Building and Structural Engineering

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Building

A building and skybridge in Munich, Germany.

Example of a religious building : the Great Mosque of Kairouan, founded in 670, dates in its present state from the 9th century; situated in Kairouan, Tunisia.

In architecture, construction, engineering and real estate development the word **building** may refer to one of the following:

1. Any human-made structure used or intended for supporting or sheltering any use or continuous occupancy, or
2. An act of construction

Buildings come in a wide amount of shapes and functions, and have been adapted throughout history for a wide number of factors, from building materials available, to weather conditions, to land prices, ground conditions, specific uses and aesthetic reasons.

Buildings serve several needs of society – primarily as shelter from weather and as general living space, to provide privacy, to store belongings and to comfortably live and work. A building as a shelter represents a physical division of the human habitat (a place of comfort and safety) and the *outside* (a place that at times may be harsh and harmful).

Ever since the first cave paintings, buildings have also become objects or canvasess of artistic expression. In recent years, interest in sustainable planning and building practices has also become part of the design process of many new buildings.

Definitions

Building is defined in many aspects as:

- As a Civil Engineering structures such as a house,worship center,Factories etc. that has a foundation,wall,roof etc. that protect human being and their properties from direct harsh effect of weather like rain,wind,sun etc.
- The act of constructing, erecting, or establishing.
- The art of constructing edifices, or the practice of civil architecture.
- That which is built; a fabric or edifice constructed, as a house, a church, castle, arena/ stadium, etc.
- The act of constructing or building something; "during the construction we had to take a detour"; "his hobby was the building of boats"
- The commercial activity involved in constructing buildings; "their main business is home construction"; "workers in the building trades"
- A structure that has a roof and walls and stands more or less permanently in one place; "there was a three-storey building on the corner"; "it was an imposing edifice"
- The occupants of a building; "the entire building complained about the noise"

To differentiate buildings in the usage here, from other buildings and other structures that are *not* intended for continuous human occupancy, the latter are called non-building structures or simply structures.

Structural height in technical usage is the height to the highest architectural detail on building from street-level. Depending on how they are classified, spires and masts may or may not be included in this height. Spires and masts used as antennas are not generally included.

The definition of a *low-rise vs. a high-rise* building is a matter of debate, but generally three stories or less is considered low-rise.

History

The first shelter on Earth constructed by a relatively close ancestor to humans is believed to be built 500,000 years ago by an early ancestor of humans, Homo erectus.

Types

A timber framing house in Marburg, Germany.

Residential

Residential buildings are called houses/homes, though buildings containing large numbers of separate dwelling units are often called apartment buildings / blocks to differentiate them from the more 'individual' house.

Building types may range from one-room wood-framed, masonry, or adobe dwellings to multi-million dollar high-rise buildings able to house thousands of people. Increasing settlement density in buildings (and closer distances between buildings) is usually a response to high ground prices resulting from many people wanting to live close to work or similar attractors.

Multi-storey

Some of Denver's multi-storey buildings.

A multi-storey building is a building that has multiple floors above ground in the building.

Multi-storey buildings aim to increase the area of the building without increasing the area of the land the building is built on, hence saving land and, in most cases, money (depending on material used and land prices in the area).

Creation

The practice of designing, constructing, and operating buildings is most usually a collective effort of different groups of professionals and trades. Depending on the size, complexity, and purpose of a particular building project, the project team may include:

- A real estate developer who secures funding for the project;
- One or more financial institutions or other investors that provide the funding
- Local planning and code authorities
- A Surveyor who performs an ALTA/ACSM and construction surveys throughout the project;
- Construction managers who coordinate the effort of different groups of project participants;
- Licensed architects and engineers who provide building design and prepare construction documents;
- Landscape architects;
- Interior designers;

- Other consultants;
- Contractors who provide construction services and install building systems such as climate control, electrical, plumbing, Decoration, fire protection, security and telecommunications;
- Marketing or leasing agents;
- Facility managers who are responsible for operating the building.

Regardless of their size or intended use, all buildings in the US must comply with zoning ordinances, building codes and other regulations such as fire codes, life safety codes and related standards.

Vehicles—such as trailers, caravans, ships and passenger aircraft—are treated as "buildings" for life safety purposes.

Ownership and funding

- Mortgage loan
- Real estate developer

Planning and design

- Architecture
- Building construction
- Civil engineering
- Mechanical, electrical, and plumbing design
- Quantity surveying
- Structural engineering
- Urban planning

Building services

Physical plant

Any building requires a certain amount of internal infrastructure to function, which includes such elements like heating / cooling, power and telecommunications, water and wastewater etc. Especially in commercial buildings (such as offices or factories), these can be extremely intricate systems taking up large amounts of space (sometimes located in separate areas or double floors / false ceilings) and constitute a big part of the regular maintenance required.

Conveying systems

Systems for transport of people within buildings:

- Elevator
- Escalator

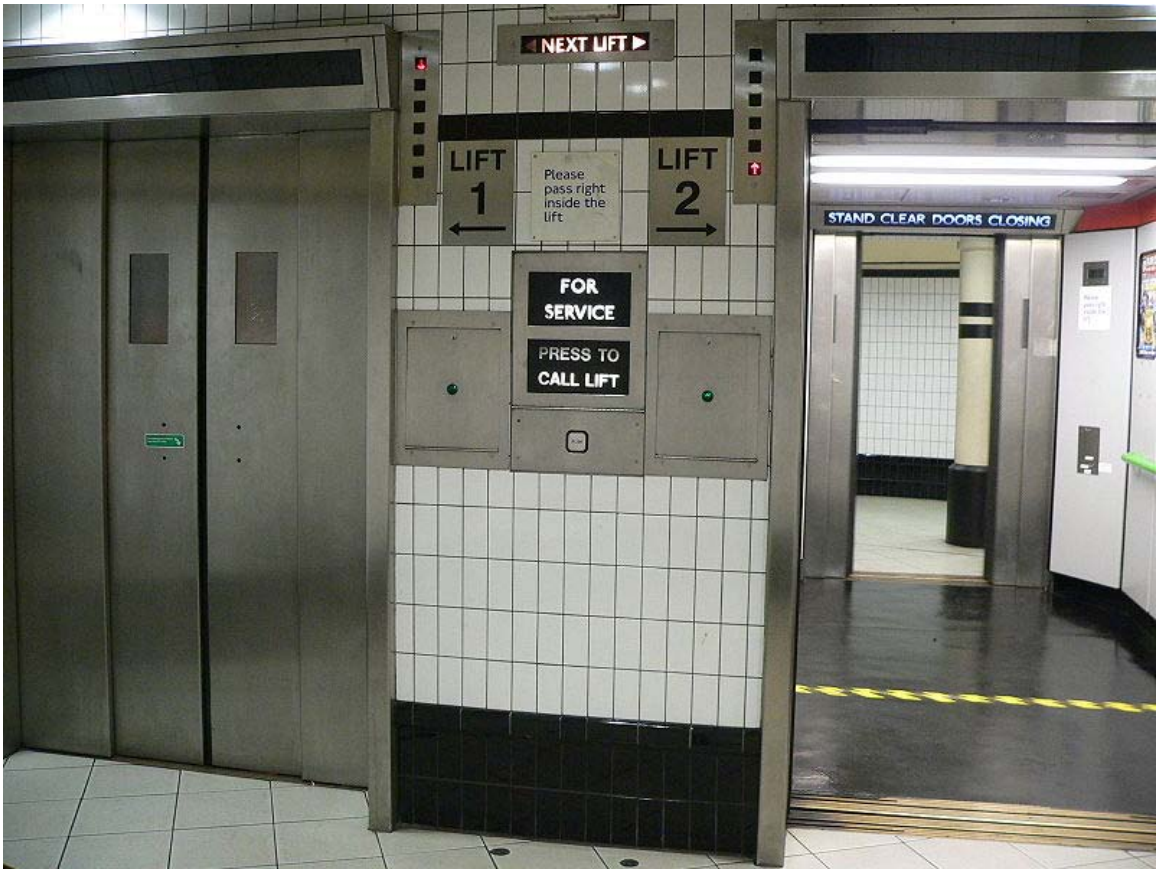
- Moving sidewalk (horizontal and inclined)

Systems for transport of people between interconnected buildings:

- Skyway
- Underground city

Chapter 2

Elevator



A set of lifts in the lower level of a London Underground station in the United Kingdom. The arrows indicate each lift's position and direction of travel.

This elevator to the Alexanderplatz U-Bahn station in Berlin is built with glass walls, exposing the inner workings.

An **elevator** (or **lift** in British English) is a vertical transport equipment that efficiently moves people or goods between floors (levels, decks) of a building, vessel or other structure. Elevators are generally powered by electric motors that either drive traction cables or counterweight systems like a hoist, or pump hydraulic fluid to raise a cylindrical piston like a jack.

Languages other than English may have loanwords based on either *elevator* (e.g., Korean & Japanese) or *lift* (e.g., Russian & Cantonese).

Because of wheelchair access laws, elevators are often a legal requirement in new multi-storey buildings, especially where wheelchair ramps would be impractical.

Design

Some people argue that lifts began as simple rope or chain hoists. A lift is essentially a platform that is either pulled or pushed up by a mechanical means. A modern day lift consists of a cab (also called a "cage" or "car") mounted on a platform within an enclosed space called a shaft or sometimes a "hoistway". In the past, lift drive mechanisms were powered by steam and water hydraulic pistons or by hand. In a "traction" lift, cars are

pulled up by means of rolling steel ropes over a deeply grooved pulley, commonly called a sheave in the industry. The weight of the car is balanced with a counterweight. Sometimes two lifts always move synchronously in opposite directions, and they are each other's counterweight.

The friction between the ropes and the pulley furnishes the traction which gives this type of lift its name.

Hydraulic lifts use the principles of hydraulics (in the sense of hydraulic power) to pressurize an above ground or in-ground piston to raise and lower the car. Roped hydraulics use a combination of both ropes and hydraulic power to raise and lower cars. Recent innovations include permanent magnet motors, machine room-less rail mounted gearless machines, and microprocessor controls.

The technology used in new installations depends on a variety of factors. Hydraulic lifts are cheaper, but installing cylinders greater than a certain length becomes impractical for very high lift hoistways. For buildings of much over seven stories, traction lifts must be employed instead. Hydraulic lifts are usually slower than traction lifts.

Lifts are a candidate for mass customization. There are economies to be made from mass production of the components, but each building comes with its own requirements like different number of floors, dimensions of the well and usage patterns.

Elevator doors

Elevator doors protect riders from falling into the shaft. The most common configuration is to have two panels that meet in the middle, and slide open laterally. In a cascading configuration (potentially allowing wider entryways within limited space), the doors run on independent tracks so that while open, they are tucked behind one another, and while closed, they form cascading layers on one side. This can be configured so that two sets of such cascading doors operate like the center opening doors described above, allowing for a very wide elevator cab. In less expensive installations the elevator can also use one large "slab" door: a single panel door the width of the doorway that opens to the left or right laterally. Some buildings have elevators with the single door on the shaft way, and double cascading doors on the cab.

Machine room-less

General

for a single or a group of elevators.

Machine room-less elevators are designed so that most of its components fit within the shaft containing the elevator car; and a small cabinet houses the elevator controller. Other than the machinery being in the hoistway, the equipment is similar to a normal traction elevator.

This new design was first developed by Kone in 1996.

Benefits

- creates more usable space
- use less energy (70-80% less than hydraulic elevators)
- uses no oil
- all components are above ground similar to roped hydraulic type elevators (this takes away the environmental concern that was created by the hydraulic cylinder on direct hydraulic type elevators being stored underground)
- slightly lower cost than other elevators
- can operate at faster speeds than hydraulics but not normal traction units

Detriments

- Equipment can be harder to service and maintain.
- No code has been approved for the installation of Residential elevator Equipment.

Facts

- Noise level is at 50-55 dBA (A-weighted decibels), which can be lower than some but not all types of elevators
- Usually used for low-rise to mid-rise buildings
- The motor mechanism is placed in the hoistway itself
- The US was slow to accept the commercial MRL Elevator because of codes

---national and local building codes did not address elevators without machine rooms. Residential MRL Elevators are still not allowed by the ASME A17 code in the US.

Elevator Traffic Calculations

Round trip time calculations

The majority of elevator designs are developed from Up Peak Round Trip Time calculations as described in the following publications:- CIBSE Guide D: Transportation Systems in Building Elevator Traffic Handbook, Theory and Practice. Gina Barney The Vertical Transportation Handbook. George Strakosch

Traditionally these calculations have formed the basis of establishing the Handling Capacity of an elevator system.

Modern Installations with more complex elevator arrangements have led to the development of more specific formulae such as the General Analysis calculation.

Subsequently this has been extended for Double Deck elevators.

Simulation

Elevator traffic simulation software can be used to model complex traffic patterns and elevator arrangements that cannot necessarily be analysed by RTT calculations.

Lift traffic patterns

There are four main types of elevator traffic patterns that can be observed in most modern office installations. They are up peak traffic, down peak traffic, lunch time (two way) traffic and interfloor traffic.

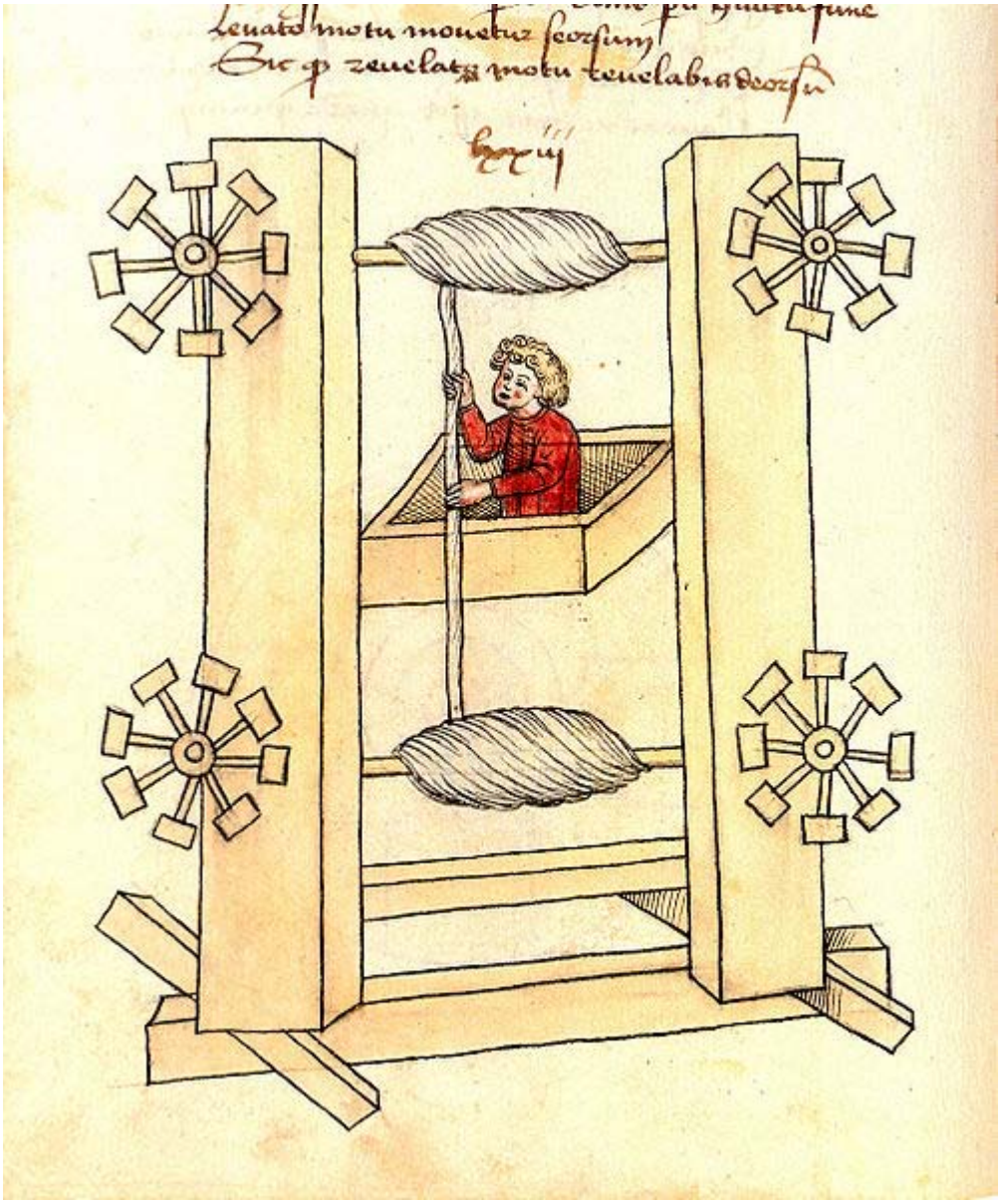
Elevator modernization

Most elevators are built to provide about 20 years of service, as long as service intervals specified and periodic maintenance/inspections by the manufacturer are followed. As the elevator ages and equipment become increasingly difficult to find or replace, along with code changes and deteriorating ride performance, a complete overhaul of the elevator may be suggested to the building owners.

A typical modernization consists of controller equipment, electrical wiring and buttons, position indicators and direction arrows, hoist machines and motors (including door operators), and sometimes door hanger tracks. Rarely are car slings, rails, or other heavy structures changed. The cost of an elevator modernization can range greatly depending on which type of equipment is to be installed.

Modernization can greatly improve operational reliability by replacing mechanical relays and contacts with solid-state electronics. Ride quality can be improved by replacing motor-generator-based drive designs with Variable-Voltage, Variable Frequency (V3F) drives, providing near-seamless acceleration and deceleration. Passenger safety is also improved by updating systems and equipment to conform to current code.

History



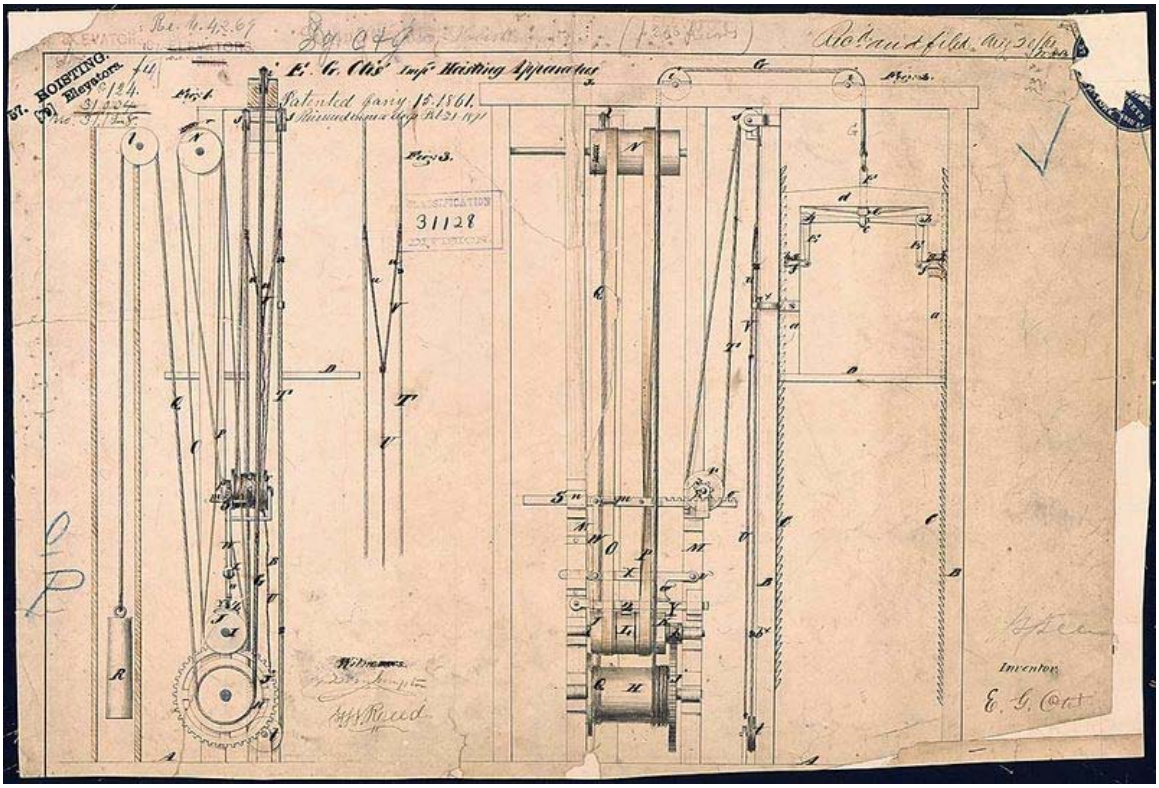
Elevator design by the German engineer Konrad Kyeser (1405)

The first reference to an elevator is in the works of the Roman architect Vitruvius, who reported that Archimedes (c. 287 BC – c. 212 BC) built his first elevator probably in 236 BC. In some literary sources of later historical periods, elevators were mentioned as cabs on a hemp rope and powered by hand or by animals. It is supposed that elevators of this type were installed in the Sinai monastery of Egypt.

In 1000, the *Book of Secrets* by Ibn Khalaf al-Muradi in Islamic Spain described the use of an elevator-like lifting device, in order to raise a large battering ram to destroy a

fortress. In the 17th century the prototypes of elevators were located in the palace buildings of England and France.

The ancient and medieval elevators used the drive system based on hoist. The invention of another system. based on the screw drive, was perhaps the most important step in elevator technology since ancient times, which finally led to the creation of modern passenger elevators. The first screw drive elevator was built by Ivan Kulibin and installed in Winter Palace in 1793, while several years later another Kulibin's elevator was installed in Arkhangelskoye near Moscow. In 1823, an "ascending room" made its debut in London.



Elisha Otis' elevator patent drawing, 15 January 1861.

In the middle 1800s, there were many types of crude elevators that carried freight. Most of them ran hydraulically. The first hydraulic elevators used a plunger below the car to raise or lower the elevator. A pump applied water pressure to a plunger, or steel column, inside a vertical cylinder. Increasing the pressure caused the elevator to ascend. The elevator also used a system of counter-balancing so that the plunger did not have to lift the entire weight of the elevator and its load. The plunger, however, was not practical for tall buildings, because it required a pit as deep below the building as the building was tall. Later a rope-geared elevator with multiple pulleys was developed.

Henry Waterman of New York is credited with inventing the "standing rope control" for an elevator in 1850.

In 1852, Elisha Otis introduced the safety elevator, which prevented the fall of the cab if the cable broke. The design of the Otis safety elevator is somewhat similar to one type still used today. A governor device engages knurled roller(s), locking the elevator to its guides should the elevator descend at excessive speed. He demonstrated it at the New York exposition in the Crystal Palace in a dramatic, death-defying presentation in 1854.

On March 23, 1857 the first Otis passenger elevator was installed at 488 Broadway in New York City. The first elevator shaft preceded the first elevator by four years. Construction for Peter Cooper's Cooper Union building in New York began in 1853. An elevator shaft was included in the design for Cooper Union, because Cooper was confident that a safe passenger elevator would soon be invented. The shaft was cylindrical because Cooper felt it was the most efficient design. Later Otis designed a special elevator for the school. Today the Otis Elevator Company, now a subsidiary of United Technologies Corporation, is the world's largest manufacturer of vertical transport systems.

The first electric elevator was built by Werner von Siemens in 1880. The safety and speed of electric elevators were significantly enhanced by Frank Sprague. The inventor Anton Freissler developed the ideas of von Siemens and built up a successful enterprise in Austria-Hungary.

The development of elevators was led by the need for movement of raw materials including coal and lumber from hillsides. The technology developed by these industries and the introduction of steel beam construction worked together to provide the passenger and freight elevators in use today.

In 1874, J.W. Meaker patented a method which permitted elevator doors to open and close safely. U.S. Patent 147,853

In 1882, when hydraulic power was a well established technology, a company later named the London Hydraulic Power Company was formed. It constructed a network of high pressure mains on both sides of the Thames which, ultimately, extended to 184 miles and powered some 8,000 machines, predominantly lifts (elevators) and cranes.

In 1880 Werner Von Siemens of Germany invented the electric elevator. The hydraulic and electric lifts are commonly in use today.

In 1887, African American Inventor Alexander Miles of Duluth, Minnesota patented an elevator with automatic doors that would close off the elevator shaft.

Elevator safety

Pneumatic vacuum elevators

Pneumatic Vacuum Elevators operate without cables or pistons and can be installed more easily and quickly than their alternatives since their housing is comprised of prefabricated

sections which are considerably narrower than conventional lift shafts. These sections are transparent and afford the passenger a near 360° view. Other notable features of the vacuum elevator are as follows... • No pit excavation, hoist way, or machine room needed. • Installation within one to two days • Two to four stops for residential, marine, and stage use (35ft. total rise) • Ideal for new and existing homes due to the minimal space needed to fit the elevator • Self-supporting structure: the elevator can rest on any existing ground floor • “Green Elevator” : minimal energy consumption used during ascent and no energy used during descent • Minimal maintenance: no oils or lubrication required for the elevator • Absolute safety in case of a power failure since the moving car automatically descends to the lowest level and the electro-mechanical door will open to let the passenger out • Elevator runs on 220Volts and cabin electric circuits are 24 volts, eliminating the risk of shock

Cable-borne elevators

Statistically speaking, elevators are extremely safe. Their safety record is unsurpassed by any other vehicle system. In 1998, it was estimated that approximately eight 100-millionths of one percent (1 in 12 million) of elevator rides resulted in an anomaly, and the vast majority of these were minor things such as the doors failing to open. For all practical purposes, there are no cases of elevators simply free-falling and killing the passengers inside; of the 20 to 30 elevator-related deaths each year, most of them are maintenance-related - for example, technicians leaning too far into the shaft or getting caught between moving parts, and most of the rest are attributed to easily avoidable accidents, such as people stepping blindly through doors that open into empty shafts or being strangled by scarves caught in the doors. In fact, prior to the September 11th terrorist attacks, the only known free-fall incident in a modern cable-borne elevator happened in 1945 when a B-25 bomber struck the Empire State Building in fog, severing the cables of an elevator cab, which fell from the 75th floor all the way to the bottom of the building, seriously injuring (though not killing) the sole occupant - the female elevator operator. However, there was an incident in 2007 at a Seattle children's hospital, where a ThyssenKrupp ISIS machine room-less elevator free-fell until the safety brakes were engaged. This was due to a flaw in the design where the cables were connected at one common point, and the kevlar ropes had a tendency to overheat and cause slipping (or, in this case, a free-fall). While it is possible (though extraordinarily unlikely) for an elevator's cable to snap, all elevators in the modern era have been fitted with several safety devices which prevent the elevator from simply free-falling and crashing. An elevator cab is typically borne by six or eight hoist cables, each of which is capable on its own of supporting the full load of the elevator plus twenty-five percent more weight. In addition, there is a device which detects whether the elevator is descending faster than its maximum designed speed; if this happens, the device causes copper brake shoes to clamp down along the vertical rails in the shaft, stopping the elevator quickly, but not so abruptly as to cause injury. This device is called the governor, and was invented by Elisha Graves Otis. In addition, a hydraulic buffer is installed at the bottom of the shaft to cushion any impact somewhat.

Hydraulic elevators

Past problems with early hydraulic elevators meant those built prior to a code change in 1972 were subject to possible catastrophic failure. The code had previously required only single-bottom hydraulic cylinders. In the event of a cylinder breach, an uncontrolled fall of the elevator might result. Because it is impossible to verify the system completely without a pressurized casing (as described below), it is necessary to remove the piston to inspect it. The cost of removing the piston is such that it makes no economic sense to re-install the old cylinder; therefore it is necessary to replace the cylinder and install a new piston. Another solution to protect against a cylinder blowout is to install a "life jacket." This is a device which, in the event of an excessive downward speed, clamps onto the cylinder and stops the car. A device known as a rupture valve is often attached to the hydraulic inlet/outlet of the piston and can be adjusted for a maximum flow rate. If a pipe or hose were to break (rupture), the flow rate of the rupture valve will surpass a set limit and mechanically stop the outlet flow of hydraulic fluid, thus stopping the piston and the car in the down direction.

In addition to the safety concerns for older hydraulic elevators, there is risk of leaking hydraulic oil into the aquifer and causing potential environmental contamination. This has led to the introduction of PVC liners (casings) around hydraulic cylinders which can be monitored for integrity.

In the past decade, recent innovations in inverted hydraulic jacks have eliminated the costly process of drilling the ground to install a borehole jack. This also eliminates the threat of corrosion to the system and increases safety.

Mine-shaft elevators

Safety testing of mine shaft elevator rails is routinely undertaken. The method involves destructive testing of a segment of the cable. The ends of the segment are frayed, then set in conical zinc molds. Each end of the segment is then secured in a large, hydraulic stretching machine. The segment is then placed under increasing load to the point of failure. Data about elasticity, load, and other factors is compiled and a report is produced. The report is then analyzed to determine whether or not the entire rail is safe to use.

Uses of elevators

A residential elevator in Singapore.

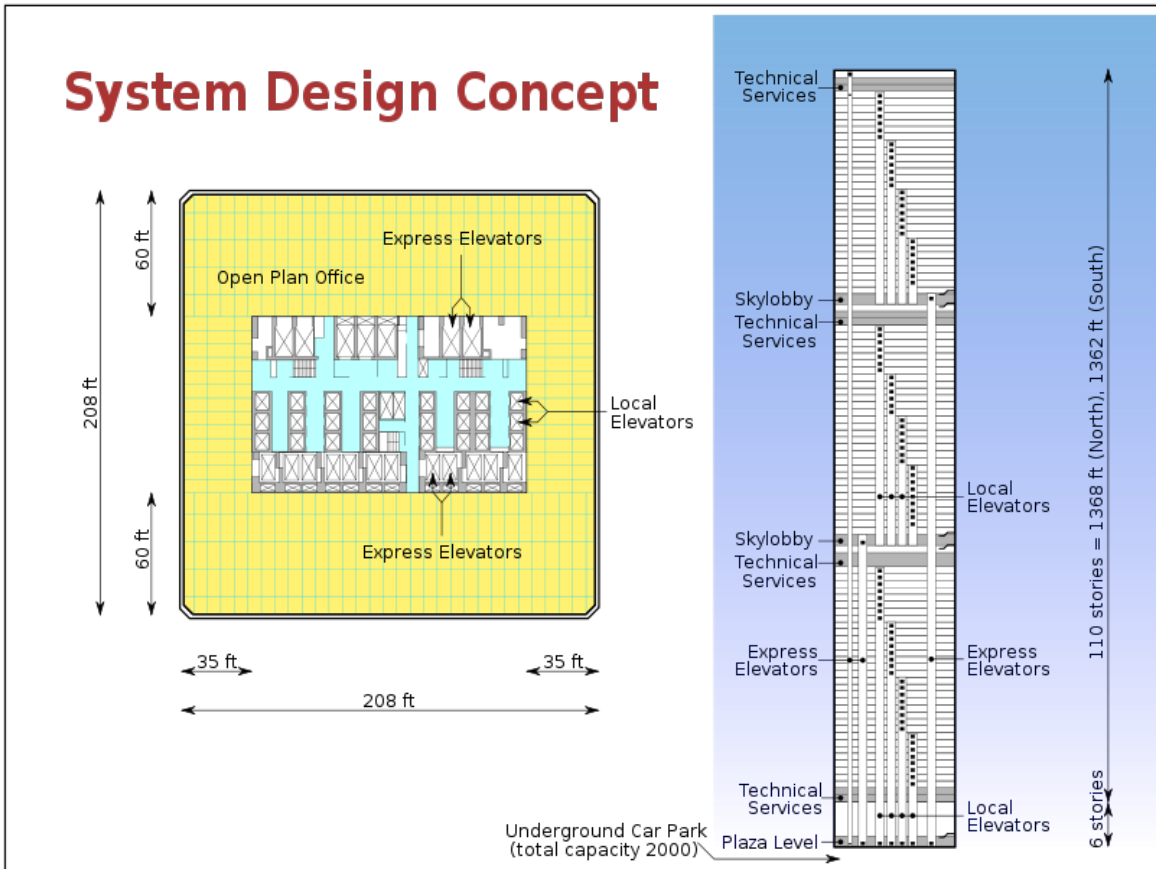
Passenger service

A passenger elevator is designed to move people between a building's floors.

Passenger elevators capacity is related to the available floor space. Generally passenger elevators are available in capacities from 1,000 to 6,000 pounds (450–2,700 kg) in 500 lb (230 kg) increments. Generally passenger elevators in buildings eight floors or less are hydraulic or electric, which can reach speeds up to 200 ft/min (1.0 m/s) hydraulic and up to 500 ft/min electric. In buildings up to ten floors, electric and gearless elevators are likely to have speeds up to 500 ft/min (2.5 m/s), and above ten floors speeds begin at 500 ft/min (2.5 m/s) up to 2000 ft/min (10 m/s).

Sometimes passenger elevators are used as a city transport along with funiculars. For example, there is a 3-station underground public elevator in Yalta, Ukraine, which takes passengers from the top of a hill above the Black Sea on which hotels are perched, to a tunnel located on the beach below. At Casco Viejo station in the Bilbao Metro, the elevator that provides access to the station from a hilltop neighborhood doubles as city transportation: the station's ticket barriers are set up in such a way that passengers can pay to reach the elevator from the entrance in the lower city, or vice versa.

Types of passenger elevators



The former World Trade Center's twin towers used skylobbies, located on the 44th and 78th floors of each tower.

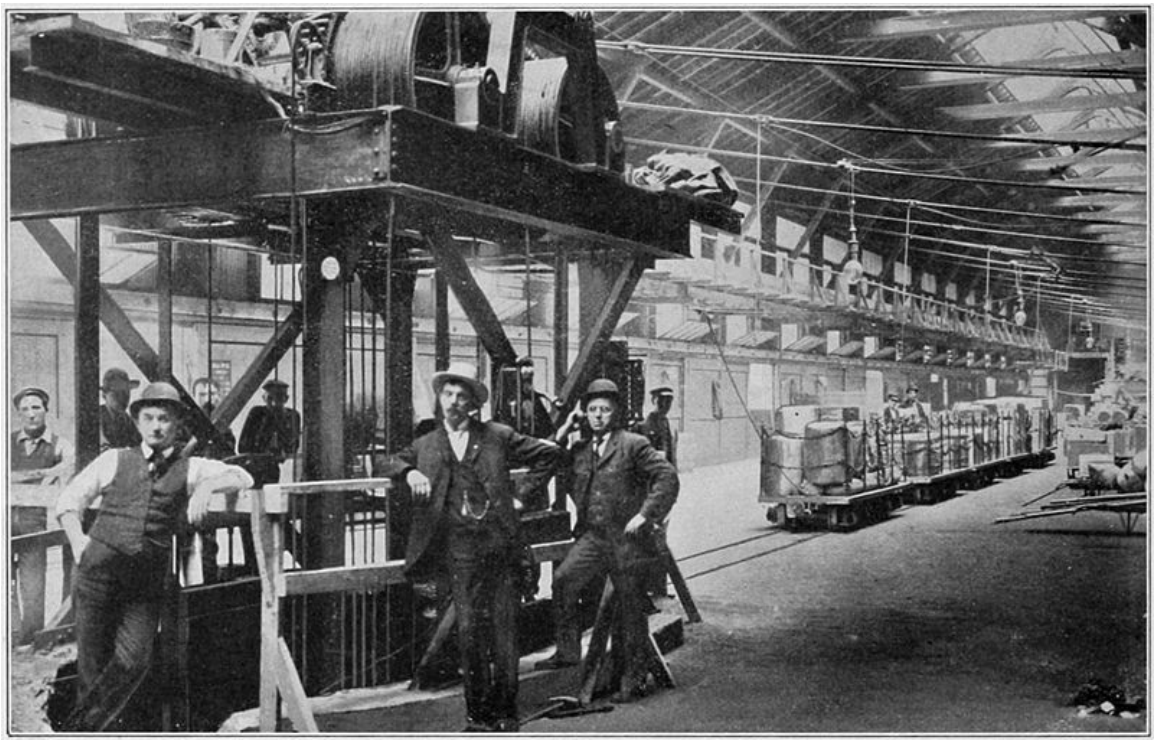
Passenger elevators may be specialized for the service they perform, including: hospital emergency (Code blue), front and rear entrances, a television in high rise buildings, double decker, and other uses. Cars may be ornate in their interior appearance, may have audio visual advertising, and may be provided with specialized recorded voice instructions.

An **express elevator** does not serve all floors. For example, it moves between the ground floor and a skylobby, or it moves from the ground floor or a skylobby to a range of floors, skipping floors in between. These are especially popular in eastern Asia.

Capacity

Residential elevators may be small enough to only accommodate one person while some are large enough for more than a dozen. Wheelchair, or platform lifts, a specialized type of elevator designed to move a wheelchair 6 ft (1.8 m) or less, often can accommodate just one person in a wheelchair at a time with a load of 1000 lb (450 kg).

Freight elevators

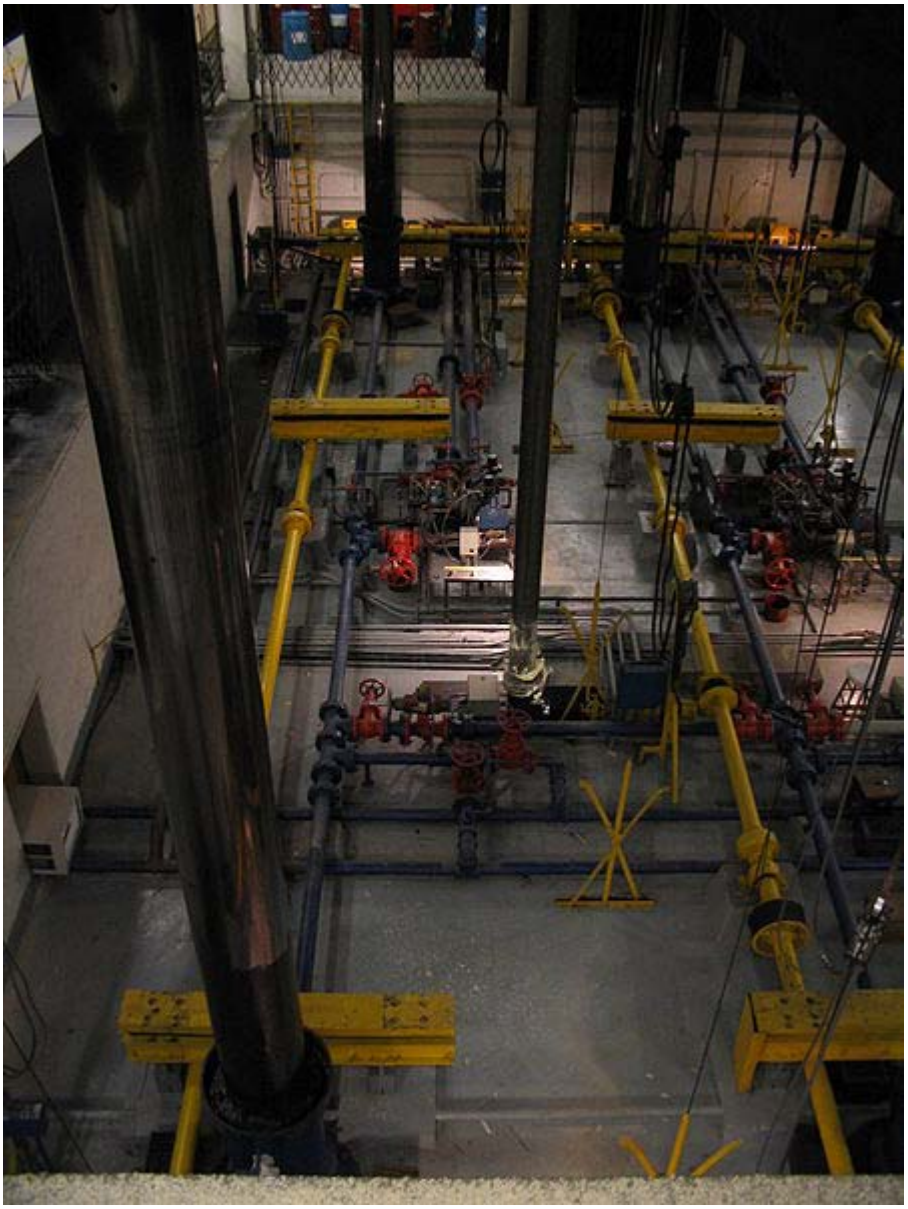


A specialized elevator from 1905 for lifting narrow gauge railroad cars between a railroad freight house and the Chicago Tunnel Company tracks below.

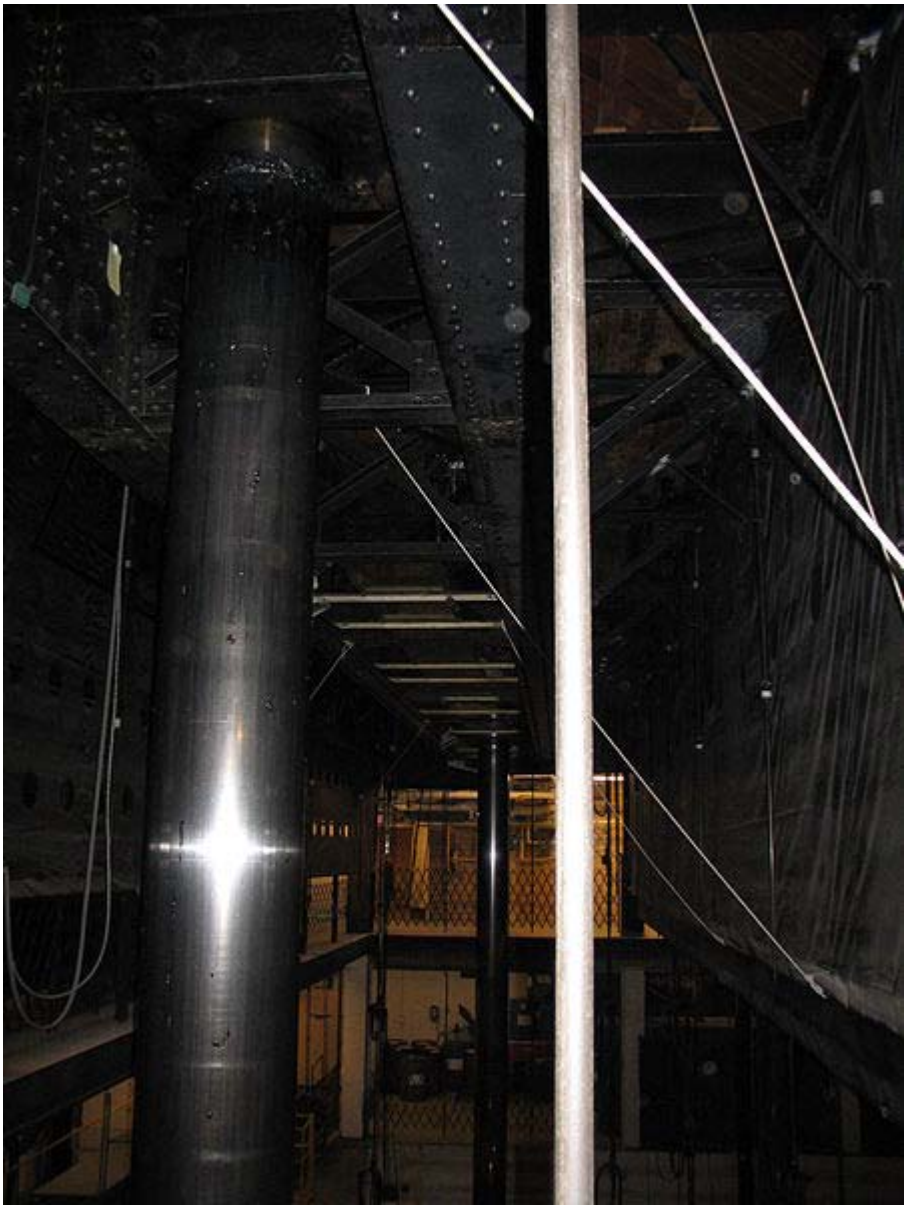
A freight elevator, or goods lift, is an elevator designed to carry goods, rather than passengers. Freight elevators are generally required to display a written notice in the car that the use by passengers is prohibited (though not necessarily illegal), though certain freight elevators allow dual use through the use of an inconspicuous riser. Freight elevators are typically larger and capable of carrying heavier loads than a passenger elevator, generally from 2,300 to 4,500 kg. Freight elevators may have manually operated doors, and often have rugged interior finishes to prevent damage while loading and unloading. Although hydraulic freight elevators exist, electric elevators are more energy efficient for the work of freight lifting.

Stage lifts

Stage and orchestra lifts are specialized lifts, typically powered by hydraulics, that are used to lift entire sections of a theater stage. For example, Radio City Music Hall has four such lifts: an "orchestra lift" that covers a large area of the stage, and three smaller lifts near the rear of the stage. In this case, the orchestra lift is powerful enough to raise an entire orchestra, or an entire cast of performers (including live elephants) up to stage level from below.



The pit beneath the orchestra lift at Radio City Music Hall



Orchestra lift at Radio City Music Hall as viewed from beneath the stage

Vehicle elevators

Vehicular elevators are used within buildings or areas with limited space (in lieu of ramps), typically to move cars into the parking garage or manufacturer's storage. Geared hydraulic chains (not unlike bicycle chains) generate lift for the platform and there are no counterweights. To accommodate building designs and improve accessibility, the platform may rotate so that the driver only has to drive forward. Most vehicle elevators have a weight capacity of 2 tons.

Rare examples of extra-heavy elevators for 20-ton lorries, and even for railcars (like one that was used at Dnipro Station of the Kiev Metro) also occur.

Boat elevators

In some smaller canals, boats and small ships can pass between different levels of a canal with a boat lift rather than through a canal lock.

Aircraft elevators

An F/A-18C on an aircraft elevator of the USS *Kitty Hawk*

On aircraft carriers, elevators carry aircraft between the flight deck and the hangar deck for operations or repairs. These elevators are designed for much greater capacity than other elevators, up to 200,000 pounds (90 tonnes) of aircraft and equipment. Smaller elevators lift munitions to the flight deck from magazines deep inside the ship.

On some passenger double-deck aircraft such as the Boeing 747, Lockheed L-1011 or other widebody aircraft, lifts transport flight attendants and food and beverage trolleys from lower deck galleys to upper passenger carrying decks.

Residential elevator

The residential elevator is often permitted to be of lower cost and complexity than full commercial elevators. They may have unique design characteristics suited for home furnishings, such as hinged wooden shaft-access doors rather than the typical metal sliding doors of commercial elevators. Construction may be less robust than in commercial designs with shorter maintenance periods, but safety systems such as locks on shaft access doors, fall arrestors, and emergency phones must still be present in the event of malfunction.

Limited Use / Limited Application

The limited-use, limited-application (LU/LA) elevator is a special purpose passenger elevator used infrequently, and which is exempt from many commercial regulations and accommodations. For example, a LU/LA is primarily meant to be handicapped accessible, and there might only be room for a single wheelchair and a standing passenger.

Dumbwaiter

Dumbwaiters are small freight elevators that are intended to carry food rather than passengers. They often link kitchens with rooms on other floors.

Paternoster

A paternoster in Berlin, Germany

A special type of elevator is the paternoster, a constantly moving chain of boxes. A similar concept, called the manlift or humanlift, moves only a small platform, which the rider mounts while using a handhold and was once seen in multi-story industrial plants.

Scissor lift

The scissor lift is yet another type of lift. As most of these lifts are self-contained, these lifts can be easily moved to where they are needed.

Rack-and-pinion lift

The rack-and-pinion lift is another type of lift. This lifts are simpler in construction, but noisy and slow. They are nonetheless the most used type of lift for buildings under construction (to move materials and tools up and down).

Material handling belts and belt elevators

A different kind of **elevator** is used to transport material. It generally consists of an inclined plane on which a conveyor belt runs. The conveyor often includes partitions to prevent the material from sliding backwards. These elevators are often used in industrial and agricultural applications. When such mechanisms (or spiral screws or pneumatic transport) are used to elevate grain for storage in large vertical silos, the entire structure is called a grain elevator.

There have occasionally been lift belts for humans; these typically have steps about every seven feet along the length of the belt, which moves vertically, so that the passenger can stand on one step and hold on to the one above. These belts are sometimes used, for example, to carry the employees of parking garages, but are considered too dangerous for public use.

Types of hoist mechanisms

There are at least four means of moving an elevator:

Pneumatic Vacuum Elevators

Pneumatic Vacuum Elevators operate without cables or pistons and can be installed more easily and quickly than their alternatives since their housing is comprised of prefabricated sections which are considerably narrower than conventional lift shafts. These sections are transparent and afford the passenger a near 360° view. Other notable features of the vacuum elevator are as follows... • No pit excavation, hoist way, or machine room needed. • Installation within one to two days • Two to four stops for residential, marine, and stage use (35ft. total rise) • Ideal for new and existing homes due to the minimal space needed to fit the elevator • Self-supporting structure: the elevator can rest on any existing ground floor • “Green Elevator” : minimal energy consumption used during ascent and no energy used during descent • Minimal maintenance: no oils or lubrication required for the elevator • Absolute safety in case of a power failure since the moving car automatically descends to the lowest level and the electro-mechanical door will open to let the passenger out • Elevator runs on 220Volts and cabin electric circuits are 24 volts, eliminating the risk of shock

Traction elevators

- *Geared and gearless traction elevators*

Geared traction machines are driven by AC or DC electric motors. Geared machines use worm gears to control mechanical movement of elevator cars by "rolling" steel hoist ropes over a drive sheave which is attached to a gearbox driven by a high speed motor. These machines are generally the best option for basement or overhead traction use for speeds up to 500 ft/min (2.5 m/s).

Gearless traction machines are low speed (low RPM), high torque electric motors powered either by AC or DC. In this case, the drive sheave is directly attached to the end of the motor. Gearless traction elevators can reach speeds of up to 2,000 ft/min (10 m/s), or even higher. A brake is mounted between the motor and drive sheave (or gearbox) to hold the elevator stationary at a floor. This brake is usually an external drum type and is actuated by spring force and held open electrically; a power failure will cause the brake to engage and prevent the elevator from falling.

In each case, cables are attached to a hitch plate on top of the cab or may be "underslung" below a cab, and then looped over the drive sheave to a counterweight attached to the opposite end of the cables which reduces the amount of power needed to move the cab. The counterweight is located in the hoist-way and rides a separate railway system; as the car goes up, the counterweight goes down, and vice versa. This action is powered by the traction machine which is directed by the controller, typically a relay logic or computerized device that directs starting, acceleration, deceleration and stopping of the elevator cab. The weight of the counterweight is typically equal to the weight of the elevator cab plus 40-50% of the capacity of the elevator. The grooves in the drive sheave are specially designed to prevent the cables from slipping. "Traction" is provided to the ropes by the grip of the grooves in the sheave, thereby the name. As the ropes age and the traction grooves wear, some traction is lost and the ropes must be replaced and the sheave repaired or replaced. Sheave and rope wear may be significantly reduced by ensuring that all ropes have equal tension, thus sharing the load evenly. Rope tension equalisation may be achieved using a rope tension gauge, and is a simple way to extend the lifetime of the sheaves and ropes.

Elevators with more than 100' (30 m) of travel have a system called compensation. This is a separate set of cables or a chain attached to the bottom of the counterweight and the bottom of the elevator cab. This makes it easier to control the elevator, as it compensates for the differing weight of cable between the hoist and the cab. If the elevator cab is at the top of the hoist-way, there is a short length of hoist cable above the car and a long length of compensating cable below the car and vice versa for the counterweight. If the compensation system uses cables, there will be an additional sheave in the pit below the elevator, to guide the cables. If the compensation system uses chains, the chain is guided by a bar mounted between the counterweight railway lines.

Hydraulic elevators

- *Conventional hydraulic elevators*. They use an underground cylinder, are quite common for low level buildings with 2-5 floors (sometimes but seldom up to 6-8 floors), and have speeds of up to 200 feet/minute (1 meter/second).

- *Holeless hydraulic elevators* were developed in the 1970s, and use a pair of above ground cylinders, which makes it practical for environmentally or cost sensitive buildings with 2, 3, or 4 floors.
- *Roped hydraulic elevators* use both above ground cylinders and a rope system, which combines the reliability of inground hydraulic with the versatility of holeless hydraulic, even though they can serve up to 8-10 floors.

Climbing elevator

A climbing elevator is a self-ascending elevator with its own propulsion. The propulsion can be done by an electric or a combustion engine. Climbing elevators are used in guyed masts or towers, in order to make easy access to parts of these constructions, such as flight safety lamps for maintenance. An example would be the Moonlight towers in Austin, Texas, where the elevator holds only one person and equipment for maintenance.

Elevator air conditioning

Concept

Elevator air conditioning is fast becoming a popular concept around the world. The primary reason for installing an elevator air conditioner is the comfort that it provides while traveling in the elevator. It stabilizes the condition of the air inside the lift car. Some elevator air conditioners can be used in countries with cold climates if a thermostat is used to reverse the refrigeration cycle to warm the lift car.

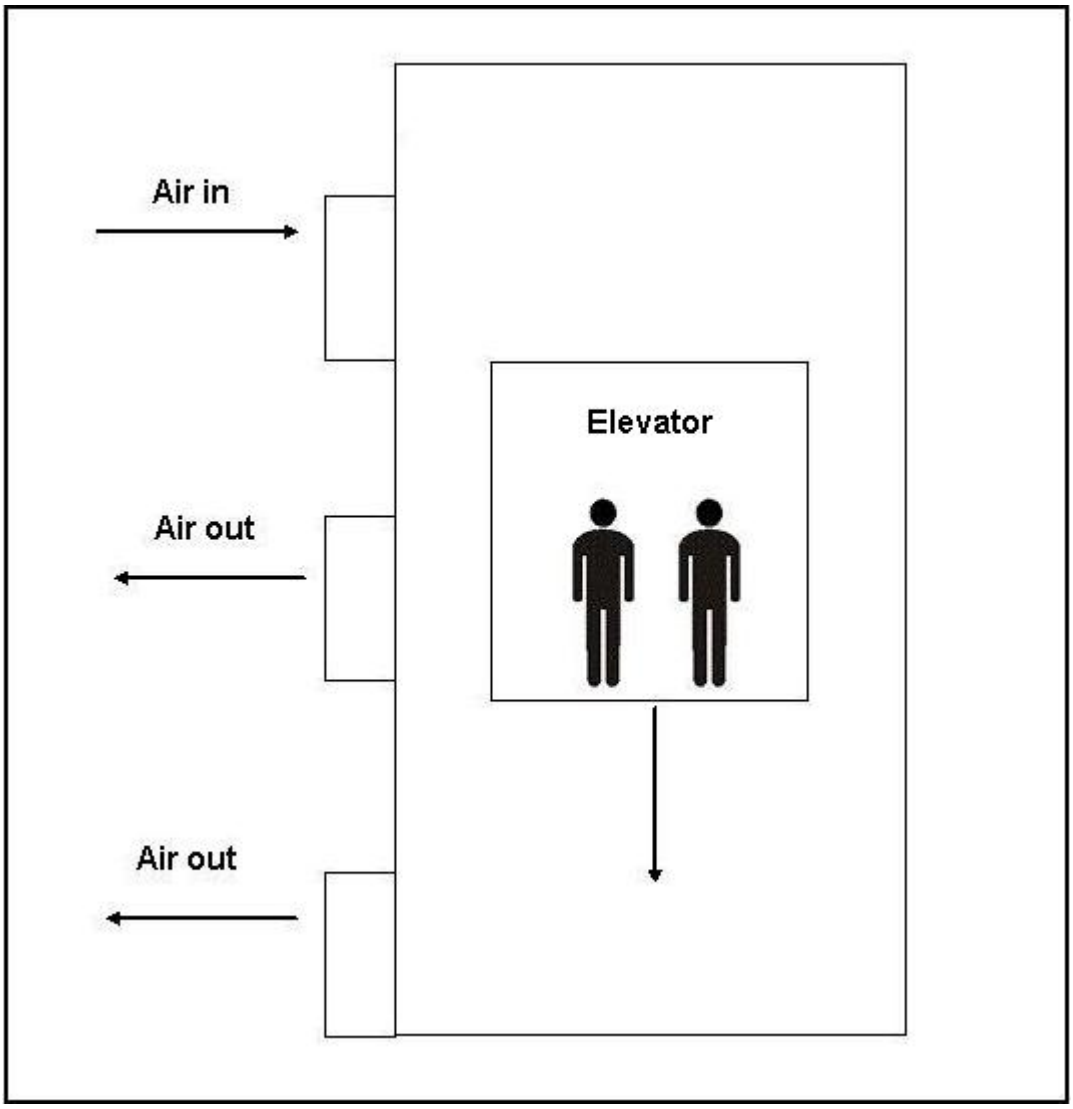
Health

One of the benefits of installing an elevator air conditioner is the clean air it provides. Air was typically drawn from the elevator shaft or hoistway into the car using a motorized fan. This air could contain dust mites, germs and bacteria. With an elevator air conditioner, the air is much cleaner because it is recirculated within the car itself and is usually filtered to remove contaminants. A poorly maintained air-conditioning system may promote the growth and spread of microorganisms, but as long as the air conditioner is kept clean, these health hazards can be avoided.

Drawbacks

Heat generated from the cooling process is rejected into the hoistway. The elevator cab (or car) is not air-tight, and some of this heat will reenter the car and reduce the overall cooling effect, which may be less than ideal.

Energy



Elevator airflow diagram

The air from the lobby constantly leaks into the elevator shaft due to elevator movements as well as elevator shaft ventilation requirements. Using this conditioned air in the elevator does not increase energy costs. However, by using an independent elevator air conditioner to achieve better temperature control inside the car, more energy will be used.

Condensation

Air conditioning poses a problem to elevators because of the condensation that occurs. The condensed water produced has to be disposed of; otherwise, it would create flooding in the elevator car and hoistway.

Ways to remove condensed water

There are at least four ways to remove condensed water from the air conditioner. However, each solution has its pros and cons.

Atomizing

Atomizing, also known as misting the condensed water, is another way to dispose of the condensed water. Spraying ultra-fine water droplets onto the hot coils of the air conditioner ensures that the condensed water evaporates quickly.

Though this is one of the best methods to dispose of the condensed water, it is also one of the costliest because the nozzle that atomizes the water easily gets choked. The majority of the cost goes to maintaining the entire atomizing system.

Boiling

Disposing of condensed water works by firstly collecting the condensed water and then heating it to above boiling point. The condensed water is eventually evaporated, thereby disposing of it.

Consumers are reluctant to employ this system because of the high rate of energy used just to dispose of this water.

Cascading

The cascading method works by flowing the condensed water directly onto the hot coils of the air conditioner. This eventually evaporates the condensed water.

The downside of this technology is that the coils have to be at extremely high temperature for the condensed water to be evaporated. There is a chance that the water might not evaporate entirely and that would cause water to overflow onto the exterior of the car.

Drainage system

Drainage system works by creating a sump to collect the condensed water and using a pump to dispose it through a drainage system.

It is an efficient method, but it comes at a heavy price because the cost of building the sump. Moreover, maintaining the pump to make sure it operates is very expensive. Furthermore, the pipes used for drainage would look ugly on the exterior. This system also cannot be implemented on a built project.

Controlling elevators

General controls

Typical freight elevator control station

A modern internal control panel. Notice the buttons labeled 1 above G.

A typical modern passenger elevator will have:

- Space to stand in, guardrails, seating cushion (luxury)
- Overload sensor—prevents the elevator from moving until excess load has been removed. It may trigger a voice prompt or buzzer alarm. This may also trigger a "full car" indicator, indicating the car's inability to accept more passengers until some are unloaded.
- Electric fans or air conditioning units to enhance circulation and comfort.
- Call buttons to choose a floor. Some of these may be key switches (to control access). In some elevators, certain floors are inaccessible unless one swipes a security card or enters a passcode (or both). In the United States and other countries, call button text and icons are raised to allow blind users to operate the elevator; many have Braille text besides.
- A set of doors kept locked on each floor to prevent unintentional access into the elevator shaft by the unsuspecting individual. The door is unlocked and opened by a machine sitting on the roof of the car, which also drives the doors that travel with the car. Door controls are provided to close immediately or reopen the doors. Objects in the path of the moving doors will either be detected by sensors or physically activate a switch that reopens the doors. Otherwise, the doors will close after a preset time.

- A stop switch (not allowed under British regulations) to halt the elevator while in motion and often used to hold an elevator open while freight is loaded. Keeping

an elevator stopped for too long may trigger an alarm. Unless local codes require otherwise, this will most likely be a key switch.

- An alarm button or switch, which passengers can use to signal that they have been trapped in the elevator.

Some elevators may have one or more of the following:

- An elevator telephone, which can be used (in addition to the alarm) by a trapped passenger to call for help.
- Hold button: This button delays the door closing timer, useful for loading freight and hospital beds.
- Call cancellation: A destination floor may be deselected by double clicking.
- Access restriction by key switches, RFID reader, code keypad, hotel room card, etc..
- One or more additional sets of doors that can serve different floor plans. For example, in an elevated crosswalk setup, the front doors may open on the street level, and the rear doors open on the crosswalk level.
- Security camera
- Plain walls or mirrored walls giving the illusion of larger area
- Glass windowpane providing a view of the building interior or onto the streets.

Other controls, which are generally inaccessible to the public (either because they are key switches, or because they are kept behind a locked panel), include:

- Fireman's service, phase II key switch
- Switch to enable or disable the elevator.
- An *inspector's* switch, which places the elevator in inspection mode (this may be situated on top of the elevator)
- Manual up/down controls for elevator technicians, to be used in inspection mode, for example.
- An *independent service*/*exclusive mode* will prevent the car from answering to hall calls and only arrive at floors selected via the panel. The door should stay open while parked on a floor. This mode may be used for temporarily transporting goods.
- Attendant service mode.

Controls in early elevators

Manual pushbutton elevator controls.

Otis 1920s controller, operational in NYC apartment building.

- Some older freight elevators are controlled by switches operated by pulling on adjacent ropes. Safety interlocks ensure that the inner and outer doors are closed before the elevator is allowed to move.
- Early elevators had no automatic landing positioning. Elevators were operated by elevator operators using a motor controller. The controller was contained within a cylindrical container about the size and shape of a cake container and this was operated via a projecting handle. This allowed some control over the energy supplied to the motor (located at the top of the elevator shaft or beside the bottom of the elevator shaft) and so enabled the elevator to be accurately positioned — if the operator was sufficiently skilled. More typically the operator would have to "jog" the control to get the elevator reasonably close to the landing point and then

direct the outgoing and incoming passengers to "watch the step". After stopping at the landing the operator would open the door/doors. Some slightly later lifts though, had door(s) that could be operated by the same control (so when the lever is moved in the desired direction, between the idle and motion points there is a trigger to close the doors. When the handle is moved to idle, the doors open again.) This sort of arrangement was used sometimes in subway stations. Manually operated elevators were generally refitted or the cabs replaced by automatic equipment by the 1950s. The major exception is freight elevators which today are just as commonly operated manually as automatically, and even when equipped with automatic controls, are often operated by an attendant to ensure efficiency.

- Early automatic elevators used relays as logic gates to control them, which began to be replaced by microprocessors in the late 1980s.
- Large buildings with multiple elevators of this type also had an *elevator dispatcher* stationed in the lobby to direct passengers and to signal the operator to leave with the use of a mechanical "cricket" noisemaker.
- Some elevators still in operation have pushbutton manual controls.

External controls

An external control panel

Elevators are typically controlled from the outside by up and down buttons at each stop. When pressed at a certain floor, the elevator arrives to pick up more passengers. If the particular elevator is currently serving traffic in a certain direction, it will only answer hall calls in the same direction unless there are no more calls beyond that floor.

In a group of two or more elevators, the call buttons may be linked to a central dispatch computer, such that they illuminate and cancel together. This is done to ensure that only one car is called at one time.

Key switches may be installed on the ground floor so that the elevator can be remotely switched on or off from the outside.

In sky lobby elevator systems, one selects the intended destination floor (in lieu of pressing "up") and is then notified which elevator will serve their request.

Floor numbering

Elevator buttons showing the missing 13th floor

The elevator algorithm

The elevator algorithm, a simple algorithm by which a single elevator can decide where to stop, is summarized as follows:

- Continue traveling in the same direction while there are remaining requests in that same direction.
- If there are no further requests in that direction, then stop and become idle, or change direction if there are requests in the opposite direction.

The elevator algorithm has found an application in computer operating systems as an algorithm for scheduling hard disk requests. Modern elevators use more complex heuristic algorithms to decide which request to service next. An introduction to these

algorithms can be found in the "Elevator traffic handbook: theory and practice" given in the references below.

Destination Control System

Some skyscraper buildings and other types of installation feature a destination operating panel where a passenger registers their floor calls before entering the car. The system lets them know which car to wait for, instead of everyone boarding the next car. In this way, travel time is reduced as the elevator makes fewer stops for individual passengers, and the computer distributes adjacent stops to different cars in the bank. Although travel time is reduced passenger waiting times may be longer as they will not necessarily be allocated the next car to depart. During the down peak period the benefit of destination control will be limited as passengers have a common destination.

It can also improve accessibility, as a mobility-impaired passenger can move to his or her designated car in advance.

Inside the elevator there is no call button to push, or the buttons are there but they cannot be pushed - except door opening and alarm button – they only indicate stopping floors.

The idea of destination control was originally conceived by Leo Port from Sydney in 1961 but at that time lift controllers were implemented in relays and were unable to optimise the performance of destination control allocations.

The system was first pioneered by Schindler Elevator in 1992 as the Miconic 10. Manufacturers of such systems claim that average traveling time can be reduced by up to 30%.

However, performance enhancements cannot be generalized as the benefits and limitations of the system are dependent on many factors. One problem is that the system is subject to gaming. Sometimes, one person enters the destination for a large group of people going to the same floor. The dispatching algorithm is usually unable to completely cater for the variation, and latecomers may find the elevator they are assigned to is already full. Also, occasionally, one person may press the floor multiple times. This is common with up/down buttons when people believe this to be an effective way to hurry elevators. However, this will make the computer think multiple people are waiting and will allocate empty cars to serve this one person.
To prevent this problem, in one implementation of destination control, every user gets an RFID card to identify himself so the system knows every user call and can cancel the first call if the passenger decides to travel to another destination to prevent empty calls. The newest invention knows even where people are located and how many on which floor because of their identification, either for the purposes of evacuating the building or for security reasons.

The same destination scheduling concept can also be applied to public transit such as in group rapid transit.

Special operating modes

Anti-Crime Protection (ACP)

Anti-Crime Protection will force each car to stop at a pre-defined landing and open its doors. This allows a security guard or a receptionist at the landing to visually inspect the passengers. The car stops at this landing as it passes to serve further demand.

Up peak (MIT)

During Up Peak mode (also called Moderate Incoming Traffic), elevator cars in a group are recalled to the lobby to provide expeditious service to passengers arriving at the building, most typically in the morning as people arrive for work or at the conclusion of a lunch-time period. Elevators are dispatched one-by-one when they reach a pre-determined passenger load, or when they have had their doors opened for a certain period of time. The next elevator to be dispatched usually has its hall lantern or a "this car leaving next" sign illuminated to encourage passengers to make maximum use of the available elevator system capacity.

The commencement of Up Peak may be triggered by a time clock, by the departure of a certain number of fully loaded cars leaving the lobby within a given time period, or by a switch manually operated by a building attendant.

Down peak

During Down Peak mode, elevator cars in a group are sent away from the lobby towards the highest floor served, after which they commence running down the floors in response to hall calls placed by passengers wishing to leave the building. This allows the elevator system to provide maximum passenger handling capacity for people leaving the building.

The commencement of Down Peak may be triggered by a time clock, by the arrival of a certain number of fully loaded cars at the lobby within a given time period, or by a switch manually operated by a building attendant.

Sabbath service (SHO)

In areas with large populations of observant Jews or in facilities catering to Jews, one may find a "Sabbath elevator". In this mode, an elevator will stop automatically at every floor, allowing people to step on and off without having to press any buttons. This prevents violation of the Sabbath prohibition against operating electrical devices when Sabbath is in effect for those who observe this ritual.

However, Sabbath mode has the side effect of wasting considerable amounts of energy, needlessly running the elevator car sequentially up and down every floor of a building, repeatedly servicing floors where it is not needed. For a tall building with many floors,

the car must move on a frequent enough basis so as to not cause undue delay for potential users that will not touch the controls as it opens the doors on every floor up the building.

Independent service (ISC)

Independent service is a special service mode found on most elevators. It is activated by a key switch either inside the elevator itself or on a centralized control panel in the lobby. When an elevator is placed on independent service, it will no longer respond to hall calls. (In a bank of elevators, traffic is rerouted to the other elevators, while in a single elevator, the hall buttons are disabled). The elevator will remain parked on a floor with its doors open until a floor is selected and the door close button is held until the elevator starts to travel. Independent service is useful when transporting large goods or moving groups of people between certain floors.

Inspection service (INS)

Inspection service is designed to provide access to the hoistway and car top for inspection and maintenance purposes by qualified elevator mechanics. It is first activated by a key switch on the car operating panel usually labeled 'Inspection', 'Car Top', 'Access Enable' or 'HWENAB'. When this switch is activated the elevator will come to a stop if moving, car calls will be canceled (and the buttons disabled), and hall calls will be assigned to other elevator cars in the group (or canceled in a single elevator configuration). The elevator can now only be moved by the corresponding 'Access' key switches, usually located at the top-most (to access the top of the car) and bottom-most (to access the elevator pit) landings. The access key switches will bypass the door lock circuit for the floor it is located on and allow the car to move at reduced inspection speed with the hoistway door open. This speed can range from anywhere up to 60% of normal operating speed on most controllers, and is usually defined by local safety codes.

Elevators have a car top inspection station that allows the car to be operated by a mechanic in order to move it through the hoistway. Generally, there are three buttons - UP, RUN, and DOWN. Both the RUN and a direction button must be held to move the car in that direction, and the elevator will stop moving as soon as the buttons are released. Most other elevators have an up/down toggle switch and a RUN button. The inspection panel also has standard power outlets for work lamps and powered tools.

Fire service mode (EFS)

Depending on the location of the elevator, fire service code will vary state to state and country to country. Fire service is usually split up into two modes: Phase One and Phase Two. These are separate modes that the elevator can go into.

Phase one mode is activated by a corresponding smoke sensor or heat sensor in the building. Once an alarm has been activated, the elevator will automatically go into phase one. The elevator will wait an amount of time, then proceed to go into nudging mode to tell everyone the elevator is leaving the floor. Once the elevator has left the floor,

depending on where the alarm was set off, the elevator will go to the Fire Recall Floor. However, if the alarm was activated on the fire recall floor the elevator will have an alternate floor to recall to. When the elevator is recalled, it proceeds to the recall floor and stops with its doors open. The elevator will no longer respond to calls or move in any direction. Located on the fire recall floor is a fire service key switch. The fire service key switch has the ability to turn fire service off, turn fire service on or to bypass fire service. The only way to return the elevator to normal service is to switch it to bypass after the alarms have reset.

Phase two mode can only be activated by a key switch located inside the elevator on the centralized control panel. This mode was created for firefighters so that they may rescue people from a burning building. The phase two key switch located on the COP has three positions: off, on, and hold. By turning phase two on, the firefighter enables the car to move. However, like independent service mode, the car will not respond to a car call unless the firefighter manually pushes and holds the door close button. Once the elevator gets to the desired floor it will not open its doors unless the firefighter holds the door open button. This is in case the floor is burning and the firefighter can feel the heat and knows not to open the door. The firefighter must hold door open until the door is completely opened. If for any reason the firefighter wishes to leave the elevator, they will use the hold position on the key switch to make sure the elevator remains at that floor. If the firefighter wishes to return to the recall floor, they simply turn the key off and close the doors.

Fire Service is for emergency use only, although fire service keys can be purchased on eBay, and other websites. Only trained responders should use this feature, and it is by no means a safe way to escape from a burning building.

Medical emergency/'Code Blue' service (EHS)

Commonly found in hospitals, Code Blue service allows an elevator to be summoned to any floor for use in an emergency situation. Each floor will have a 'Code Blue' recall key switch, and when activated, the elevator system will immediately select the elevator car that can respond the fastest, regardless of direction of travel and passenger load. Passengers inside the elevator will be notified with an alarm and indicator light to exit the elevator when the doors open.

Once the elevator arrives at the floor, it will park with its doors open and the car buttons will be disabled to prevent a passenger from taking control of the elevator. Medical personnel must then activate the Code Blue key switch inside the car, select their floor and close the doors with the door close button. The elevator will then travel non-stop to the selected floor, and will remain in Code Blue service until switched off in the car. Some hospital elevators will feature a 'hold' position on the Code Blue key switch (similar to fire service) which allows the elevator to remain at a floor locked out of service until Code Blue is deactivated.

Emergency power operation (EPR)

Many elevator installations now feature emergency power systems which allow elevator use in blackout situations and prevent people from becoming trapped in elevators.

Traction elevators

When power is lost in a traction elevator system, all elevators will initially come to a halt. One by one, each car in the group will return to the lobby floor, open its doors and shut down. People in the remaining elevators may see an indicator light or hear a voice announcement informing them that the elevator will return to the lobby shortly. Once all cars have successfully returned, the system will then automatically select one or more cars to be used for normal operations and these cars will return to service. The car(s) selected to run under emergency power can be manually overridden by a key or strip switch in the lobby. In order to help prevent entrapment, when the system detects that it is running low on power, it will bring the running cars to the lobby or nearest floor, open the doors and shut down.

Hydraulic elevators

In hydraulic elevator systems, emergency power will lower the elevators to the lowest landing and open the doors to allow passengers to exit. The doors then close after an adjustable time period and the car remains unusable until reset, usually by cycling the elevator main power switch. Typically, due to the high current draw when starting the pump motor, hydraulic elevators aren't run using standard emergency power systems. Buildings like hospitals and nursing homes usually size their emergency generators to accommodate this draw. However, the increasing use of current limiting motor starters, commonly known as "Soft-Start" contactors, avoid much of this problem and the current draw of the pump motor is less of a limiting concern.

Elevator convenience features

Elevator floor indicator

Elevators may feature talking devices as an accessibility aid for the blind. In addition to floor arrival notifications, the computer announces the direction of travel, and notifies the passengers before the doors are to close.

In addition to the call buttons, elevators usually have floor indicators (often illuminated by LED) and direction lanterns. The former are almost universal in cab interiors with more than two stops and may be found outside the elevators as well on one or more of the floors. Floor indicators can consist of a dial with a rotating needle, but the most common types are those with successively illuminated floor indications or LCDs. Likewise, a change of floors or an arrival at a floor is indicated by a sound, depending on the elevator.

Direction lanterns are also found both inside and outside elevator cars, but they should always be visible from outside because their primary purpose is to help people decide whether or not to get on the elevator. If somebody waiting for the elevator wants to go up, but a car comes first that indicates that it is going down, then the person may decide not to get on the elevator. If the person waits, then one will still stop going up. Direction indicators are sometimes etched with arrows or shaped like arrows and/or use the convention that one that lights up red means "down" and green means "up". Since the color convention is often undermined or overrided by systems that do not invoke it, it is

usually used only in conjunction with other differentiating factors. An example of a place whose elevators use only the color convention to differentiate between directions is the Museum of Contemporary Art in Chicago, where a single circle can be made to light up green for "up" and red for "down." Sometimes directions must be inferred by the position of the indicators relative to one another.

In addition to lanterns, most elevators have a chime to indicate if the elevator is going up or down either before or after the doors open, usually in conjunction with the lanterns lighting up. Universally, one chime is for up, two is for down, and none indicates an elevator that is 'free'.

Observatory service elevators often convey other facts of interest, including elevator speed, stopwatch, and current position (altitude), as with the case for Taipei 101's service elevators.

Standards

The mechanical and electrical design of elevators is dictated according to various standards (aka elevator codes), which may be international, national, state, regional or city based. Whereas once many standards were prescriptive, specifying exact criteria which must be complied with, there has recently been a shift towards more performance-based standards where the onus falls on the designer to ensure that the elevator meets or exceeds the standard.

Some of the national elevator standards include:

- Australia – AS1735
- Canada – CAN/CSA B44
- Europe – EN 81 series (EN 81-1, EN 81-2, EN 81-28, EN 81-70, EN 12015, EN 12016, EN 13015, etc.)
- USA – ASME A17

Because an elevator is part of a building, it must also comply with standards relating to earthquake resilience, fire standards, electrical wiring rules and so forth.

The American National Elevator Standards Group (ANESG) sets an elevator weight standard to be 2200 lbs.

Additional requirements relating to access by disabled persons, may be mandated by laws or regulations such as the Americans with Disabilities Act.

US and Canadian elevator standard specifics

A typical elevator style (Dover/ThyssenKrupp Impulse fixtures) found in many modern residential and small commercial buildings.

In most US and Canadian jurisdictions, passenger elevators are required to conform to the American Society of Mechanical Engineers' Standard A17.1, Safety Code for Elevators and Escalators. In Canada the document is the CAN/CSA B44 Safety Standard, which was harmonized with the US version in the 2000 edition. In addition, passenger elevators may be required to conform to the requirements of A17.3 for existing elevators where referenced by the local jurisdiction. Passenger elevators are tested using the ASME A17.2 Standard. The frequency of these tests is mandated by the local jurisdiction, which may be a town, city, state or provincial standard.

Passenger elevators must also conform to many ancillary building codes including the Local or State building code, National Fire Protection Association standards for Electrical, Fire Sprinklers and Fire Alarms, Plumbing codes, and HVAC codes. Also, passenger elevators are required to conform to the Americans with Disabilities Act and other State and Federal civil rights legislation regarding accessibility.

Residential elevators are required to conform to ASME A17.1. Platform and Wheelchair lifts are required to comply with ASME A18.1 in most US jurisdictions.

Most elevators have a location in which the permit for the building owner to operate the elevator is displayed. While some jurisdictions require the permit to be displayed in the elevator cab, other jurisdictions allow for the operating permit to be kept on file elsewhere – such as the maintenance office – and to be made available for inspection on demand. In such cases instead of the permit being displayed in the elevator cab, often a notice is posted in its place informing riders of where the actual permits are kept.

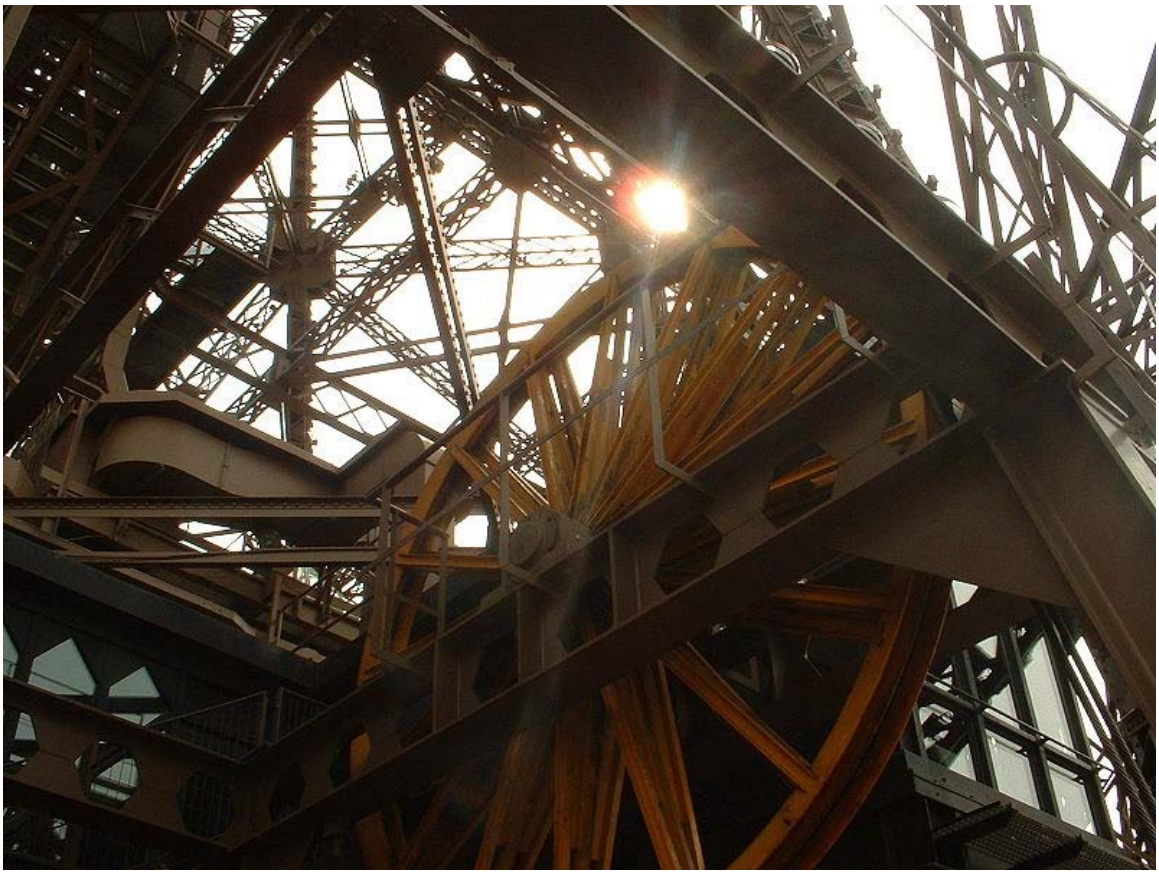
Unique elevator installations

World statistics

Country	Number of elevators installed	
Italy	-	United States 700,000
People's Republic of China	610,000	

As of January 2008, Italy is the nation with the most elevators installed in the world, with 850,000 elevators installed that run more than one hundred million lifts every day, followed by United States with 700,000 elevators installed and People's Republic of China with 610,000 elevators installed since 1949. In Brazil, it is estimated that there are approximately 300,000 elevators currently in operation. The world's largest market for elevators is Italy with more than 1,629 million euros of sales and 1,224 million euros of internal market.

Eiffel Tower



An elevator pulley in the Eiffel Tower.

The Eiffel Tower has Otis double-deck elevators built into the legs of the tower, serving the ground level to the first and second levels. Even though the shaft runs diagonally upwards with the contour of the tower, both the upper and lower cars remain horizontally level. The offset distance of the two cars changes throughout the journey.

There are four elevator cars of the traditional design that run from the second level to the third level. The cars are connected to their opposite pairs (opposite in the elevator landing/hall) and use each other as the counterweight. As one car ascends from level 2, the other descends from level 3. The operations of these elevators are synchronized by a light signal in the car.

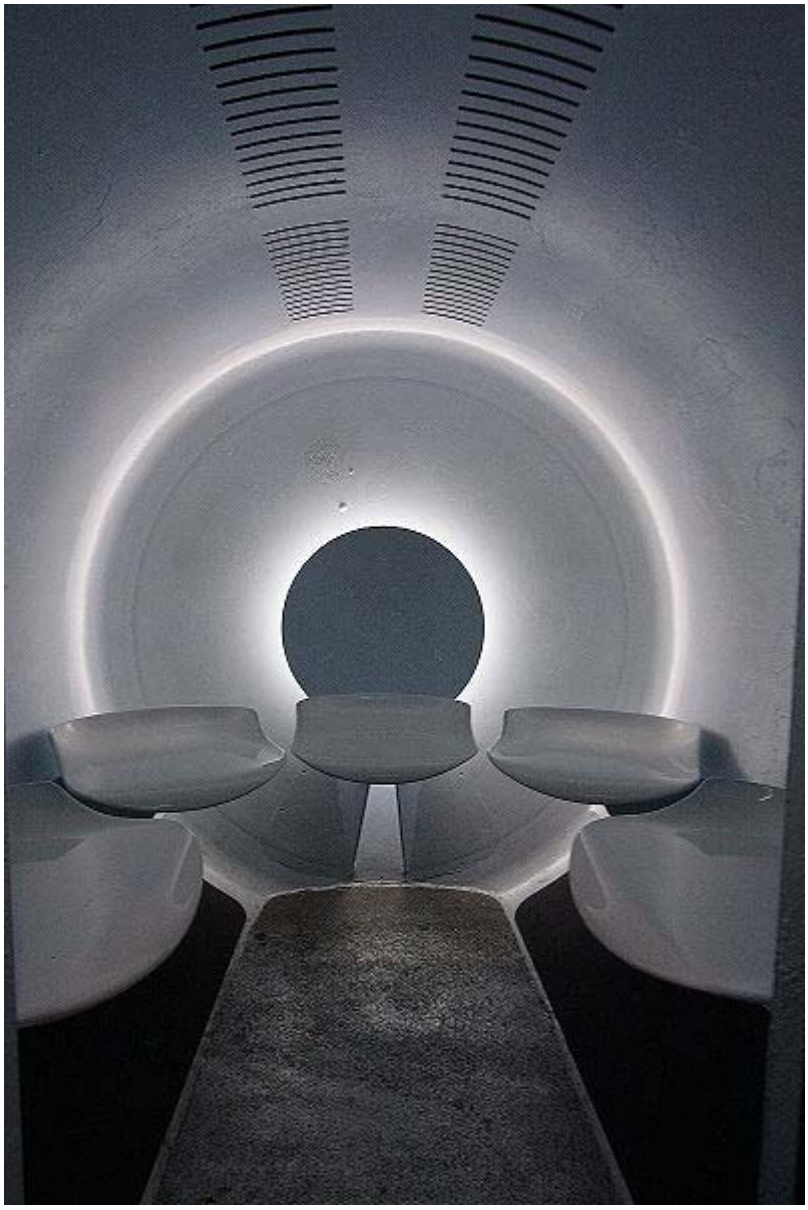
Taipei 101

The observation deck elevator floor indicator in the Taipei 101.

Double deck elevators are used in the Taipei 101 office tower. Tenants of even-numbered floors first take an escalator (or an elevator from the parking garage) to the 2nd level, where they will enter the upper deck and arrive at their floors. The lower deck is turned off during low-volume hours, and the upper deck can act as a single-level elevator stopping at all adjacent floors. For example, the 85th floor restaurants can be accessed from the 60th floor sky-lobby. Restaurant customers must clear their reservations at the reception counter on the 2nd floor. A bank of express elevators stop only on the sky lobby levels (36 and 60, upper deck car), where tenants can transfer to "local" elevators.

The high speed observation deck elevators accelerate to a world-record certified speed of 1010 meters per minute (60.6 km/h) in 16 seconds, and then it slows down for arrival with subtle air pressure sensations. The door opens after 37 seconds from the 5th floor. Special features include aerodynamic car and counterweights, and cabin pressure control to help passengers adapt smoothly to pressure changes. The downwards journey is completed at a reduced speed of 600 meters per minute, with the doors opening at the 52nd second.

The Gateway Arch



The interior of one of the Gateway Arch tramway cars

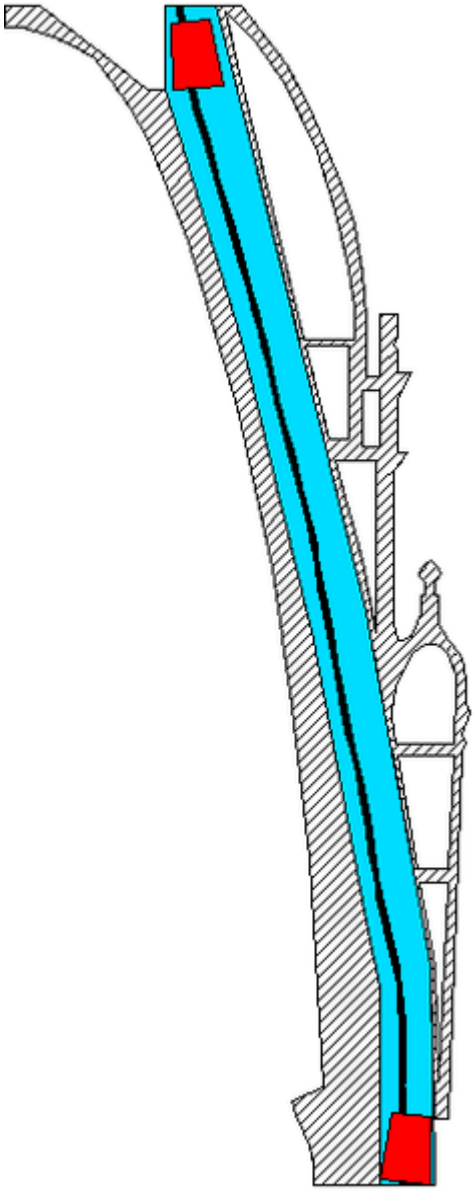
The Gateway Arch in St. Louis, Missouri has a unique elevator system which carries passengers from the visitors' center underneath the Arch to the observation deck at the top of the structure.

Called a *tram* or *tramway*, people enter this unique tramway much as one would enter an ordinary elevator, through double doors. Passing through the doors the passengers in small groups enter a horizontal cylindrical compartment containing seats on each side and a flat floor. A number of these compartments are linked to form a train. These compartments each individually retain an appropriate level orientation by tilting while the entire train follows curved tracks up one leg of the arch.

There are two tramways within the Arch, one at the north end, and the other at the south end. The entry doors have windows, so people traveling within the Arch are able to see the interior structure of the Arch during the ride to and from the observation deck. At the beginning of the trip the cars hang from the drive cables, but as the angle of the shaft changes, they end up beside and then on top of the cables.

View up the shaft of the elevator at the new city hall, Hannover, Germany.

New City Hall, Hanover, Germany



Elevator in the new city hall, Hannover, Germany, showing the cabin at the bottom and the top

The elevator in the New City Hall in Hanover, Germany is a technical rarity, and unique in Europe, as the elevator starts straight up but then changes its angle by 15 degrees to follow the contour of the dome of the hall. The cabin therefore tilts 15 degrees during the ride. The elevator travels a height of 43 meters. The new city hall was built in 1913. The elevator was destroyed in 1943 and rebuilt in 1954.

Luxor Inclinator Elevator

In Las Vegas, Nevada, at the Luxor Hotel, is the Inclinator. The shape of this casino is a pyramid. Therefore, the elevator travels up the side of the pyramid at a 39 degree angle. Although people refer to this "inclined elevator" as an inclinator, this is incorrect.

Twilight Zone Tower of Terror

The Twilight Zone Tower of Terror is the common name for a series of elevator attractions at the Disney's Hollywood Studios park in Orlando, the Disney's California Adventure park in Anaheim, the Walt Disney Studios Park in Paris and the Tokyo DisneySea park in Tokyo. The central element of this attraction is a simulated free-fall achieved through the use of a high-speed elevator system. For safety reasons, passengers are seated and secured in their seats rather than standing. Unlike most traction elevators, the elevator car and counterweight are joined using a rail system in a continuous loop running through both the top and the bottom of the drop shaft. This allows the drive motor to pull down on the elevator car from underneath, resulting in downward acceleration greater than that of normal gravity. The high-speed drive motor is used to rapidly lift the elevator as well.

The passenger cabs are mechanically separated from the lift mechanism, thus allowing the elevator shafts to be used continuously while passengers board and embark from the cabs. Multiple elevator shafts are used to further improve passenger throughput. The doorways of the top few "floors" of the attraction are open to the outdoor environment, thus allowing passengers to look out from the top of the structure.

"Top of the Rock" elevators

Guests ascending to the 67th, 69th, and 70th level observation decks (dubbed "Top of the Rock") atop the GE Building at Rockefeller Center in New York City ride a high-speed glass-top elevator. When entering the cab, it appears to be any normal elevator ride. However, once the cab begins moving, the interior lights turn off and a special blue light above the cab turns on. This lights the entire shaft, so riders can see the moving cab through its glass ceiling as it rises and lowers through the shaft. Music plays and various animations are also displayed on the ceiling. The entire ride takes about 60 seconds.

Disneyland, Anaheim, California

Part of the Haunted Mansion attraction at Disneyland in Anaheim, California, takes place on an elevator. The "stretching room" on the ride is actually an elevator that travels downwards, giving access to a short underground tunnel which leads to the rest of the attraction. The elevator has no ceiling and its shaft is decorated to look like walls of a mansion. Because there is no roof, passengers are able to see the walls of the shaft by looking up, which gives the illusion of the room stretching. The Haunted Mansion attraction at Disney World does not feature this, rather it gives you the illusion it is moving while it remains stationary.

Elevators for urban transport

In some towns where terrain is difficult to navigate, elevators are used as part of urban transport systems. Examples:

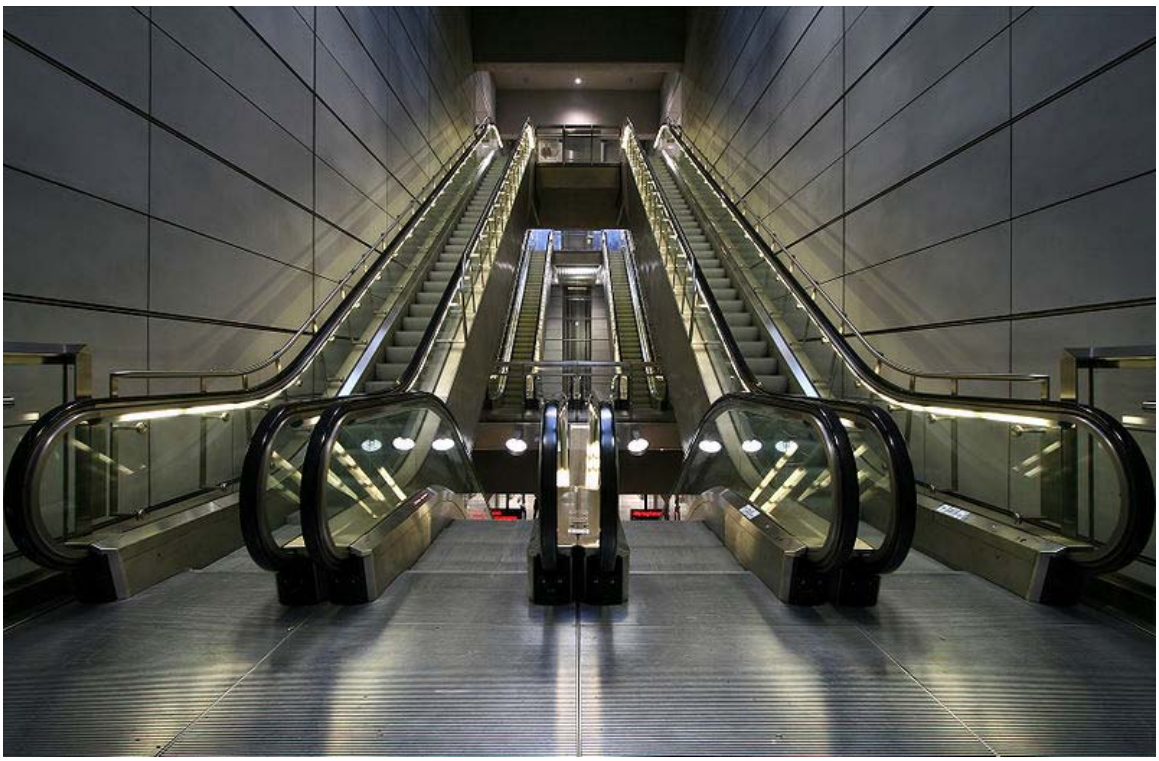
- Almada, Portugal: *Elevador da Boca do Vento*
- Asansor, Izmir, Turkey
- Ascensores de Valparaíso, urban funicular in Valparaíso, Chile
- Bad Schandau Elevator in Bad Schandau, Germany
- Barcelona, Spain - Elevator and cableway line connecting the port terminal to Montjuic hill
- Bilbao - Casco Viejo Bilbao Metro station (fare-paying elevator connecting upper and lower neighbourhoods, as well as the station)
- Coimbra, Portugal: *Elevador do Mercado*
- Genoa, Italy - eleven public elevators
- Hammetschwand Elevator in Bürgenstock, Switzerland
- Jersey City, New Jersey elevator at Bergen Hudson Light Rail station at 9th Street and Palisade Avenue.
- Katarina Elevator in Stockholm, Sweden
- Lisbon, Portugal: *Elevador de Santa Justa*, *Castelo* (planned), *Chiado* (closed), *Município/Biblioteca* (demolished)
- Luxembourg
- Lynchburg, Virginia - Outdoor Public elevator

Shanklin Cliff lift in Shanklin, Isle of Wight

- Marburg, Germany - some parts of the historic city core built on higher ground (Uppertown, "Oberstadt" in German) are accessible from the lower street level by elevators. These elevators are unique in servicing also various buildings partially embedded in the steep-sloping terrain.
- Monaco, seven elevators
- Naples, Italy - three public elevators
- Oporto, Portugal: *Elevador da Ribeira*
- Oregon City Municipal Elevator in Oregon City, Oregon, United States
- Salvador, Bahia, Brazil: *Elevador Lacerda*
- Santa Justa Lift in Lisbon, Portugal
- Shanklin Cliff Lift in Shanklin, Isle of Wight
- Skyway in Nagasaki, Japan
- Yalta, Ukraine

Chapter 3

Escalator



Escalators in a Copenhagen Metro station, Denmark, 2007.

An **escalator** is a moving staircase – a conveyor transport device for carrying people between floors of a building. The device consists of a motor-driven chain of individual, linked steps that move up or down on tracks, allowing the step treads to remain horizontal.

Escalators are used around the world to move pedestrian traffic in places where elevators would be impractical. Principal areas of usage include department stores, shopping malls, airports, transit systems, convention centers, hotels, and public buildings.

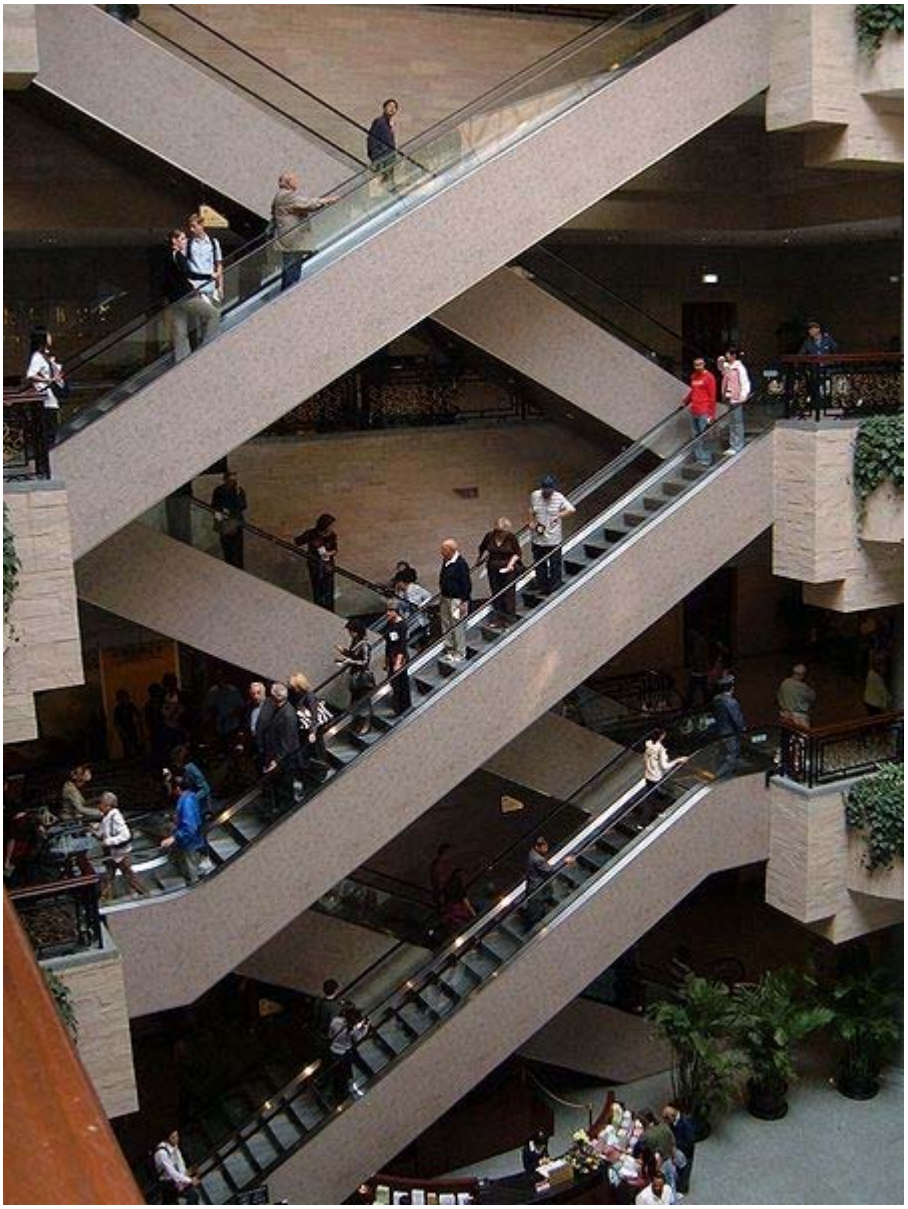
The benefits of escalators are many. They have the capacity to move large numbers of people, and they can be placed in the same physical space as one might install a staircase. They have no waiting interval (except during very heavy traffic), they can be used to guide people toward main exits or special exhibits, and they may be weatherproofed for outdoor use.

In 2004, it was estimated that the United States had 30,000 escalators, and that people used escalators 90 billion times each year.

Design, components, and operation

Operation and layout

Escalators, like moving walkways, are powered by constant-speed alternating current motors and move at approximately 1–2 feet (0.30–0.61 m) per second. The typical angle of inclination of an escalator to the horizontal floor level is 30 degrees with a standard rise up to about 60 feet (18 m). Modern escalators have single piece aluminum or steel steps that move on a system of tracks in a continuous loop.



"**Crisscross**" layout

"**Multiple parallel**" layout

"**Parallel**" layout

Escalators have three typical configuration options: **parallel** (up and down escalators "side by side or separated by a distance", seen often in metro stations and multilevel motion picture theaters), **crisscross** (minimizes structural space requirements by "stacking" escalators that go in one direction, frequently used in department stores or shopping centers), and **multiple parallel** (two or more escalators together that travel in one direction next to one or two escalators in the same bank that travel in the other direction).

Escalators are required to have moving handrails that keep pace with the movement of the steps. The direction of movement (up or down) can be permanently the same, or be controlled by personnel according to the time of day, or automatically be controlled by whoever arrives first, whether at the bottom or at the top (the system is programmed so that the direction is not reversed while a passenger is on the escalator).

Design and layout considerations

A number of factors affect escalator design, including physical requirements, location, traffic patterns, safety considerations, and aesthetic preferences. Foremost, physical factors like the vertical and horizontal distance to be spanned must be considered. These factors will determine the pitch of the escalator and its actual length. The ability of the

building infrastructure to support the heavy components is also a critical physical concern. Location is important because escalators should be situated where they can be easily seen by the general public. In department stores, customers should be able to view the merchandise easily. Furthermore, up and down escalator traffic should be physically separated and should not lead into confined spaces.

Traffic patterns must also be anticipated in escalator design. In some buildings, the objective is simply to move people from one floor to another, but in others there may be a more specific requirement, such as funneling visitors towards a main exit or exhibit. The number of passengers is important because escalators are designed to carry a certain maximum number of people. For example, a single-width escalator traveling at about 1.5 feet (0.46 m) per second can move an estimated 170 persons per five minute period. The carrying capacity of an escalator system must match the expected peak traffic demand, presuming that passengers ride single file. This is crucial for applications in which there are sudden increases in the number of riders. For example, escalators at stations must be designed to cater for the peak traffic flow discharged from a train, without causing excessive bunching at the escalator entrance.

In this regard, escalators help in controlling traffic flow of people. For example, an escalator to an exit effectively discourages most people from using it as an entrance, and may reduce security concerns. Similarly, escalators often are used as the exit of airport security checkpoints. Such an egress point would generally be staffed to prevent its use as an entrance, as well.

It is preferred that staircases be located adjacent to the escalator if the escalator is the primary means of transport between floors. It may also be necessary to provide an elevator lift adjacent to an escalator for wheelchairs and disabled persons. Finally, consideration should be given to the aesthetics of the escalator. The architects and designers can choose from a wide range of styles and colors for the handrails and balustrades.

Model sizes and other specifications

Escalator step widths and energy usage

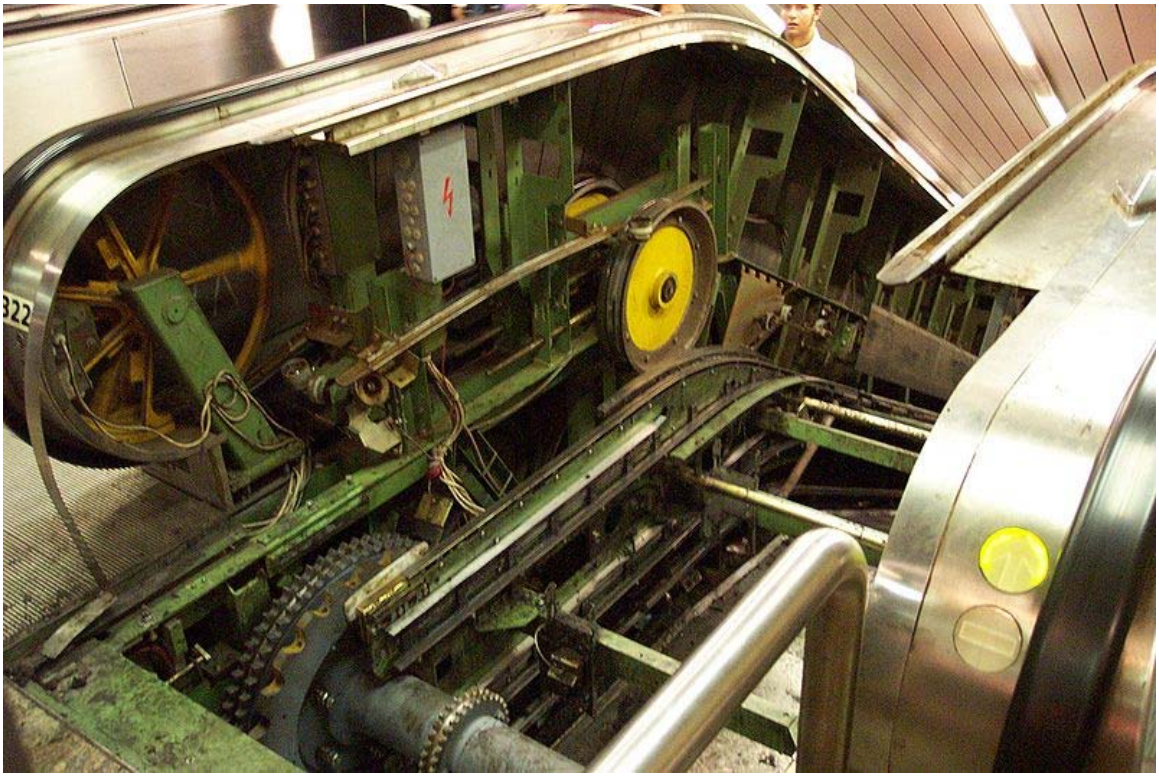
Size	Width (between balustrade panels)	Single-step capacity	Applications	Energy consumption
Very small	400 mm (16 in)	One passenger, with feet together	A rare historic design found mostly in older department stores	3.7 kW (5.0 hp)
Small	600 mm (24 in)	One passenger	Low-volume sites, uppermost levels of department stores, when space is limited	3.7 kW (5.0 hp)
Medium	800 mm (31 in)	One passenger +	Shopping malls,	7.5 kW (10.1

		one package or one piece of luggage	department stores, smaller airports	hp)
Large	1,000 mm (39 in)	Two passengers – one may walk past another	Mainstay of metro systems, larger airports, train stations, some retail usage	7.5 kW (10.1 hp)

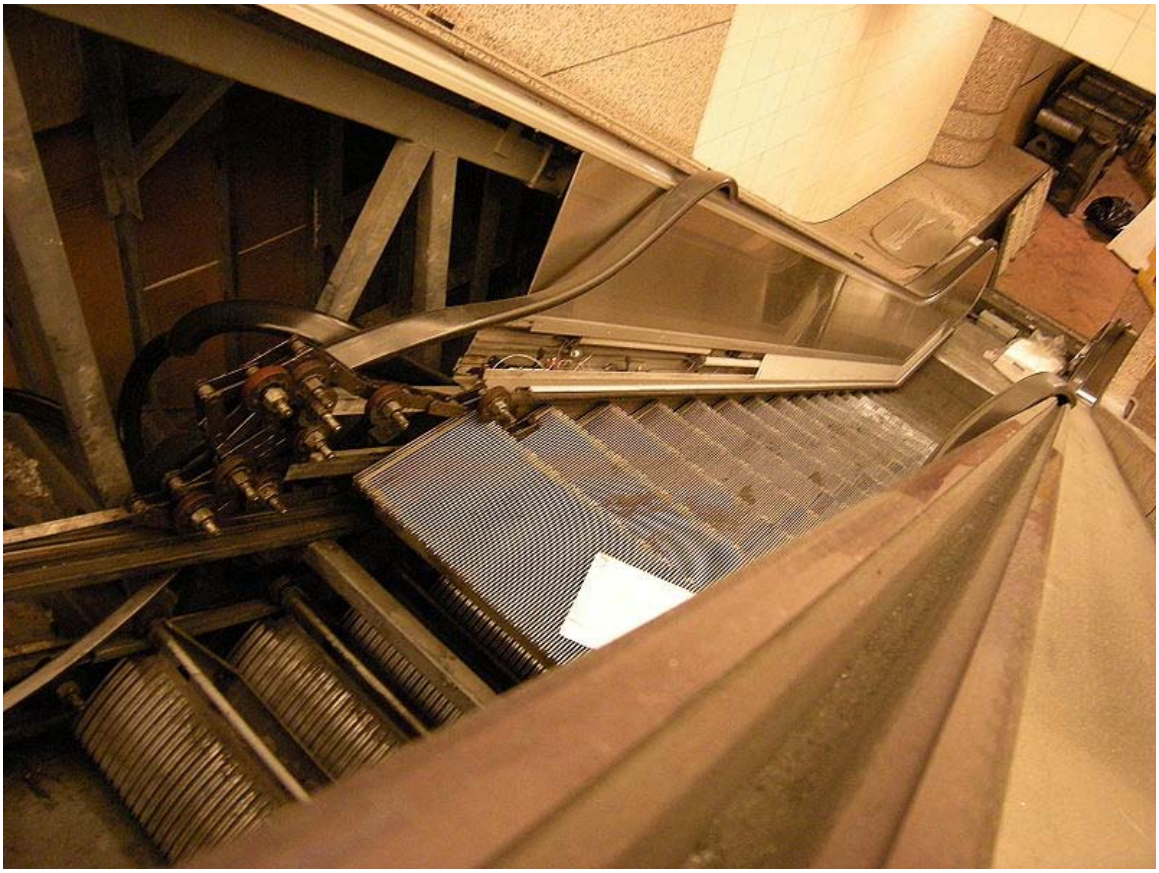
Components

An escalator being repaired at Town Hall Station in Sydney, Australia.

A "freestanding" escalator reveals its inner components through the transparent truss.



Escalator truss connects to the landing platform (lower left). Also visible: exposed drive gears (center) for steps and handrail drive (left).



View of escalator steps on continuous chain.

An escalator equipped with a "bellows" handrail. The bracelets are colored grey, with occasional strings of black ones to appear as moving spacers.

Landing platforms

These two platforms house the curved sections of the tracks, as well as the gears and motors that drive the stairs. The top platform contains the motor assembly and the main drive gear, while the bottom holds the step return idler sprockets. These sections also anchor the ends of the escalator truss. In addition, the platforms contain a floor plate and a combplate. The floor plate provides a place for the passengers to stand before they step onto the moving stairs. This plate is flush with the finished floor and is either hinged or removable to allow easy access to the machinery below. The combplate is the piece between the stationary floor plate and the moving step. It is so named because its edge has a series of cleats that resemble the teeth of a comb. These teeth mesh with matching cleats on the edges of the steps. This design is necessary to minimize the gap between the stair and the landing, which helps prevent objects from getting caught in the gap.

Truss

The truss is a hollow metal structure that bridges the lower and upper landings. It is composed of two side sections joined together with cross braces across the bottom and just below the top. The ends of the truss are attached to the top and bottom landing platforms via steel or concrete supports. The truss carries all the straight track sections connecting the upper and lower sections.

Tracks

The track system is built into the truss to guide the step chain, which continuously pulls the steps from the bottom platform and back to the top in an endless loop. There are actually two tracks: one for the front wheels of the steps (called the step-wheel track) and one for the back wheels of the steps (called the trailer-wheel track). The relative positions of these tracks cause the steps to form a staircase as they move out from under the combplate. Along the straight section of the truss the tracks are at their maximum distance apart. This configuration forces the back of one step to be at a 90-degree angle relative to the step behind it. This right angle bends the steps into a shape resembling a staircase. At the top and bottom of the escalator, the two tracks converge so that the front and back wheels of the steps are almost in a straight line. This causes the stairs to lay in a flat sheetlike arrangement, one after another, so they can easily travel around the bend in the curved section of track. The tracks carry the steps down along the underside of the truss until they reach the bottom landing, where they pass through another curved section of track before exiting the bottom landing. At this point the tracks separate and the steps once again assume a staircase configuration. This cycle is repeated continually as the steps are pulled from bottom to top and back to the bottom again.

Steps

The steps themselves are solid, one piece, die-cast aluminum or steel. Yellow demarcation lines may be added to clearly indicate their edges. In most escalator models manufactured after 1950, both the riser and the tread of each step is cleated (given a ribbed appearance) with comblike protrusions that mesh with the combplates on the top and bottom platforms and the succeeding steps in the chain. Seeberger- or "step-type" escalators (see below) featured flat treads and smooth risers; other escalator models have cleated treads and smooth risers. The steps are linked by a continuous metal chain that forms a closed loop. The front and back edges of the steps are each connected to two wheels. The rear wheels are set further apart to fit into the back track and the front wheels have shorter axles to fit into the narrower front track. As described above, the position of the tracks controls the orientation of the steps.

Handrail

The handrail provides a convenient handhold for passengers while they are riding the escalator. In an escalator, the handrail is pulled along its track by a chain that is connected to the main drive gear by a series of pulleys. It is constructed of four distinct sections. At the center of the handrail is a "slider", also known as a "glider ply", which is a layer of a cotton or synthetic textile. The purpose of the slider layer is to allow the handrail to move smoothly along its track. The next layer, known as the "tension member", consists of either steel cable or flat steel tape, and provides the handrail with tensile strength and flexibility. On top of tension member are the inner construction components, which are made of chemically treated rubber designed to prevent the layers from separating. Finally, the outer layer—the only part that passengers actually see—is the cover, which is a blend of synthetic polymers and rubber. This cover is designed to resist degradation from environmental conditions, mechanical wear and tear, and human vandalism.

In the factory, handrails are constructed by feeding rubber through a computer-controlled extrusion machine to produce layers of the required size and type in order to match specific orders. The component layers of fabric, rubber, and steel are shaped by skilled workers before being fed into the presses, where they are fused together.
In the mid-twentieth century, some handrail designs consisted of a rubber bellows, with rings of smooth metal cladding called "bracelets" placed between each coil. This gave the handrail a rigid yet flexible feel. Additionally, each bellows section was no more than a few feet long, so if part of the handrail was damaged, only the bad segment needed to be replaced. These forms of handrail have largely been replaced with conventional fabric-and-rubber railings.

Safety

Safety is also major concern in escalator design. In India where women wear saris, there are heavy chances of getting the *pallu* entangled in the escalator special *sari guard* is inbuilt in most escalators.

There is a risk of feet injuries for children wearing footwear such as Crocs and flip-flops that might get caught in escalator mechanisms. This was due to the softness of the shoe's material combined with the smaller size of children's feet.

Fire protection of an escalator floor opening may be provided by adding automatic sprinklers or fireproof shutters to the opening, or by installing the escalator in an enclosed fire-protected hall. To limit the danger of overheating, ventilation for the spaces that contain the motors and gears must be provided.

Accidents and litigation

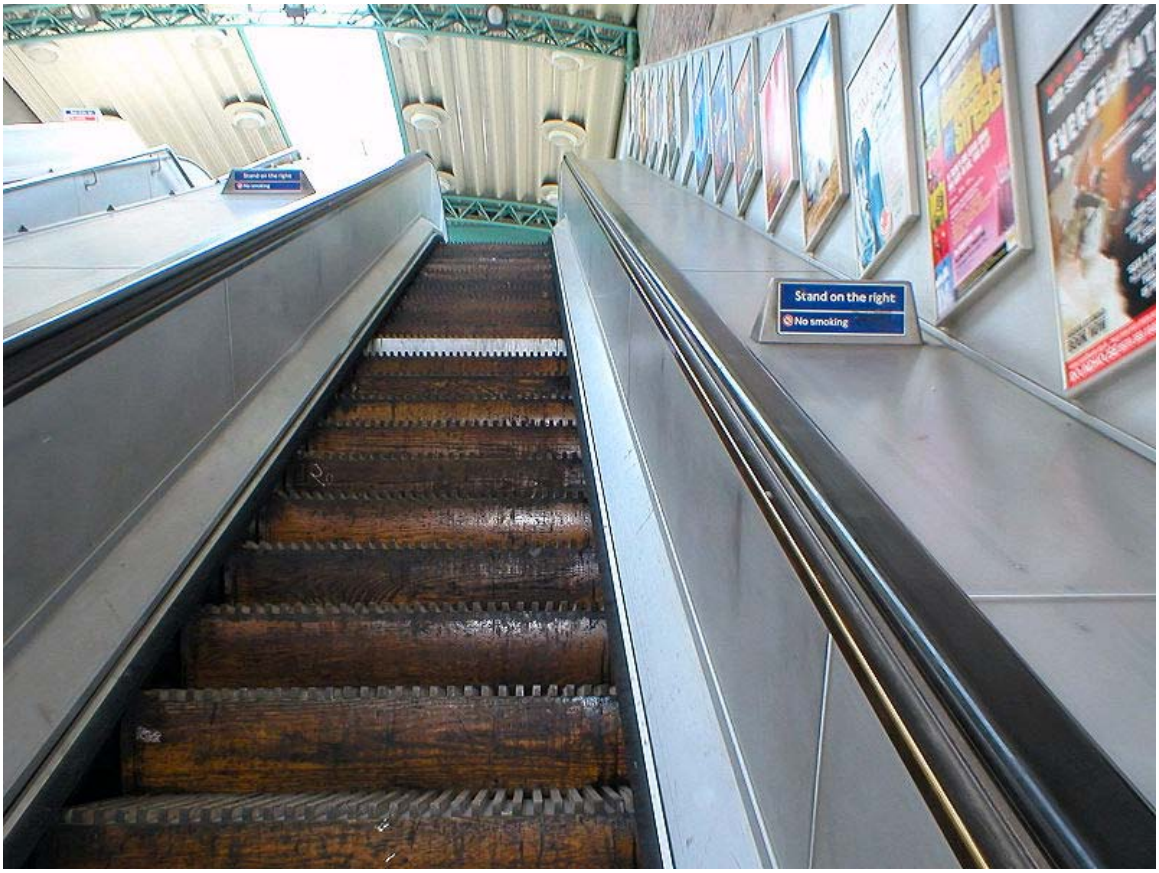
Accidents

There have been reports of people falling off a moving escalator or getting their shoe stuck in part of the escalator; shoe laces are a hazard when loose. Some accidents are caused by improper or unsafe use such as riding the hand rails (see bullet points below) or by escalator spinning. A few fatal accidents are:

- Eight people died and 30 more were injured on Wednesday, February 17, 1982, when an escalator collapsed on the Moscow Metro. Wrongly set up service brakes were later blamed for the accident.
- 31 people died after a fire, begun in the undercarriage of an MH-type Otis escalator, exploded into the ticketing hall at King's Cross St. Pancras station in 1987.
- On Monday, December 13, 1999, 8-year-old Jyotsna Jethani was killed at New Delhi's international airport. Jethani fell into a gaping hole that resulted from improper maintenance.

- On Saturday, June 15, 2002, Andrea Albright, a 24-year-old J.C. Penney employee in Columbia, Maryland, was critically injured while riding the store's escalator from the first to the second level. She somehow got her head caught between the escalator rail and a low ceiling. In 2005, her parents sued the property manager, two design firms, and the escalator company for $5 million.
- On New Years Eve, 2004, escalators at the Taipei City Hall Station kept moving commuters onto the overcrowded island platform. A woman whose hair got caught in the escalator received 20 stitches to the scalp.
- Francisco Portillo, a Salvadoran sushi chef, died after being strangled when his sweatshirt got caught in an escalator at the Porter Square MBTA station in Cambridge, Massachusetts on February 21, 2005. He was allegedly drunk at the time.
- On Saturday, September 13, 2008, an 11-year old boy died after falling off an escalator in Lyngdal, Norway. On Monday, April 20, 2009, a teenage boy died after getting very serious skull injuries after falling off an escalator in Falun, Sweden. On Friday, June 26, 2009, a man died after falling off an escalator in Helsingborg, Sweden. All three were riding the handrail.

Lessons of the King's Cross fire



Greenford station escalators (2006).

The King's Cross fire illustrated the demanding nature of escalator upkeep and the devices' propensity to collect "fluff" when not properly maintained.

Since the station was part of a public institution (the London Underground) and there was a substantial casualty rate, the incident yielded vociferous public outcry as riders and victims' families demanded the removal of all wooden escalators systemwide. In the official inquiry that followed, the Fennell Report, it was determined that the fire started slowly, smoldered virtually undetected for a time, then exploded into the ticketing hall above in a phenomenon known as the "trench effect." This slow-burning fire, Fennell found, was allegedly kindled by a discarded unextinguished cigarette, which was shown in laboratory tests to be a more powerful ignition source than a lit match. In the escalators' undercarriage, approximately 8,800 kilograms (19,000 lb) of accumulated detritus acted as a wick to a neglected buildup of interior lubricants; wood veneers, paper and plastic advertisements, solvent-based paint, plywood in the ticket hall, and melamine combustion added to the impact of the calamity. Taking this particular situation as an example, one could easily speculate that any accretion of flammable fuels, cloth, or scraps (the "fluff" denoted by Fennell) could likewise lead to a devastating fire.

Consequentially, older wooden escalators were removed from service in the London Underground, though at least one set remains in operation, at Greenford Station. Additionally, sections of the London Underground that were actually below ground were made nonsmoking; eventually the whole system became a smoke-free zone.

Litigation

In the 1930s, at least one suit was filed against a department store, alleging that its escalators posed an attractive nuisance, responsible for a child's injury. These cases were almost always dismissed. Moreover, continual updating of escalator safety codes facilitated increased levels of consumer safety as well as a reduction in court cases.

Legislation and escalators

United States

Despite their considerable scope, two Congressional Acts, the Rehabilitation Act of 1973 and the Americans with Disabilities Act of 1990 (ADA), did not directly affect escalators or their public installations. Since Section 504 of the Rehabilitation Act included public transportation systems, for a few years, the United States Department of Transportation considered designs to retrofit existing escalators for wheelchair access. Nonetheless, Foster-Miller Associates' 1980 plan, *Escalator Modification for the Handicapped* was ultimately ignored in favor of increased elevator installations in subway systems. Likewise, the ADA provided more accessibility options, but expressly excluded escalators as "accessible means of egress," advocating neither their removal nor retention in public structures.

Codes and regulation

In the United States and Canada, new escalators must abide by ASME A17.1 standards, and old/historic escalators must conform to the safety guidelines of ASME A17.3. In Europe, the escalator safety code is EN115.

Key safety features developed over time

Notice on escalators in Spain.

To enhance passenger safety, newer models of escalators are equipped with one or more of the following safety implementations, as per ASME A17.1 code:

- Antislide devices: Raised circular objects that often stud the escalator balustrade. Sometimes informally called "hockey pucks" due to their appearance, their purpose is to prevent objects (and people) from precipitously sliding down the otherwise smooth metallic surface.
- Combplate impact switches: Stop the escalator if a foreign object gets caught between the steps and the combplate on either end.
- Deflector brush: A long continuous brush made of stiff bristles running up the sides of the escalator just above the step level. This helps deflect garments, shoes, and other items away from the gap between the moving steps and the skirt board.
- Emergency stop button: At each end of the escalator (in some models, also on the balustrade), a large red button can be pressed to stop the device in the event of an

emergency. Typically, an alarmed transparent plastic guardplate covers the button; restarting requires turning a key.

- Extended balustrades: Allows riders to grasp the handrail before setting foot on an escalator, to ease customer comfort and stability/equilibrium. (The effect is similar to the flat steps described below.)
- Flat steps: Like a moving walkway, the first two or three steps at either end of the escalator are flat. This gives the passenger extra time to orient him/herself when boarding, and more time to maintain balance when exiting. Longer escalators often have four or more flat steps.
- Handrail inlet switches: . Sensors located at the bottom and top of the unit that guard the handrail termini. If something gets caught in these locations, a hard fault is generated in the controller, and the escalator shuts down automatically.
- Handrail speed sensors: These sensors are usually optical, and monitor how fast the handrail moves. If the sensor notices a speed difference between the handrail and the steps, it sounds an alarm, pauses, and then automatically stops the escalator. In these situations, the escalator must be serviced by authorized personnel before returning to an operable state.
- Missing step detectors: Depending on the manufacturer and model, this sensor is either optical or physical. When a missing step is detected, the escalator automatically shuts down.
- Raised step edges: In some models, a difference in tread height is utilized to keep passengers' feet from the skirt board.
- Safety instructions: A sign, typically posted on both escalator newels at the entrance landing platform. In some situations, safety precautions are posted on walls near the escalator, included on freestanding signs, or—as in some models—printed on the riser surface itself.
- Sensor switch: In automatic-start/stop escalators, this sensor automatically engages the escalator motion when a rider is detected on the first step of the entrance landing platform, and stops the escalator when there are no riders on the unit.
- Step demarcation lights: Either fluorescent or LED lights (traditionally green in color) located inside the truss. The illumination between the steps improves the passengers' awareness of the step divisions.
- Step demarcation lines: In order to clearly delineate the edges of each individual step, manufacturers offer steps trimmed in yellow, either painted or with plastic inserts.

Safe riding: official safety foundation guidelines

While some escalator accidents are caused by a mechanical failure, most can be avoided by following some simple safety precautions. The Elevator Escalator Safety Foundation is a major advocate for safe riding in the United States and Canada, sponsors National Elevator Escalator Safety Week each year, and publishes its own suggestions for safe riding.

History

Inventors and manufacturers

Nathan Ames

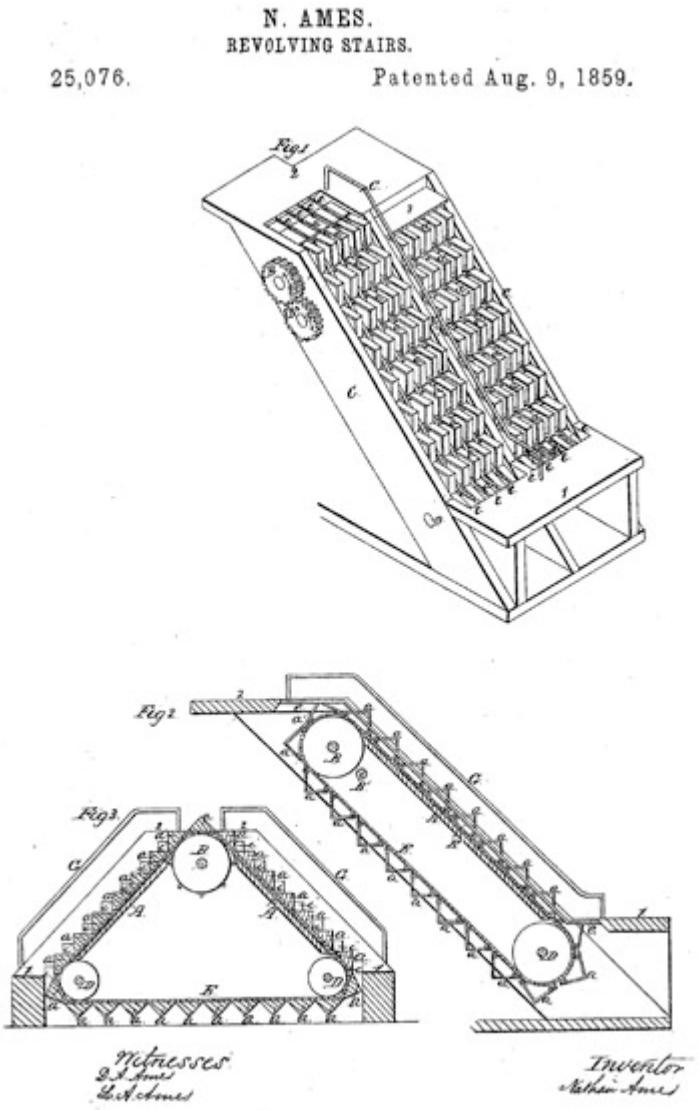


Illustration from U.S. Patent #25,076: Revolving Stairs. Issued August 9, 1859 to Nathan Ames.

Nathan Ames, a patent solicitor from Saugus, Massachusetts, is credited with patenting the first "escalator" in 1859, despite the fact that no working model of his design was ever built. His invention, the "revolving stairs", is largely speculative and the patent specifications indicate that he had no preference for materials or potential use (he noted that steps could be upholstered or made of wood, and suggested that the units might

benefit the infirm within a household use), though the mechanization was suggested to run either by manual or hydraulic power.

Leamon Souder

In 1889, Leamon Souder successfully patented the "stairway", an escalator-type device that featured a "series of steps and links jointed to each other". No model was ever built. This was the first of at least four escalator-style patents issued to Souder, including two for spiral designs (U. S. Patent Nos. 723,325 and 792,623).

Jesse Wilford Reno, George A. Wheeler, and Charles Seeberger

In 1892, Jesse W. Reno patented the "Endless Conveyor or Elevator." A few months after Reno's patent was approved, George A. Wheeler patented his ideas for a more recognizable moving staircase, though it was never built. Wheeler's patents were bought by Charles Seeberger; some features of Wheeler's designs were incorporated in Seeberger's prototype built by the Otis Elevator Company in 1899.

Reno produced the first working escalator (he actually called it the "inclined elevator") and installed it alongside the Old Iron Pier at Coney Island, New York in 1896. This particular device was little more than an inclined belt with cast-iron slats or cleats on the surface for traction, and traveled along a 25° incline. A few months later, the same prototype was used for a monthlong trial period on the Manhattan side of the Brooklyn Bridge. Reno eventually joined forces with Otis Elevator Company, and retired once his patents were purchased outright. Some Reno-type escalators were still being used in the Boston subway until construction for the Big Dig precipitated their removal. The Smithsonian Institution considered re-assembling one of these historic units from 1914 in their collection of Americana, but "logistics and reassembly costs won out over nostalgia", and the project was discarded.

Around May 1895, Charles Seeberger began drawings on a form of escalator similar to those patented by Wheeler in 1892. This device actually consisted of flat, moving stairs, not unlike the escalators of today, except for one important detail: the step surface was smooth, with no comb effect to safely guide the rider's feet off at the ends. Instead, the passenger had to step off sideways. To facilitate this, at the top or bottom of the escalator the steps continued moving horizontally beyond the end of the handrail (like a miniature moving sidewalk) until they disappeared under a triangular "divider" which guided the passenger to either side. Seeberger teamed with Otis Elevator Company in 1899, and together they produced the first commercial escalator which won the first prize at the Paris 1900 *Exposition Universelle* in France. Also on display at the *Exposition* were Reno's inclined elevator, a similar model by James M. Dodge and the Link Belt Machinery Co., and two different devices by French manufacturers Hallé and Piat.

Early European manufacturers: Hallé, Hocquardt, and Piat

Piat installed its "stepless" escalator in Harrods Knightsbridge store on Wednesday, November 16, 1898, though the company relinquished its patent rights to the department store. Noted by Bill Lancaster in *The Department Store: a Social History*, "customers unnerved by the experience were revived by shopmen dispensing free smelling salts and cognac." The Harrods unit was a continuous leather belt made of "224 pieces . . . strongly linked together traveling in an upward direction," and was the first "moving staircase" in England.

Hocquardt received European patent rights for the *Fahrtreppe* in 1906. After the *Exposition*, Hallé continued to sell its escalator device in Europe, but was eventually eclipsed in sales by other major manufacturers.

Major competitors and product nomenclature

In the first half of the twentieth century, several manufacturers developed their own escalator products, though they had to market their devices under different names, due to Otis' hold on the trademark rights to the word "escalator." New York-based Peelle Company called their models the ***Motorstair***, and Westinghouse called their model an ***Electric Stairway***. The Toledo-based Haughton Elevator company referred to their product as simply ***Moving Stairs***.

Manufacturing mergers and buyouts: the playing field narrows

Kone and Schindler introduced their first escalator models several decades after the Otis Elevator Co., but grew to dominance in the field over time. Today, they, Mitsubishi, and ThyssenKrupp are Otis' primary rivals.

Schindler now stands as the largest maker of escalators and second largest maker of elevators in the world, though their first escalator installation did not occur until 1936. In 1979, the company entered the United States market by purchasing Haughton Elevator; nine years later, Schindler assumed control of the North American escalator/elevator operations of Westinghouse.

Kone expanded internationally by acquisition in the 1970s, buying out Swedish elevator manufacturer Asea-Graham, and purchasing other minor French, German, and Austrian elevator makers before assuming control of Westinghouse's European elevator business. As the last "big four" manufacturers held on to the escalator market, KONE first acquired Montgomery Elevator Company, then took control of Germany's Orenstein & Koppel *Rolltreppen*.

Model development and design types

"Cleat-type" escalators

Jesse Reno's escalators did not resemble modern escalators too closely. Passengers' feet tilted upward at an angle, and the treads consisted of cleated metal (initially) or wood (later models). Reno worked on his own for several years, gaining success with installations from Toronto to Cape Town, South Africa. Similar units of the day by other manufacturers resembled conveyor belts more than moving staircases. For a time, Otis Elevator sold Reno's escalators as their own "cleat-type" escalators.

"Step-type" escalators

Seeberger's model, bought by Otis, clearly became the first "step-type" escalator, so called after its visual likeness to steps on a regular staircase. The company later combined the best aspects of both inventions (guiding slats and flat steps) and in 1921 produced an escalator similar to the type used today: they called it the "L-type" escalator. It was succeeded by the "M-type", the "O-type", and current models by Otis such as the "NCE-type" escalator.

Spiral escalators: from Reno to Mitsubishi

A spiral escalator in Hong Kong.

Reno, in addition to his notoriety for the first “practical” escalator in public use, also bears the unique distinction of designing the very first escalators installed in any underground subway system – a single spiral escalator at Holloway Road tube station in London in 1906. The experimental device never saw public use, and was forgotten for several decades. The remains of this are now in the London Transport Museum's depot in Acton. Also the first fully operational spiral escalator, Reno’s design was nonetheless only one in a series of several similar proposed contraptions. Souder patented two spiral designs (see above), Wheeler drafted spiral stairway plans in 1905, Seeberger devised at least two different spiral units between 1906 and 1911 (including an unrealized arrangement for the London Underground), and Gilbert Luna obtained West German, Japanese, and United States patents for his version of a spiral escalator by 1973. When interviewed for the *Los Angeles Times* that year, Luna was in the process of soliciting “major firms” for acquisition of his patents and company, but statistics are unclear on the outcome of his endeavors in that regard.

The Mitsubishi Electric Corporation was most successful in its development of "spiral" (more "curve" than true spiral) escalators, and has sold them exclusively since the mid-1980s. The world's first "practical" spiral escalator—a Mitsubishi model—was installed in Osaka, Japan, in 1985.

In use, a major planning advantage presented by spiral escalators is that they take up much less horizontal floor space than traditional units, which frequently house large machine rooms underneath the truss.

Etymology

Several authors and historians have contributed their own differing interpretations of the source of the word “escalator”, and some degree of misinformation has heretofore proliferated on the Internet. For reference, contradictory citations by seven separate individuals, including the Otis Elevator Company itself, are provided below.

Name development and original intentions

Charles Seeberger trademarked the word "escalator" in 1900, to coincide with his device’s debut at the *Exposition Universelle*. According to his own account, in 1895, his legal counsel advised him to name his new invention, and he then set out to devise a title for it on his own. As evidenced in Seeberger's own handwritten documents, archived at the Otis Elevator Company headquarters in Farmington, Connecticut, the inventor consulted "a Latin lexicon" and "adopted as the root of the new word, 'Scala'; as a prefix, 'E' and as a suffix, 'Tor.'" His own rough translation of the word thus created was "means of traversing from", and he intended for the word to be pronounced, "es·ˈkæl ·ə·tər" (es-**CAL**-a-tor).

"Escalator" was not a combination of other French or Greek words, and was never a derivative of "elevator" in the original sense, which means "one who raises up, a deliverer" in Latin. Similarly, the root word "*scala*" does not mean "a flight of steps", but

is defined by Lewis and Short's *A Latin Dictionary* as the singular form of the plural noun "*scalae*", which denotes any of the following: "a flight of steps or stairs, a staircase; a ladder, [or] a scaling-ladder."

The alleged intended capitalization of "escalator" is likewise a topic of debate. Seeberger's trademark application lists the word not only with the "E" but also with all of the letters capitalized (in two different instances), and he specifies that, "any other form and character of type may be employed . . . without altering in any essential manner the character of [the] trade-mark." That his initial specifications are ostensibly inconsistent, and since Otis Elevator Co. advertisements so frequently capitalized all of the letters in the word, suppositions about the "capital 'e'" are difficult to formulate.

Derivatives of 'escalator'

The verb "escalate" originated in 1922, and has two uses, the primary: "to climb or reach by means of an escalator" or "to travel on an escalator", and the secondary: "to increase or develop by successive stages; *spec.* to develop from 'conventional' warfare into nuclear warfare." The latter definition was first printed in the *Manchester Guardian* in 1959, but grew to prominent use during the late 1960s and early 1970s.

Loss of trademark rights

In 1950, the landmark case *Haughton Elevator Co. v. Seeberger* precipitated the end of Otis' reign over exclusive use of the word "escalator", and simultaneously created a cautionary study for companies and individuals interested in trademark retention. Confirming the contention of the Examiner of Trademark Interferences, Assistant Commissioner of Patents Murphy's decision rejected the Otis Elevator Company's appeal to keep their trademark intact, and noted that "the term 'escalator' is recognized by the general public as the name for a moving stairway and not the source thereof", observing that the Otis Elevator Co. had "used the term as a generic descriptive term…in a number of patents which [had] been issued to them and…in their advertising matter." All trademark protections were removed from the word "escalator", the term was officially genericized, and it fell into the public domain.

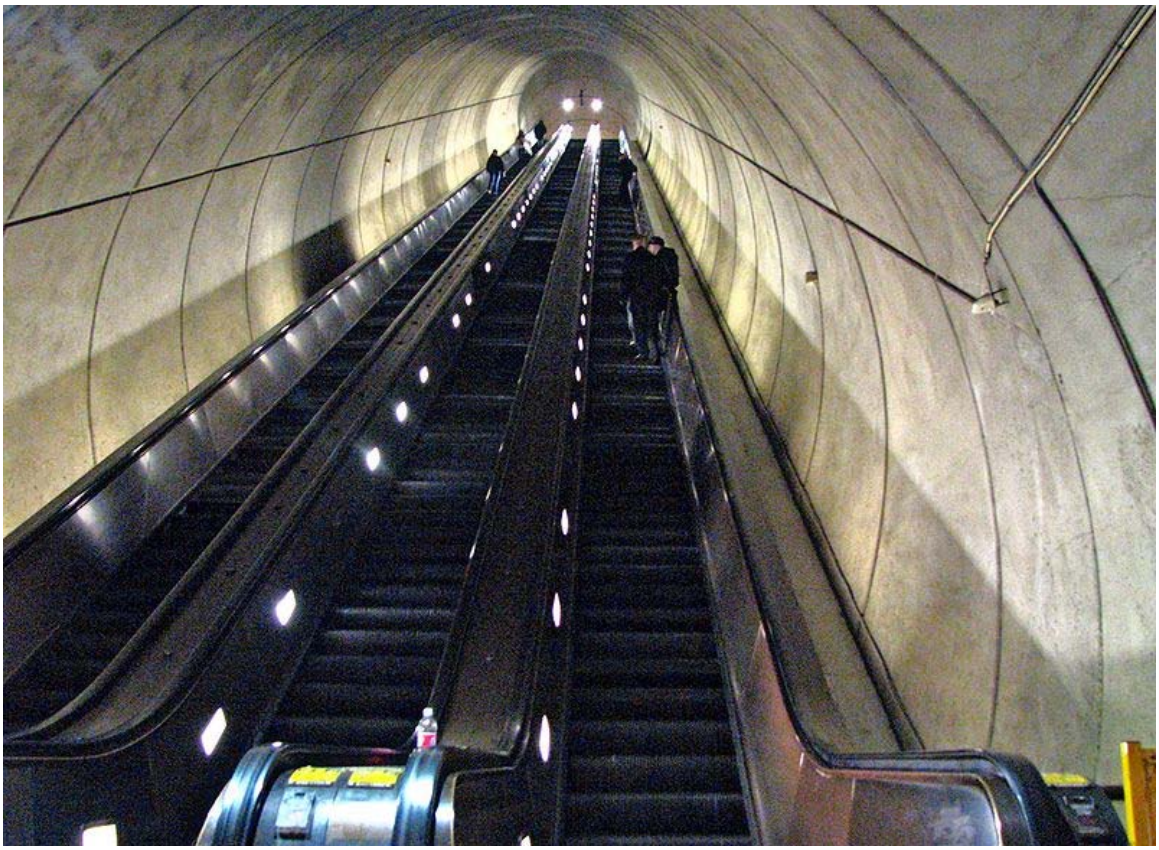
Primary uses and application

Department stores/shopping

As noted above, a few escalator types were installed in major department stores (including Harrods) before the *Expo*. Escalators proved instrumental in the layout and design of shopping venues in the twentieth century.

By 1898, the first of Reno's "inclined elevators" were incorporated into the Bloomingdale Bros. store at Third Avenue and 59th Street. This was the first retail application of the devices in the US, and no small coincidence, considering that Reno's

primary financier was Lyman Bloomingdale, co-owner of the department store with brother Joseph Bloomingdale.



The longest escalators in the Western Hemisphere, at the Wheaton station, Washington DC Metro

Public transportation

The first "standard" escalator installed on the London Underground was a Seeberger model at Earls Court. Noted above, London's Underground installed a rare spiral escalator designed by Reno, William Henry Aston and Scott Kietzman for the Holloway Road Underground station in 1906; it was run for a short time but was taken out of service the same day it debuted. The older lines of the London Underground had many escalators with wooden treads (ca. 1930s) until they were rapidly replaced following the King's Cross fire, noted above.

Other applications

Factories and other industrial production environments

In 1905, the American Woolen Company’s Wood Mill in Lawrence, Massachusetts (then "the largest single worsted mill in the world") utilized Otis' Seeberger-type "reversible" escalators to carry its workers between floors four times a day. The machines did not run

all day: rather, escalators ran solely to transport employees to/from midday meals and in/out of the mill. In its advertising, Otis Elevator Company hailed this unconventional use for its unique benefits to both workers and owners: "The profitable and practicable feature of the Escalator, from the viewpoint of the owner, is the increased efficiency of each operator due to the elimination of stair climbing."

Military use

In San Francisco, an escalator at Hunters Point Naval Shipyard was used to convey personnel between the first and third floors. At the time of its construction in 1948, it was touted thus: "[it has the] highest lift of any industrial building in the world. It rises 42 feet."

Escalators were also utilized on aircraft carriers such as the USS *Hornet* (CV-12), to transport pilots from "ready rooms" to the flight deck.

Extant historic escalator models

Macy's Herald Square store in New York City holds some of the more famous historic escalators. The models shown here, retrofitted with metal steps in the 1990s, are among the oldest of the store's 40 escalators. Otis "L-type" escalators with distinctive wood treads (not shown) have operated in the store since 1927.

Wooden treads on a 1930s Otis escalator at Wynyard railway station, Sydney, Australia

A few notable examples of historic escalators still in operation are:

Australia

- Town Hall Railway Station, Sydney, Australia
- Wynyard Railway Station, Sydney, Australia

Europe

- St. Anna Pedestrian Tunnel underneath the Schelde in Antwerp, Belgium. This tunnel was opened in 1933.
- Tyne Cyclist and Pedestrian Tunnel, Tyne and Wear, England

  -These escalators, manufactured by Waygood Otis in 1951, were "believed to be the longest single lift escalators in the world", at the time of installation. Presumably the first escalators in Britain designed specifically for cyclists, they are also "thought to be still" the longest escalators in the United Kingdom. At most, they may be the longest extant wooden escalators in operation in the world.

- Greenford Station, Greenford, England

North America

- Macy's Herald Square department store, Otis L-type units with wood treads and replacement metal treads, New York, New York
- Kaufmann's department store (now Macy's), two 16-inch (400 mm) Otis L-type units with original floorplates, several 40-inch (1000 mm) Otis escalators ca. 1950s, Pittsburgh, Pennsylvania
- Westfield San Francisco Centre (formerly The Emporium), chrome-and-glass escalator by Eleanor LeMaire for Otis, San Francisco, California

Escalators: superlatives

Longest systems

- Central-Mid-Levels escalator: in Hong Kong, tens of thousands of commuters travel each work day between Central, the central business district, and the Mid-levels, a residential district hundreds of feet uphill, using this long distance system of escalators and moving walkways. It is the world's longest outdoor escalator *system* (not a single escalator span), at a total length of 2,600 feet (790 m). It goes only one way at a time; the direction reverses depending on rush hour traffic direction.
- Ocean Park, Hong Kong: a long escalator system connecting two parts of the Park, with an overall length of 730 feet (220 m).

Longest examples

Asia and Europe

Several "metro" or "subway" systems in Central and Eastern Europe feature very long escalators.

- In the Park Pobedy station of the Moscow Metro, opened in 2003, the escalators are 126.8 m (63.4 m high), or 740 steps, long, and take nearly three minutes to transit. Deep underground stations in St. Petersburg have escalators up to approximately 142 m long (71 m high).
- The Kiev Metro Kreschatik station's lower-level second exit escalator (a type ЛТ-2, circa 1965), lifts riders 216 feet (66 m), or 743 steps, up a 432-foot (132 m)-long incline.
- The longest escalator in Prague is at the Náměstí Míru station at 290 feet (88 m).
- The longest escalator of a European shopping mall is at MyZeil, Frankfurt, Germany, with a length of 150 feet (46 m).
- The tallest escalator on the London Underground system is at Angel station with a length of 197 feet (60 m), and a vertical rise of 90 feet (27 m).
- The longest wooden escalators in the United Kingdom are at the Tyne Tunnel, with a length of 200 feet (61 m). (See above.)

- The longest escalator on the Stockholm Metro, and in Western Europe, is at Västra skogen with a length of 220 feet (67 m) and in Helsinki Metro at Kamppi station with a length of 210 feet (64 m).
- The largest "single truss escalator" is in the Bentall Centre in Kingston upon Thames in Greater London, UK. It connects the ground floor with the second floor with only top and bottom supports.

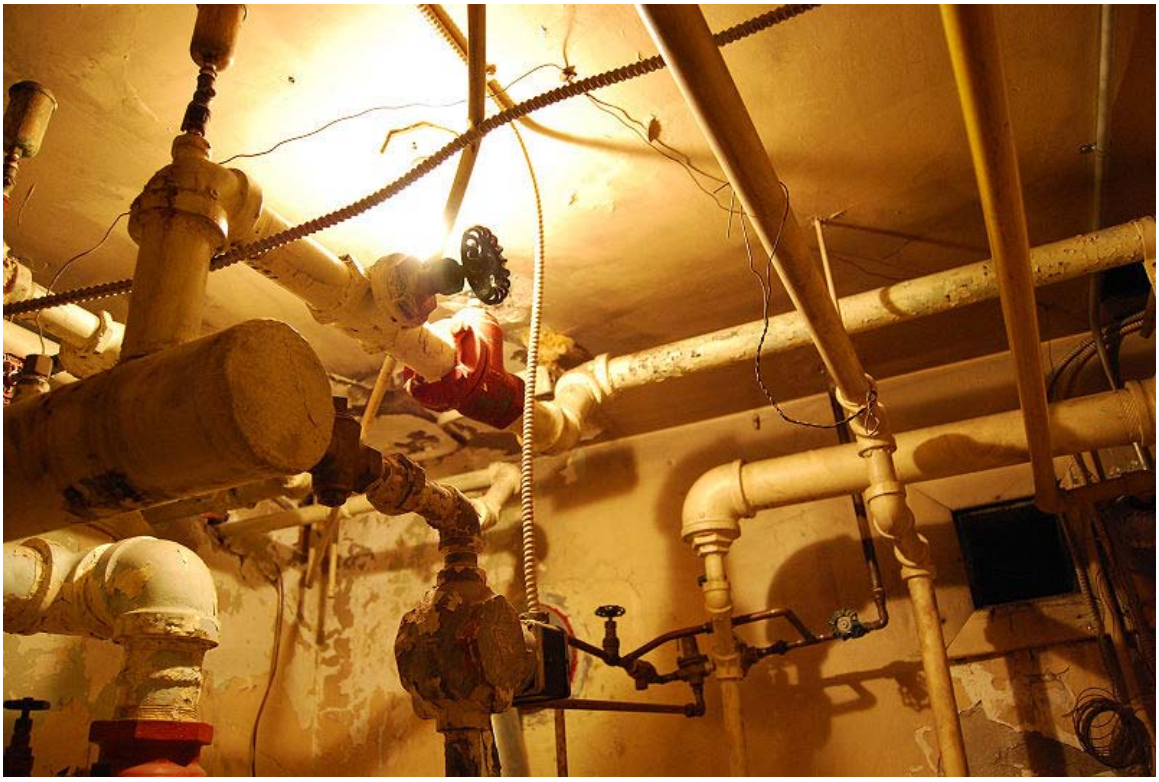
North and South America

View from bottom of Porter Square escalator, 2010

- The longest set of single-span uninterrupted escalators in the Western Hemisphere is at the Wheaton station of the Washington Metro system. They are 230 feet (70 m) long with a vertical rise of 115 feet (35 m), and take what is variously described as 2 minutes and 45 seconds or nearly three-and-a-half minutes, to ascend or descend without walking.
- The longest *freestanding* (supported only at the ends) escalator in the world is inside CNN Center's atrium in Atlanta, Georgia. It rises 8 stories and is 205 feet (62 m) long. Originally built as the entrance to the amusement park The World of Sid and Marty Krofft, the escalator is now used for CNN studio tours.

Chapter 4

Plumbing



A complex arrangement of rigid steel piping, stop valves regulate flow to various parts of the building.

Water and sewage pipes of a Jerusalem building built around 1930.

Plumbing (from the Latin *plumbum* for lead, as pipes were once made from lead) is the skilled trade of working with pipes, tubing and plumbing fixtures for drinking water systems and the drainage of waste. A **plumber** is someone who installs or repairs piping systems, plumbing fixtures and equipment such as water heaters. The plumbing industry is a basic and substantial part of every developed economy due to the need for clean water, and proper collection and transport of wastes.

Plumbing also refers to a system of pipes and fixtures installed in a building for the distribution of potable water and the removal of waterborne wastes. Plumbing is usually distinguished from water and sewage systems, in that a plumbing system serves one building, while water and sewage systems serve a group of buildings or a city.

History

Roman lead pipe with a folded seam, at the Roman Baths in Bath, England.

Plumbing was extremely rare until the growth of modern cities in the 19th century. At about the same time public health authorities began pressing for better waste disposal systems to be installed. Earlier, the waste disposal system merely consisted of collecting waste and dumping it on ground or into a river. Standardized earthen plumbing pipes with broad flanges making use of asphalt for preventing leakages appeared in the urban settlements of the Indus Valley Civilization by 2700 B.C. Plumbing originated during the ancient civilizations such as the Greek, Roman, Persian, Indian, and Chinese civilizations as they developed public baths and needed to provide potable water, and drainage of wastes. The Romans used lead pipe inscriptions to prevent water theft. Improvement in plumbing systems was very slow, with virtually no progress made from the time of the

Roman system of aqueducts and lead pipes until the 19th century. Eventually the development of separate, underground water and sewage systems eliminated open sewage ditches and cesspools. Most large cities today pipe solid wastes to treatment plants in order to separate and partly purify the water before emptying into streams or other bodies of water. The use of lead for potable water declined sharply after World War II because of the dangers of lead poisoning. At this time, copper piping was introduced as a better and safer alternative to lead pipes.

Another material used for plumbing pipes, particularly water main, was hollowed wooden logs wrapped in steel banding. Logs used for water distribution were used in England close to 500 years ago. The US cities began using hollowed logs in the late 18th through the 19th centuries.

Materials

Water systems of ancient times relied on gravity for the supply of water, using pipes or channels usually made of clay, lead, bamboo wood or stone. Present-day water-supply systems use a network of high-pressure pumps, and pipes are now made of copper, brass, plastic, or other nontoxic material. Present-day drain and vent lines are made of plastic, steel, cast-iron, and lead. Lead is not used in modern water-supply piping due to its toxicity.

The "straight" sections of plumbing systems are of **pipe** or **tube**. A pipe is typically formed via casting or welding, where a tube is made through extrusion. Pipe normally has thicker walls and may be threaded or welded, where tubing is thinner-walled and requires special joining techniques such as "brazing", "compression fitting", "crimping", or for plastics, "solvent welding".

Fittings and valves

Piping being placed for a sink.

In addition to the straight pipe or tubing, many fittings are required in plumbing systems, such as valves, elbows, tees, and unions. The piping and plumbing fittings and valves articles discuss these features further.

Fixtures

Plumbing fixtures are designed for the end-users. Some examples of fixtures include water closets (also known as toilets), urinals, bidets, showers, bathtubs, utility and

kitchen sinks, drinking fountains, ice makers, humidifiers, air washers, fountains, and eye wash stations.

Equipment

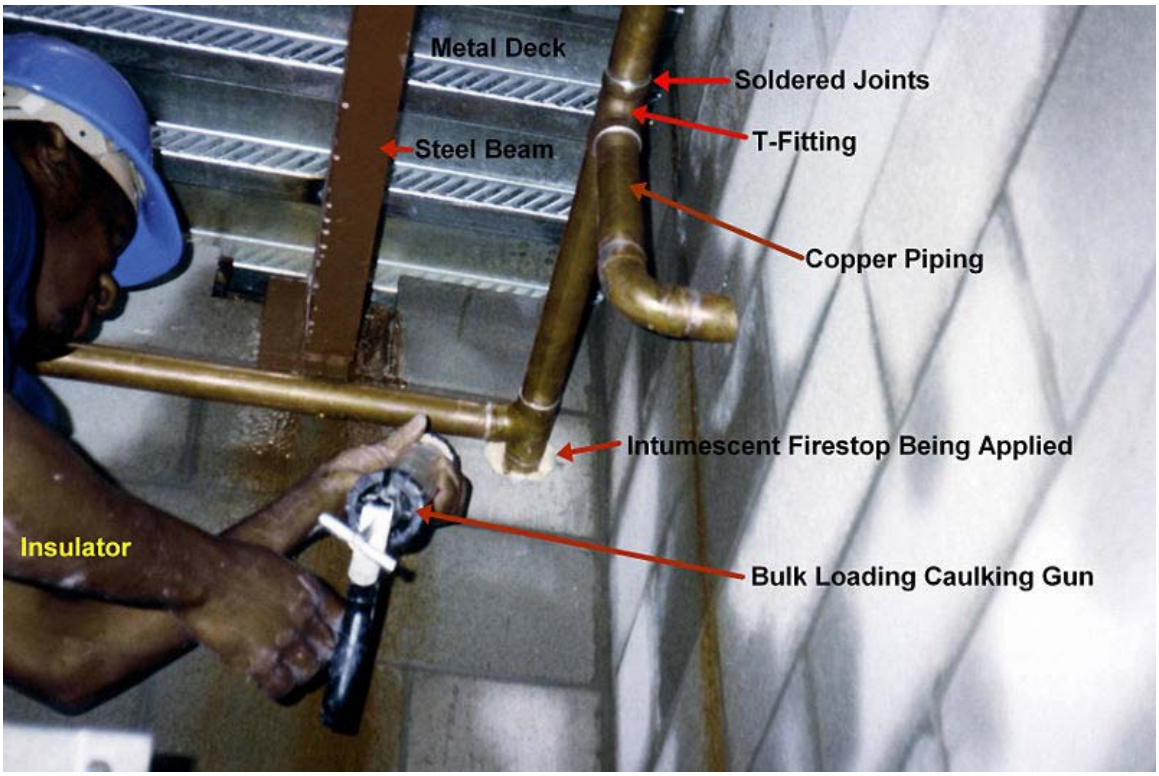
A plumber wrench for working on pipes and fittings

Plumbing equipment, not present in all systems, include, for example, water meters, pumps, expansion tanks, backflow preventers, filters, water softeners, water heaters, wrenches, heat exchangers, flaring pliers, gauges, and control systems.

Now there is more equipment that is technologically advanced and helps plumbers fix problems without the usual hassles. For example, plumbers use video cameras for

inspections of hidden leaks or problems, they use hydro jets, and high pressure hydraulic pumps connected to steel cables for trench-less sewer line replacement.

Systems



Copper **piping** system in a building with intumescent firestop being installed by an insulator, Vancouver, British Columbia, Canada.

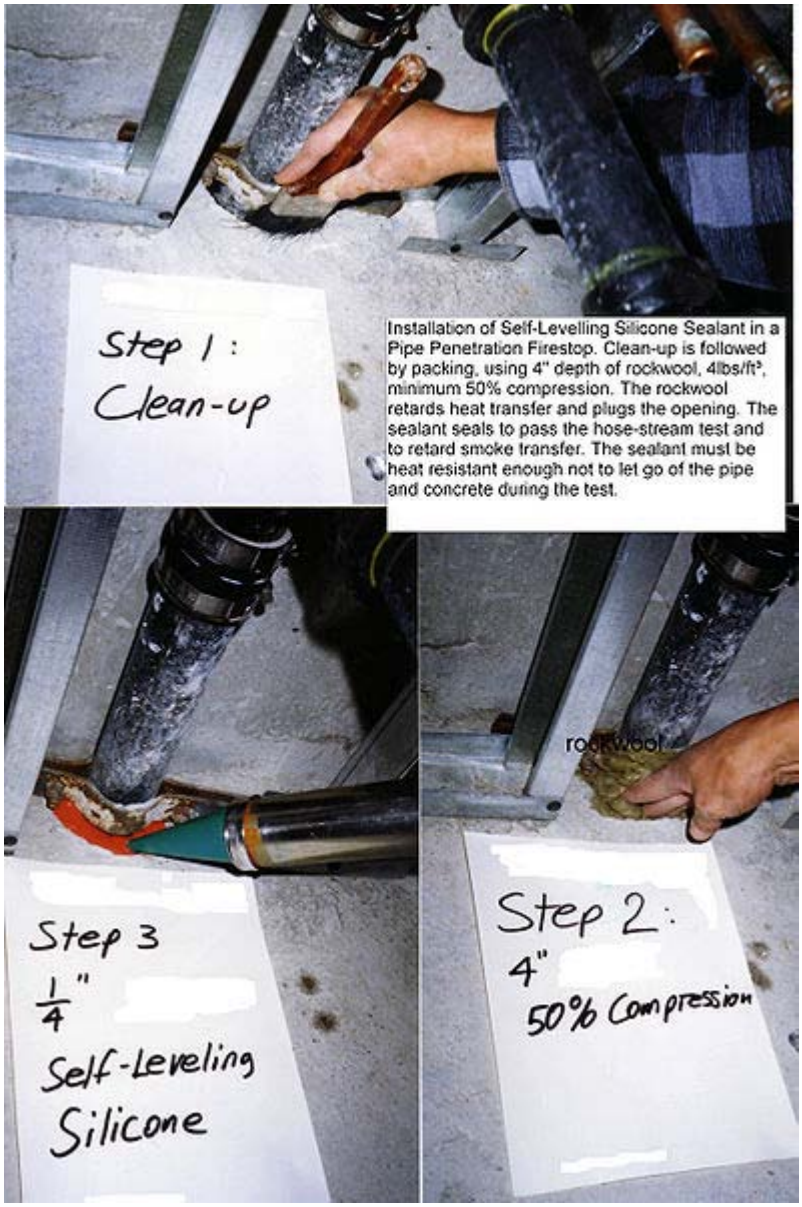
The major categories of plumbing systems or subsystems are:

- Potable cold and hot water supply
- Traps, drains, and vents
- Septic systems
- Rainwater, surface, and subsurface water drainage
- Fuel gas piping

For their environmental benefit and sizable energy savings hot water heat recycling units are growing in use throughout the residential building sectors. Further ecological concern has seen increasing interest in grey-water recovery and treatment systems.

The New York City steam system is an example of a large district heating system.

Firestopping



Self-levelling silicone firestop installation in mechanical service penetration in 2 hour rated concrete floor.

Firestopping is required where mechanical penetrants traverse fire-resistance rated wall and floor assemblies, or membranes thereof. This work is usually done worldwide by the insulation trade and/or specialty firestop sub-contractors.

Regulation

Much of the plumbing work in populated areas is regulated by government or quasi-government agencies due to the direct impact on the public's health, safety, and welfare.

Plumbing installation and repair work on residences and other buildings generally must be done according to plumbing and building codes to protect the inhabitants of the buildings and to ensure safe, quality construction to future buyers. If permits are required for work, plumbing contractors typically secure them from the authorities on behalf of home or building owners. In the United Kingdom the professional body is the newly Chartered Institute of Plumbing and Heating Engineering (educational charity status) and it is true that the trade still remains virtually ungoverned; there are no systems in place to monitor or control the activities of unqualified plumbers or those home owners who choose to undertake installation and maintenance works themselves, despite the health and safety issues which arise from such works when they are undertaken incorrectly *Health Aspects of Plumbing (HAP)* published jointly by the World Health Organization (WHO) and the World Plumbing Council (WPC). WPC has subsequently appointed a representative to the World Health Organization to take forward various projects related to Health Aspects of Plumbing.

Chapter 5

Curtain Wall

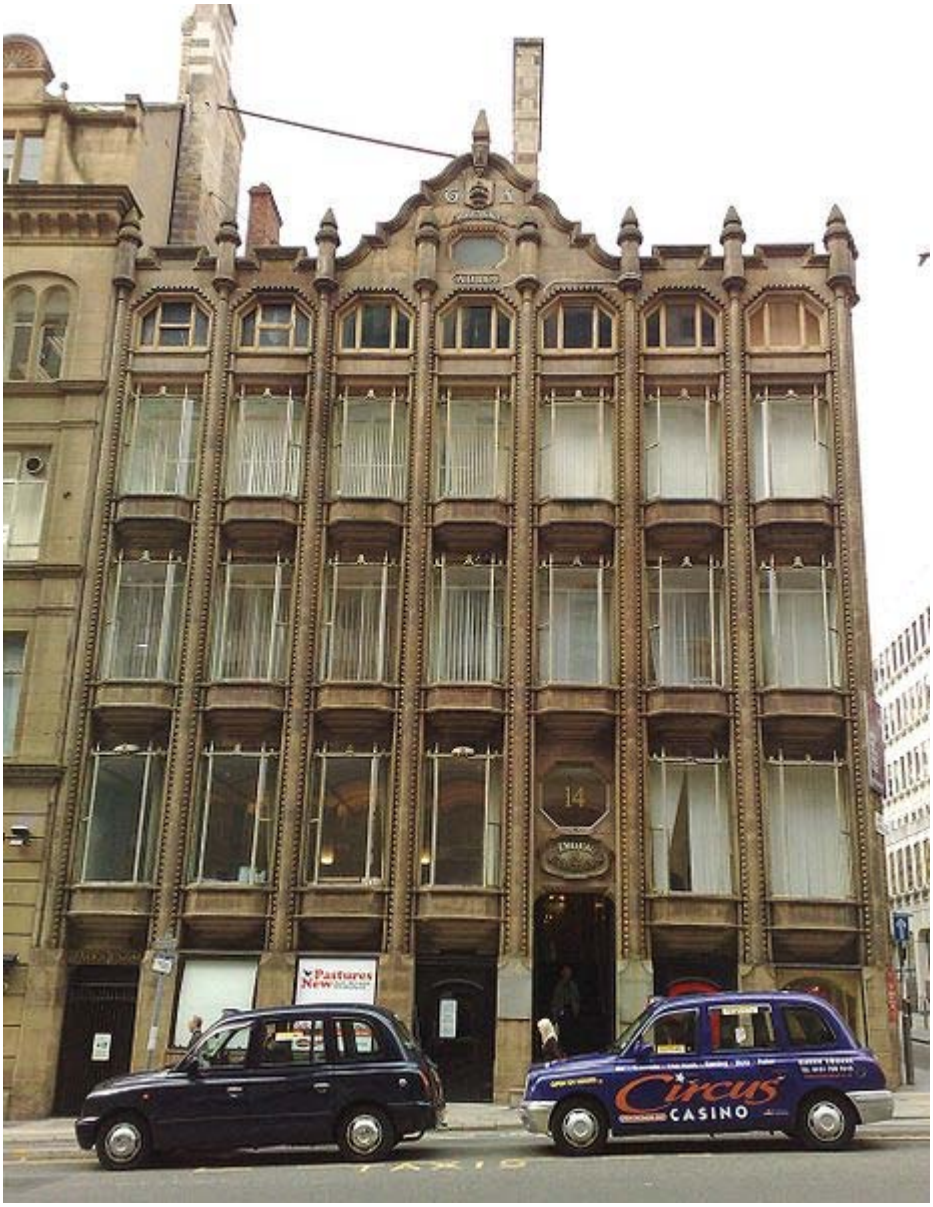
Glass curtain wall of the Bauhaus Dessau

A **curtain wall** is an outer covering of a building in which the outer walls are non-structural, but merely keep out the weather. As the curtain wall is non-structural it can be made of a lightweight material reducing construction costs. When glass is used as the curtain wall, a great advantage is that natural light can penetrate deeper within the building. The curtain wall façade does not carry any dead load weight from the building other than its own dead load weight. The wall transfers horizontal wind loads that are incident upon it to the main building structure through connections at floors or columns of the building. A curtain wall is designed to resist air and water infiltration, sway induced by wind and seismic forces acting on the building, and its own dead load weight forces.

Curtain walls are typically designed with extruded aluminum members, although the first curtain walls were made of steel. The aluminium frame is typically infilled with glass, which provides an architecturally pleasing building, as well as benefits such as daylighting. However, parameters related to solar gain control such as thermal comfort and visual comfort are more difficult to control when using highly-glazed curtain walls. Other common infills include: stone veneer, metal panels, louvers, and operable windows or vents.

Curtain walls differ from store-front systems in that they are designed to span multiple floors, and take into consideration design requirements such as: thermal expansion and contraction; building sway and movement; water diversion; and thermal efficiency for cost-effective heating, cooling, and lighting in the building.

History



Oriel Chambers, Liverpool, England,1864. The world's first glass curtain walled building. The stone mullions are decorative.

16 Cook Street, Liverpool, England,1866. Extensive use of floor to ceiling glass is used, enabling light penetration deeper into the building maximizing floor space.

A building project in Wuhan China, the difference in progress between the two towers illustrates the relationship between the inner load bearing structure and the exterior glass curtain.

Prior to the middle of the nineteenth century, buildings were constructed with the exterior walls of the building (bearing walls, typically masonry) supporting the load of the entire structure. The development and widespread use of structural steel and later reinforced concrete allowed relatively small columns to support large loads and the exterior walls of buildings were no longer required for structural support. The exterior walls could be non-load bearing and thus much lighter and more open than the masonry load bearing walls of the past. This gave way to increased use of glass as an exterior façade and the modern day curtain wall was born.

Oriel Chambers in Liverpool, England, was the world's first metal framed glass curtain walled building in 1864, followed by 16 Cook Street, Liverpool, in 1866. Both buildings were designed and built by local architect Peter Ellis. The extensive glass walls allowed light to penetrate further into the building utilising more floor space and reducing lighting costs in short winter months. Oriel Chambers comprises 43,000 sq ft (4,000 m^2) set over a maximum of five floors as the elevator had not been invented.

Some of the first curtain walls were made with steel mullions and the plate glass was attached to the mullions with asbestos or fiberglass modified glazing compound.

Eventually silicone sealants or glazing tape were substituted. Some designs included an outer cap to hold the glass in place and to protect the integrity of the seals. The first curtain wall installed in New York City was this type of construction. Earlier modernist examples are the Bauhaus in Dessau and the Hallidie Building in San Francisco.

The 1970's began the widespread use of aluminum extrusions for mullions. Aluminum offers the unique advantage of being able to be easily extruded into nearly any shape required for design and aesthetic purposes. Today, the design complexity and shapes available are nearly limitless. Custom shapes can be designed and manufactured with relative ease.

Similarly, sealing methods and types have evolved over the years, and as a result, today's curtain walls are high performance systems which require little maintenance.

Stick systems

The vast majority of curtain walls are installed long pieces (referred to as *sticks*) between floors vertically and between vertical members horizontally. Framing members may be fabricated in a shop, but all installation and glazing is typically performed at the jobsite.

Unitized systems

Unitized curtain walls entail factory fabrication and assembly of panels and may include factory glazing. These completed units are hung on the building structure to form the building enclosure. Unitized curtain wall has the advantages of: speed; lower field installation costs; and quality control within an interior climate controlled environment. The economic benefits are typically realized on large projects or in areas of high field labor rates.

Rainscreen principle

A common feature in curtain wall technology, the rainscreen principle theorizes that equilibrium of air pressure between the outside and inside of the "rainscreen" prevents water penetration into the building itself. For example the glass is captured between an inner and an outer gasket in a space called the glazing rebate. The glazing rebate is ventilated to the exterior so that the pressure on the inner and outer sides of the exterior gasket is the same. When the pressure is equal across this gasket water cannot be drawn through joints or defects in the gasket.

Design

Curtain wall systems must be designed to handle all loads imposed on it as well as keep air and water from penetrating the building envelope.

Loads

The loads imposed on the curtain wall are transferred to the building structure through the anchors which attach the mullions to the building. The building structure design must account for these loads.

Dead load

Dead load is defined as the weight of structural elements and the permanent features on the structure. In the case of curtain walls, this load is made up of the weight of the mullions, anchors and other structural components of the curtain wall, as well as the weight of the infill material. Additional dead loads imposed on the curtain wall, such as sunshades, must be accounted for in the design of the curtain wall components and anchors.

Wind load

Wind load acting on the building is the result of wind blowing on the building. This wind pressure must be resisted by the curtain wall system since it envelops and protects the building. Wind loads vary greatly throughout the world, with the largest wind loads being near the coast in hurricane-prone regions. For each project location, building codes specify the required design wind loads. Often, a wind tunnel study is performed on large or unusually shaped buildings. A scale model of the building and the surrounding vicinity is built and placed in a wind tunnel to determine the wind pressures acting on the structure in question. These studies take into account vortex shedding around corners and the effects of surrounding area

Seismic load

Seismic loads need to be addressed in the design of curtain wall components and anchors. In most situations, the curtain wall is able to naturally withstand seismic and wind induced building sway because of the space provided between the glazing infill and the mullion. In tests, standard curtain wall systems are able to withstand three inches (75 mm) of relative floor movement without glass breakage or water leakage. Anchor design needs to be reviewed, however, since a large floor-to-floor displacement can place high forces on anchors. (Additional structure must be provided within the primary structure of the building to resist seismic forces from the building itself.)

Snow load

Snow loads and live loads are not typically an issue in curtain walls, since curtain walls are designed to be vertical or slightly inclined. If the slope of a wall exceeds 20 degrees or so, these loads may need to be considered.

Thermal load

Thermal loads are induced in a curtain wall system because aluminum has a relatively high coefficient of thermal expansion. This means that over the span of a couple of floors, the curtain wall will expand and contract some distance, relative to its length and the temperature differential. This expansion and contraction is accounted for by cutting horizontal mullions slightly short and allowing a space between the horizontal and vertical mullions. In unitized curtain wall, a gap is left between units, which is sealed from air and water penetration by wiper gaskets. Vertically, anchors carrying wind load only (not dead load) are slotted to account for movement. Incidentally, this slot also accounts for live load deflection and creep in the floor slabs of the building structure.

Blast load

Accidental explosions and terrorist threats have brought on increased concern for the fragility of a curtain wall system in relation to blast loads. The bombing of the Alfred P. Murrah Federal Building in Oklahoma City, Oklahoma, has spawned much of the current research and mandates in regards to building response to blast loads. Currently, all new federal buildings in the U.S. and all U.S. embassies built on foreign soil, must have some provision for resistance to bomb blasts.

Since the curtain wall is at the exterior of the building, it becomes the first line of defense in a bomb attack. As such, blast resistant curtain walls must be designed to withstand such forces without compromising the interior of the building to protect its occupants. Since blast loads are very high loads with short durations, the curtain wall response should be analyzed in a dynamic load analysis, with full-scale mock-up testing performed prior to design completion and installation.

Blast resistant glazing consists of laminated glass, which is meant to break but not separate from the mullions. Similar technology is used in hurricane-prone areas for the protection from wind-borne debris.

Infiltration

Air infiltration is the air which passes through the curtain wall from the exterior to the interior of the building. The air is infiltrated through the gaskets, through imperfect joinery between the horizontal and vertical mullions, through weep holes, and through imperfect sealing. The American Architectural Manufacturers Association (AAMA) is an industry trade group in the U.S. that has developed voluntary specifications regarding acceptable levels of air infiltration through a curtain wall . This limit is expressed (in America) in cubic feet per minute per square foot of wall area at a given test pressure. (Currently, most standards cite less than 0.6 CFM/sq ft as acceptable.) Testing is typically conducted by an independent third party agency using the ASTM E-783 standard.

Water penetration is defined as any water passing from the exterior of the building through to the interior of the curtain wall system. Sometimes, depending on the building specifications, a small amount of controlled water on the interior is deemed acceptable. AAMA Voluntary Specifications allow for water on the interior, while the underlying

ASTM E - 1105 test standard would disqualify a test subject if any water is seen inside. To test the ability of a curtain wall to withstand water penetration, a water rack is placed in front a mock-up of the wall with a positive air pressure applied to the wall. This represents a wind driven heavy rain on the wall. Field quality control checks are also performed on installed curtain walls, in which a calibrated spray nozzle is used to spray water on the curtain wall for a specified time in order to investigate known leaks or leading up to a validation test like the ASTM E-1105.

Deflection

One of the disadvantages of using aluminum for mullions is that its modulus of elasticity is about one-third that of steel. This translates to three times more deflection in an aluminum mullion compared to the same steel section under a given a load. Building specifications set deflection limits for perpendicular (wind-induced) and in-plane (dead load-induced) deflections. It is important to note that these deflection limits are not imposed due to strength capacities of the mullions. Rather, they are designed to limit deflection of the glass (which may break under excessive deflection), and to ensure that the glass does not come out of its pocket in the mullion. Deflection limits are also necessary to control movement at the interior of the curtain wall. Building construction may be such that there is a wall located near the mullion, and excessive deflection can cause the mullion to contact the wall and cause damage. Also, if deflection of a wall is quite noticeable, public perception may raise undue concern that the wall is not strong enough.

Deflection limits are typically expressed as the distance between anchor points divided by a constant number. A deflection limit of L/175 is common in curtain wall specifications, based on experience with deflection limits that are unlikely to cause damage to the glass held by the mullion. Say a given curtain wall is anchored at 12 foot (144 in) floor heights. The allowable deflection would then be 144/175 = 0.823 inches, which means the wall is allowed to deflect inward or outward a maximum of 0.823 inches at the maximum wind pressure. HOWEVER, some panels require stricter movement restrictions, or certainly those that prohibit a torque-like motion.

Deflection in mullions is controlled by different shapes and depths of curtain wall members. The depth of a given curtain wall system is usually controlled by the area moment of inertia required to keep deflection limits under the specification. Another way to limit deflections in a given section is to add steel reinforcement to the inside tube of the mullion. Since steel deflects at 1/3 the rate of aluminum, the steel will resist much of the load at a lower cost or smaller depth.

Strength

Strength (or maximum usable stress) available to a particular material is not related to its material stiffness (the material property governing deflection); it is a separate criterion in curtain wall design and analysis. This often affects the selection of materials and sizes for design of the system. For instance, a particular shape in aluminum will deflect almost

three times as much as the same steel shape for an equivalent load (see above), though its strength (i.e. the maximum load it can sustain) may be equivalent or even slightly higher, depending on the grade of aluminum. Because aluminum is often the material of choice, given its lower unit weight and better weathering capability as compared with steel, deflection is usually the governing criteria in curtain wall design.

Thermal criteria

Relative to other building components, aluminum has a high heat transfer coefficient, meaning that aluminum is a very good conductor of heat. This translates into high heat loss through aluminum curtain wall mullions. There are several ways to compensate for this heat loss, the most common way being the addition of thermal breaks. *Thermal breaks* are barriers between exterior metal and interior metal, usually made of polyvinyl chloride (PVC). These breaks provide a significant decrease in the thermal conductivity of the curtain wall. However, since the thermal break interrupts the aluminum mullion, the overall moment of inertia of the mullion is reduced and must be accounted for in the structural analysis of the system.

Thermal conductivity of the curtain wall system is important because of heat loss through the wall, which affects the heating and cooling costs of the building. On a poorly performing curtain wall, condensation may form on the interior of the mullions. This could cause damage to adjacent interior trim and walls.

Rigid insulation is provided in spandrel areas to provide a higher R-value at these locations.

Infills

Infill refers to the large panels that are inserted into the curtain wall between mullions. Infills are typically glass but may be made up of nearly any exterior building element.

Regardless of the material, infills are typically referred to as *glazing*, and the installer of the infill is referred to as a *glazier*. More commonly this trade is now known as Fenestration.

Glass

The French hothouse at the Jardin des Plantes, built by Charles Rohault de Fleury from 1834 to 1836, is an early example of metal and glass curtain wall architecture.

By far the most common glazing type, glass can be of an almost infinite combination of color, thickness, and opacity. For commercial construction, the two most common thicknesses are 1/4 inch (6 mm) monolithic and 1 inch (25 mm) insulating glass. Presently, 1/4 inch glass is typically used only in spandrel areas, while insulating glass is used for the rest of the building (sometimes spandrel glass is specified as insulating glass as well). The 1 inch insulation glass is typically made up of two 1/4-inch lites of glass with a 1/2 inch (12 mm) airspace. The air inside is usually atmospheric air, but some inert gases, such as argon, may be used to offer better thermal transmittance values. In residential construction, thicknesses commonly used are 1/8 inch (3 mm) monolithic and 5/8 inch (16 mm) insulating glass. Larger thicknesses are typically employed for buildings or areas with higher thermal, relative humidity, or sound transmission requirements, such as laboratory areas or recording studios.

Glass may be used which is transparent, translucent, or opaque, or in varying degrees thereof. *Transparent* glass usually refers to *vision* glass in a curtain wall. Spandrel or vision glass may also contain translucent glass, which could be for security or aesthetic purposes. *Opaque* glass is used in areas to hide a column or spandrel beam or shear wall behind the curtain wall. Another method of hiding spandrel areas is through *shadow box*

construction (providing a dark enclosed space behind the transparent or translucent glass). Shadow box construction creates a perception of depth behind the glass that is sometimes desired.

Fabric veneer

Fabric is another type of material which is common for curtain walls. Fabric is often times much less expensive and serves as a less permanent solution. Unlike glass or stone, fabric is much faster to install, less expensive, and often times much easier to modify after it is installed.

Stone veneer

Thin blocks (3 to 4 inches (75-100 mm)) of stone can be inset within a curtain wall system to provide architectural flavor. The type of stone used is limited only by the strength of the stone and the ability to manufacture it in the proper shape and size. Common stone types used are: Arriscraft(calcium silicate);granite; marble; travertine; and limestone.

Panels

Metal panels can take various forms including aluminum plate; thin composite panels consisting of two thin aluminum sheets sandwiching a thin plastic interlayer; and panels consisting of metal sheets bonded to rigid insulation, with or without an inner metal sheet to create a sandwich panel. Other opaque panel materials include fiber-reinforced plastic (FRP), stainless steel, and terracotta. Terracotta curtain wall panels were first used in Europe, but only a few manufacturers produce high quality modern terracotta curtain wall panels.

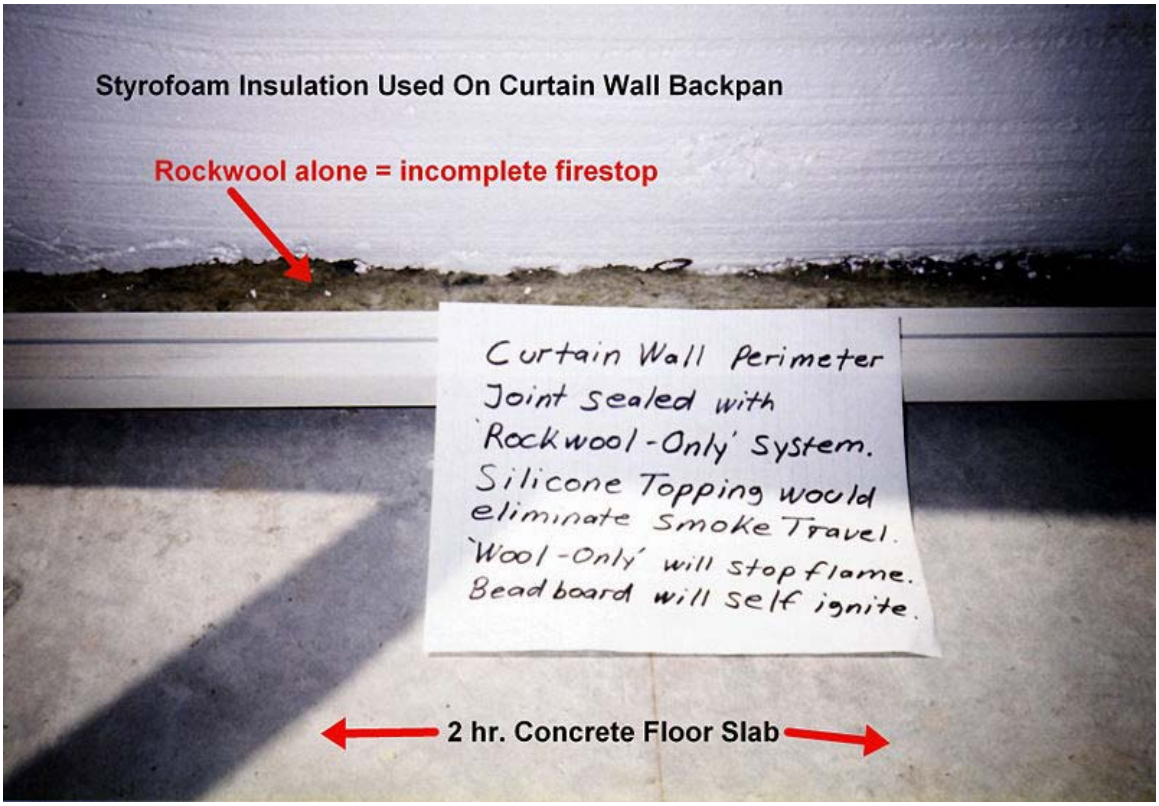
Louvers

A louver is provided in an area where mechanical equipment located inside the building requires ventilation or fresh air to operate. They can also serve as a means of allowing outside air to filter into the building to take advantage of favorable climatic conditions and minimize the usage of energy-consuming HVAC systems. Curtain wall systems can be adapted to accept most types of louver systems to maintain the same architectural sightlines and style while providing the necessary functionality.

Windows and vents

Most curtain wall glazing is fixed, meaning there is no access to the exterior of the building except through doors. However, windows or vents can be glazed into the curtain wall system as well, to provide required ventilation or operable windows. Nearly any window type can be made to fit into a curtain wall system.

Fire safety



Combustible Polystyrene insulation in point contact with sheet metal backban. Incomplete firestop in the perimeter slab edge, made of rockwool without topcaulking.

Firestopping at the "perimeter slab edge", which is a gap between the floor and the backpan of the curtain wall is essential to slow the passage of fire and combustion gases between floors. Spandrel areas must have non-combustible insulation at the interior face of the curtain wall. Some building codes require the mullion to be wrapped in heat-retarding insulation near the ceiling to prevent the mullions from melting and spreading the fire to the floor above. It is important to note that the firestop at the perimeter slab edge is considered a continuation of the fire-resistance rating of the floor slab. The curtain wall itself, however, is not ordinarily required to have a rating. This causes a quandary as Compartmentalization (fire protection) is typically based upon *closed* compartments to avoid fire and smoke migrations beyond each engaged compartment. A curtain wall by its very nature prevents the completion of the compartment (or envelope). The use of fire sprinklers has been shown to mitigate this matter. As such, unless the building is sprinklered, fire may still travel up the curtain wall, if the glass on the exposed floor is shattered due to fire influence, causing flames to lick up the outside of the building. Falling glass can endanger pedestrians, firefighters and firehoses below. An example of this is the First Interstate Tower fire in Los Angeles, California. The fire here leapfrogged up the tower by shattering the glass and then consuming the aluminium skeleton holding the glass. Aluminium's melting temperature is 660°C, whereas building fires can reach 1,100°C. The melting point of aluminium is typically reached within

minutes of the start of a fire. Firestops for such building joints can be qualified to UL 2079 -- Tests for Fire Resistance of Building Joint Systems. Sprinklering of each floor has a profoundly positive effect on the fire safety of buildings with curtain walls. In the case of the aforementioned fire, it was specifically the activation of the newly installed sprinkler system, which halted the advance of the fire and allowed effective suppression. Had this not occurred, the tower would have collapsed onto fire crews and into an adjacent building, while on fire. Exceptionally sound cementitious spray fireproofing also helped to delay and ultimately to avoid the possible collapse of the building, due to having the structural steel skeleton of the building reach the critical temperature, as the post-mortem fire investigation report indicated. This fire proved the positive collective effect of both active fire protection (sprinklers) and passive fire protection (fireproofing).

Fireman knock-out glazing panels are often required for venting and emergency access from the exterior. Knock-out panels are generally fully tempered glass to allow full fracturing of the panel into small pieces and relatively safe removal from the opening.

Maintenance and repair

Curtain walls and perimeter sealants require maintenance to maximize service life. Perimeter sealants, properly designed and installed, have a typical service life of 10 to 15 years. Removal and replacement of perimeter sealants require meticulous surface preparation and proper detailing.

Aluminum frames are generally painted or anodized. Factory applied fluoropolymer thermoset coatings have good resistance to environmental degradation and require only periodic cleaning. Recoating with an air-dry fluoropolymer coating is possible but requires special surface preparation and is not as durable as the baked-on original coating.

Anodized aluminum frames cannot be "re-anodized" in place, but can be cleaned and protected by proprietary clear coatings to improve appearance and durability.

Exposed glazing seals and gaskets require inspection and maintenance to minimize water penetration, and to limit exposure of frame seals and insulating glass seals to wetting.

Chapter 6

Framing (Construction) & Foundation (Engineering)

Framing (Construction)

A two-story wooden-frame house under construction—the location of the upper floor platform is readily discerned by the wide joists between the floors, and the upper structure rests on this platform.

Framing, in construction known as **light-frame construction**, is a building technique based around structural members, usually called studs, which provide a stable frame to which interior and exterior wall coverings are attached, and covered by a roof comprising

horizontal ceiling joists and sloping rafters (together forming a truss structure) or manufactured pre-fabricated roof trusses—all of which are covered by various sheathing materials to give weather resistance.

Modern light-frame structures usually gain strength from rigid panels (plywood and other plywood-like composites such as oriented strand board (OSB) used to form all or part of wall sections, but until recently carpenters employed various forms of diagonal bracing (called *wind braces*) to stabilize walls. Diagonal bracing remains a vital interior part of many roof systems, and in-wall wind braces are required by building codes in many municipalities or by individual state laws in the United States.

Light frame construction using standardized dimensional lumber has become the dominant construction method in North America and Australia because of its economy. Use of minimal structural materials allows builders to enclose a large area with minimal cost, while achieving a wide variety of architectural styles. The ubiquitous platform framing and the older balloon framing are the two different light frame construction systems used in North America.

Walls

Wall framing in house construction includes the vertical and horizontal members of exterior walls and interior partitions, both of bearing walls and non-bearing walls. These *stick* members, referred to as studs, wall plates and lintels (*headers*), serve as a nailing base for all covering material and support the upper floor platforms, which provide the lateral strength along a wall. The platforms may be the boxed structure of a ceiling and roof, or the ceiling and floor joists of the story above. The technique is variously referred to colloquially in the building trades as *stick and frame*, *stick and platform*, or *stick and box* as the sticks (studs) give the structure its vertical support, and the box shaped floor sections with joists contained within length-long post and lintels (more commonly called *headers*), supports the weight of whatever is above, including the next wall up and the roof above the top story. The platform, also provides the lateral support against wind and holds the stick walls true and square. Any lower platform supports the weight of the platforms and walls above the level of its component headers and joists.

Framing lumber should be grade-stamped, and have a moisture content not exceeding 19%.

There are three historically common methods of framing a house.

- Post and Beam, which is now used predominately in barn construction.
- Balloon framing using a technique suspending floors from the walls was common until the late 1940s, but since that time, platform framing has become the predominant form of house construction.
- Platform framing often forms wall sections horizontally on the sub-floor prior to erection, easing positioning of studs and increasing accuracy while cutting the necessary manpower. The top and bottom plates are end-nailed to each stud with

two nails at least 3.25 in (83 mm) in length (*16d* or *16 penny* nails). Studs are at least doubled (creating posts) at openings, the jack stud being cut to receive the lintels(headers) that are placed and end-nailed through the outer studs.

Wall sheathing, usually a plywood or other laminate, is usually applied to the framing prior to erection, thus eliminating the need to scaffold, and again increasing speed and cutting manpower needs and expenses. Some types of exterior sheathing, such as asphalt-impregnated fibreboard, plywood, oriented strand board and waferboard, will provide adequate bracing to resist lateral loads and keep the wall square, but construction codes in most jurisdictions will require a stiff plywood sheathing. Others, such as rigid glass-fibre, asphalt-coated fibreboard, polystyrene or polyurethane board, will not. In this latter case, the wall should be reinforced with a diagonal wood or metal bracing inset into the studs. In jurisdictions subject to strong wind storms (hurricane countries, tornado alleys) local codes or state law will generally require both the diagonal wind braces and the stiff exterior sheathing regardless of the type and kind of outer weather resistant coverings.

Corners

A multiple-stud post made up of at least three studs, or the equivalent, is generally used at exterior corners and intersections to secure a good tie between adjoining walls and to provide nailing support for the interior finish and exterior sheathing. Corners and intersections, however, must be framed with at least two studs.

Nailing support for the edges of the ceiling is required at the junction of the wall and ceiling where partitions run parallel to the ceiling joists. This material is commonly referred to as 'dead wood' or backing.

Exterior wall studs

Wall framing in house construction includes the vertical and horizontal members of exterior walls and interior partitions. These members, referred to as studs, wall plates and lintels, serve as a nailing base for all covering material and support the upper floors, ceiling and roof.

Exterior wall studs are the vertical members to which the wall sheathing and cladding are attached. They are supported on a bottom plate or foundation sill and in turn support the top plate. Studs usually consist of 2 × 4 in (51 × 100 mm) or 2 × 6 in (51 × 150 mm) lumber and are commonly spaced at 16 in (410 mm) on centre. This spacing may be changed to 12 in (300 mm) or 24 in (610 mm) on centre depending on the load and the limitations imposed by the type and thickness of the wall covering used. Wider 2 × 6 in (51 × 150 mm) studs may be used to provide space for more insulation. Insulation beyond that which can be accommodated within a 3.5 in (89 mm) stud space can also be provided by other means, such as rigid or semi-rigid insulation or batts between 2 × 2 in (51 × 51 mm) horizontal furring strips, or rigid or semi-rigid insulation sheathing to the outside of the studs. The studs are attached to horizontal top and bottom wall plates of 2 in (nominal) (38 mm) lumber that are the same width as the studs.

Interior partitions

Interior partitions supporting floor, ceiling or roof loads are called loadbearing walls; others are called non-loadbearing or simply partitions. Interior loadbearing walls are framed in the same way as exterior walls. Studs are usually 2 × 4 in (51 × 100 mm) lumber spaced at 16 in (410 mm) on centre. This spacing may be changed to 12 in (300 mm) or 24 in (610 mm) depending on the loads supported and the type and thickness of the wall finish used.

Partitions can be built with 2 × 3 in (51 × 76 mm) or 2 × 4 in (51 × 100 mm) studs spaced at 16 or 24 in (400 or 600 mm) on center depending on the type and thickness of the wall finish used. Where a partition does not contain a swinging door, 2 × 4 in (51 × 100 mm) studs at 16 in (410 mm) on centre are sometimes used with the wide face of the stud parallel to the wall. This is usually done only for partitions enclosing clothes closets or cupboards to save space. Since there is no vertical load to be supported by partitions, single studs may be used at door openings. The top of the opening may be bridged with a single piece of 2 in (nominal) (38 mm) lumber the same width as the studs. These members provide a nailing support for wall finish, door frames and trim.

Lintels (headers)

Lintels (or, headers) are the horizontal members placed over window, door and other openings to carry loads to the adjoining studs. Lintels are usually constructed of two pieces of 2 in (nominal) (38 mm) lumber separated with spacers to the width of the studs and nailed together to form a single unit. The preferable spacer material is rigid insulation. The depth of a lintel is determined by the width of the opening and vertical loads supported.

Wall Sections

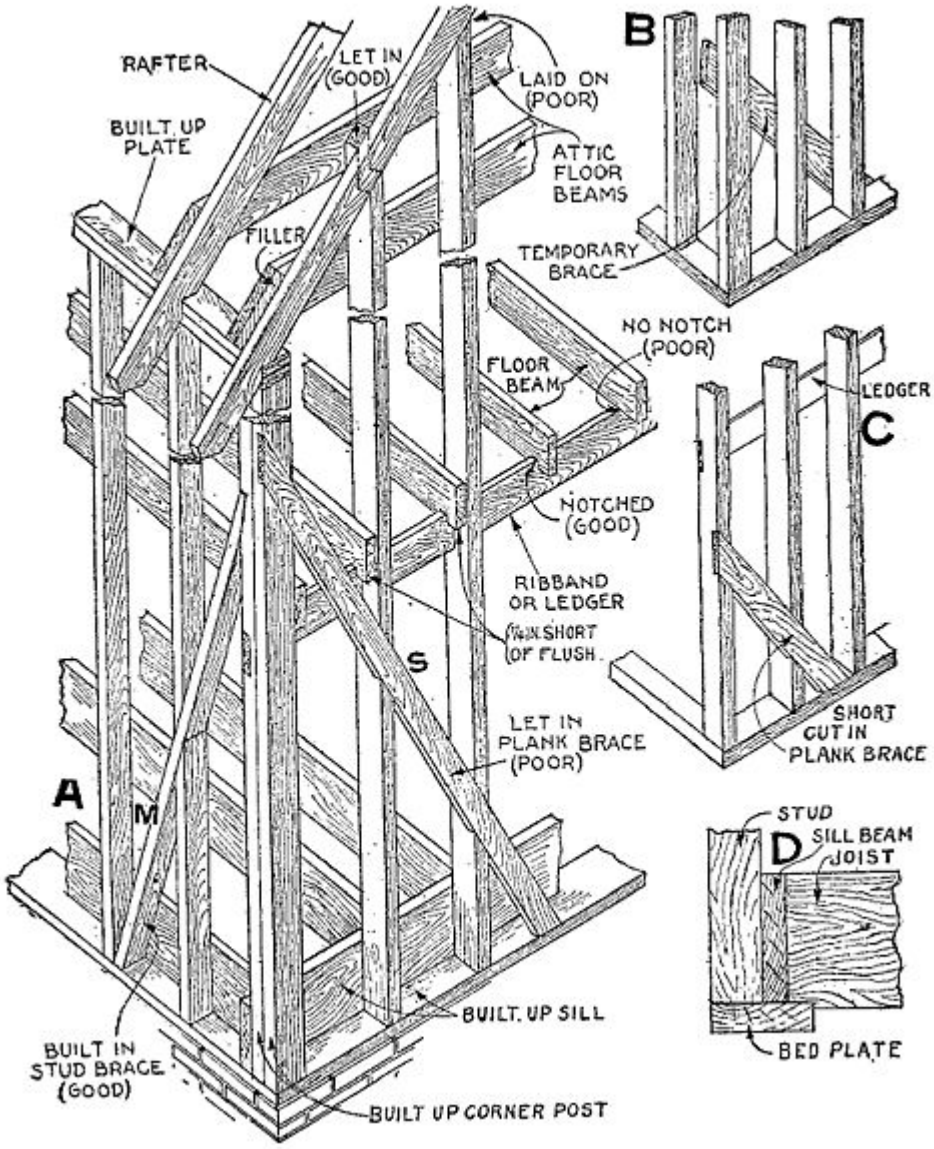
The complete wall sections are then raised and put in place, temporary braces added and the bottom plates nailed through the subfloor to the floor framing members. The braces should have their larger dimension on the vertical and should permit adjustment of the vertical position of the wall.

Once the assembled sections are plumbed, they are nailed together at the corners and intersections. A strip of polyethylene is often placed between the interior walls and the exterior wall, and above the first top plate of interior walls before the second top plate is applied to attain continuity of the air barrier when polyethylene is serving this function.

A second top plate, with joints offset at least one stud space away from the joints in the plate beneath, is then added. This second top plate usually laps the first plate at the corners and partition intersections and, when nailed in place, provides an additional tie to the framed walls. Where the second top plate does not lap the plate immediately underneath at corner and partition intersections, these may be tied with 0.036 in (0.91

mm) galvanized steel plates at least 3 in (76 mm) wide and 6 in (150 mm) long, nailed with at least three 2.5 in (64 mm) nails to each wall.

Balloon framing



Balloon framing is a method of wood construction—also known as "Chicago construction" in the 19th century—used primarily in Scandinavia, Canada and the United States (up until the mid-1950s). It utilizes long continuous framing members (studs) that run from sill plate to eave line with intermediate floor structures nailed to them, with the heights of window sills, headers and next floor height marked out on the studs with a storey pole. Once popular when long lumber was plentiful, balloon framing has been largely replaced by *platform framing*.

While no one is sure who introduced balloon framing in the U.S., the first building using balloon framing was probably a warehouse constructed in 1832 in Chicago by George Washington Snow. The following year, Augustine Taylor (1796–1891) constructed St. Mary's Catholic Church in Chicago using the balloon framing method. Alternately, the balloon frame has been shown to have been introduced in Missouri as much as fifty years earlier.

The name comes from a French Missouri type of construction, *maison en boulin*. The curious name of this framing technique is conventionally thought to be a derisive one. Historians have fabricated the following story: As Taylor was constructing his first such building, St. Mary's Church, in 1833, skilled carpenters looked on at the comparatively thin framing members, all held together with nails, and declared this method of construction to be no more substantial than a balloon. It would surely blow over in the next wind! Though the criticism proved baseless, the name stuck.

Although lumber was plentiful in 19th century America, skilled labor was not. The advent of cheap machine-made nails, along with water-powered sawmills in the early 19th century made balloon framing highly attractive, because it did not require highly-skilled carpenters, as did the dovetail joints, mortises and tenons required by post-and-beam construction. For the first time, any farmer could build his own buildings without a time-consuming learning curve.

It has been said that balloon framing populated the western United States and the western provinces of Canada. Without it, western boomtowns certainly could not have blossomed overnight. It is also a fair certainty that, by radically reducing construction costs, balloon framing improved the shelter options of poorer North Americans. For example, many 19th century New England working neighborhoods consist of balloon-constructed three-story apartment buildings referred to as triple deckers.

The main difference between platform and balloon framing is at the floor lines. The balloon wall studs extend from the sill of the first story all the way to the top plate or end rafter of the second story. The platform-framed wall, on the other hand, is independent for each floor.

Balloon framing has several disadvantages as a construction method:

1. The creation of a path for fire to readily travel from floor to floor. This is mitigated with the use of firestops at each floor level.
2. The lack of a working platform for work on upper floors. Whereas workers can readily reach the top of the walls being erected with platform framing, balloon construction requires scaffolding to reach the tops of the walls (which are often two or three stories above the working platform).
3. The requirement for long framing members.
4. In certain larger buildings, a noticeable down-slope of floors towards central walls, caused by the differential shrinkage of the wood framing members at the perimeter versus central walls. Larger balloon-framed buildings will have central

bearing walls which are actually platform framed and thus will have horizontal sill and top plates at each floor level, plus the intervening floor joists, at these central walls. Wood will shrink much more across its grain than along the grain. Therefore, the cumulative shrinkage in the center of such a building is considerably more than the shrinkage at the perimeter where there are many fewer horizontal members. Of course, this problem, unlike the first three, takes time to develop and become noticeable.

5. Present day balloon framing buildings have considerably higher heating costs, due to the lack of insulation separating a room from its exterior walls.

Since steel is generally more fire-resistant than wood, and steel framing members can be made to arbitrary lengths, balloon framing is growing in popularity again in light gauge steel stud construction. Balloon framing provides a more direct load path down to the foundation. Additionally, balloon framing allows more flexibility for tradesmen in that it is significantly easier to pull wire, piping and ducting without having to bore through or work around framing members.

Platform framing

In Canada and the United States, the most common method of light-frame construction for houses and small apartment buildings as well as some small commercial buildings is *platform framing*.

The framed structure sits atop a concrete (most common) or treated wood foundation. A sill plate is anchored, usually with 'J' bolts to the foundation wall. Generally these plates must be pressure treated to keep from rotting. The bottom of the sill plate is raised a minimum 6 inches (150 mm) above the finished grade by the foundation. This again is to prevent the sill-plate from rotting as well as providing a termite barrier.

The floors, walls and roof of a framed structure are created by assembling (using nails) consistently sized framing elements of dimensional lumber (2×4, 2×6, etc.) at regular spacings (12 in, 16 in, and 24 in on center. Sometimes the lesser known -19.2" on center-method is used), forming stud-bays (wall) or joist-bays (floor). The floors, walls and roof are typically made torsionally stable with the installation of a plywood or composite wood skin referred to as sheathing. Sheathing has very specific nailing requirements (such as size and spacing); these measures allow a known amount of shear force to be resisted by the element. Spacing the framing members properly allows them to align with the edges of standard sheathing. In the past, tongue and groove planks installed diagonally were used as sheathing. Occasionally, wooden or galvanized steel braces are used instead of sheathing. There are also engineered wood panels made for shear and bracing.

The floor, or the platform of the name, is made up of joists (usually 2x6, 2×8, 2×10 or 2×12, depending on the span) that sit on supporting walls, beams or girders. The floor joists are spaced at (12 in, 16 in, and 24 in on center) and covered with a plywood subfloor. In the past, 1x planks set at 45-degrees to the joists were used for the subfloor.

Where the design calls for a framed floor, the resulting platform is where the framer will construct and stand that floor's walls (interior and exterior load bearing walls and space-dividing, non-load bearing partitions). Additional framed floors and their walls may then be erected to a general maximum of four in wood framed construction. There will be no framed floor in the case of a single-level structure with a concrete floor known as a *slab on grade*.

Stairs between floors are framed by installing stepped *stringers* and then placing the horizontal *treads* and vertical *risers*.

A framed roof is an assembly of rafters and wall-ties supported by the top story's walls. Prefabricated and site-built trussed rafters are also used along with the more common stick framing method. *Trusses* are engineered to redistribute tension away from wall-tie members and the ceiling members. The roof members are covered with sheathing or strapping to form the roof deck for the finish roofing material.

Floor joists can be engineered lumber (trussed, I-joist, etc.), conserving resources with increased rigidity and value. They allow access for runs of plumbing, HVAC, etc. and some forms are pre-manufactured.

Double framing is a style of framing used to reduce heat loss and air infiltration. Two walls are built around the perimeter of the building with a small gap in between. The inner wall carries the structural load of the building and is constructed as described above. The exterior wall is not load bearing and can be constructed using lighter materials. Insulation is installed in the entire space between the outside edge of the exterior wall and the inside edge of the interior wall. The size of the gap depends upon how much insulation is desired. The vapour barrier is installed on the outside of the inner wall, rather than between the studs and drywall of a standard framed structure. This increases its effectiveness as it is not perforated by electrical and plumbing connections.

Materials

Light-frame materials are most often wood or rectangular steel tubes or C-channels. Wood pieces are typically connected with nails or screws; steel pieces are connected by screws. Preferred species for linear structural members are softwoods such as spruce, pine and fir. Light frame material dimensions range from 38 mm by 89 mm (1.5 in by 3.5 in; i.e., a two-by-four) to 5 cm by 30 cm (two-by-twelve inches) at the cross-section, and lengths ranging from 2.5 m (8.2 ft) for walls to 7 m (23 ft) or more for joists and rafters. Recently, architects have begun experimenting with pre-cut modular aluminum framing to reduce on-site construction costs.

Wall panels built of studs are interrupted by sections that provide rough openings for doors and windows. Openings are typically spanned by a header or lintel that bears the weight of structure above the opening. Headers are usually built to rest on trimmers, also called jacks. Areas around windows are defined by a sill beneath the window, and cripples, which are shorter studs that span the area from the bottom plate to the sill and

sometimes from the top of the window to a header, or from a header to a top plate. Diagonal bracings made of wood or steel provide shear (horizontal strength) as do panels of sheeting nailed to studs, sills and headers.

Light-gauge metal stud framing

Wall sections usually include a bottom plate which is secured to the structure of a floor, and one, or more often two top plates that tie walls together and provide a bearing for structures above the wall. Wood or steel floor frames usually include a rim joist around the perimeter of a system of floor joists, and often include bridging material near the center of a span to prevent lateral buckling of the spanning members. In two-story construction, openings are left in the floor system for a stairwell, in which stair risers and treads are most often attached to squared faces cut into sloping stair stringers.

Interior wall coverings in light-frame construction typically include wallboard, lath and plaster or decorative wood paneling.

Exterior finishes for walls and ceilings often include plywood or composite sheathing, brick or stone veneers, and various stucco finishes. Cavities between studs, usually placed 40–60 cm (16–24 in) apart, are usually filled with insulation materials, such as fiberglass batting, or cellulose filling sometimes made of recycled newsprint treated with boron additives for fire prevention and vermin control.

In natural building, straw bales, cob and adobe may be used for both exterior and interior walls. The part of a structural building that goes diagonally across a wall is called a T-bar. It stops the walls from collapsing in gusty winds.

Roofs

Roofs are usually built to provide a sloping surface intended to shed rain or snow, with slopes ranging from 1 cm of rise per 15 cm (less than an inch per linear foot) of rafter length, to steep slopes of more than 2 cm per cm (two feet per foot) of rafter length. A light-frame structure built mostly inside sloping walls comprising a roof is called an A-frame.

Roofs are most often covered with shingles made of asphalt, fiberglass and small gravel coating, but a wide range of materials are used. Molten tar is often used to waterproof flatter roofs, but newer materials include rubber and synthetic materials. Steel panels are popular roof coverings in some areas, preferred for their durability. Slate or tile roofs offer more historic coverings for light-frame roofs.

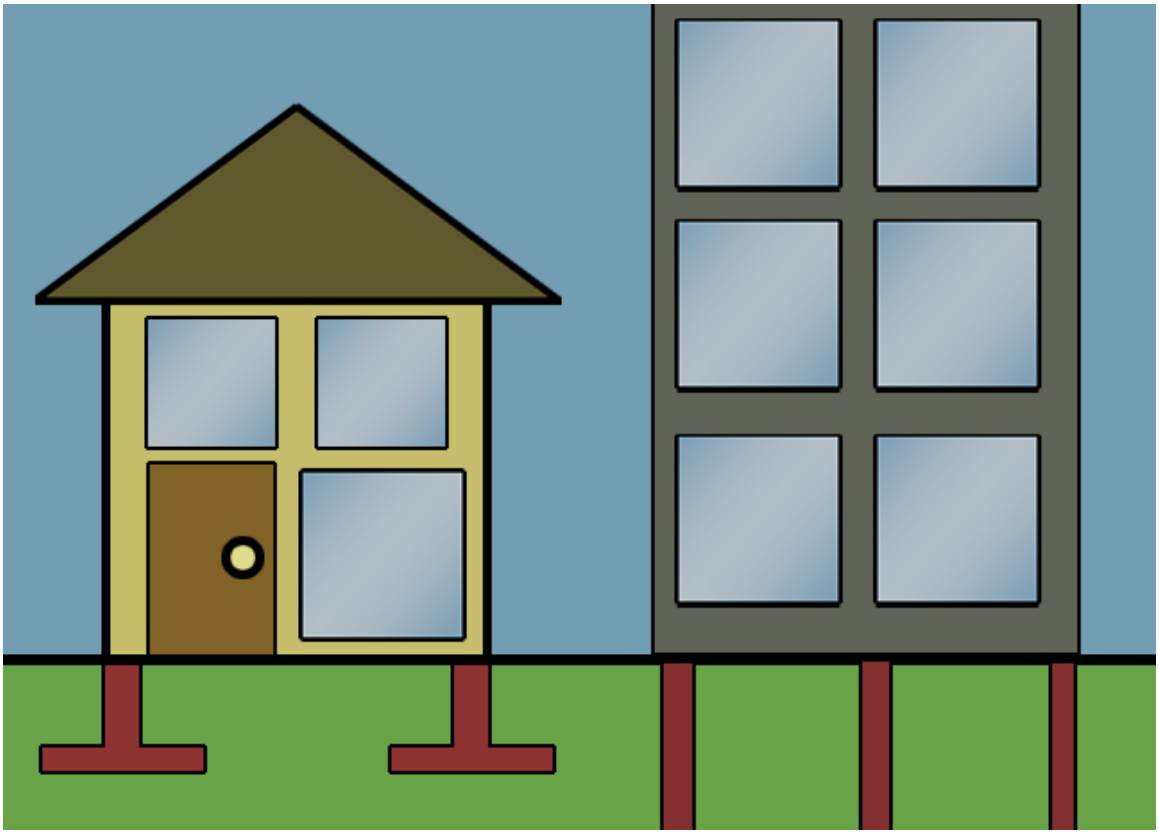
Light-frame methods allow easy construction of unique roof designs. Hip roofs, which slope toward walls on all sides and are joined at hip rafters that span from corners to a ridge. Valleys are formed when two sloping roof sections drain toward each other. Dormers are small areas in which vertical walls interrupt a roof line, and which are topped off by slopes at usually right angles to a main roof section. Gables are formed when a length-wise section of sloping roof ends to form a triangular wall section. Clerestories are formed by an interruption along the slope of a roof where a short vertical wall connects it to another roof section. Flat roofs, which usually include at least a nominal slope to shed water, are often surrounded by parapet walls with openings (called scuppers) to allow water to drain out. Sloping crickets are built into roofs to direct water away from areas of poor drainage, such as behind a chimney at the bottom of a sloping section.

Structure

Light-frame buildings are often erected on monolithic concrete slab foundations that serve both as a floor and as a support for the structure. Other light-frame buildings are built over a crawlspace or a basement, with wood or steel joists used to span between foundation walls, usually constructed of poured concrete or concrete blocks.

Engineered components are commonly used to form floor, ceiling and roof structures in place of solid wood. I-joists (closed-web trusses) are often made from laminated woods, most often chipped poplar wood, in panels as thin as 1 cm (0.4 in), glued between horizontally laminated members of less than 4 cm by 4 cm (*two-by-twos*), to span distances of as much as 9 m (30 ft). Open web trussed joists and rafters are often formed of 4 cm by 9 cm (*two-by-four* [sic]) wood members to provide support for floors, roofing systems and ceiling finishes.

Foundation (Engineering)



Shallow foundations of a house versus the deep foundations of a Skyscraper.

A **foundation** (also called a **groundsill**) is a structure that transfers loads to the earth. Foundations are generally broken into two categories: shallow foundations and deep foundations.

Footing types

Shallow footings

Shallow footings are, usually, embedded a meter or so into soil. One common type is the spread footing which consists of strips or pads of concrete (or other materials) which extend below the frost line and transfer the weight from walls and columns to the soil or bedrock. Another common type is the slab-on-grade footing where the weight of the building is transferred to the soil through a concrete slab placed at the surface.Ref

Deep footings

A **deep footing** is used to transfer a load from a structure through an upper weak layer of soil to a stronger deeper layer of soil. There are different types of deep footings including helical piles, impact driven piles, drilled shafts, caissons, piers, and earth stabilized columns. The naming conventions for different types of footings vary between different engineers. Historically, piles were wood, later steel, reinforced concrete, and pre-tensioned concrete.

Monopile footings

A **monopile footing** utilizes a single, generally large-diameter, footing structural element to support all the loads (weight, wind, etc.) of a large above-surface structure.

A large number of monopile footings have been utilized in recent years for economically constructing fixed-bottom offshore wind farms in shallow-water subsea locations. For example, a single wind farm off the coast of England went online in 2008 with over 100 turbines, each mounted on a 4.7-meter-diameter monopile footing in ocean depths up to 18 meters of water. An earlier (2002) wind farm in the North Sea west of Denmark utilizes 80 large monopiles of 4 meter diameter sunk 25 meters deep into the seabed.

Base-isolating footings

Base isolator being tested at the UCSD Caltrans-SRMD facility

Base-isolating footings, also known as *seismic* or *base isolation system*, is a collection of structural elements which is intended to substantially decouple a superstructure from its substructure resting on a shaking ground thus protecting a building or non-building structure's integrity during a potentially devastating earthquake. The base-isolating system may be constructed on either a shallow footing or a deep footing substructure.

The base-isolating footing design is believed to be a powerful tool of contemporary earthquake engineering pertaining to the passive structural vibration control technologies.

Design

Footings are designed to have an adequate load capacity with limited settlement by a geotechnical engineer, and the footing itself is designed structurally by a structural engineer.

Inadequate foundations in muddy soils below sea level caused these houses in the Netherlands to subside.

The primary design concerns are settlement and bearing capacity. When considering settlement, total settlement and differential settlement is normally considered. Differential settlement is when one part of a foundation settles more than another part. This can cause problems to the structure the foundation is supporting. It is necessary that a foundation not be loaded beyond its bearing capacity or the foundation will "fail".

Other design considerations include scour and frost heave. Scour is when flowing water removes supporting soil from around a footing (like a pier supporting a bridge over a river). Frost heave occurs when water in the ground freezes to form ice lenses.

Changes in soil moisture can cause expansive clay to swell and shrink. This swelling can vary across the footing due to seasonal changes or the effects of vegetation removing moisture. The variation in swell can cause the soil to distort, cracking the structure over it. This is a particular problem for house footings in semi-arid climates such as South Australia, Southwestern US, Turkey, Israel, Iran and South Africa where wet winters are followed by hot dry summers. Raft slabs with inherent stiffness have been developed in Australia with capabilities to resist this movement.

When structures are built in areas of permafrost, special consideration must be given to the thermal effect the structure will have on the permafrost. Generally, the structure is designed in a way that tries to prevent the permafrost from melting.