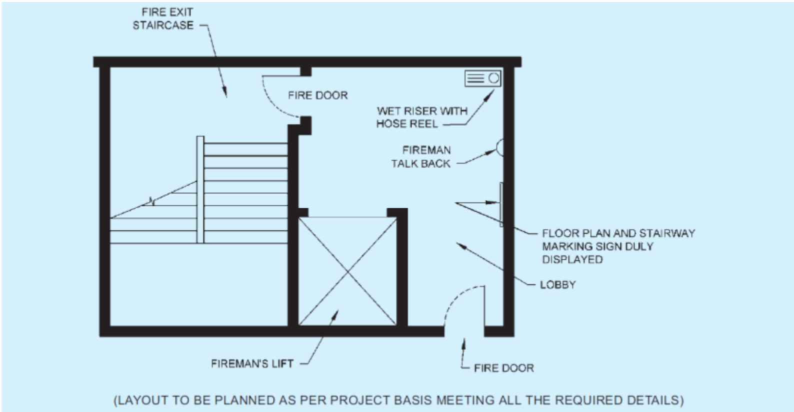
4 Fire doors in exits shall not be allowed to be on hold open position and kept closed and to close by 'door closure – spring mechanism'.

5 Fire curtains shall not be allowed as fire exits. If so provided, for compartmentation, independent fire door shall be provided meeting the requirement for fire door in exits as above (of the width as required) within the prescribed travel distance requirement.

- Fire Exit Hardware — A door-latching assembly incorporating an actuating member or panic bar that releases the latch bolt upon the application of a force in the direction of egress travel, provided on exits.
- Firefighting Shaft (Fire Tower) – An enclosed shaft having protected area of 120 min fire resistance rating comprising protected lobby, staircase and fireman's lift, connected directly to exit discharge or through exit passageway with 120 min fire resistant wall at the level of exit discharge to exit discharge. These shall also serve the purpose of exit requirement/strategy for the occupants. The

respective floors shall be approachable from fire-fighting shaft enabling the fire fighters to access the floor and also enabling the fire fighters to assist in evacuation through fireman’s lift. The firefighting shaft shall be equipped with 120 min fire doors. The firefighting shaft shall be equipped with firemen talk back, wet riser and landing valve in its lobby, to fight fire by fire fighters (*see* Fig. D for a typical fire-fighting shaft).

- Fire Resistance — Fire resistance is a property of an element of building construction and is the measure of its ability to satisfy for a stated period, some or all of the following criteria:
  a) *Load bearing capacity* (*Stability*) (*R*) – the ability of a load bearing element to withstand fire exposure without any loss of structural stability.
  b) *Integrity* (*E*) – resistance to penetration of flame and hot gases.
  c) *Insulation* (*I*) – resistance to temperature rise on the unexposed face up to a maximum of 180°C at any single point and average temperature of 140°C.



NOTES

1 Where such lobbies and staircase in the firefighting shaft are naturally ventilated/cross-ventilated, the shaft may not be enclosed and fire door need not be provided.

2 For all enclosed firefighting shaft, the shaft’s lobby should have floor plan duly displayed for the information of fire fighters.

Fig D Typical Fire-Fighting Shaft (Layout to be Planned Project Basis Meeting All the Required Details)

- Fire Resistance Rating — The time that a material or construction will withstand the standard fire exposure as determined by fire test done in accordance with the standard methods of fire tests of materials/structures as per the accepted standards [IS/ISO 834 Parts (1,4,5,6,7,8,9)].

NOTES

1 The requirement of rating of various building elements as given in this Part shall be applicable in accordance with the provisions given in as per the accepted standards.

2 The fire resistance rating shall be specified in terms of minutes.

3 Fire resistance rating for non-structural material/assembly shall bear a label of compliance to such rating as per the approval of competent authority based on testing and evaluation. The label shall be permanently affixed to the material/assembly and may carry other relevant details such as name and type of the product, and manufacturer's details.

- Fire Resistant Wall — Fire resistance rated wall, having opening(s) with specified fire resistant rating, which restricts the spread of fire from one part of a building to another part of the same building.
- Fire Separation — The distance in metre, measured from the external wall of the building concerned to the external wall of any other building on the site, or from other site, or from the opposite side of street or other public space for the purpose of preventing the spread of fire.
- Fire Stop — A fire resistant material, or construction, having a fire resistance rating of not less than the fire separating elements, installed in concealed spaces or between structural elements of a building to prevent the spread/propagation of fire and smoke through walls, ceilings and the like as per the laid down criteria.

NOTES

1) Fire stop assembly for through penetrations is a combination of firestop compatible for use with the penetrant, penetration items such as cables, cable tray, conduits, ducts, pipes, etc, and their means of

support through the wall or opening that together restores the fire resistance rating of the fire separating elements in terms of its integrity and/or insulation properties.
2) Fire stop assembly for joints is the one where fire stop with movement capability is used to seal the linear joints between adjacent fire separating elements, to maintain the fire resistance of the separating elements, which should be installed within its tested design limits with regard to size of the joint, type of assembly, and anticipated compression and extension of the joint.

Fire Prevention

Fire prevention aspects are detailed in clause 3 of Part 4. The following building occupancy classification and mixed occupancy as well as minor occupancy have been detailed out:

Designation	Character	Sub-classification
Group A	Residential	− Lodging or rooming houses (A-1) − One- or two-family dwelling (A-2) − Dormitories (A-3) − Apartment houses (flats) (A-4) − Hotels (A-5) − Starred hotels (A-6)
Group B	Educational	− Schools up to senior secondary level (B-1) − Others/training institutions (B-2)
Group C	Institutional	− Hospitals and Sanatoria (C-1) − Custodial institutions (C-2) − Penal & mental institutions (C-3)
Group D	Assembly	− D-1 to D-6 − D-7 Underground and elevated MRTS
Group E	Business	− E-1 to E-5 (offices, banks, labs, computer, telephone exchanges, broadcasting stations)
Group F	Mercantile	− F-1 to F-3 (shops, departmental stores, markets & underground shopping centres)
Group G	Industrial	− Low hazard (G-1) − Moderate hazard (G-2) − High hazard (G-3)
Group H	Storage	-
Group J	Hazardous	-

The Code suggests demarcation of a city or an area under the Authority into three distinct zone called “Fire Zones” based on the inherent nature of fire hazard of respective buildings, as follows:

Category of fire zone	Occupancy Group	Type of Construction
Fire Zone No. 1	A, B, C, D, E-1 (small offices), F	1, 2, 3, or 4
Fire Zone No. 2	E-2 to E-5, G-1, G-2	1, 2 or 3
Fire Zone No. 3	G-3, Group H, J	1 or 2

Such zones are relevant for various land use development planning purposes. The Code also provides clarification with respect to changes in Fire Zones boundaries, overlapping fire zones, requirements for temporary building/structures, restriction of type of construction for new buildings, and restrictions on existing buildings.

Four types of construction based on fire resistance ratings of various structural and non-structural elements in a building have been specified namely, Type 1, Type 2, Type 3 and Type 4, as in Table A, as follows:

Table A Fire Resistance Ratings of Structural and Non-structural Elements (Minutes)

Sl No.	Structural Element		Type of Construction			
			Type 1	**Type 2**	**Type 3**	**Type 4**
i)	Exterior walls: a) Fire separation less than 3.7 m	a) Bearing b) Non-bearing	240 120	120 90	120 60	60 60
	b) Fire separation of 3.7 m or more but less than 9 m	a) Bearing b) Non-bearing	240 90	120 60	120 60	60 60
	c) Fire separation of 9 m or more	a) Bearing b) Non-bearing	240 60	120 60	120 60	60 60
ii)	Fire separation assemblies (like fire check doors)		120	120	120	120
iii)	Fire enclosures of exits		120	120	120	120
iv)	Shafts for services, lift hoist way and refuse chutes		120	120	120	120
v)	Vertical separation between adjacent tenant spaces		60	60	60	60
vi)	Dwelling unit separation:					
	a) Load bearing		120	120	60	60
	b) Non-load bearing		60	60	30	30
vii)	Interior bearing walls, bearing partitions, columns, beams, girders, trusses (other than roof trusses) and framing	a) Supporting more than one floor b) Supporting one floor only c) Supporting a roof only	240 180 180	120 90 90	120 60 60	120 60 60
viii)	Walls supporting structural Members		180	90	60	60
ix)	Floor construction		120	90	60	60
x)	Roof construction	a) 5 m or less in height to lowest member b) More than 5 m but less than 6.7 m in height to lowest member c) 6.7 m or more in height to lowest member	120 60 0	90 60 0	60 60 0	60 60 0

NOTES

1 The above fire resistance rating shall be required to achieve the respective type of construction unless otherwise specified in the respective clauses for different applications/use.

2 In case of lift bank, the partition wall, if any, need not be of fire rating specified in this Table.

The following general requirements of all individual building occupancies have also been covered in detail:

a) General requirements
b) Buildings under construction
c) Maximum height, floor area ratio and open spaces
d) Openings in fire resistance walls and floors
e) Service ducts and shafts
f) Refuse chutes
g) Vertical opening between floors
h) Electrical installation
i) Emergency power for fire and life safety systems
j) Substations (dry type, oil filled), transformers, standby supply, lightening protection
k) Escape lighting and exact signage
l) Air conditioning, ventilation and smoke control
m) Glass façade and glazing
n) Surface interior finishes
o) Fire command centre

Life Safety

The life safety aspects of the building occupants have been detailed through requirements of adequate means of egress, which cover the following:

1) General exit requirements (doorway, staircase, passage way, refuge area, level changes, walking surfaces and basement)

It also clarifies through figure 5 of Part 4, the minimum headroom measurements as shown in Fig. E.

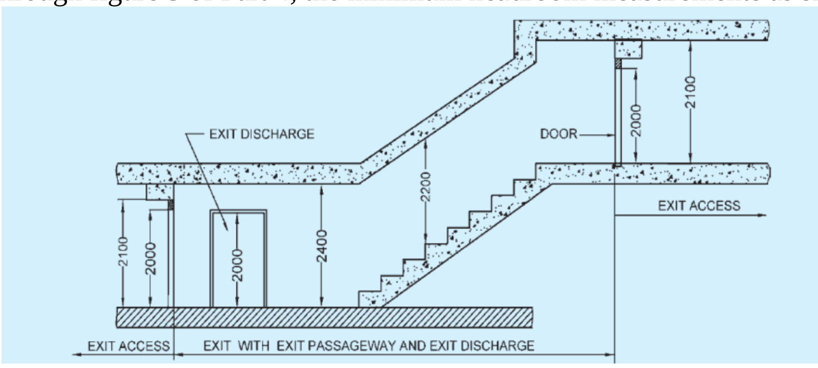


Fig. E Minimum Head Room Measurements

2) Occupant load (number of people in a given area)

The Part 4 brings clarity w.r.t calculation of occupant load for various occupancy types in its Table 3 read along with the notes given thereunder.

Part 4 also requires that the assembly occupancies and call centres shall display, limiting occupant load details positioned in a conspicuous place near the entrance of each of such respective occupancy to avoid possible overcrowding and overloading. The display shall preferably be engraved on a metal plate of not less than 300 mm x 200 mm, with letters of height and width not less than 50 mm, with detail of occupancy, area and occupancy load (*see* Fig. F)

Fig. F Typical Certificate Displaying Limiting Number of Occupants

3) Egress components (exit access, exit, exit discharge, capacity factors, travel distance, internal and external staircases, curved stairs, ramps, pressurization). These have been comprehensively detailed, first through the definition given and under the life safety provisions through conspicuous provisions along with illustration as also clarity brought in calculation of capacity of means of egress giving example as well as series of illustrations.
4) Compartmentation :The provision has been completely rationalized with compartmentation area given occupancy wise based on logic.
5) Smoke control (smoke exhaust and pressurization of areas both above ground and below ground)
6) Gas supply (pipes, fume hoods, grease filters, thermal detectors, cylinder and manifold location, pressure regulating stations, gas meters)
7) Hazard areas, gas/oil storage yard
8) Fire detection and alarm
9) Fire officer (his qualification, experiences, roles)
10) Fire drills and fire orders (detailed in Annex D of Part 4)

Fire Protection

Requirements of the following fire protection systems/installations have been listed to actively fight and douse the fire:

i) Fire extinguishers/fixed fire-fighting installations
ii) Static water storage tanks
iii) Fire-fighting pump house
iv) Automatic sprinkler installations
v) Automatic high velocity and medium velocity water spray systems
vi) Fixed foam installations
vii) Gas based suppression systems
viii) Automatic water mist systems
ix) Clean agent extinguishing systems

Also a comprehensive table specifying the minimum requirements of the above installations has been included as Table 7 (erstwhile Table 23) for various building occupancies/sub-occupancies depending upon their type, height and expanse. Water and pumping requirement have been revisited and rationalized.

Additional Occupancy-wise Requirements

Further, various additional occupancy-wise special requirements have been specified for compliance for all the nine groups of buildings covering therein, fire prevention requirements, life safety requirements, fire protection requirements, additional precautions, exceptions and deviations, if any. Further clarity brought in, for sensitive hospital buildings (C-1) as well as for assembly (D-6) occupancy are worth noticing. Principle of progressive horizontal evacuation has been detailed.

In case of hospital/institutional occupancy, it highlights that principle of progressive horizontal evacuation is of paramount consideration for hospital patients particularly those lacking self-preservation. This calls for moving occupants from a fire affected area to an adjoining area at the same level through a fire resistant wall, to protect them from the immediate dangers of fire and smoke (*see* Fig. G).

Progressive horizontal evacuation operates on the basis of evacuation from compartment to compartment and on use of adjacent compartments as temporary means of refuge. All compartments shall be divided with self-closing (door closers) fire doors with electromagnetic hold open. A coordinator shall be provided to sequence the closing of double leaf in case of emergency.

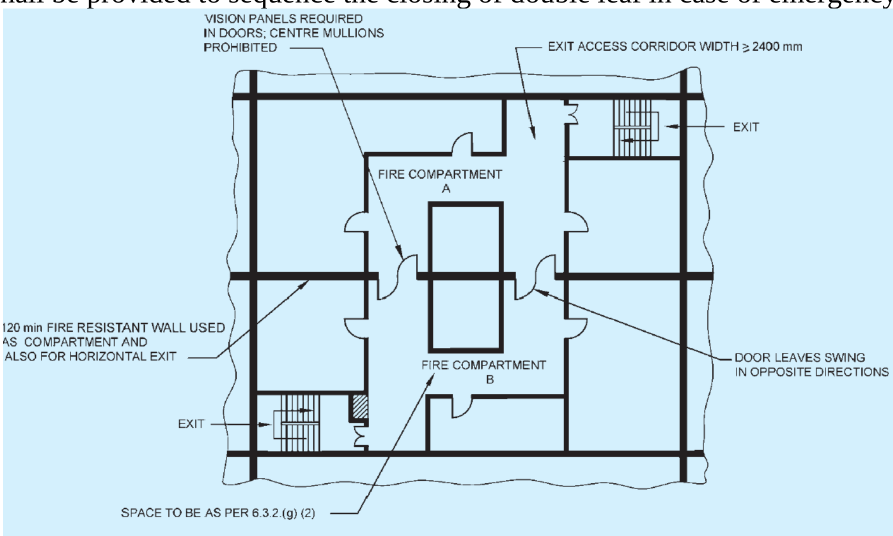


Fig G Horizontal Exits in Hospitals

Comprehensive Annexes have been included in the revised Part 4 towards ensuring the objective of fire and life safety, as follows:

Annex A	Calorific values of common materials and typical values of fire load density
Annex B	Broad classification of industrial and non-industrial occupancies into different degree of hazard
Annex C	Available data regarding fire resistance rating of various building components
Annex D	Guidelines for fire drill and evacuation procedures for high rise buildings (above 15 m in height)
Annex E	Additional requirements for high rise buildings
Annex F	Atrium
Annex G	Commercial kitchen
Annex H	Car parking facilities
Annex J	Fire and life safety requirements for metro stations
Annex K	Fire and life safety requirements for metro trainways
Annex M	Fire protection considerations for venting in industrial buildings

Fire Safety Requirements for Glazing

Glass designed in accordance with Part 6 'Structural Design, Section 8 Glass and Glazing' also need to be safe from building fires. The Code suggests that the entire glazing assembly shall be rated to that type of construction as given in Table 1of Part 4. Also, other provisions of Part 4 related to respective uses as specified therein shall be applicable. The Code clarifies that use of glass shall not be permitted for enclosures of exits and exit passageway.

Fire safety requirements for glass facade shall satisfy the following requirements suggested in the Code:

a) For fully sprinklered buildings having fire separation of 9 m or more, tempered glass in a non-combustible assembly, with ability to hold the glass in place, shall be provided. It shall be ensured that sprinklers are located within 600 mm of the glass facade providing full coverage to the glass.

NOTE – In case of all other buildings, fire resistance rating of glass facade shall be in accordance with Table 1 of Part 4.

b) All gaps between floor-slabs and facade assembly shall be sealed at all levels by approved fire-resistant sealant material of equal fire rating as that of floor slab to prevent fire and smoke propagation from one floor to another.
c) Openable panels shall be provided on each floor and shall be spaced at not more than 10 m apart measured along the external wall from centre to centre of the access openings. Such openings shall be operable at a height between 1.2 m and 1.5 m from the floor and shall be in the form of openable panels (fire access panels) of size not less than 1 000 mm x 1 000 mm opening outwards. The wordings, "FIRE OPENABLE PANEL - OPEN IN CASE OF FIRE, DO NOT OBSTRUCT" of at least 25 mm letter height shall be marked on the internal side. Such panels shall be suitably distributed on each floor based on occupant concentration. These shall not be limited to cubicle areas and shall be also located in common areas/corridors to facilitate access by the building occupants and fire personnel for smoke exhaust in times of distress.

1.6 THE BUILDING CODE PROVISIONS ON SUSTAINABLE BUILDING DEVELOPMENT

Philosophy

Modern buildings in India consume about 25 to 30 percent of total energy, and up to 30 percent of fresh potable water, and generate approximately 40 percent of total waste. India is now entering the phase of rapid urbanization. Various studies indicate that by 2050, the built-up area of all the buildings in India may become four times the current mass, which may pose a major challenge in preserving our fragile environment. Although the present energy consumption per capita in India is a fraction of that of most developed nations, but with its projected growth, unless enough measures are taken, it may lead to acceleration of environment degradation, contributing to increased carbon footprint leading to global warming and climate change.

Developed nations' approach to sustainability generally concentrates on energy conservation through high technology innovations, and use of products, materials and designs with lower embodied energy. Their green ratings are based on intent, which implies expert inputs and simulation. Indian construction industry will do better using our traditional wisdom and practices, building in harmony with nature through regional common knowledge, consuming as little as necessary, applying low cost technology innovations, using recycled materials, and recognizing performance (not intent) through easily measurable parameters wherever feasible. Sustainable building and built environment are not only environment friendly, but also result in much better health and productivity of occupants, at minimal additional initial cost over the cost of conventional buildings, while substantially reducing the life cycle cost. This minimal additional cost is offset during a few years usage of the buildings, and vast advantage in cost is accrued during the life cycle of the building.

Comprehensive Approach

The comprehensive approach relating to buildings and built environment requires to deal with all aspects relating to siting, form and design; external development and landscape; envelope optimization; selection of appropriate materials; water and waste management; building services optimization; constructional practices including selection of appropriate technologies; and commissioning, operation, maintenance and building performance tracking. The objective is not only to ensure that the building is built sustainably using optimum embodied energy but also requires optimum operational energy and least maintenance. The progressive thought requires that the building and built environment should not be designed only to reduce the adverse effect to the environment but should intend to cause positive effects to the environment, economy and the society at large. This would be possible if all of the aforesaid stages have been well understood from sustainability point of view, not only in isolation but also in context of their interaction with the other stages yielding an optimized sustainable output.

Siting, Form and Design

Before initiating the formal design process, it is critical to evaluate all the passive design options to take advantage of local site and climatic conditions. Passive techniques are very cost effective, help a building integrate better with its immediate environment and most importantly do not create any negative impact on the environment unlike active systems that may cause various negative impacts including ozone depletion and global warming. The objective, therefore, is to encourage passive design strategies for every building as a means to reduce overall energy consumption before pursuing active and mechanical means in an effort to not only save energy but also allow buildings and its operations to seamlessly integrate with its immediate environment while minimizing the overall negative impact on the environment.

The site design and development should ensure that the responsible design professional should:

a) establish if there are any protection areas such as floodplains; forest department areas; water bodies such as sea, lakes, rivers, wetlands, tributaries and/or streams; public parks and recreation areas (unless otherwise used for the purpose of the park); and agricultural land (unless serving an agriculturally related purpose such as storage, processing, transport, etc) and demonstrate that no critical natural resource is impacted by the project and/or dredging operations;
b) establish the degree to which the existing soil at site and hydrology has been disturbed prior to development and demonstrate various site erosion protection measures taken including measures to preserve top soil and existing vegetation, minimize soil disturbance; and
c) identify and ensure removal of existing invasive vegetation on site and that no invasive vegetation is planted post completion.

External Development and Landscape

To achieve sustainability objectives, this should ensure proper landscape design including microclimatic conditions, barrier free external landscape, noise reduction/mitigating practices, pervious paving design, avoiding heat-island effect, preserving to soil, ensuring ecological design to conserve bio-diversity through protection and use of existing vegetation, rain water harvesting, etc. The external access design should be so done as to reduce environmental impacts from parking facilities, promote mass rapid transit systems, provide for bicycle lanes and pedestrian access, provide neighbourhood connectivity, walkability and safety.

Envelope Optimization

The building envelope should be utilized to conserve energy substantially. Well designed building envelope maximizes daylight, natural ventilation (access to fresh air) and views to the exterior, and enables to modulate solar heat gain and control/reduce noise. The building envelope may also be designed to integrate systems for renewable and rainwater harvesting. In general, the design strategies drawn from long experience in the country in its various climatic zones may be taken into account.
Building envelope components and their configuration largely determine the amount of heat gain or loss and wind that enters inside the building. The primary components of building envelope which affect the performance of a building, are walls, roof, fenestration (openings with or without glazing), floor, and surface finishes.

Various methodologies to achieve the thermal performance with use of insulating materials along with design of openings with shading devices are available for proper design of building envelope. Also, there are envelope optimization methods available which could be used with advantage. Various traditional technologies such as inverted earthern pots for roof insulation, mud phuska and brick bat coba, have been used for ages. Similarly, use of screens (*jalli*) make effective windows which reduce heat ingress and yet allow the air movement.

Materials

Environmental Concerns and Human Health and Safety

Increased demand for building materials creates a major and diversified impact on the environment. Excessive extraction of raw material depletes non-renewable natural resources very rapidly. Even during some extraction process, waste is generated whose disposal may pose problems. Sometimes extraction processes may also affect the natural environment and wildlife. Transportation of building materials from one place to another is also a major indirect factor leading to harmful effects. During manufacturing or processing of some materials like plastics, harmful gases are generated, which are dangerous for human health and the environment. There are many frequently used building materials like reconstituted wood products, paints, glues, carpet and upholstery, which may release gases, fumes, etc, from the chemical components used, even long after the use/installation. These Volatile Organic Compounds (VOCs) affect the environment and human health and may cause headaches, dizziness, respiratory problems, and even major diseases in human and other living beings.

Minimizing Green House Gas (GHG) Emission

Construction sector in the country is a major consumer of energy resulting in the largest share of CO_2 emissions in the atmosphere. Cement, steel and bricks, the largest and bulk consumption items in the construction industry, are contributors of large CO_2 emissions. It is estimated that close to a tonne of CO_2 is emitted during the production of every tonne of cement, resulting in very high GHG emission. Similarly, concrete, which is a very widely used construction material has very high GHG emission. Minimizing the consumption of such conventional materials which may contribute to substantial GHG emission, by using alternative materials and alternative methods and techniques can considerably reduce energy and CO_2 emissions.

Selection of Building Materials

Building materials choices are important in sustainable design because of the extensive network of activities such as extraction, processing and transportation steps required for making a material, and activities involved thereafter till building construction and even thereafter. These activities may pollute the air, soil and water, as well as destroy natural habitats and deplete natural resources. One of the most effective strategies for minimizing the environmental impacts of material usage is to reuse existing buildings. Rehabilitation of existing building, their shell and non-shell components, not only reduces the volume of solid waste generated and its subsequent diversion to landfills but also the environmental impacts associated with the production, delivery and use or installation of new building materials.

The use of rapidly renewable materials, recycled materials minimizes the adverse impact of natural resource consumption in the manufacture of new building materials. The use of local materials supports the local economy and reduces the negative impact of transportation. Therefore, an ideal sustainable building material is not only environment friendly, causes no adverse impact on health of occupants, is readily available, can be reclaimed, can be recycled and is made from renewable raw material, but also uses predominantly renewable energy in its extraction, production and transportation. Practically, this kind of ideal material may not be available, hence when selecting sustainable materials, it may be best to choose materials which fulfil most of these criteria.

Life Cycle Assessment (LCA) of Building Materials

LCA of building materials intends to assess the potential environmental impacts in every stage in the life cycle of a material (*see* Fig. H) right from the raw material sourcing, processing, manufacturing and finishing, up to the operational product installation, operation, maintenance and ultimately the deconstruction, reuse/ recycling or disposal. It is a tool to determine the environmental suitability of any building material for a thorough understanding of the environmental impact and the improvement which can be employed at every stage of a material, so as to make a decision for selection of a material in terms of criteria such as embodied energy, performance, durability, etc.

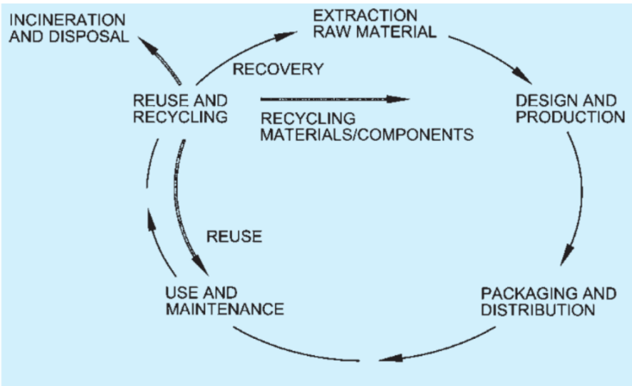


Fig H Life Cycle of Building Material

A description of life cycle analysis with respect various relevant criteria may involve:

a) *Embodied energy* - Embodied Energy is an important factor to be considered in the Life Cycle Assessment of a material. Minimizing embodied energy means minimizing the impact on the environment. Embodied energy data is often collected using input and output analysis. In any building construction use of materials with lower embodied energy should be considered. Table B gives classification of building materials based on their energy intensity and gives the comparative embodied energy of few building materials.

Table B Classification of Materials Based on Energy Intensity

SN o	Category of material	Energy intensity (Range) (GJ/tonne)	Examples
1	High energy	>50	Aluminium, Stainless Steel, Plastics, Copper, Zinc
2	High energy	5-50	Cement, Steel, Glass, Bitumen, Solvents, Cardboard and Paper, Lead.
3	Medium energy	0.5-5	Lime, Gypsum plaster board, Burnt clay brick, Burnt clay brick with improved vertical shaft kiln, Aerated blocks, Hollow concrete blocks Gypsum plaster, Concrete blocks, Timber, wood products, Medium density fiber board, Cellulose insulation, in-situ concrete

4	Low energy	<0.5	Sand, aggregate, Fly ash and fly ash based products, Cement stabilized earth block, Straw bale, bamboo, Stone

b) *Resource reuse and upgradation* – It includes saving a material from disposal and utilizing it by renovating, repairing, restoring, or generally improving the appearance, performance, quality, functionality, or value of a product. Efforts should be made to reuse existing, previously occupied buildings – including the structure, envelope and elements, after removing or replacing the elements which have risk of failure/contamination during construction or occupancy. Upgradation of systems should be done in the areas of energy and water efficiency where the previously installed systems are not environment friendly or efficient.

c) *Recycled content* – To reduce the demand for virgin materials, effort should be made to use the products with identifiable recycled content.

d) *Reusable or recyclable* – Effort should be made to select materials that can be easily dismantled and reused or recycled at the end of their useful life.

e) *Natural, plentiful* – Effort should be made to use materials which are bio-based and naturally harvested from sustainably managed sources.

f) *Bio-degradable* – Consider using materials which are bio-degradable so that they can be harmlessly disposed at the end of their life cycle.

g) *Indigenous or locally available* – Effort should be made to use building materials, components, and systems which are found locally or regionally, saving energy and resources for transportation of materials to the project site.

h) *Rapidly renewable material* – Effort should be made to use materials which replenish substantially faster than traditional extraction demand (for example, bamboo, or fast growing/plantation timber species which can be planted and harvested in less than a 10-year cycle) to reduce the demand for limited/finite resources.

i) *Materials compliant with clean air and clean water* – Effort should be made to select those materials that emit few or no carcinogens, reproductive toxicants, VOCs, etc, and which maximize resource and energy efficiency while reducing the growth of biological contaminants in buildings. Such materials that enhance the indoor air quality and consume less water as well as help in reducing water consumption should be considered for use.

j) *Materials having low ozone depletion potential* – Efforts should be made to select materials which do not use in their manufacture, chemicals that have an ozone depleting potential (ODP).

Water and Waste Management

Sustainable approach to water and waste management requires planning and design of building functions to integrate issues of water and waste management system at the early stages of project evolution, their management during construction activity and subsequently during occupancy and use of building. At the scale of building complex or at township level, the opportunities for water efficiency and waste management are large. Sustainable approach for water and waste management should, therefore, include such management aspects in respect of external development and landscaping. The sustainable approach should finally adopt an integrated approach to water supply, water waste and solid waste management aimed to create built facilities with zero anthropogenic waste design solution.

Following are the broad aspects for achieving sustainable water and waste management:

a) *Conceptualization, planning and design stage* – Water is essential to create livable neighbourhoods and public spaces. The function of a water supply system is to provide water from a source identified through considered selection, treat the same to render it suitable for its intended use, and deliver it to the user at the time and in the quantity desired. Major considerations during planning and design include yield and quality of raw water sources; topography, geology, population density of service areas; intended uses of water; and treatment of waste water. Since these considerations may vary from project to project, all water and waste management system solutions are unique. Planning and design of water and waste management system needs a holistic approach. The system should integrate functions, water supply systems, waste water system (including grey water use), storm water management (including rain water harvesting) and solid waste management and waste to energy systems. The complexity of holistic design process requires coordinated decision-making process.

b) *Construction stage* – Objective of construction stage is to create the built facility. The concerns of efficient water use and waste have a potential to be ignored. It is essential to establish systems for water and waste management so that the project teams monitor water consumption, control wastes and dispose off in an environmentally appropriate manner. There is a scope for selection of materials and technologies, which are water efficient. Value engineering of material and technology selection should be undertaken so that the solutions are appropriate to the project peculiarities as well as environmental constraints. Construction including in environmentally sensitive sites, necessitates compliance to legal and statutory requirements for water and waste management.

c) *Performance during use and corrective action* – Building projects are planned, designed and executed in accordance with the anticipated functional use. However, it is reasonable to expect some variance during use. Building use is a dynamic process and functional use is constantly evolving during life of a building. Also, engineering system designs are optimum solutions based on assumptions, which can only be validated during actual use. Design of systems should be done within a considered tolerance of functional use. The performance of water consumption should be monitored during use and compared with the benchmarks (industry specific, building specific or established standards) given in the national standards and corrective actions undertaken. In this respect, it is important to design systems that facilitate monitoring. Appropriate metering and corrective improvements should be integrated in the system design detailing. It may be desirable to design water system taking functional homogeneity into account and facilitate function specific corrections in response to environmental considerations and opportunities for conservation.

Building Services Optimization

Optimization of electro-mechanical services is one of the important aspects towards achieving a sustainable building. Reduction in heating, cooling and lighting loads through climate-responsive designs and conservation practices can enhance the energy efficiency of a building. In addition, an integrated project delivery (IPD) approach results in a well-designed, cost effective solution wherein all building systems and components can in coherence facilitate overall functionality as well as required environmental performance. The passive design features and proper initial planning helps in reduced energy demand and, therefore, the same should be carefully analyzed prior to actual sizing of equipment where provided.

In addition to achieving the optimum energy performance, the building should also provide the desirable thermal and visual comfort to its occupants. Incorporating solar passive techniques in a building optimizes building performance by minimizing the use of artificial energy and thereby minimizing load on conventional systems for heating, cooling, ventilation, lighting, etc.

Solar passive techniques that can be adopted in different climate zones of India are:

1) landscaping (to reduce heat island effect);
2) optimum building orientation;
3) arrangement and shape of buildings;
4) effective surface to volume ratio;
5) location and size of openings on building facade;
6) glazing type and performance;
7) shading devices on windows and judicious selection of building materials.

Prior to developing the design drawings, the design team should carry out a thorough review of the fundamental assumptions, owner’s brief and available resources on site, in an integrated manner, addressing the key target issues such as the following:

1) *Building orientation* – Building orientation affects many aspects ranging from energy performance to visual simulation of the building. Building location and its exposure to solar direct radiation affect the HVAC design, day-lighting strategies and the overall energy demand.

2) *Building envelope* – Building envelope provides a starting point for determining heat transfer coefficients for external walls/ceiling/roof and glazing.
3) *Harvest site energy* – Project should explore the use of natural resources such as daylight, variations in ambient temperature (economizer cycles) to reduce cooling/heating demand and utilize solar/wind energy. For large projects, the master planning team should explore district level solutions and identify potential site integrated opportunities.
4) *Design assumptions and internal load assessment* – Energy demand reduction may be accomplished by carefully analyzing the initial design assumptions and by reducing internal heating and/or cooling loads and interior lighting improvement. It can be achieved through multiple design strategies such as reducing the overall building footprint, reviewing the indoor temperature design criteria to allow for a wider acceptable band, on-demand operation of utilities (using sensors to link the operation to an established criterion), climate responsive envelope, etc.
5) *Maximize efficiency* – Energy consumptions should be optimized to avoid over-sizing of equipment rating. It may be achieved by analyzing the estimated monthly and annual energy consumption profiles of the building and compare the same with building peak loads. Computer based design tools may be used to identify feasible energy conservation measures for a building.
This would further require adopting appropriate natural and mechanical ventilation strategies, passive heating techniques, passive cooling techniques, pre-cooling of ventilation air, low energy mechanical cooling techniques, etc. For air-conditioned buildings, the HVAC System may be designed keeping in view, the aspects like appropriate equipment sizing, selection of unitary/ variable refrigerant flow systems/central system for air-conditioning based on the actual needs, use of refrigerants having zero ozone depletion potential (ODP) and least global warming potential (GWP), use of efficient systems/methodologies in respect of chillers, chilled water pumping systems, thermal energy storage technique, vapour absorption system, air handling units, fans and blowers, controls, etc.

In respect of electrical system, efforts should be made to select electrical installations and systems which are energy efficient, while complying with the national Standards for the same which provide apart from efficiency, the various other important requirements including relating to performance and safety.

The requirements for energy efficient design of electrical installations in buildings may be classified under the following four categories:
a) Minimizing losses in the power distribution system,
b) Reduction of losses and energy wastage in the utilization of electrical power,
c) Reduction of losses due to the associated power quality problems, and
d) Appropriate metering and energy monitoring facilities.

The active energy efficiency measures include making use of energy saving equipment, low energy lighting, efficient motors, low loss transformers, efficient appliances, suitable power carrying devices and optimized electrical distribution. These active measures along with high efficiency standby emergency generating plants using diesel, natural gas, alternate fuel, etc coupled with high efficiency uninterruptible power supply (UPS) systems contribute towards sustainable development. Passive features include good practices like simple switching off (to turn off a device when not in use), paying attention to vampire electric loads (associated with electronic appliances like computers), etc.

The optimal use of daylight should be made to reduce the load of the electric lighting system by dimming or switching off luminaires when natural light provides ample illuminance for the task performed in the space. Daylight harvesting has a significant energy saving potential if it is integrated with the building design after comprehensive understanding of site, building orientation, weather conditions, materials and system design. Lamps, luminaries, ballasts and the controlling systems should be monitored for achieving energy efficiency through artificial lighting. Factors that play crucial role in designing an energy efficient lighting system are reflectance, design of interior spaces, efficiency of lighting systems, task lighting, controlling systems, and monitoring and maintenance.

Similarly, efficiency needs to be achieved in other services like lifts, escalators and travelators with least environmental impact. In case of high rise buildings with multiple lifts having peak traffic demand, to increase the efficiency, the destination control system wherein passengers key-in their destination before entering the elevator and which optimizes the number of trips made by the lifts, may be installed. The controller groups the people such that the stops are minimized and travel time reduced.

Also, all efforts should be made to utilize in the building, the renewable energy available in various forms for which the following considerations should be made:

a) *Solar energy utilization* – Solar energy may be utilized in building through the following applications:
   1) Solar water heating systems
   2) *Solar steam systems for cooking, laundry, etc*.
   3) *Solar assisted refrigeration/air conditioning systems*
   4) *Solar Photovoltaic Systems*

b) *Wind energy utilization*

c) *Waste Utilization*
   1) Waste heat utilization
   2) *Solid waste utilization*

d) *Bio-Fuels*

e) *Hydropower*

f) *Other Renewable Energy Sources*

Constructional Practices

The framework for sustainable construction practices includes the following issues:

a) Pre-construction pre-requisites;
b) Planning for sustainable construction;
c) Preparation of sustainable construction management plan;
d) Planning, monitoring and control of environmental descriptors;
e) Sustainable work execution procedures;
f) Effective use of water;
g) Construction waste management;
h) Post-construction closeout;
i) Construction methodology for heritage buildings; and
j) Alternative use, de-construction, dismantling, demolition.

In each of these stages, there is extensive requirement of sustainability related interventions which may range from adoption of proper construction methodology; safe constructional practices; planning, monitoring and control of environmental descriptors; construction waste management including identification, segregation, re-use and recycling of wastes, and restoration of dereliction caused to site and re-use of top soil; etc. This would also require comprehensive construction project management including time, cost, quality, health and safety, scope, risk, procurement, human resource and communication management.

Commissioning, Operation, Maintenance and Building Performance Tracking:

Typically, the first step in the commissioning process should involve formation of a commissioning team that comprises the owner, users, occupants, operation and maintenance (O&M) staff, and design professionals and owners. The next step is the preparation of the project requirements, which should address building systems such as lighting, air-conditioning, water systems, etc as well as the design intent and the functional specifications for the key building systems. The project design document should include a commissioning plan. Prior to the handover stage, the commissioning team should verify the installation of the systems, conduct functional performance testing, training of the O&M personnel, etc. A post occupancy commissioning report should be provided to the owner and/or relevant authorities once the necessary tests have been conducted and the areas that need correction have been rectified. In all commissioning processes, the elements relating to sustainability should be ensured for their proper operation at subsequent stages.

During the handover stage, records of meter readings for the different building systems, and other data should be provided to the asset management team. A simple guide for occupants will help the team understand the working of the systems in the building.

O&M programmes that focus on improving energy efficiency of building systems can help save energy without a significant capital investment. From small to large sites, these savings can represent significant savings each year, and can be achieved with minimal cash outlays.

Building maintenance is a wide subject covering not only maintenance of building services but also the maintenance of all other aspects including the structure itself. Effective operation and maintenance is one of the most cost-effective methods for ensuring reliability, safety and efficiency of a building. Inadequate maintenance of energy-using systems is one of the major causes of energy waste. Energy losses from steam, air and water leaks, uninsulated lines, maladjusted or inoperable controls and from poor maintenance are often considerable. Also, inadequate maintenance of systems that consume water, including plumbing and HVAC systems (as applicable), can result in excessive usage of water. Good maintenance practices result in substantial savings in consumption of energy and water, and should be considered as a resource.

Subsequent to the commissioning and handover stage, regular monitoring of the performance should be carried out which will provide information on whether the set environmental performance and targets have been met or not. As part of the measurement and verification (M&V) process, an ongoing monitoring of the energy and water systems should be carried out. This will ensure ongoing accountability of energy and water consumption during the life of building.

1.7 IMPLEMENTATION OF THE CODE

The National Building Code of India is intended to serve as a model for adoption by PWDs and other construction departments, local bodies and other construction agencies. Existing PWD codes, municipal byelaws and other regulatory media could either be replaced by the National Building Code of India or suitably modified to cater to local conditions.

In the case of municipal corporations, municipalities and other local bodies which are the main agencies to regulate the building activity within the jurisdiction of the cities and towns, it is the administrative requirements and byelaws provisions for the health safety aspects which should mainly constitute the coverage of their byelaws. Guidelines on all these aspects are included in the National Building Code of India. The information cited above is mainly covered in Part 2 and Part 3 of the Code. The other parts of the Code are equally valid and should be referred to in the byelaws. The Part 4 Fire and Life Safety has been drafted in a manner so as to facilitate its easy adoption in the state fire regulations. The relevant Act/Rules/Regulations should be revised and revamped to bring the same in complete harmony with Part 4 ensuring its fool proof implementation with the objective of saving life and property in the event of fire.

In the case of Public Works Departments of the States and Centre, MES, Railways and other government construction agencies who would regulate the construction within their jurisdiction with the help of their handbooks, codes and specifications of works, it is the information contained in Part 0, 4, 5, 6, 7, 8, 9, 10 and 11 of the Code which should mainly be used/adopted to modernize their regulatory media. The PWD specifications and handbooks dealing with the materials specifications and the construction procedures for various items of work, should utilize the provisions given in Parts 5, 7 and 11 of the Code to update these documents. The structural design requirements including for building glazing and use of glass, and procedure for the design and installation of various services, etc, are not covered in detail in the above codes and detailed information on the same is given in Parts 6, 8, 9 and 11 of the Code. Even though the essential contents of the departmental code should be aimed only for the design and construction of the buildings, there are certain planning requirements which should also be included in these codes, which are covered in Parts 3 and 4; depending upon the setup in each department, information from the above parts should be included in their regulations. In the case of other construction agencies like public sector projects, the whole Code would be applicable to them and implementation of the complete Code would result in substantial economies along with safety. Similarly the private construction agencies should make full use of the provisions of the Code.

1.8 THE PUBLICATION

The Code has been published in two volumes containing all the Parts and Sections. Besides, five separate groups to cater largely to the interests/agency dealing with different aspects of building activity have also been published as follows:

Complete Code in Volume 1 and 2 (Parts 0 to 12 – all sections included)
Group 1 (Parts 0, 1, 2, 3, 4, 5, Part 10 Sections 1 & 2 and Part 11) – For Planning Building/Development work
Group 2 (Part 0, Part 6 Sections 1 to 8 and Part 11) – For Structural Design
Group 3 (Part 0, 7, 11 and Part 12) – For Aspects relating to Construction and Asset and Facility Management
Group 4 (Part 0, Part 8 Sections 1 to 6 and Part 11) – For Building Services
Group 5 (Part 0, Part 9 Sections 1 to 4 and Part 11) – For Plumbing Services

However, while using a particular group, it may be borne in mind that there are other areas of information available in other groups which would require the attention of the same agency even if not directly connected with that phase of work. For example, while Group 1 would mainly help in planning the building schemes, Group 4 and Group 5 also draw the attention from the point of view of preplanning in respect of building and plumbing services.

1.9 CONCLUSION

Considering the national need for housing and infrastructure development, a large number of Indian Standards have been brought out in the important fields of planning, designing and construction of buildings, as also on the methodologies for enabling speedier construction and requirements for low income housing. Also, number of Indian Standards has been developed for ensuring sound practices and safety during construction and the durability and safety of structures. Considering the erection of modern, tall and mixed occupancy buildings with complex building services, the focus has been, of late, on buildings and their services which are inherently safe in the event of fire.

The unprecedented exercise of revision of the Code through the 22 expert panels and other groups involving 1000 experts who in around 50 meetings spread over two years, worked consistently lead to a landmark third revision of NBC, reflective of the state-of-the-art, applicable international practices and aspirations of the citizens of the country. The revised Code has the necessary ingredients for ensuring safe and orderly development of our villages, towns and cities. With the kind of buildings, malls, multiplexes, commercial eateries, car parking including mechanized and multilevel, metro stations and trainways, assembly buildings, as also integrated townships, coming up throughout the county, Section 8 Glass and Glazing of Part 6 Structural Design of NBC 2016 read along with other Parts/Sections would serve as an effective tool for design and construction engineers, architects, planners, building services engineers, other professionals, government construction departments and other construction agencies, builders and developers and for administrators/local bodies to ensure safe, healthy and sustainable use of glass in buildings.

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2. USE OF GLASS AND GLAZING IN INDIAN BUILDINGS AS PER NBC 2016: DESIGN CONSIDERATIONS, TYPES AND TESTING

By

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2.1 INTRODUCTION

Due to the wide variety of benefits and advantages, Glass has been used largely in buildings in the last three decades in India. From being used as a small window pane to complete envelopes with multiple functional benefits, Glass has become one of the most preferred materials for Architects and Engineers in modern buildings. Various functional aspects including energy efficiency, safety, structural stability, acoustics, aesthetics and comfort has made Glass as an important building material in the construction Industry. Owing to the increasing awareness and huge need for high performance glass and glazing products, the Indian Standards for use of the same has been either revised or formulated to match the international standards. Indian Standards formulating body 'Bureau of Indian Standards (BIS)' has given due importance to Architectural Glass and Glazing Systems in their recent version of National Building Code (NBC) of India 2016.

The following sections of National Building Code (NBC) 2016 provides the complete guidelines for the use of glass and glazing systems in buildings.

- Part 6: Structural design, Section 8- Glass and Glazing
- Part 11: Approach to Sustainability
- Part 4: Fire and Life Safety

This theme paper would provide detailed inputs to Structural Engineers, Architects, Civil engineers and Professionals in the construction value chain to understand the design considerations, types and testing of glass and glazing systems used in Indian buildings as per the National Building Code 2016 and other relevant Indian Codes and Standards. For complete specifications and details, the National Building Code of India, 2016 shall be referred.

2.2 DESIGN CONSIDERATIONS:

There are several design considerations to be followed for the use of glass and glazing systems in buildings. These design considerations are widely applicable on the following types of Indian buildings.

a. Residential	**b.** Commercial (Business, Mercantile)	**c.** Educational	**d.** Institutional
e. Assembly	**f.** Industrial	**g.** Storage	**h.** Hazardous

Glass and Glazing Systems when suitably selected and used effectively, provides huge benefits of comfort, energy efficiency, safety, fire resistance, sound insulation, aesthetics and others in the building.

The following design considerations and methodology based on National Building Code of India 2016 should be followed to ensure the right use of glass and glazing systems in Indian buildings.

- General Considerations
- Considerations on Safety and Structural aspects
- Considerations for Energy Efficiency
- Considerations for Acoustical Comfort.

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2.3 GENERAL CONSIDERATIONS

Following basic considerations must be given appropriate importance at planning stage to achieve apt selection and design of glass in building facades,

a. Location
b. Climatic Zone
c. Orientation
d. Building details.
e. Natural ventilation - Window to Wall Ratio

2.3.1 Location

Location advantage to be leveraged by laying more emphasis on use of safe and passive solar building design techniques to facilitate the occupant comfort and safety.

2.3.2 Climatic Zones

Regions having similar characteristic features of a climate are grouped under one climate zone. Indian subcontinent is divided into five climate zones, viz. Hot and Dry, Warm and Humid, Temperate, Composite, and Cold. For the five climate zones, the parameters required to be considered for planning and design of vertical fenestration are elaborated in NBC 2016: Part 11 Approach to Sustainability

2.3.3 Orientation

A good oriented building helps to save cost on the façade and takes advantage of the natural day lighting, wind movement, micro-climates, natural drainage, and topography. Ideal orientation for any building would depend on the direction in which the maximum glazing area on the elevation is facing.

2.3.4 Building Details

Building form plays an important role in selection of right kind of façade elements. Floor depth and corresponding glazing area surrounding the floor decides on what optical and thermal parameters of glass needs to be used. Detailed analysis is needed to check the energy efficiency considering all building factors.

2.3.5 Natural ventilation (Window to Wall Ratio)

Natural ventilation allows more transparency and daylight through windows and other openings in the building and it is generally calculated in terms of window to wall ratio (WWR). The window-to-wall ratio is the measure of the percentage area determined by dividing the building's total glazed area by its exterior envelope wall area. Window area will have impact on the building's heating, cooling, and lighting as well as relating it to the natural environment in terms of access to daylight, ventilation and views.

$$WWR\ (\%) = \frac{\sum Glazing\ area\ m^2}{\sum Gross\ Exterior\ wall\ area\ m^2} \tag{1}$$

2.4 CONSIDERATIONS ON SAFETY AND STRUCTURAL ASPECTS

Like any other building material, glass used in building facades also must adhere to the considerations of strength and serviceability. In general, glass in building facades will be subjected to both in-plane and out-of-plane loading. But response is usually dominated by the out-of-plane wind loading.

2.4.1 Types of Loads

Following are the types of loads that may act on the glass used in building facades.

- **Dead Load**

Dead weight of the glass and glazing system must be calculated as per IS 875 (part 1) and must be transferred appropriately to the supporting members. Further, in case of inclined sloped glazing the corresponding components of the total glass and glazing system weight shall be used.

- **Wind Load**

The wind load is the effect of wind pressure which is dependent on the location, building height, topography and ground roughness factor. Detailed evaluation of the wind load is to be performed as per IS 875 (part 3).

- **Imposed Load**

Appropriate uniformly distributed load (UDL) and concentrated load are selected in accordance to IS 875 (Part 2) based on nature of the building (for eg, residential, institutional, industrial, etc.,) and nature of activity under each building type. Allowances for BMU access loading should also be superimposed with live load plausibly.

Note: In case of concentrated loads,

a) The point load shall be applied as a uniformly distributed load over a circular area of $0.01m^2$.

b) For a glazed panel supported on all edges, the point loading shall be applied at the centre.

c) For free glazing edges, the point load shall be applied adjacent to the centre of the free edge.

d) The ultimate limit state design wind pressure shall not be greater than 1.2 kPa. For greater design wind pressures, the glass shall be separately designed to withstand wind loading in accordance with Design Wind Pressure as per IS 875 Part 3.

- **Seismic Design**

In Seismic design the building is subjected to random motion of the ground at its base, which induces inertia forces in the building that in turn cause stresses. This is displacement-type loading on the building. Due consideration shall be given for the seismic load as per NBC 2016 and IS 1893 (Part 1)

2.4.2 Methodology and Stepwise Procedure for Determining Glass Thickness

While selecting the glass for application, the thickness and type of glass required shall satisfy the following criteria:

a) Effective wind pressure resistance
b) Safety with respect to human impact

Based on these two primary criteria, following step-wise procedure is prescribed:

- **Step 1**: Selection of Glass type (Annealed / Toughened / Laminated / IGU)
- **Step 2**: Basic Design Considerations
- **Step 3**: Check for maximum aspect ratio
- **Step 4**: Calculation of the Design Wind pressure (P_d) as per IS 875 (Part 3)
- **Step 5**: Determination of Strength Factor and computation of net wind pressure (P_{net})
- **Step 6**: Trial glass thickness assumption with respect to design wind pressure (P_d), glass type and support condition from (table 19 to table 27 (Clause 6.1.9) of Part 6 - Section 8 of NBC 2016)
- **Step 7**: Approximate Deflection Calculation at the Centre of the glass panel
- **Step 8**: Check for maximum allowable deflection
- **Step 9**: Glass thickness calculation using the empirical relationship as per NBC 2016

Note: Scope of the above methodology

The thickness calculation of glass as stated is applicable only when following criteria is observed.

a) Ultimate limit state wind pressure shall not be greater than 10.0 kPa.

b) For laminated glass, the two sheets are of equal thickness and the interlayer material is either polyvinyl butyral or an equivalent type of interlayer with a modulus of elasticity of about 24MPa and a Poisson's ratio of 0.50 at 20 °C.

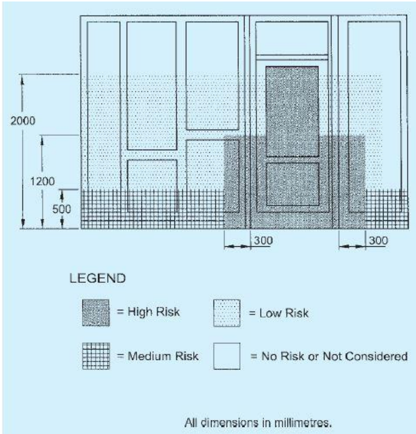
c) Design flexural tensile strength of glass depends upon the design strength obtained after applying a factor of safety of 2.5. The minimum design strength of normal glass for thickness up to 6 mm is 16.7 N/mm^2 and for thickness above 6 mm is 15.2 N/mm^2

- **Step 1:** Selection of Glass type (Annealed / Toughened / Laminated / IGU)

The selection of the type of glass is governed by the critical location criteria and the energy efficiency criteria (which is discussed in detail in section 2.5).

Critical location

Critical locations are parts of a building most likely to be subjected to accidental human impact. Where any glazing is within 1.5 m above the floor level of a building, it is considered likely to be subjected to human impact and hence Safety Glass should be used in such critical locations.



Safety glass should also be used,

a) Where, there is danger of falling infill glass material(s) from overhead glazing.
b) The danger of falling due to a change in floor level.
c) In case of balustrades, stairs and floors.

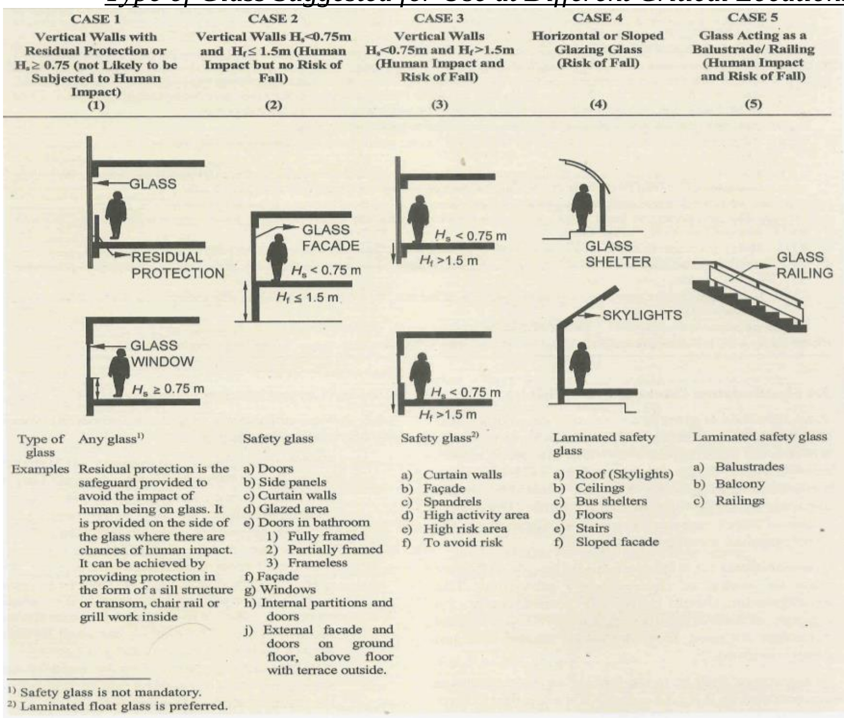
Based on study, some of the locations in buildings that are found to be more vulnerable to human impact than others are shown in the adjacent figure where necessary precaution should be taken.

- In and around doors, low windows
- Door side panels
- Panels mistaken for a doorway or opening
- Panels at low levels in walls and partitions
- Bathrooms
- Building associated with special activities, for example gyms, enclosed swimming pools, etc
- Schools and child care facilities and
- Nursing homes and old age care facilities

Appropriate precautions should be taken to reduce or avoid injuries due to glass breakage by;

✓ Selecting glass of suitable type, thickness, size and quality as per relevant Indian standards
✓ Enhancing a person's awareness of presence of glass by making glass visible (manifestation of glass), and
✓ Minimizing manual handling of large pieces of glass during installation.

Type of Glass Suggested for Use at Different Critical Locations / Cases In Buildings



	CASE 1 Vertical Walls with Residual Protection or $H_s \geq 0.75$ (not Likely to be Subjected to Human Impact) (1)	CASE 2 Vertical Walls $H_s<0.75$m and $H_f \leq 1.5$m (Human Impact but no Risk of Fall) (2)	CASE 3 Vertical Walls $H_s<0.75$m and $H_f>1.5$m (Human Impact and Risk of Fall) (3)	CASE 4 Horizontal or Sloped Glazing Glass (Risk of Fall) (4)	CASE 5 Glass Acting as a Balustrade/ Railing (Human Impact and Risk of Fall) (5)
Type of glass	Any glass[1]	Safety glass	Safety glass[2]	Laminated safety glass	Laminated safety glass
Examples	Residual protection is the safeguard provided to avoid the impact of human being on glass. It is provided on the side of the glass where there are chances of human impact. It can be achieved by providing protection in the form of a sill structure or transom, chair rail or grill work inside	a) Doors b) Side panels c) Curtain walls d) Glazed area e) Doors in bathroom 1) Fully framed 2) Partially framed 3) Frameless f) Façade g) Windows h) Internal partitions and doors j) External facade and doors on ground floor, above floor with terrace outside.	a) Curtain walls b) Façade c) Spandrels d) High activity area e) High risk area f) To avoid risk	a) Roof (Skylights) b) Ceilings c) Bus shelters d) Floors e) Stairs f) Sloped facade	a) Balustrades b) Balcony c) Railings

[1] Safety glass is not mandatory.
[2] Laminated float glass is preferred.

Notes:

1. H_f corresponds to height of fall of human being or glass in case of change in level and H_s corresponds to the sill height with reference to floor height.
2. In case of mirror glazing, it should conform to the requirements of other safety glass unless it is fully backed by a solid material.
3. In Case 2 and Case 3, if the smaller dimension of the pane is 250 mm or less and its area is 0.5 m^2 or less, glass other than safety glass may be used, provided that its nominal thickness is not less than 6mm (applicable to vertical glazing).
4. Toughened or laminated safety glass should meet respective test requirements as given in respective Indian Standard specifications (Refer IS 2553 – Part 1 & IS 17004)

5. The effective toughened glass thickness and / or laminated glass configuration shall be determined case by case with regard to,
   - other solicitations (wind load, snow load, dead load, and human load);
   - the overall dimension (length, width of surface);
   - the aspect ratio of the glass; and
   - the glazing fixing type (framing, bolted system, structural system, etc)
6. Precautions against chances of injuries due to broken glass falling on people include:
   - Broken annealed glass falling on people can cause grievous or even fatal injuries; hence it is recommended to use safety glass in locations other than defined in case 1 where the risk of people getting hurt by falling glass is high.
   - Toughened safety (tempered) glass has a safe breakage pattern, as it breaks and disintegrates into small and relatively harmless particles. However, thick toughened glass particles may stay interlocked, and fall as lumps of these multiple particles and can cause a minor or medium injury mainly due to the weight of the cluster.
   - Laminated safety glass shall generally not fall out of fixing. However, where laminated glass with both glasses toughened, used for horizontal or sloped glazing, in case of failure of both toughened glasses, it may crumble as a blanket and fall out of fixing. This factor needs to be considered while designing horizontal and sloped glazing. Further, when the slope is acute, inner pane facing the floor should be laminated; and when the slope is obtuse, the outer pane facing the ground / floor should be laminated and all obtuse angle sloped glazing shall be continuously capped for safety reasons.
   - Any broken glass in any glazing should be removed immediately on breakage.
   - Strength of the glazing system should be such that it has the ability to hold glass in place and prevent it from falling out as a whole.
   - For over-head applications like skylights, canopies for the safety of maintenance workers and people underneath, the broken laminated glass shall be capable of sustaining a load of 100kg for a minimum duration 30 min.
7. In case of external laminated glass facades, openable portions have to be left at regular distances for fire-fighting and smoke exhaust. This portion should be of toughened (safety tempered) glass and clearly indicated by suitable visible marking.
8. If insulating glass unit (IGU) is used in situations mentioned above, then one of the following shall apply:
   - If IGU is installed in areas subjected to human impact on either side, then both the panes of the unit shall meet the requirements as per IS 2553 (Part) 1
   - In situations where access is restricted to one side of the unit, then only the accessible side should meet the safety requirements of this Section.
9. Enhance person's awareness of presence of glass by making it visible (manifestation).

❖ **Step 2:** Basic Design Considerations

The following factors shall be adhered while determinating the appropriate thickness of glass:

a) The maximum area of the glass panel is restricted to 15 m^2.
b) The maximum span of the glass panel is restricted to 4 m.
c) The aspect ratio of the glass panel should be greater than 1.5. If it is less than 1.5, next higher available thickness should be selected.
d) The shape of the glass panel should be rectangular and must be properly secured.
e) Design minimum thickness of laminated glass will be the maximum value of thickness specified in the table 5 (clause 4.7.1) of Part 6, Section 8 of NBC 2016.

❖ **Step 3:** Check for maximum aspect ratio.

Aspect Ratio is the Ratio of a longer side of glass pane to its shorter side. The design of the thickness using empirical relation shall be valid up to a limiting aspect ratio AR_{max}. The value of AR_{max} for different thickness of glass are given in Table 16 (clause 6.1.5) of Part 6 – Section 8 of NBC 2016.

❖ **Step 4:** Calculation of the Design Wind pressure (P_d) as per IS 875 (Part 3)

The basic wind speed (V_b) for any site shall be obtained from IS 875 (Part 3):2015 and shall be modified to include the following effects to get design wind speed (V_z) at any height z, for the selected structure:

- Risk level (K_1 factor)
- Terrain roughness and height of structure, (K_2 factor)
- Topography, (K_3 factor) and
- Importance factor for the cyclonic region (K_4 factor)

It can be expressed as:

$$\boldsymbol{V_z = V_b * K_1 * K_2 * K_3 * K_4} \tag{2}$$

<u>Determination of design wind pressure at height Z (P_z)</u>

Design wind pressure (P_z) is an important parameter governing the thickness of glass to be used in the window panels

Design wind pressure (P_z), may be defined using the following equation:

$$\boldsymbol{P_z = \left(0.6V_z^2\right) * (K_d * K_a * K_c)} \tag{3}$$

Here, K_d= wind directionality factor, Ka= Area Averaging factor, Kc = Combination factor.

This pressure needs to be combined with appropriate pressure coefficient ($Cp_{external}$ and $Cp_{internal}$) to obtain the design pressure P_d as per IS 875 (Part 3)

<u>Determination of Design wind pressure P_d</u>

The design wind pressure P_d can be obtained as

$$\boldsymbol{P_d = P_z} * (Cp_{external} \pm Cp_{internal})$$

$$\boldsymbol{P_d = \left(0.6V_z^2\right) * (K_d * K_a * K_c)} * (Cp_{external} \pm Cp_{internal}) \tag{4}$$

❖ **Step 5:** Determination of Strength Factor and computation of net wind pressure (P_{net})

<u>Strength Factor (P_f)</u>

To determine the thickness of laminated / tempered / insulating glass, the design wind pressure P_d is modified by dividing it by the strength or pressure factor P_f dependent on the type of glass. The values of the P_f are given in table below. (as per part 6 Section 8 of NBC 2016)

S. No	Glass Type	P_f	S. No	Glass Type	P_f
1	Normal (Annealed)	1.00	4	Insulated	1.50
2	Laminated	0.80	5	Heat Strengthened	1.60
3	Tempered	2.50	6	Wired glass	0.50

$$\boldsymbol{P_{net} = \frac{P_d}{P_f}} \tag{5}$$

This P_{net} is the pressure component that will be used in the empirical equation to ascertain the thickness of the glass in step 9.

❖ **Step 6**: Trial glass thickness assumption with respect to design wind pressure (P_d), glass type and support condition from (table 19 to table 27 (Clause 6.1.9) of Part 6 - Section 8 of NBC 2016)

❖ **Step 7**: Approximate Deflection Calculation at the Centre of the glass panel

Maximum glass deflection (*w*) as a function of plate geometry and load may be calculated using the following equation:

$$\boldsymbol{w = t * e^{r_0 + r_1 X + r_2 X^2}} \tag{6}$$

Here,

$$X = ln\left\{ln\left(\frac{q(a.b)^2}{Et^4}\right)\right\}$$

$$r_0 = 0.553 - 3.83\left(\frac{a}{b}\right) + 1.11\left(\frac{a}{b}\right)^2 - 0.0969\left(\frac{a}{b}\right)^3$$

$$r_1 = -2.29 + 5.83\left(\frac{a}{b}\right) - 2.17\left(\frac{a}{b}\right)^2 + 0.2067\left(\frac{a}{b}\right)^3$$

$$r2 = 1.485 - 1.908\left(\frac{a}{b}\right) + 0.815\left(\frac{a}{b}\right)^2 - 0.0822\left(\frac{a}{b}\right)^3$$

- **Step 8**: Check for maximum allowable deflection: Deflection at the centre of the glass as calculated in the step 7 above should be less than the allowable deflection specified as per NBC 2016:
  - Monolithic glass — shortest span/60 or 19 mm, whichever is the least.
  - Double glazed unit — shortest span/90 or 19 mm, whichever is the least.

- **Step 9**: Glass thickness calculation using the empirical relationship as per NBC 2016: The empirical relation between the wind pressure, area of the glass panel and the required glass thickness depends on the support condition available:

- **Glass Panels Supported on all four sides**

$$P_{net} * A = 200T^k \quad (for\ T \leq 6\ mm) \tag{7}$$

$$P_{net} * A = 200T^k + 1900 \quad (for\ T > 6\ mm) \tag{8}$$

Where, k = Constant for corresponding thickness of float glass (refer table below, obtained as per part 6 Section 8 of NBC 2016)

K value for the corresponding thickness of float glass										
T (mm)	3	4	5	6	8	10	12	15	19	25
K	1.683	1.732	1.753	1.765	1.57	1.578	1.583	1.579	1.569	1.569

This relation is valid for the glass having the minimum design strength of the material as mentioned in the scope and maximum aspect ratio discussed above. However, if the aspect ratio exceeds the prescribed values, the design will be carried out in accordance with the methodology applicable to glass supported on two opposite sides.

- **Glass Supported on Two opposite sides**

Normal and laminated glass panels supported on two opposite sides can be designed using following empirical relations	**Tempered/toughened panels** supported on two opposite sides can be designed using following empirical relations:
1) For $T \leq 6$ mm : $$b = \frac{4.39 * T}{\sqrt{(P_{net}/P_f)}}$$	**For $T \leq 6$ mm :** $$b = \frac{3.2688 * T}{\sqrt{(P_{net}/P_f)}}$$
For $T > 6$ mm : $$b = \frac{4.22 * T}{\sqrt{(P_{net}/P_f)}}$$	**For $T > 6$ mm :** $$b = \frac{2.9069 * T}{\sqrt{(P_{net}/P_f)}}$$
Where, b = span in m; and P_f = Strength factor	

- ✓ For insulated glass, the thickness of only one glass pane shall be considered. If the glass pane are of different thickness, the minimum of the two thickness shall be considered.
- ✓ For laminated glass, the thickness of the PVB has not been considered. The value to be used is, T = standard nominal thickness – thickness of PVB.
- ✓ For non-linear analysis, specialist literature may be consulted.

2.4.3 Example: Model Calculation for Glass Thickness

Problem Statement:
Design a glass panel (thickness) in façade of a commercial tower situated in Mumbai (central locality). Building and façade parameters are as follows,
Building category**:** General building, Height = 100 m, Length = 50 m, Width = 30 m, Panel dimensions: a = 2.25m; b=1.5 m, Support conditions: all four sides linearly supported. Facade provided with a residual protection of height 0.75 m to avoid human impact.

Solution Procedure:
Step 1: Selection of Glass type (Annealed / Toughened / Laminated / IGU)
Let us consider heat strengthened monolithic glass panel is to be used in the façade.

Step 2: Basic Design Considerations

- **Area of Glass**: $2.25\ m\ X\ 1.5\ m = 3.375\ m^2$ is less than 15 m^2(maximum glass panel area allowed.)
- **Maximum span of glass panel =** 2.25 m < 4m (maximum glass panel area allowed.)

Step 3: Check for maximum aspect ratio.
Aspect Ratio= longer side/ shorter side

$$= \frac{2.25}{1.5} \quad 1.5 < AR_{max}$$

Step 4: Calculation of the Design Wind pressure (P_d) as per IS 875 (Part 3)
Wind speed (at height z):

$$\boldsymbol{V_z = V_b * K_1 * K_2 * K_3 * K_4}$$

$\boldsymbol{V_b}$ = 44 m/s (Basic wind speed for Mumbai location)
$\boldsymbol{K_1}$= 1.00 (Since it is a general building with a design life of 50 years)
$\boldsymbol{K_2}$ = 1.15 (Since the height of the building is 75 m and the terrain category falls under category 4, Terrain with numerous large high closely spaced obstruction. This category represents large city centers, generally with obstruction above 25m and well developed industrial complexes).
$\boldsymbol{K_3}$ = 1.00 (clause 6.3.3.1 of IS 875- Part 3)
$\boldsymbol{K_4}$ = 1.00 (clause 6.3.4 of IS 875- Part 3)

$$\boldsymbol{V_z = V_b * K_1 * K_2 * K_3 * K_4}$$

$$\boldsymbol{V_z = 44 * 1 * 1.15 * 1 * 1}$$

$$\boldsymbol{V_z = 50.60\ m/s}$$

Design wind pressure (P_z), may be defined using the following equation:

$$\boldsymbol{P_z = \left(0.6V_z^2\right) * (K_d * K_a * K_c)}$$

$$\boldsymbol{P_z} = (\boldsymbol{0.6}(50.6)^2) * (\boldsymbol{1} * \boldsymbol{1} * \boldsymbol{1})$$

$$\boldsymbol{P_z = 1536.21\ N/m^2}$$

$\boldsymbol{K_d}$ = 1 (Note 2 of Clause: 7.2 of IS 875- Part 3)
$\boldsymbol{K_a}$ = 1.00 (as per 7.2.2.1 and table 4 of IS 875- Part 3)
$\boldsymbol{K_c}$ = 1.00 (Clause: 7.3.3.13 of IS 875- Part 3)
The design wind pressure P_d can be obtained as

$$\boldsymbol{P_d = P_z} * (Cp_{external} \pm Cp_{internal})$$

$$\boldsymbol{P_d = 1536.21} * (-1.20 - 0.5)$$

$$\boldsymbol{P_d = 2611.56\ N/\ m^2}$$

Where, $Cp_{external}$ =-1.20 (for $\frac{h}{w} = 2.5$ & $\frac{l}{w} = 1.33$, from Table 5 and clause 7.3.3.1 of IS 875- Part 3), $Cp_{internal} = -0.5$ (for medium openings about 5 to 20 % of wall area, clause 7.3.2.2 of IS 875- Part 3)

Step 5: Determination of Strength Factor and computation of net wind pressure (P_{net})

Strength Factor (P_f)=1.60 (for, heat strengthened glass, Table 15, Part 6, section 8, NBC 2016)

$$\boldsymbol{P_{net} = \frac{P_d}{P_f} = \frac{2611.56}{1.60} = 1632.225\ N/m^2}$$

Step 6: Trial glass thickness assumption

Selection of trial glass thickness from table 19 to table 27, Part 6, Section 8 of NBC 2016 depends on type of glass, support condition and net design pressure. Therefore, select the trial thickness of glass as 8mm.

Step 7: Approximate Deflection Calculation at the Centre of the glass panel

$$\boldsymbol{w = t * e^{r_0 + r_1 X + r_2 X^2}}$$

Here, $X = ln\left\{ln\left(\frac{q(a.b)^2}{Et^4}\right)\right\}$

$$r_0 = 0.553 - 3.83\left(\frac{a}{b}\right) + 1.11\left(\frac{a}{b}\right)^2 - 0.0969\left(\frac{a}{b}\right)^3$$

$$r_1 = -2.29 + 5.83\left(\frac{a}{b}\right) - 2.17\left(\frac{a}{b}\right)^2 + 0.2067\left(\frac{a}{b}\right)^3$$

$$r_2 = 1.485 - 1.908\left(\frac{a}{b}\right) + 0.815\left(\frac{a}{b}\right)^2 - 0.0822\left(\frac{a}{b}\right)^3$$

$$X = ln\left\{ln\left(\frac{1632.225 * 10^{-6}(2250 * 1500)^2}{71.7 * 10^3 * 8^4}\right)\right\} = 1.4226,$$

$$r_0 = 0.553 - 3.83\left(\frac{2250}{1500}\right) + 1.11\left(\frac{2250}{1500}\right)^2 - 0.0969\left(\frac{2250}{1500}\right)^3 = -3.02$$

$$r_1 = -2.29 + 5.83\left(\frac{2250}{1500}\right) - 2.17\left(\frac{2250}{1500}\right)^2 + 0.2067\left(\frac{2250}{1500}\right)^3 = 2.270$$

$$r_2 = 1.485 - 1.908\left(\frac{2250}{1500}\right) + 0.815\left(\frac{2250}{1500}\right)^2 - 0.0822\left(\frac{2250}{1500}\right)^3 = 0.179$$

$$w = 8 * e^{-3.021 + (2.270)*(1.4226) + 0.179*(1.4226)^2}$$

$$\boldsymbol{w = 14.16\ mm}$$

Step 8: Check for maximum allowable deflection

Deflection at the centre of the glass as calculated in the step 7 above should be less than the allowable deflection specified as per NBC 2016:

Monolithic glass — shortest span/60 or 19 mm.

Therefore,

allowable deflection $= \frac{shorter\ span}{60}\ or\ 19mm$

$= \frac{1500}{60}\ or\ 19mm$ (whichever is least)

$= 19mm$

Hence, the glass thickness selected is safe under deflection check.

Step 9: Glass thickness calculation using the empirical relationship as per NBC 2016

$$P_{net} * A = 200T^k + 1900\ \ (for\ T > 6\ mm)$$

$$1632.225 * 3.375 = 200T^{1.57} + 1900 \;\; (for\; T > \; 6\, mm)$$

$$T = 6.312\; mm$$

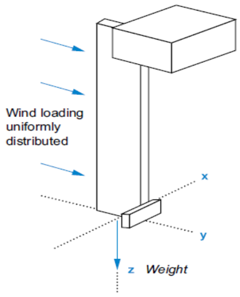
Required thickness is 6.312 mm and our selected thickness is 8 mm. Hence the selected thickness is safe.

2.4.4 Glazing System

It includes all the components of façade which are responsible to fix the glass panel to the primary supporting structure. It comprises of aluminium frame (combination of mullion and transoms), sealants, gaskets, hardware and other associated accessories.

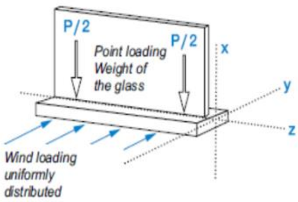
2.4.4.1 Mullion

Vertical framing member in facades is known as mullion. The mullions go from floor to floor and are fixed by the anchoring points. In general, the anchoring should be left longitudinally free in the lower profile (to accommodate the expansion of the metal), thus ensuring that the vertical forces always produce stretching (tensile stresses) in the profiles, and never compression. The mullion is mainly subjected to the horizontal pressure of the wind, uniformly distributed along its length and to the vertical forces of its own weight and the load of the glass and panels as shown in the adjacent figure.



2.4.4.2 Transoms:

The horizontal framing member in the façade is known as transom. It is present between two mullions and acts similar to the secondary beams in a building frame. The transom is subjected to bi-axial bending; first by the forces acting in the vertical plane produced by its own weight and the weight of the panes or panels it must support and second, by the forces acting in the horizontal plane produced by the pressure of the wind.

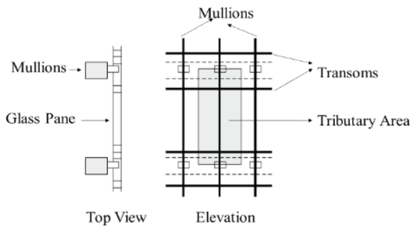


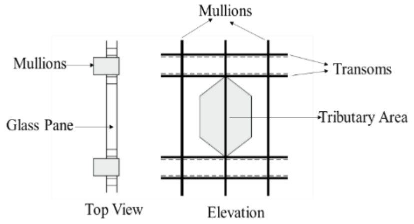
For the sake of simplicity in design it can be assumed (in consultation with the structural engineer) that the mullions of lightweight façades alone withstand the wind loading and that the transoms alone must support the weight of the components that rest upon them.

With respect to load, the following hypotheses apply:

- **Mullions**

In the case of curtain wall façades, where the components pass in front of the floors, the mullions must withstand a wind loading onto a rectangular surface similar to that shown in the adjacent figure





In the case of infill grid façades, i.e. inserted between the floors, the mullions must withstand the wind loading acting on a trapezoidal surface as shown in the adjacent figure

Further to transfer the load on to the primary structure, the glazing system must be supported at its extremities such that its deflection is limited and compatible with the structure of the façade or alternatively there must be sufficient degree of freedom between them so that while remaining secure, the façade is not subjected to any stress arising from distortion of the primary structure. In terms of static calculations, the mullions can be compared to a profile that has its extremities simply supported or that has one extremity embedded and the other supported and is subjected to a distributed load.

The distribution of load will be rectangular in the case of a curtain wall and trapezoidal in the case of a panel façade, as in the latter case the transoms do indeed contribute to the distribution of the load, being fixed to the floors of the building. It is always assumed that the free expansion of the mullions is permitted.

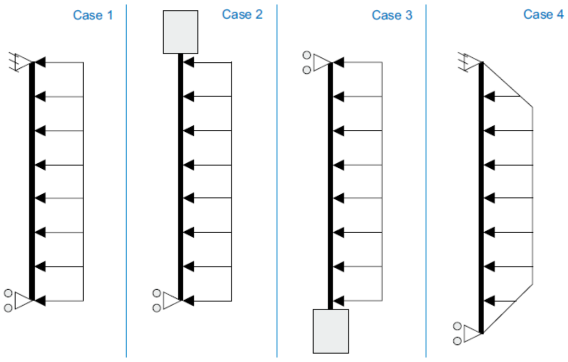
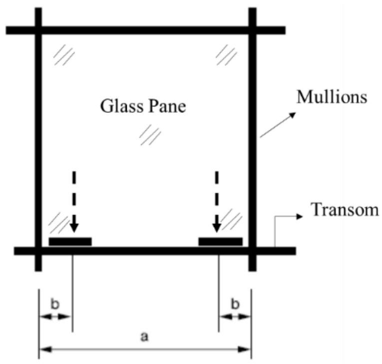


Fig: Loading criteria

In view of the constructional difficulty of producing real embedding (Cases 2 and 3) that approaches the "theoretical embedding" condition (this should be verified in a test laboratory), the calculation is always carried out with the mullion assumed to be supported at both extremes (Cases 1 and 4).

- **Transoms**

The transoms can be assumed only to bear the vertical load of the components of the weight of the glass panel upon them. Consequently, the transom can be considered as a profile that is simply supported at its extremities. The weight of the glass panel can be considered to act as point loads as shown in the adjacent figure. Here, a is the span of the transom, b is the distance between support and point of application of dead weight of the glass pane.



From the design perspective, mullions will be considered similar to the beam element, subjected to distributed loading (uniform/ varying). Similarly, transoms will also be designed as a beam element, subjected to two-point loads, acting in vertical plane (in the plane of glass panel) and the distributed loading due to wind, in the plane perpendicular to glass panel. To design both members, it must be compliant to

a) Strength criteria: stress induced in the member (mullion/transom) due to above discussed loading should not exceed the maximum permissible stress in the material as per IS 8147: 1976.
b) Serviceability criteria: Deflection induced due to loads should not exceed allowable deflection as specified in NBC 2016 and IS 8147: 1976.

Criteria	Check to be performed.	Reference Standard
Compliance of strength criteria	• Check for bending stress • Check for shear stress • Check for combined bending and axial tension • Check for combined bending and shear • Check for Bending about both the axis (Transoms Sections) • Check for lateral torsional buckling	Clauses 7 and 8 section 3 of IS 8147:1976
Compliance of Serviceability Criteria	Check for maximum allowable deflection	NBC 2016–Part 6–Section 8

According to NBC 2016, the maximum allowable deflection for mullions / transoms when exposed to the force of the wind.

Mullions:

1. Single height glazing — Span/ 175 or 19 mm, whichever is less.
2. Double height glazing — For spans up to 4110 mm, same as single height glazing; and for spans above 4110 mm the same shall be (Span/240) + 6.35 mm.

Note:

Verify compliance of mullion with respect to the deflection at edge of the glass which is limited to 15mm for DGU as per NBC 2016 Part 6 Section 8 Clause 6.3.6.2-d

Transoms:

The maximum frontal deflection of the transoms under wind loading, should not exceed

- Span / 175 or 19 mm, ***whichever is the least for wind load***

The maximum vertical deflection permitted, under its own weight load, should not exceed

- Span / 500 or 3 mm, ***whichever is the least for dead load***.

2.4.5 Sealant, Gaskets and Hardware

1. Silicone Sealant

a. **Acetoxy Sealant**: Acetoxy silicone sealants release acetic acid (which smells a little like vinegar) as they cure, this is the most commonly used - it is more rigid and the full cure is quick. On the downside it not suitable for concrete, bricks and other porous subtracts.

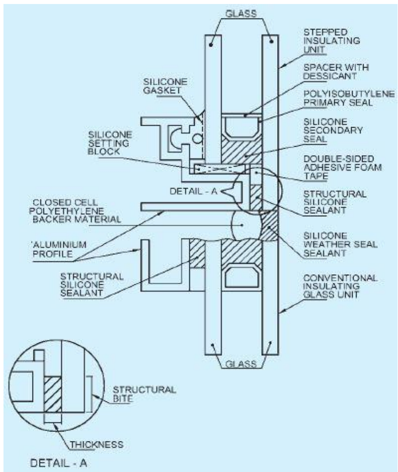
b. **Neutral Sealant:** Neutral silicone sealants release alcohol as they cure, and has almost no smell, they have better adhesive properties for a greater number of materials including uPVC, most other plastics, glass, aluminium, lead, stone and masonry.

Structural silicone

Structural Silicone is a polymerized adhesive which is used to attach glass, metal or other materials to the structure of a building through which wind load and other impact loads on the façade are transferred from the glass or panel to the structure of the building. The structural silicone sealant must maintain adhesive and cohesive integrity as the façade is subjected to the various loads, thermal stresses and movements. The following are the common types of Sealants

Determination of structural bite of Structural Silicone

The structural bite requirement is directly proportional to the wind load and the dimension of glass. Higher the wind load and larger the dimensions of the glass are, the greater the amount of structural bite required. The controlling variables which affect the structural bite requirement are the maximum short span dimension of glass and the design wind load that the structural glazing system should be designed to accommodate.



With a sealed IGU, there may be load sharing between the two panes of glass. If so and both panes are of the same thickness, the lateral load (P) is shared almost equally; thus, the secondary seal bite is calculated as one half that of the structural requirement. If of unequal thickness, the load shared by each pane will vary depending on the difference in thickness. Further details are to be obtained from the manufacturer.

(A) Structural bite calculation for wind load and glass dimension

$$\text{Minimum structural bite} = \frac{\begin{array}{c}\text{Glass short span dimension} * \\ \text{Wind load} * \ 0.5\end{array}}{\begin{array}{c}\text{Maximum allowable} \\ \text{design stress}\end{array}} \qquad (9)$$

Notes:

1. Glass Short Span Dimension (SSD) is the shorter of the two dimensions (in meter) of the rectangular glass panel.

2. Wind load is the maximum wind pressure in Pascal for a return period of 10 years based on local regulations.
3. The maximum allowable design stress for the type of the structural sealant is selected.

(B) **Structural bite calculation for dead load (clause 6.3.8.1 of NBC 2016)**

$$\text{Minimum structural bite (m)} = \frac{\text{weight of glass (Kg)}}{\text{(Perimeter of the glass (m)} * \text{sealant dead load design strength (Kg/m}^2\text{))}} = \frac{\rho gTA}{Ps} \tag{10}$$

Where: P = perimeter (if the horizontal frame members will not be supporting the glass or will deflect under the dead load of the glass, consider 2 x Height only)

For structural bonding applications the adhesion of sealant to the coated profile is critical. Requirement of primer is to be ascertained prior to commencement of any application. Similarly, all prescribed quality tests to be performed on the two-part sealant during preparation of DGU

2. Acrylic Sealant

Acrylic sealant is a synthetic, water-based ingredient made from acrylic resins, used for caulking, jointing and filling cracks and gaps. Acrylic sealants are paintable. The proper application of a sealant involves not only choosing a material with appropriate physical and chemical properties, but also having a good understanding of joint design, substrates to be sealed, performance needed, and the economic costs involved in the installation and maintenance of a joint sealant.

Typical considerations for selecting a sealant type for use in the construction industry are:

- ***Joint Design:*** The specifics of a joint design must match up with a sealant's movement capabilities for the installed conditions. The practicality of installation of the sealant and other joint elements and the desired aesthetic appearance also need to be considered.
- ***Physical and Chemical Properties:*** Properties of the sealant such as, modulus of elasticity, its stress/strain recovery characteristics, tear strength, and fatigue resistance are all factors that influence sealant performance in a joint. The sealant polymeric type along with additives such as fillers and plasticizers will affect the performance of the product.
- ***Durability Properties:*** The adhesion of a sealant to a specific substrate(s) and its aging characteristics as they relate to resistance to among others ultra-violet radiation, moisture, temperature, cyclic joint movement, movement during curing, and bio-degradation can profoundly influence the service life of the installed sealant.
- ***Application/Installation Properties****:* Important considerations include the consistency of the sealant (pourable or gunnable), pot life and tooling time, tack free time, application temperature range, and low temperature "gunnability" (i.e. ability to be dispensed easily by sealant gun). Sealants used for interior applications, even in high-rise or light commercial structures, will have properties and needs different from those used in other applications, such as structural sealant glazing or exterior building facade seals.

❖ **Gaskets**

A gasket is a material which is available in various profiles, generally incorporated in the glazing systems for preventing leakage and for other important performance factors. Most gaskets form a seal as a result of compression of the bulk material, but some gaskets form a seal by deflection, either of a cantilevered arm or a hollow tube and others work by wiping contact with minimal deflection. To seal effectively a gasket must remain in compression. However, the force exerted by a gasket in compression will gradually decrease over a period due to the effects of creep and stress relaxation. There will also be a reduction in recovery of compression when the load is removed. The selection of the required type of gasket shall be based on their ability to limit air leakage and water penetration, allow relative movement between components, distribute and absorb loads and accommodate tolerances. The selection and installation of the gasket should also ensure that no contraction occurs post installation / handover as this would result in leakages.

Based on the method of fixing, the types of gaskets are as follows:

- Push-in gaskets are designed to be fitted into a groove in the mounting surface, prior to the formation of the joint.
- Drive-in or wedge gaskets are designed to be forced into the gap between the mounting surface and contact surface, usually as the last stage in sealing the joint. A drive-in gasket can usually be removed by pulling it from the joint, although it may be manufactured with a rigid strip that makes this difficult.
- Slide-in gaskets are designed to slide into a groove on the mounting surface but must be installed from the end of the groove. A slide-in gasket can usually only be removed by sliding it out from the end of the groove.

The most commonly used gasket materials are,

- EPDM
- Butyl
- Neoprene
- Thermos-plastic rubbers
- Silicone
- Hypalon

❖ Preformed tapes

Preformed tapes come in rolls. The tape consists of pigments, resins, and reflective materials and comes ready to use with or without adhesives. Additional adhesive (primer) can be applied to enhance the bond. Typical requirements of preformed butyl and foam tapes can be found in the below Table.

Typical Properties of Preformed Tapes		
SI No	**Properties**	**Requirement**
1	Low temperature flex	No Cracks at -23°C
2	Weight Loss	2 percent, *Max*
3	Vehicle migration	1 paper stained maximum and this stain shall be no more than 3.2mm from edge of sample maximum
4	Backing removal	No transfer of tape compound to the paper
5	Yield strength	41.4 kPa, *Min*
6	Compression Recovery	Compression index, 1.22 N/mm^2 *Max*
7	Water absorption	Weight gain, Max after boiling, 40 Kg/m^3, *Max*
8	Flow test	Loss of height, 60 percent, *Max*

❖ Hardware

The following factors shall be considered during selection of anchors to ensure proper performance during its service life.

1. Diameter and Length
2. Material and Coating
3. Load direction
4. Base material
5. Anchor spacing and edge distance
6. Embedment depth
7. Environmental condition

Diameter

The following parameters shall be calculated for the selection of the anchor diameter

- Dead load acting on the anchor
- Live load incident to the anchor (wind load- tensile or shear)
- Weight of bracket, aluminum channels and other associated components

The following parameters shall be considered to ensure proper performance of the anchor during its service life

Length: The length of the anchor is primarily based on the thickness of the glazing components which must be fastened to the base material. Insufficient length shall lead to pull out failure.

Material: The two types of materials which are used in the manufacturing of anchors are Stainless Steel and Galvanized Iron. Stainless steel is most widely used since it offers higher resistance to corrosion when used in locations subjected to high humidity and in coastal region.

Coating: The following table shall be used as a guide for selecting the type of coating to be used in an anchor for corresponding environmental condition.

Environmental Condition	Coating to be used
Particular influence of moisture	Zinc plated
Occasional exposure to condensation and in coastal areas/slightly corrosive	Hot-dip galvanised
Heavy condensation/ corrosion	Stainless Steel

Load Direction: Based on the orientation of the anchor, they are incident to shear loading, tensile loading and combined loading of force and hence the proper diameter and depth of anchorage must be selected.

Base Material: The material characteristic of the base material plays a major role in avoiding failure in the anchorage. The material shall be of suitable grade, have minimum thickness shall be properly cured and have the necessary compressive stress.

Anchor Spacing & Edge Distance: Anchor spacing is the minimum distance between two anchor centre lines without an influence on the tensile or shear failure load of either anchor. The load bearing capacity of an anchor is influenced by an adjacent anchor and thus the minimum anchor spacing specified by the manufacturer shall be adhered. Due to reduced material volume, a minimum edge distance must be maintained to prevent the edge from breaking away prematurely when the anchor is installed, and to achieve the full load bearing capacity of the anchor.

Embedment Depth: Embedment depth is a critical factor in determining load capacity of an anchor. Anchors installed less than minimum depth will stress the base material above its limits and may cause failure during installation or expansion of the anchor.

Environmental Condition: Environmental conditions like temperature, humidity, salinity etc will affect the performance of the anchors and may lead to pre-mature failure. Hence careful selection of the material and coating should be done when selecting anchors which are to be installed in location subjected to adverse environmental impact such as coastal region.

❖ **Pressure plate**

A pressure plate is an extruded aluminium profile used to fix the glass panel to the main mullion by means of mechanical screws. This is used instead of a sealant in certain cases.

❖ **Brackets**

Brackets are used in the main structural part that transfers the frame load to the slabs. They are used for connection and are either welded or bolted. There are different types of brackets which are selected based on the site condition. Brackets are never standardized on a building they are customised depending on load, building, weather, etc.,

Brackets are generally made of mild steel or aluminium and are used for connecting frames to slabs or other building elements. Brackets are used to attach curtain walling to the supporting structure. Curtain walling is normally positioned in front of the supporting structure and brackets are required to connect the curtain wall to the structure. Fixings are then required to attach the brackets to the structure.
The bracket used has the following functions:

- acts as a fix point for screwing the profiles into position in the round hole - in this case, the profile is fixed, transmission of own weight and wind loads
- acts as a sliding point for screwing the profiles into position in the slot hole - in this case the profile slides in the slot holes, transmission of wind loads only.

❖ **Backer rods**

A backer rod is the typical backer material for most weather seal joints. The role of a backer rod is to allow a sealant to be installed and tooled to a proper joint profile. Once the sealant cures, the backer material must not restrict the movement of the sealant or cause 3-sided adhesion. To provide sufficient backpressure during sealant installation, the backer rod should be sized ~25% larger than the joint opening.

When selecting a backer rod, consider the following:

- Open-cell polyurethane backer rod allows the sealant to cure through the backer rod, which is beneficial when fast sealant cure is desired. Open-cell polyurethane backer rod can absorb water, which may have a detrimental effect in certain joint types.
- Closed-cell polyethylene backer rod may outgas if punctured during installation, requiring it to be left for 20 minutes before application of the sealant.
- Other back-up materials such as expanding foam tapes or glazing gaskets should be reviewed or tested for compatibility prior to use.
- When a backer rod cannot be positioned in a joint opening, a Teflon or polyethylene tape should be used to prevent three-sided adhesion.

❖ **Glazing block**

Glazing blocks have the role of fixing the location of the glass unit in the frame so that load transfer occurs over the anchor points or junctions of the fixed frame or over the suspension points of an opening vent.

Glazing blocks differentiate themselves depending on their role as

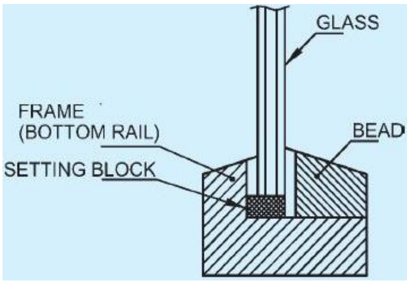
A. Setting block B. Location block C. Distance piece

(A) Setting blocks:

Setting blocks are used between the bottom edge of the unit and the frame to centralize and equally support both panes of glass. The number and location of setting blocks is shown in below figure. Generally, setting blocks shall be:

a) positioned at quarter points or not less than 30 mm from the corner, whichever is lesser
b) the minimum width of each setting block shall be not less than the glass thickness; and
c) if a glazing bridge is used then the thickness of the glazing bridge can be added to the thickness of the setting block to achieve the minimum gap of 6mm between the edges of glass and the framing member.

Setting blocks shall be located to equally support all panes of glass and shall be fixed to prevent displacement during installation and service. The minimum length of each setting block (or two blocks side by side) shall be 25 mm in length for every square meter of glass area, with a minimum length of 50 mm. When wood is used as the material for setting blocks, only the seasoned ones should be used as green wood may shrink laterally (in the process of attaining equilibrium moisture content over a period of time) and result in loosened installations.



For example, a 3.0 m^2 glass area, 3.0 x 25 mm = 75 mm long, that is, 75 mm is the length of each setting block. Setting blocks shall be of resilient, load-bearing, non- absorbent, rot-proof, and material that is compatible with all other glazing materials conforming to available Indian standards that may come into contact with the blocks. The width and location of the setting block should not restrict water drainage. Extruded rubber material with 80-90 shore A hardness is recommended. Shaped Setting blocks will be required for a glazing platform.

(B) Location blocks:

Location blocks are used between the edges of the glass and the frame to prevent movement of the glass within the frame by thermal expansion or when the window or door is opened or closed. They are required to prevent the weight of the glass from causing the frame to become out of square. Location blocks shall be,

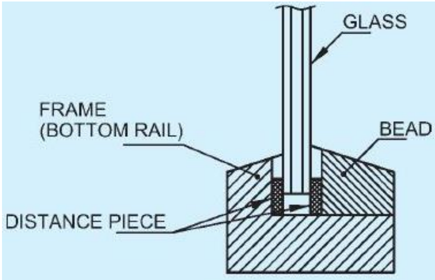
a) of a minimum of 25 mm in length;

b) at least as wide as the glass thickness; positively located to prevent displacement in service
c) sufficiently resilient to accommodate movement within the frame, without imposing stress on the glass, and of resilient, non- absorbent material

Extruded rubber material with 55 - 65 shore A hardness is recommended.

(C) Distance Pieces

Distance pieces are the components which are required to prevent displacement of glazing compounds or sealant by external loadings such as wind pressure. Distance pieces, as shown in the adjacent figure, used where required, shall be,



a) of resilient, non-absorbent material;
b) 25 mm long and of a height to suit the depth of the rebate and the method of glazing; and
c) spaced opposite each other, approximately 50mm from each corner at intervals of not more than 300mm.

The thickness shall be equal to the front and back clearance, to retain the glass firmly in the frame. Extruded rubber material with 55 - 65 shore A hardness is required.

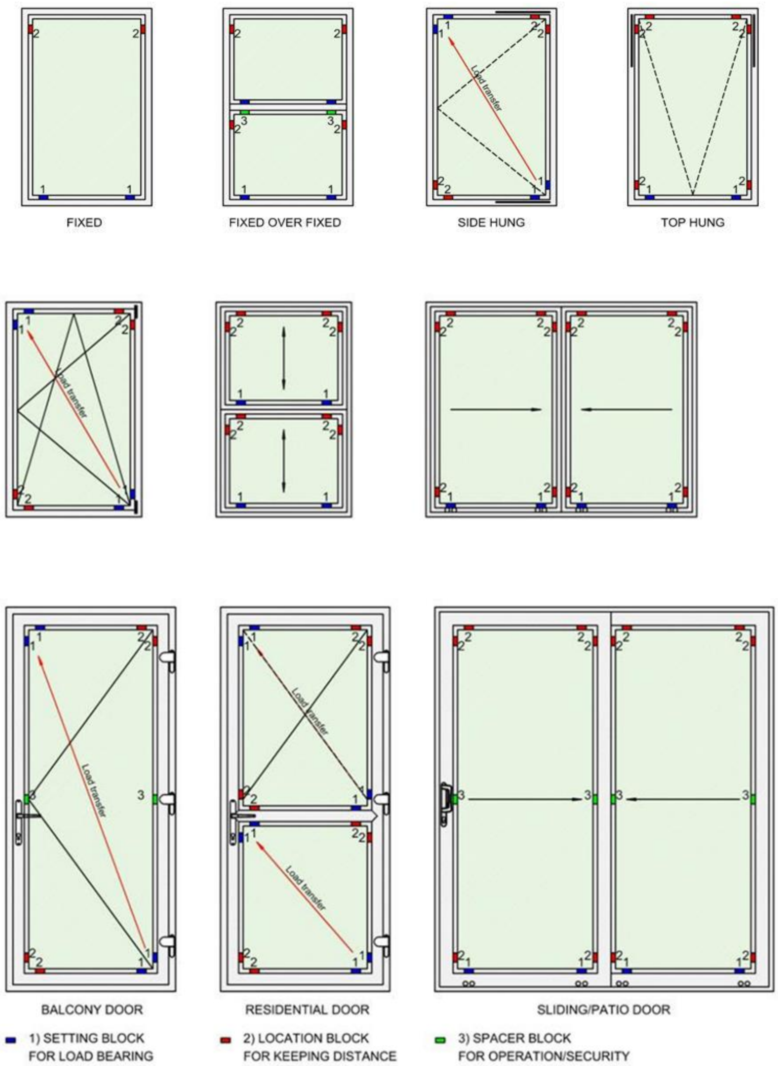


Fig: Suggested placements of the Glazing Blocks

2.5 CONSIDERATIONS FOR ENERGY EFFICIENCY

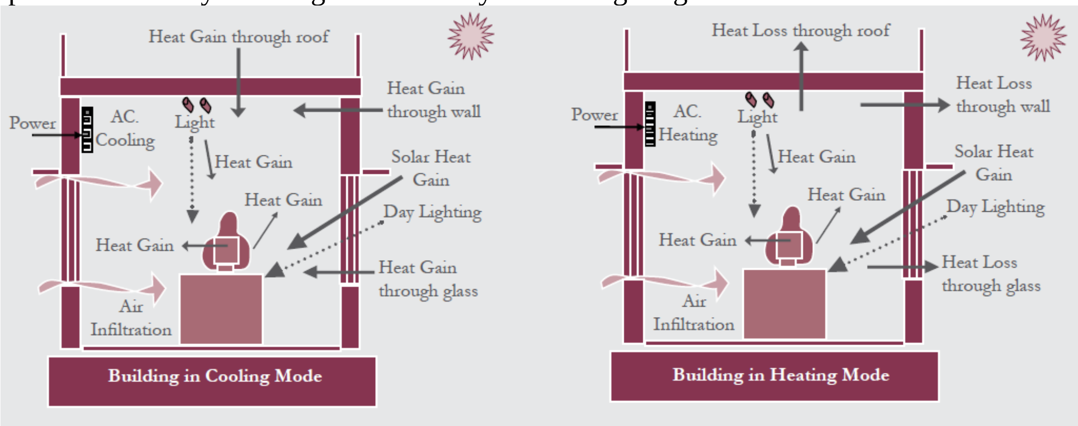
Glass and glazing design must take into consideration introduction of daylighting into the interior space of the building and to manage the external and internal heat loads. External loads include solar heat gains through fenestration, heat losses across the glass surfaces and unwanted air infiltration in the building whereas internal loads include heat released by the electric lighting systems, equipment and people working in the building space.

Proper orientation of a building and due consideration to the size and placement of windows at the design stage can provide the advantage of daylighting. To maintain thermal comfort and minimize internal cooling / heating loads, the envelope needs to regulate and optimize heat transfer through roof, walls, windows, doors and other opening.

An integrated building design considers the Envelope, the Heating Ventilation and Cooling (HVAC) system and the Lighting system as a whole rather than dealing with these independently. Changing the specifications of one system can affect the performance of the other two significantly. For instance, investments in energy-efficient windows or increased envelope airtightness can result in a smaller HVAC system, thereby reducing its first cost as well as recurring energy cost. Similarly, an inefficient lighting system not only increases lighting energy consumption but could also increases the cooling load on HVAC system thereby increasing the energy consumption further.

When a building is in cooling mode, solar heat gains need to be minimized within the building space while optimizing daylight and intake of outside air. Outside air could be introduced particularly during evening/night hours when the ambient temperature drops. This strategy cools the thermal mass in the building during night hours and reduces overall cooling load during the next day. On the other hand, if the building is in a heating mode, the envelope needs to be designed with appropriate glazing selection coupled with shading strategy, to enhance solar heat gains during the daytime. Therefore, in practice, the architects and building designers need to integrate and balance these varying requirement considerations while designing an energy-efficient building.

Thus, the main goal of glass and glazing design should be to provide visual and thermal comfort to the occupants and thereby reducing the electricity cost for lighting and HVAC



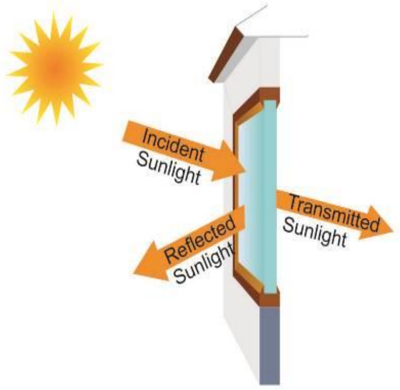
2.5.1 Design Factors

The following factors / components of a glazing system shall be considered during design for achieving energy efficiency.

- Light transmittance and glare
- Thermal Transmittance (Solar Heat Gain co-efficient and U value)
- Window size and placement
- Frames
- Shading devices
- Air infiltration

2.5.1.1 Light transmittance and glare

Light transmission is defined as the fraction of visible light at normal incidence transmitted through the glazing. Dirt on glazing reduces the light transmission, often to an appreciable extent before becoming noticeable. To ensure daylighting levels are adequate, an allowance for the reduced light transmission should be made in daylighting calculation by introducing a 'dirt factor' between 0.7 and 1.0. Therefore regular cleaning of the glass becomes important.



Glare results from the excessive contrast of illumination or from an excess of illumination in the field of view. When correctly designed, natural lighting should not give a glaring problem. Even when the light transmission of the glazing is as low as 10 percent some 10,000 lux can still be experienced and glare shall almost certainly occur.

Glare can be reduced by some form of mechanical shading, for example, a canopy, an overhanging floor, a balcony or a louvre system. Alternatively, internal screening can be provided by louvres or blinds. It may also be possible to re-orientate the glazing in order to avoid entry of direct solar radiation. Alternatively, the interior layout can be suitably designed to eliminate glare. Glazing products with light transmission lower than 50 percent can reduce discomfort glare. These products decrease the sky luminance component, but permanently reducing the admission of daylight. Alternatively, shading devices, movable or fixed, may be used.

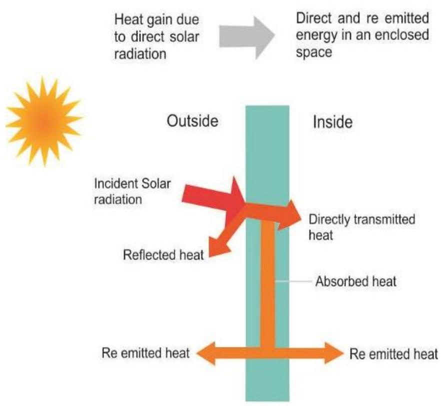
External shading devices have a great advantage as they address the solar energy transmission before entering into the building to keep the heat out. The internal shading devices will reduce glare but will not be able to prevent the solar energy from coming in the building and then this energy has to be mitigated by air-conditioning or ventilation.

Other methods of reducing the problems of glare should be considered including,

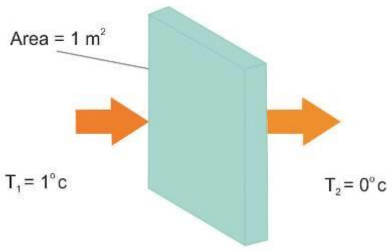
a) installation of windows in more than one wall to raise the general background illumination and in so doing, to reduce the contrast between a window and its surrounding surfaces
b) use of light-colored matt finishes for the window frames and the surrounding surfaces
c) splayed reveals, to assist in reducing the contrast between the window and its surroundings
d) use of slender glazing bars and transoms of high reflectance and
e) lowering window sills to allow increased illumination to enter, which increases the adaptation level and reduces the likelihood of discomfort glare

2.5.1.2 Thermal Transmittance

The total solar energy transmitted through the glass from the outside environment is the part of solar radiation which is transmitted directly through the glass and the part which is re-emitted from the glass after being absorbed. This heat energy which is transmitted through the glass has to be limited in-order to achieve thermal comfort for the occupants and also to reduce the energy demands of the building. This is governed by the Solar Factor or Solar Heat Gain Coefficient (SHGC) of the glass.



SHGC is the ratio of solar heat gain that passes through the fenestration to the total incident solar radiation that falls on it. SHGC is expressed as a number between 0 and 1. The lower the SHGC, the more a product is blocking solar heat gain.



The other part to be looked at is the transfer of heat from outside to inside environment through the glass, due to the temperature difference. This is known as U value which is the rate of heat flow through one square metre of glazing when there is a temperature difference of 1°C. The lower the 'U' value, the better it is. Coated glasses can be used as an option for cutting down the heat transmission through the glass since they offer better thermal performance. Solar control glasses have special coatings on them which reduce the amount of solar radiation passing through the glass thereby reducing the amount of heat gain through the glass. Due to these coatings, the amount of light passing through the glass would also be reduced. Care has to be taken while selecting these glasses so that an optimum balance between the light and heat transmittance is achieved.

Low emissivity (low-E) coatings have a surface emissivity of less than 0.2. The use of such a coating on glass improves the thermal insulation. They are more efficient when used on the cavity surfaces of IGUs. Certain types of low-E glasses such as silver-based are used in double glazed units only, as the silver oxide coating will get oxidized if used in single glazed.

Insulating Glass Units (IGU) is a very effective way to reduce transfer through the glazing when used in conjunction with solar control or low-E or reflective coated glass. These units combine the performance parameters of the individual coated glasses along with the air gap inside the hermetically sealed unit to provide an overall increased reduction of heat transfer. Increasing the width of the air gap would further improve the thermal insulation of the IGUs. Use of inert gasses like argon and krypton in the air gap would also further improve the level of thermal insulation provided by the IGU.

2.5.1.3 Window Size and Placement

a) Height of Window Head

The higher the window head, the deeper will be the penetration of daylight

b) Sill height (height from floor to the bottom of the window)

The optimum sill for good illumination as well for good ventilation should be between the workspace and head level of a person. Windows close to task areas should be with an optimum visual transmission with good insulation performance as they may be source of thermal discomfort.

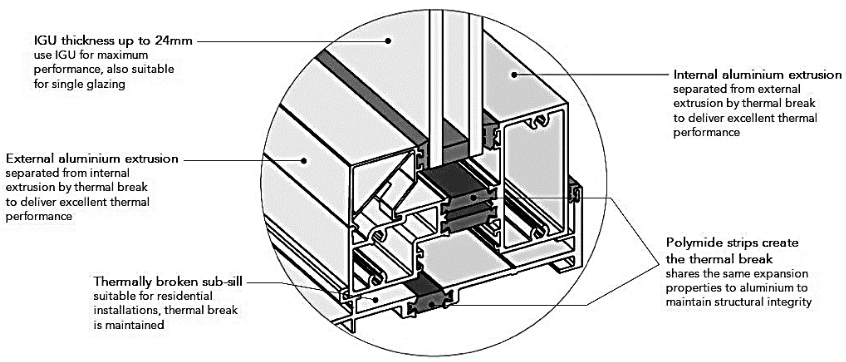
c) Use of separate apertures for view and daylight

For good lighting and glare control, the window should have clear glass with maximum daylight penetration and tinted glass below the clear glass for glare control.

d) Window Wall Ratio (WWR)

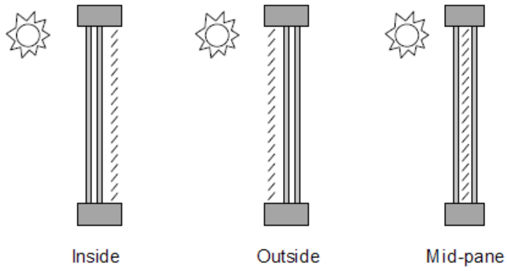
2.5.1.4 Frames

For energy efficiency, some frames are designed with internal thermal breaks that reduce heat flow through the frame. These thermally broken frames can resist heat flow considerably better as compared to those without thermal breaks. The sealing between the openings and the window frames and between the opening sashes of windows and fixed portions are important areas to be addressed as major heat loss happens from this area due to poor design of sealant material. Adequate provision shall also be made to ensure that the frames are not susceptible to water ingress in case of driving rain.

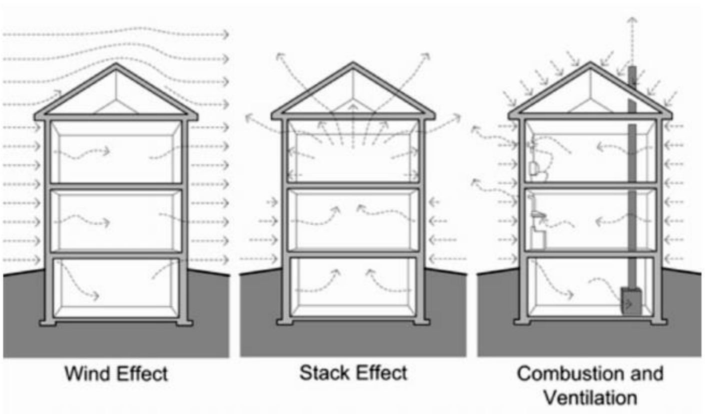


2.5.1.5 Shading devices

Shading devices can be employed which help in keeping out the heat, block uncomfortable direct sun and soften harsh daylight contrasts. Shading devices are also critical for visual and thermal comfort and for minimizing mechanical cooling loads. Shading devices can be combined with the use of energy efficient glass to further reduce the solar heat entering through the glazing system. Exterior or interior shading devices such as awnings, louvered screens, sunscreens, venetian blinds, roller shades and drapes can complement and enhance the performance of windows with low SHGC. Manual shading devices have an advantage that they can be adjusted to vary heat transmission with the time of day and season. It is desirable to break a single overhang with larger depth into multiple overhangs of smaller length. It enhances the amount of (diffused) daylight penetration in the space. Another alternative is to use screens which are effective in cutting down the heat transfer and at the same time allowing air movement.



2.5.1.6 Air infiltration



Inadequate control of airflow through the building envelope is often a primary factor contributing to premature building envelope failures. If moisture-laden air is permitted to travel through the building envelope, the moisture may, under certain environmental conditions condense within the walls of the structure and may even cause corrosion or rotting of the structural components and also staining of the interior and / or exterior façade. Air infiltration may be caused by wind pressure, stack pressure or fan pressure. Wind creates a positive pressure on the windward face and negative pressure on the non-windward (leeward) facing walls, which pulls the air out of the building. Wind causes infiltration on one side of a building and exfiltration on the other. The stack effect is when warm air moves upward in a building because it’s lighter than cold air and escapes out of the upper levels of the building, through penetrations and cracks in the building envelope or other openings. The rising warm air reduces the pressure in the base of the building, forcing cold air to infiltrate through open doors, windows, or other openings. The stack effect basically causes air infiltration on the lower portion of a building and exfiltration on the upper part. Mechanical equipment such as fans and blowers causes the movement of air within buildings and through enclosures, which can generate pressure differences. If more air is exhausted from a building than is supplied, a net negative pressure is generated, which can induce unwanted airflow through the building envelope.

Considerations for controlling air infiltration

- Ensuring continuity of each component serving its role in resisting infiltration such as a window assembly or a curtain and they must be interconnected to prevent air leakage at the joints between materials, components, assemblies, and systems.
- Effective structural support shall be ensured such that all components must resist the positive or negative structural loads that are imposed on them by wind, stack effect, and HVAC fan pressures without rupture, displacement or undue deflection and thereby resist air infiltration through them. Design considerations must be made such that this load shall be safely transferred to the structure and provision of adequate resistance to these pressures by fasteners, tapes, adhesives, etc.

2.5.2 Compliance Methods for Daylighting and Thermal Properties of Glass and Glazing System

After establishment of the climatic zone where the building would be located, the best method for compliance shall be selected.

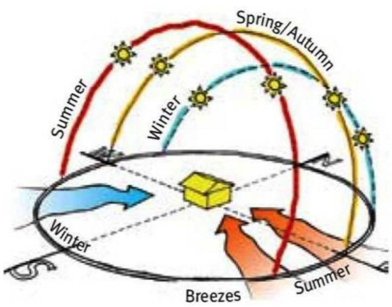
a) **Prescriptive method:** This method specified a set of prescriptive requirements for building systems and components. Compliance with these requirements can be achieved by meeting or exceeding the specific levels described for each individual element of the building systems. Envelope optimization using this method shall be carried out in accordance with NBC 2016 - Part 11 Approach to sustainability – Annex B.

b) **Envelope trade-off method:** This is a systems-based approach, where the thermal performance of individual envelope components can be reduced, if compensated by higher efficiency in other building components. This method offers more creativity and flexibility to the designer rather than sticking on to the prescriptive values. Thus, even if one component of the envelope has a lower performance value, it can be compensated by another component of the building envelope having a higher thermal performance. Reference to the same shall be made to NBC 2016 - Part 11 Approach to sustainability – Annex C

c) **Whole building performance method:** In this method analysis in made on the various components of the whole building including thermal, lighting, ventilation occupancy and other energy consuming processed taking place within the building to simulate and predict its energy performance. During this simulation various parameters such as building geometry, orientation, building materials, building façade design and characteristics, climate, indoor environmental conditions, occupant activities and schedules, HVAC and lighting system and other parameters are considered for analysis. Further details on whole building performance method can be referred from NBC 2016 - Part 11 Approach to sustainability - Annex D

2.5.3 ANALYSIS FOR CHOOSING THE RIGHT GLASS

a) Building Orientation Analysis

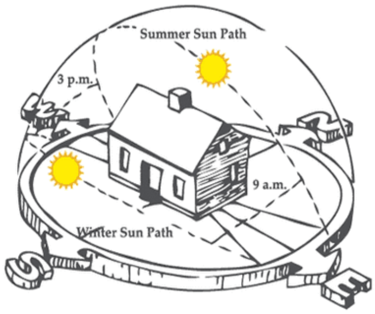


Design for orientation is a fundamental step to ensure that buildings work with the passage of the sun across the sky. Knowledge of sun paths for any site is fundamental in design building facades to let in light and passive solar gain, as well as reducing glare and overheating to the building interior. It also gives us an understanding of how the sun interacts with your building in high summer and the depths of winter.

Well-oriented buildings maximise daylighting through building facades thereby reducing the need for artificial lighting. Zoning can be done to ensure different functional uses receive sunlight at different times of the day. The building that maximises sunlight is ideal for the incorporation of passive solar collection techniques that can reduce carbon use and enhance user comfort. Housing in temperate regions can benefit from admitting the sun into the building interior.

Office buildings typically consider the reduction of excessive solar gain and glare. This is because of a greater preponderance of glazed facades and also higher internal heat gains from people, computers,etc.

b) Sun Path Analysis

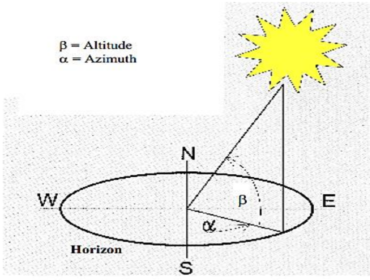


Sun path analysis helps us in understanding the impact of the orientation of buildings and determining the best orientation to understand the impact of seasonal changes in the building and its surroundings. It helps in designing appropriate artificial shading devices and selecting glass and other building materials for passive design strategy.

The Earth is made of two hemispheres - the southern hemisphere and the northern hemisphere. If the building is located near the equator, the position of the sun is right overhead. Based on the location of the building (northern or southern hemisphere) the motion and position of solar incidence changes. This directly influences the inclination of solar incidence. In the southern hemisphere, the movement of the sun is from east to west through north. While in the northern hemisphere, the movement of the sun is from east to west through south.

The sun chart can be used to locate the position of the sun at any time of day, during any month, and for any location. The sun chart helps determine the impact of the sun and shading devices, i.e., shade by surrounding elements such as trees and existing buildings.

The sun chart is also used to select glazing, shading and reflector design, exclusion of direct sunlight and knowing when the sun will be directly incident on your building. To visualize a sun chart, imagine looking up at the sky and seeing the sun's paths throughout the year. Using an imaginary dome over a building site, you can mark points where the sun's rays penetrate the dome at every hour of a day.

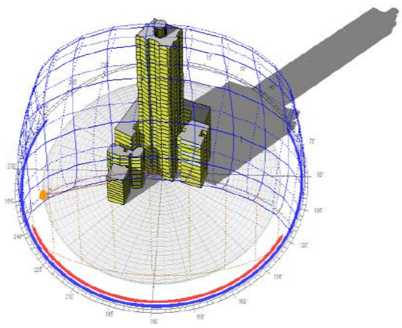


The Azimuth and Altitude can be derived for a location and time, using a sun path diagram

- Solar azimuth (α) is angle along the horizon of position of the sun, measured to the east or west of true south.
- Solar altitude (β) is the angle measured between the horizon & the position of the sun above the horizon.

Analysis helps to understand the various positioning of the sun over the building & its impact on the building, based on this the glass can be suggested for elevation specific.

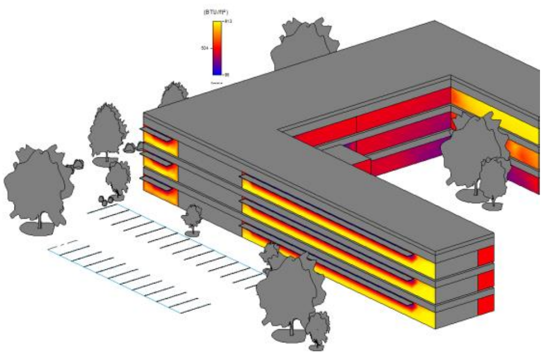
c) Site Shadow Analysis



Shading is one of the key strategies to achieve thermal comfort, as it may also affect daylight penetration. For this, daylight and thermal comfort must be considered in combination. An ideal shading strategy or device will block maximum solar radiation while still permitting daylight, views, and prevailing winds.

Shading also depends on climatic conditions and the nature of the building. Shading analysis takes into account different strategies. Horizontal strategies are best for the south, where the solar altitude is high whereas vertical strategies are best for east and west, where it is low. The shading on north can reduce effective daylight. The impact of the adjacent tower over the building and impact of shading devices inbuilt with the structure can be studied, which helps us to design the type, length, shape etc of the shading devices required.

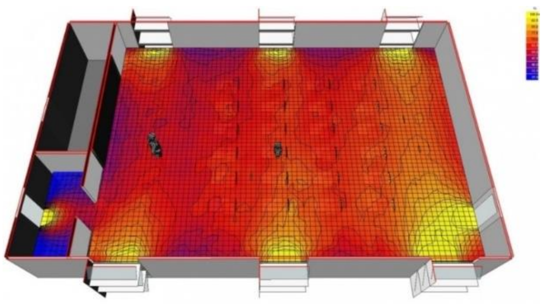
d) Solar exposure analysis



To do a detailed design for glazing and facades, it is important to understand the patterns of solar radiation that affect the building. Direct solar incident radiation is the energy transmitted from the sun which lies between the wavelength range of 250 and 2500 nm. Solar radiation is typically made up of 3% ultraviolet light, 42% visible light and 55% infrared light. Infrared radiation is the major heat carrying radiation followed by the visible and ultraviolet rays.

Analysis helps to understand the Sun impact over the elevation and from this the impact of the building can be understood. This helps to understand the peak load values and design can be done considering this.

e) Daylight Analysis



Daylight Analysis is used to find the penetration of natural light on the building floor plan or at working plane level. A good lighting strategy involves optimizing the glazed area, number of Windows, and visual light transmission of glazing. This reduces the dependency on artificial lighting. Using a glass with optimum light transmission can go a long way in curtailing the dependence on artificial lighting. The presence of natural light also rids the inmate from the claustrophobic feeling typical in many buildings with limited glazing and outdoor views. Daylighting is calculated for the overcast condition, so as to represent the worst-case condition of outdoor lux levels.

The daylighting available may be calculated in terms of 'lux levels' or 'daylight factor'. Daylight factor is the percentage of outdoor lux level reaching at a particular point on the analysis plane. If the light transmission of glass is high, it may also result in 'glare' due to exposure to direct sun, or sun rays being reflected from highly reflective surfaces. Analysis helps to understand the ideal VLT requirement for the building. A floor plan is considered and the lux levels are calculated for the planned floor for different Visible Light Transmittance percentage of glass. The glass which allows an optimum Lux level distribution with a Visual Light transmittance is chosen.

Any glass with energy performance will sacrifice certain amount of daylight although it will be transparent for vision through it to the outside. Higher the demand for energy performance, higher will be the compromise on daylight. The selection of glass should therefore start from evaluating the daylight needs and deciding the optimum VLT. This can narrow down the options of selecting the glass which shall give the good performance for the given VLT and considering the cost and aesthetics.

Floor plate geometry plays an important role as the daylight distribution will depend on the depth of the plate from the glazed area. The farthest area from glazing will be the dimmest and the nearest area will be the brightest. Courtyard plan and atrium plan have a great advantage of harnessing maximum daylight from glazed area not subjected to direct solar radiation by using glass of higher VLT.

Windows in Air-Conditioned Spaces

Windows (including both glazing and frame) affects the energy performance of a conditioned space by impacting the HVAC energy consumption and the lighting energy consumption of the building.

The types of energy flow which occur through a window impacting the HVAC energy consumption and the parameters to be considered to energy efficient windows in air-conditioned spaces can be referred from clause 8.1.3.2 of NBC 2016.

Window for Non-Conditioned / Mixed Mode Buildings

The glazing system for windows in non-conditioned spaces is usually single glazed units as the windows will be opened to allow ventilation. In non-conditioned buildings, the shading device plays a crucial role in the thermal performance of a window. Windows on facades, facing different cardinal directions should be provided by the shading devices which can cut the direct incident solar radiation for the critical solar angles. The critical Horizontal Solar Angle (HSA) and the Vertical Solar Angle (VSA) for fenestrations located on the cardinal directions should be cut down by designing appropriate shading devices. The horizontal solar angle at critical hours can be cut by the vertical fins provided as an external shading device. The vertical solar angle at critical hours can be cut by the horizontal fins provided as an external shading device. Considerations for selecting type of window and the necessary design considerations for energy efficiency and natural ventilation can be referred from clause 8.1.3.2.2 of NBC 2016.

2.6 DESIGN CONSIDERATIONS FOR ACOUSTIC PERFORMANCE

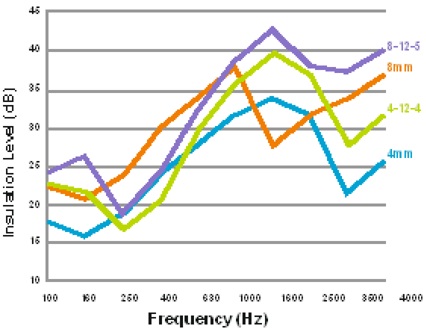
Unwanted sound is considered as noise when it intrudes in our daily lives. To minimize this intrusion all aspects of the building construction need to be evaluated. However, in this section we will only analyse the acoustic qualities of glass. The first step in this analysis is to determine the source of the unwanted noise. This is a critical step, as the noise source can vary from low frequency traffic noise to high frequency aircraft noise. Starting from a single 6mm glass lite with an STC of 31, we can achieve STC ratings of as high as 50 with different combinations of laminated and insulated glasses. Although the increase in absolute numbers seems small, it results in a big difference in performance. An increase from 28 to 38 means 90% of the noise is reduced. A change from 28 to 43 represents a noise reduction of over 95%.

2.6.1 Use Thicker Glasses

Monolithic glass has specific critical or coincident frequency at which the speed of incident sound in air matches that of bending wave of glass. At this critical frequency glass will vibrate allowing sound waves to penetrate without significant attenuation, the thickness of a single-pane glass enhances the glazing's sound insulation, for e.g., a 4mm thick glass provides an R_w of 29 dB, which can increase to 35 dB for a thickness of 12mm. However, increasing glass thickness is generally a poor choice for applications such as city structures which are primarily subjected to lower pitched sounds. This is because increasing glass thickness shifts the critical frequency trough towards lower frequencies which results in weakened protection against low pitched sound.

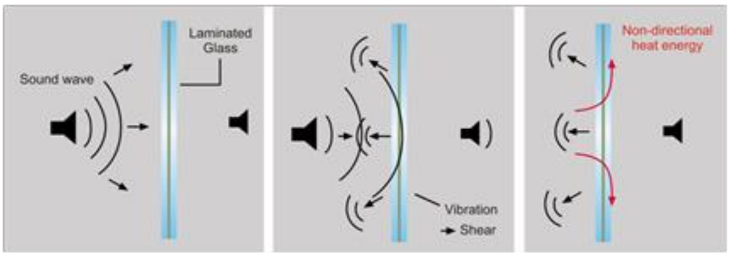
2.6.2 Use Glass configurations with different Thickness

To enhance the level of sound insulation provided by double-glazing, glasses with sufficiently different thickness should be used so that they can minimise its weakness when the overall unit reaches its critical frequency. This therefore produces a coincidence in a broader frequency zone but compared to symmetrical glazing the trough is less intense (as seen around 3,200 Hz). In this case, the increase in mass in relation to 4-12-4 glazing also helps to reduce the trough at low frequencies.

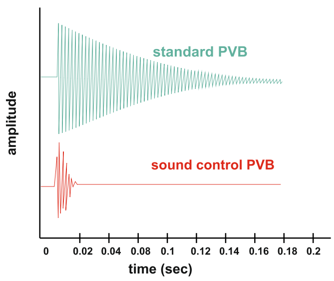


2.6.3 Use Laminated Glass

The poly vinyl butyral inter-layer (0.38m m to 1.52mm) used in laminated glass provides a dampening effect that reduces vibration by absorbing the sound waves hence reducing sound transmission. Laminated glass has superior sound insulation qualities in the higher frequency range where the noise from sources such as aircraft is a problem.



The PVB film used in laminated glasses have a shear damping effect that has substantial sound attenuation characteristics. When the outer glass layer is exposed to bending waves, the PVB layer creates a shear strain within itself and the bending of wave energy of glass is transformed to non-directional heat energy which is barely noticeable. During this phenomenon the sound waves are absorbed by the PVB layer and not transmitted to the second glass layer. This results in reduction of the amplitude of vibration and sound transmission. Increasing the inter-layer thickness has marginal effect on the performance of laminated glass. Acoustically enhanced PVB's are designed to have higher damping characteristics that further reduce the amplitude of the sound waves. The graph adjacent shows comparative decay in vibration observed

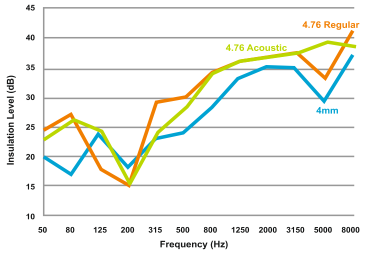


Decay of free vibration observed on laminated glass in laminated glass with Standard PVB and Acoustic PVB. The sound attenuation characteristics of PVB and acoustical PVB films can be understood by the above comparative graph. Considered here is the performance of a monolithic 4mm glass with a 4.76mm (2-0.76-2) regular PVB and 4.76mm (2-0.76-2) acoustic PVB.

Although the transmission curve for 4mm monolithic glass is shifted to lower values owing to its slightly smaller mass if compared to the laminated glasses, the superior performance of the PVB glass (and more so in the acoustic PVB laminate) is clearly evident in the coincidence region. The reduced plate vibrations below 800 Hz also help enhance the sound reduction properties of the laminated glass assembly

2.6.4 Use Combination of Insulated and Laminated Glass:

Further increases in sound-reduction performance can be achieved by using combinations of insulated and laminated glass. These units offer the dual benefit of greater mass and different frequency resonance of insulated glasses coupled with the damping effects of PVB laminated glasses. The adjacent chart demonstrates the STC and Rw performance of some common glass types. Double glazed unit with certain gases also provide sound insulation characteristics.



2.6.5 Areas around Windows:

It is important to note that no matter how good the noise insulation qualities of the windows are, there should be no gaps or cracks around the window frame. As long as the $R_w$of a window remains under 35 dB and the frame area doesn't exceed 30% of the window area, the influence of the frame on the total acoustic performance can be neglected. However as soon as R_w, lies between 35 and 40 dB, it is advised to reinforce each frame element. Windows with R_w larger than 40 dB are specific for the window concept itself which makes special advice necessary.

2.6.6 Acoustic Analysis

The choice of glass plays an important role in determining whether glass chosen for sound insulation purposes actually brings about noise reduction. Based on the location, type of building & noise level we need to understand and design the glass combination to suit the requirement.

National Building code of India 2016 – Part 8 – Section 4 covers the requirements and guidelines regarding planning against noise, acceptable noise levels and the requirements for sound insulation in buildings with different occupancies

2.7 TYPES OF GLASS AND GLAZING MATERIALS

2.7.1 Basic types of architectural glass

- ★ Base Glass
- ★ Processed Glass
- ★ Fire resistance glass

★ Base glass

A. *__Float Glass:__* Float glass (also termed as soda-lime silicate glass) is a term for flat transparent, clear or tinted glass having parallel and polished surfaces obtained by continuous casting and floatation on a metal bath.
B. *__Clear Float Glass: A__* transparent glass with neutral or near colourless appearance.
C. *__Tinted Float Glass:__* Tinted glass are manufactured by adding colourants to normal clear float glass during the manufacturing process to achieve tinting and solar-radiation absorption properties. Tinted glass when used in windows reduces heat and light penetration in buildings as compared with clear glass.

D. *Extra Clear Glass:* Greenish appearance in clear float glass is due to the presence of iron content in silica sand. This greenish appearance in float glass is significantly reduced by reducing the iron content thereby making it very clear in vision with high color rendering index.

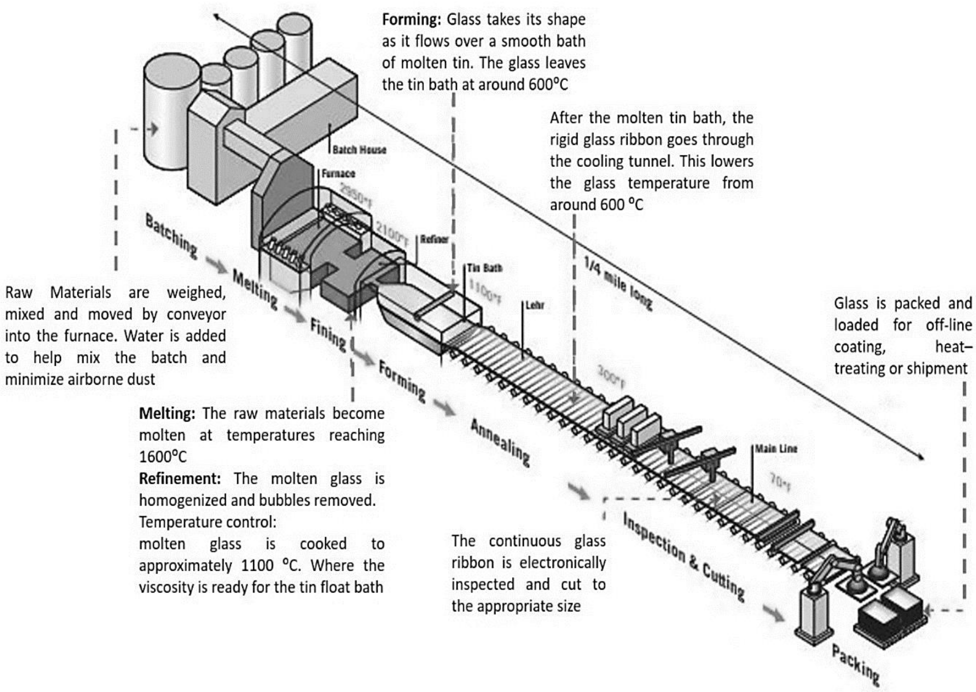


Fig: various stages in manufacturing float glass

E. Coated glass

Clear or tinted float glass can be coated to alter the spectrophotometric properties of the glass. Coatings can be solar-control or low-emissivity in nature and affect both the visual and the functional performance of the base glass.

a) Online / Pyrolytic / Hard coating

A pyrolytic coating (known as CVD (Chemical Vapour Deposition)) is metal oxide coating applied online during the float glass manufacturing process. The coating is applied by vaporizing a chemical compound over the semi-molten glass surface at high temperature of 650 to 700°C through pyrolysis (i.e. thermochemical decomposition of organic material at elevated temperature in the absence of oxygen)

Advantages	Disadvantages
Can withstand any kind of processing requirement.	Limited performance on energy parameters
Economical product	Limited range on aesthetics
Can be bent or toughened.	

b) Offline / Sputtered / Soft coating

An advanced metallic coating is applied to a glass “off-line” or after the float glass manufacturing process by a technique called magnetically enhanced cathodic sputtering under vacuum conditions. In magnetron sputtering, the material to be sputtered is made as the cathode of an electrical circuit at 500 volts. Argon gas is introduced into a vacuum chamber and glow discharge plasma occurs. Electrons are removed from the argon and leave positively charged ions which impact with target cathode. They have very high momentum and eject atoms of the cathodic material which re-condense on the glass below. Multiple coatings can be applied, and range of energy performances of glass is enhanced.

Advantages
- Superior Energy performance
- Selective coatings
- Wider range of products

F. Ceramic printed glass

Ceramic printing on glass is done with special enamels which are applied to glass before tempering process. During the heating process in tempering or bending, this enamel fuses into the glass and becomes a monolithic construction. It is thus a permanent printing. Ceramic printing is commonly done by roller coating or screen printing with ceramic frit or ceramic digital printing.

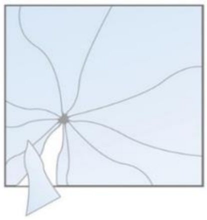
★ **Processed glass**

(A) Insulating Glass Unit:

Insulating glass unit is an assembly consisting of at least two panes of glass, separated by a spacer, hermetically sealed along the periphery, mechanically stable and durable. The moisture in the cavity between the two glasses is controlled by desiccants filled in the perforated spacer. The spacer may be aluminium, composites, plastics, etc. The spacer ensures the precise distance between the glass panes. The cavity is normally filled with dry air but can be also filled with gases such as argon or krypton for better thermal performance. The low heat conductivity of the enclosed dry gas between the glass panes drastically reduces the thermal heat transmission through the glass.

(B) Heat Strengthened Glass:

Heat Strengthened glass has a significantly increased mechanical strength, but it is not considered a safety product as when it breaks, the resultant shards are larger in size and may cause injury to persons close by. It has less mechanical resistance than toughened glass. Refer IS 16982 for the Heat strengthened glass specification

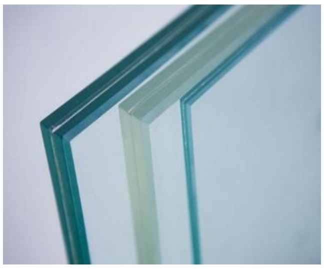


(C) Toughened Glass:

Toughened glass has high mechanical strength when compared with Heat Strengthened glass and has greater resistance to thermal shock. Toughened Glass breaks in smaller particles or fragments and hence when broken doesnot injure humans. Toughend Glass is considered as Safety glass when it complies with IS 2553 – part 1.

(D) Laminated Glass:

Laminated glass is a glass configuration made of two or more pieces of glass bonded together by Interlayer / interlayers. It is commonly used as a form of safety glass which cracks and breaks under sufficient impact, the broken glass fragments being still held together. When laminated glass is broken fragments tend to adhere to the interlayer. Laminated glass does not shatter like a single glass pane. It absorbs impact, resists penetration and remains intact even if broken, holding glass fragments in place and lowering the risk of injury. Laminated glass is capable to stop flying debris and limits or avoid splintering on opposite side of the impact. *Laminated Glass is considered as safety Glass provided it meets the requirements of IS 2553 (Part 1) for safety requirements.*



Note: Annealed, Tinted, Coated and Heat-strengthened glass are not classified as safety glasses unless laminated / toughened to meet the requirement of tests specified in IS 2553 (Part 1) for safety glass

★ **Types of fire resistance glass**

a) Wired glass,
b) Annealed fire resistant glass (AFG),
c) Tempered fire resistant glass (TFG),

d) Intumescent laminated fire resistant glass (LFG),
e) Double glazed fire resistant glass (DFG).

a) **Wired Glass**
It is a type of glass into which a wire mesh is embedded during production. Wired glass has an impact resistance similar to that of annealed glass, but in case of breakage, the mesh retains the pieces of glass. Value addition such as tempering and lamination is not possible using wired glass. (Not recommended indoors except as vision panel and for window sizes not greater than in Table below)

SI. No	**Opening Fire protection rating** (min)	**Maximum area** (m^2)	**Maximum Height** (m)	**Maximum width** (m)
1	60 to 90	0.0645	0.838	0.254
2	45	0.836	1.372	1.372
3	20	Not limited	Not limited	Not limited

b) **Annealed fire-resistant glass**
A single piece of fire-resistant glass that is tested for fire resistance for the required duration. These types of glasses can be used only in areas where human impact safety is not an issue, typically in areas like vision panels of doors.

c) **Tempered fire-resistant glass**
A single piece of specially heat-treated or chemically treated glass that is tested for fire resistance for the required duration and which has a stress pattern such that the piece when fractured reduces to numerous granular fragments, with no large jagged edges. Additionally, these glasses should have an impact resistance of highest classification.

d) **Intumescent laminated fire resistant glass**
Two or more pieces of glass held together by an interleaving layer or layers of material that as a complete system is tested for fire resistant. Fireside of the glass shall crack and break during the fire or under sufficient impact but the pieces of glass tend to adhere to the inter-layered material and do not allow the fire to penetrate the last layer of glass.

e) **Double glazed fire resistant glass**
Fire resistant glass that is used as a double glazed unit has to be tested as a complete Double Glazed Unit (DGU) or other multiple glazed units as the case may be. Double glazed fire resistant glass can be a combination of intumescent laminated fire rated or tempered fire resistant glass. Fire resistant glass cannot be combined with another glass and used as a DGU unless the combined double glazed or multiple glazed units is also tested. Both the panes of the double-glazed unit will need to satisfy the required human impact safety as mentioned above.

NOTE — *It may be noted that use of any fire rated glass has to be used in conjunction with a tested system. Fire rated glass alone cannot provide the desired fire resistance since the fire resistance of a partition or a door assembly or any glazed building element is a function of the glass, frames, hardware, gaskets and fixings which forms the glazed system.*

2.7.2 Profiles
For the framed / semi-framed systems, materials such as aluminium, stainless steel, uPVC and timber are commonly used.

a. Aluminium Alloy
Extruded aluminium alloy used for structural framing members shall be fabricated from the most appropriate grade of alloy complying with the relevant standards. The thickness of the aluminium sections should be in accordance with structural and hardware fastening requirements and shall be capable enough to meet the design requirements and satisfy the performance requirements.

Such extrusions in framing members and trims shall preferably be extruded aluminium grade 6063-T5, 6063-T6, 6060-T66, similar or stronger. 6063-T5 is to be used in shaped structures and the supporting structural calculations particularly should ensure the stress criteria. Extrusion alloy 6061 or 6105 are commonly used for higher strength. All aluminium alloys used as extruded rods / bars, tubes and profiles shall be compliant with accepted standards. Other alloys can be used provided that they meet the required physical properties and the specified performance requirements.

b. Stainless Steel
Mullions, panels, fascia, column covers, windows, doors, trim, roofing, gutters, flashing, hardware and other items where minimum maintenance is anticipated shall be of austenitic stainless steels of type 301, 302 and 304 complying with accepted standards and employed for their mechanical properties as they are highly corrosion resistant for all normal exposures.

For interior decorative applications, where regular maintenance will be provided, type 430 may be used as it has lesser corrosion resistance properties. For external applications like in coastal regions where maximum resistance to corrosion is required, stainless steel shall be of type 316. Particular attention shall be paid to the direction of the rolling grain on self-finished stainless steel components where the finish is aesthetically important.

c. uPVC
uPVC is a flexible material that is normally internally reinforced with steel or aluminium to give it the required strength and stiffness. It is easily formed to produce a wide variety of profiles. The inherent ability to make a variety of profiles, easier maintenance, corrosion resistance ability and heat resistance when used may be considered when choosing uPVC sections.

d. Timber
Timber frames are relatively stiff and particularly treated timber combined with good design and workmanship give an acceptable life. They are adopted for their inherent thermal insulation property, light weight and improved sound insulation. Tenderness to absorb moisture, if not carefully treated prior to use can lead to possible rotting or even warping resulting in air and water infiltration and regular painting and maintenance are the factors to be considered while choosing timber as the framing material.

2.7.2.1 Types of Surface Finish for Frames

a. Aluminium Frame
The main types of aluminium frame coatings are as follows

- PVDF coating
- Anodized finish
- Powder paint finish

b. Steel Frames
Surface finish on stainless steel frames plays a major role in it's resistance to corrosion and hence it is an important design aspect which must be clearly specified.
The main types of surface finishes are listed below

- Mill
- Ground
- Brushed
- Polished
- Bead blasted
- Electroplated
- Coloured
- Patterned

2.8 TESTING: SAFETY AND STRUCTURAL TESTING

2.8.1 Resistance to Human impact

Toughened Glass samples of size 1936mm x 876mm, held vertically by a wooden frame, are subjected to an impact from an impactor of mass 45kg, from a distance of 1232mm for Class A or 470mm for class B, to check whether the glass can withstand the impact without broken into fragments. Resistance to human impact/Shot bag test shall be as per IS 2553 Part 1

2.8.2 MECHANICAL STRENGTH

Glass samples of 360mm*1100mm shall be subjected to Mechanical strength testing (Four point bend test) to assess the physical/actual strength of the glass. Mechanical strength of the glass is directly related to surface compression of the glass, the higher the surface compressive value the higher the mechanical strength of the glass. The mechanical strength of the glass shall be as per IS 2553 Part 1. Toughened Glass shall have a minimum mechanical strength of 120 MPa.

2.8.3 FAÇADE TESTING

Annex F of NBC 2016 provides details of Facade testing parameters.

A pre-construction mock-up of a full-size representation of the proposed exterior glazing system is made and tested for performance parameters like air infiltration, water penetration, wind load, seismic load and deflection. It is important to utilize the same construction personnel to build the mock-up that will be at the project site.

Generally, the specimen width shall be minimum of two typical units. The height shall be not less than the full building story height or the height of the unit, whichever is greater, and shall include at least one full horizontal joint, accommodating vertical expansion, such joint being at or near the bottom of the specimen, as well as all connections at top and bottom of the units. All parts of the systems, a method of construction, the material used, anchorages, details, support systems and conditions shall be the same as that of the actual system.

Generally, the following are the minimum tests that are required to be carried out when tested in the lab.

1. **Air Infiltration Test:** Typically, a pressure differential is created across the test specimen in order to simulate wind pressure and the air leakage rate through the system is determined. The test pressures are typically specified by the project architect or consultant or the end user and are different for the air infiltration/exfiltration test.
2. **Water Penetration test:** The required pressure difference is maintained across the test specimen. Simultaneous to the application of air pressure difference, water is applied to the exterior face at the required rate while observing for any water penetration at the interior.
3. **Test for Structural Performance:** The deflection of the framing members and the behaviour of the system is determined under the influence of a specified air pressure.
4. Repeat **Air Infiltration Test** and Repeat **Water penetration**
5. **Determination of seismic performance:** This test is conducted to understand and evaluate the performance of glazing system when subjected to horizontal displacements intended to represent the effects of an earthquake or a significant wind event.

2.8.3.1 Air Infiltration / Exfiltration Test

Permissible air leakages shall be $1.5m^3/h/m^2$ for pane area and $2m^3/h/m$ for the crack length of the operable panel. The crack length is the maximum height of the shutter per interlock or per meeting stile in a slider or per overlap joint in a double leaf door or vent, in addition to the jambs. Along the width, crack length is the maximum width of the shutter at top and bottom. All operable panels shall be opened and closed 5 times prior to the commencement of the test

For facade, strip glazing, skylights and insert vents in facades, the pressure differential shall be ±150 Pa for up to buildings of height 70m and shall be ±300 Pa for buildings of height beyond 70 m. For store front, operable windows, sliding windows, For sliding doors and doors the pressure differential shall be +150 Pa.

NOTE: *Preload of 50 percent of design load for 10 s to be applied before commencement of the test.*

2.8.3.2 Static and Dynamic Water Penetration Test

If water is observed in the operable vent drainage path and the same is drained through slots after the spray is stopped it shall be considered as pass. Any water on the top surface of any exposed interior shall be considered as leakage. For sliders, only water overflowing to the interior is considered as a failure. In case of leakage, the remedy needs to be carried out and the retest shall be conducted. The rate of water spray shall be 3.4 litres / min / m^2 for a period of 15 min. The spray shall be located at a distance of 400 mm from the glass and 700 mm centre-to-centre horizontally and vertically. The pressure differential up to 35 m height shall be 300 Pa. beyond 35 m up to 70 m shall be 450 Pa and beyond 70 m shall be 600 Pa.

2.8.3.3 Structural Load Test (100 Percent Design Wind Load)

The deflection criteria of glass and framing members shall be as discussed. No damage or harmful permanent deformation of any parts except sealing materials shall be found at the maximum testing pressure. Residual displacement of a structural member shall not exceed span/1000. The slippage in supports and fixing shall not exceed 1 mm.

2.8.3.4 Seismic Racking test

Criteria shall be the movement of the sub-structure in the horizontal (+/-) directions. Optional testing for vertical movements (+/-) shall be based on sub¬ structure movement to accommodate live load, long-term creeps, column shortening and thermal elongation or contraction. No glass breakage or fall out is allowed. Any damage shall be easily reparable without any part replacements required. No wall component fallout is allowed.

2.8.3.5 Building Maintenance Unit (BMU) - Pull Out Test (When Applicable)

A tensile load of minimum 1.5 kN shall be applied on the BMU restraint in the following directions:

a) Horizontally to the right and held for a period of 1 min.
b) Horizontally to the left and held for a period of 1 min.
c) Vertically upward and held for a period of 1 min.
d) Vertically downward and held for a period of 1 min.

After each step the BMU restraint should not fail or have permanent deformation.

Note:

- If the load on the BMU restraints required by the BMU supplier is higher, the higher load shall apply.
- All BMU restraint sockets are designed for 2.7 kN

2.8.3.6 Operating Forces Test

Maximum force required to initiate opening of a sliding door is 180 N and the maximum force to maintain the motion of a sliding door or window is 115 N. For a projected top hung or parallel open vent the maximum force to maintain motion is 135 N.

2.8.3.7 Structural Proof Load Test

(150 Percent Design Wind Load and Seismic Force, If Applicable)

Under proof load test there shall be no collapse which means any one or any combination of the following:

a) Dislodgement of any glass.
b) Dislodgement of any frame, panel or any component thereof.
c) Failure of any fixing that connects the façade to the building structure, such that the test sample is unstable.
d) Failure of any stop, locking device, fastener or support which may allow an opening light to come through. The permanent deformation in framing members in excess of span/1000 is not permissible and considered as failure.

NOTE — For on-site testing, the parameters shall be tested for two / third of the laboratory values.

2.9 MATERIAL TESTING

It is essential to perform the following quality testing of glass, glazing systems and other associated materials as per the relevant Indian / ISO Standards for determining the performance of the same.

2.9.1 QUALITY TESTING OF COATED GLASS FOR ENERGY EFFICIENCY:

The energy performance properties of a coated glass are tested using a Spectrophotometer and Fourier Transform Infrared spectrometer (FTIR). Based on the physical characterization, calculations can be made to obtain the other related parameters. In case of an Insulated Glazing Unit (IGU), the overall energy performance values for the IGU can be simulated using accredited software.

The following parameters are generally obtained for the energy performance of glass and glazing. Refer IS 16231-part 2 for testing of glass for energy performance.

- Visible Light Transmittance
- Internal / External light reflectance
- Solar direct transmittance
- Solar direct reflectance internal / external
- Emissivity / U Value
- UV transmittance
- Solar Factor (SHGC)
- Shading coefficient
- Relative Heat Gain Coefficient

2.9.2 QUALITY TESTING OF COATED GLASS FOR DURABILITY

S No	Name of the test	Description
1	Condensation resistance test	Determines the durability of coated glass when subjected to a water saturated atmosphere at constant temperature
2	Acid resistance test	Determines the durability of coated glass when subjected to a sulphur dioxide saturated atmosphere at constant temperature
3	Neutral Salt Spray test	Determines the durability of coated glass when subjected to neutral, water saline atmosphere at constant temperature
4	Abrasion Resistance Test	Determines the durability of coated glass when subjected to rubbing action with a felt pad in dry conditions

2.9.3 QUALITY TESTING OF ALUMINIUM PROFILES

S No	Name of the test	Description
1	Dimension and tolerance measurement	The tolerances on dimension and form are measured using a straight table and profile projector. It includes tolerances on cross section, wall thickness, plane parallelism, convexity and concavity, angularity, corner and fillet radii, straightness and twist
2	Determination of mechanical properties	This test determines the mechanical properties including Yield strength (Upper and lower), Proof strength, Tensile strength, Percentage elongation at maximum load and Percentage elongation after fracture
3	Chemical analysis	The composition of the aluminium alloy is measured and checked for conformity

2.9.4 QUALITY TESTING OF COATED ALUMINIUM PROFILES:

Along with the test mentioned under quality of aluminium profiles, the following testing are performed for the coated aluminium profiles

S No	Name of the test	Description
1	Cross cut test	Determines the resistance of paint coatings to separation from Aluminium substrates
2	Measurement of Dry Film Thickness (DFT)	Determines the thickness of the coating layer
3	Measurement of gloss	Determines the gloss level of the coating to check for conformity
4	Acetic salt spray test	Determines the resistance of the protective coating against a corrosive atmosphere

2.9.5 QUALITY TESTING OF ANODIZED ALUMINIUM PROFILES:

Along with the test mentioned under quality of aluminium profiles, the following testing are performed for the anodized aluminium profiles

S No	Name of the test	Description
1	Measurement of anodic coating thickness	Determines the thickness of the anodic coating
2	Dye spot test	Determines the sealing quality of anodised coatings
3	Weight loss test	Determines the quality of sealed anodic oxidation coatings on aluminium profiles by measuring the loss of mass after immersion in phosphoric acid/chromic acid solution

2.9.6 QUALITY TESTING OF UPVC PROFILES

Color, Appearance, Dimensions, Profile Mass, Heat Reversion Test, Heat Ageing Test, Resistance to Impact of Falling Mass, Artificial Weathering, Welded Corner and T Joint tests

Sl. No	Characteristics	Requirements	Method of Test, Ref
1	2	3	4
i)	Vicat Softening Temperature	≥75 degree C	IS 13360 (Part 6/Sec1)
ii)	Apparent Modulus of Elasticity	≥ 2200 MPa	IS 13360 (Part 5/Sec 7)
iii)	Colour Fastness Min exposure 16GJ/m^2 for 8000 hours	ΔE^*, shall be ≤ 5 and Δb^* shall be ≤ 3.	Artificial weathering – Visual change in colour may be determined using ISO 105-A02
iv)	Heat Stability	≥30mins	ISO 182
v)	Charpy Impact Strength – pre-weathering	Table 3 of the test standard	IS 13360 (Part 5/Sec 5)
vi)	Retention of Charpy Impact Strength after artificial ageing	Table 3 of the test standard	IS 13360 (Part 5/Sec5)

2.9.7 QUALITY TESTING OF SEALANTS

A. One Part Sealant (Refer IS 11433 – Part 1 for more details on the requirements)

S no	Name of the test	Description
1	Skin-over time / elastomeric test	The purpose of this test is to ensure that the sealant cures fully and has typical elastomeric properties

B. TWO PART SEALANT (Refer IS 12118 – Part 1 for more details on the requirements)

S no	Name of the test	Description
1	Glass Test	Determine whether the two-component dispensing equipment is adequately mixing the sealant base and curing agent
2	Butterfly Test	
3	Snap Time Test	Determines if the mix ratio is correct and whether the sealant is curing properly
4	Snake Test	Determines the quality of the pump seal
5	Mixing Ratio Test	Determines the mixing ratio of the sealant
6	Peel adhesion test	Determines the adhesion quality of the sealant to a substrate
7	Adhesion test (edge seal strength)	To evaluate the bonding strength of sealant

2.9.8 QUALITY TESTING OF LAMINATED GLASS

(Refer IS 2553 (Part 1) and IS 17004 for more details on the requirements)

S No	Name of the test	Description
1	Resistance to fracture and adhesion	Determines the strength of the interlayer adhesion by subjecting the glass to impact from a steel ball of 225 gms dropped from a specific height of 4.88 mtrs or 1040 gms dropped from a specific height of 4 mtrs
2	High temperature test (Bake and Boil test)	Determines the resistance of the laminated glass when exposed to boiling water or hot air at 100ºC
3	Humidity test	Determines the resistance of the laminated glass when exposed to high humidity (without condensation) at 80% RH and 50ºC for 14 days or high humidity with condensation at 100% RH and 50ºC for 14 days
4	Human impact resistance test	Determines the safety characteristics of laminated glass towards human impact when subjected to a shot bag impact of 45 Kgs on a vertical glass at Class A drop height of 1200 mm
5	Light stability test	This test determines the resistance of laminated glass when exposed to UV radiation for a specified duration of 100 Hours

2.9.9 QUALITY TESTING OF TOUGHENED GLASS

(Refer IS 2553 (Part 1) and IS 17004 for more details on the requirements)

S no	Name of the test	Description
1	Impact / Resistance to shock	Determines the strength of the toughened glass when subjected to impact from a steel ball of 1040 gms dropped from a specific height of 1 mtr.
2	Fragmentation test	Determines the safety breakage characteristics when broken with a specified impactor and having a count of 40 particles in a square of $25cm^2$ in the coarsest region
3	Human impact resistance test	Determines the safety characteristics of toughened glass towards human impact. The glass should not break when subjected to a shot bag impact of 45 Kgs on a vertical glass at Class A drop height of 1200 mm
4	Four Point Bending Test	Determines the maximum mechanical strength of the glass which should be minimum 120 MPa

5	Warp / overall bow measurement	To check if the overall bow or deformation over the length of the toughened glass is within the specified limits
6	Surface compression measurement	Determines the compressive stress of the toughened glass

2.9.10 QUALITY TESTING OF INSULATED GLAZING UNIT(IGU)

(Refer IS 17004 for more details on the requirements)

S no	Name of the test	Description
1	Dew / Frost point test	Determines whether the IGU has excess moisture
2	Climate test	Determines the Moisture Penetration Index (MPI) by subjecting the IGU to different climatic cycles to simulate its performance over its service life
3	Argon gas level measurement	Measures the percentage of argon gas filled inside the IGU

2.9.11 QUALITY TESTING OF HEAT STRENGTHENED GLASS

(Refer IS 16984, IS 2553 (Part 1) and IS 17004 for more details on the requirements)

S no	Name of the test	Description
1	Fragmentation test	Performed to check the breakage pattern of glass
2	Four Point Bending Test	Determines the maximum mechanical strength of the glass which should be minimum 120 MPa
3	Surface compression test	Determines the compressive stress of the heat strengthened glass
4	Flatness measurement	To check if the undulation in the glass is within the permissible limit

SYMBOLS

p_{net}	net design wind pressure in N/m
A	Area of glass panel, in m2
T	Standard nominal thickness (SNT) of glass in mm
K	Constant
B	span in m
p_f	Strength factor
Cp	Net pressure coefficient as per IS 875 (Part 3)
P_z	design wind pressure as per IS 875 (Part 3) in N/m^2
V_z	design wind speed in m/s
V_b	basic wind speed based on location as per IS 873(Part 3)
K_1	Risk coefficient factor as per IS 873(Part 3)
k_2	terrain factor as per IS 873(Part 3)
k_3	topography factor as per IS 873(Part 3)
K_4	Importance factor for the cyclonic region as per IS 873(Part 3)
AR_{max}	aspect ratio
P_d	Design wind pressure
K_d	Wind directionality factor
K_a	Area averaging factor
K_c	Combination factor
Z	Zone Factor [(as per Table 2 of IS 1893 (Part 1)]
H	height of the structure
E	Young's modulus of glass, N/mm2
Q	net pressure on the pane N/mm2
G	9.81 m/s^2
S	allowable design stress for selected sealant considered for design, Pa
P	Perimeter
T	Thickness of the bite, m

REFERENCES

Reference Number	**Title of the Document**
NBC 2016	National Building Code of India 2016
IS 2553 Part 1	Safety Glass - Specifications
IS 17004	Testing method for processed glass
IS 16982	Heat Strengthened Glass – Specification
IS 16231 Part 1 to Part 4	Code of Practice for the Use of Glass in Buildings
Training Manual	IITM – GSI – IFC Skill Development Program
Testing Manual	SGRT Facility, IIT Madras
IS 1893 Part 1	Criteria for earth quake resistant design of structures: Part 1 – General provisions and buildings
IS 875 Part 3	Design loads (other than earthquake) for Buildings and Structures – Code of practice

Structural Glass Research and Testing (SGRT) facility

SGRT Facility, a joint initiative of IIT Madras and GSI is an advanced, first of its kind research and testing facility established in 2013 at the Structural Division, Civil Engineering department of IIT Madras. The SGRT facility provides the glass and glazing industry, the construction sector and academic institutions with complete research and testing facilities for determining, understanding and analyzing the energy and structural characteristics of architectural glass and glazing products and its associated materials.

Structural characteristics including the safety and security parameters, load resistance, environmental impact, human impact, object impact, material properties and other external factors deciding the effectiveness and performance of Glass and Glazing products in buildings in compliance with all relevant Indian and International codes and Standards.

Research on Structural Glass at IITM

Structural Engineering Laboratory, IITM, has carried out testing, research and development activities related to glass elements for the construction industry. Current efforts focus on systematic research carried out on the material characterisation of structural glass pertinent to structural engineering. This is augmented by the research in axial tension and compression behaviour of glass panels to ascertain their strength and serviceability limit states. One of the major research initiatives is on the structural behaviour of annealed and processed glass panels and IGUs. Integrating building physics with structural glazing, performance evaluation of glass facades under extreme wind and earthquake and codification for effective and safe use are some of the long term goals of Department of Civil Engineering, IIT Madras.

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