

Building Engineering

Raymon Carrillo



First Edition, 2012

ISBN 978-81-323-3004-2

© All rights reserved.

Published by:

Research World

4735/22 Prakashdeep Bldg,

Ansari Road, Darya Ganj,

Delhi - 110002

Email: info@wtbooks.com

Table of Contents

Chapter 1 - Architectural Engineering

Chapter 2 - Structural Engineering

Chapter 3 - Building Services Engineering

Chapter 4 - Building Automation

Chapter 5 - Home Automation

Chapter 6 - Building Information Modeling

Chapter 7 - Building Material

Chapter 8 - Construction

Chapter 9 - HVAC

Chapter 10 - Elevator

Chapter 1

Architectural Engineering



César Pelli's Ratner Athletic Center uses cables, counterweights and masts as load-bearing devices.

Architectural engineering, also known as **Building engineering**, is the application of engineering principles and technology to building design and construction. Definitions of an **architectural engineer** may refer to:

- An engineer in the structural, mechanical, electrical, construction or other engineering fields of building design and construction.
- A licensed engineering professional in parts of the United States.
- In informal contexts, and formally in some places, a professional synonymous with or similar to an architect. In some languages, "architect" is literally translated as "architectural engineer".

Engineering for building

Structural Engineering

Structural engineering involves the analysis and design of physical objects such as buildings, bridges, equipment supports, towers and walls. Those concentrating on buildings are responsible for the structural performance of a large part of the built environment and are, sometimes, informally referred to as "building engineers". Structural engineers require expertise in strength of materials and in the seismic design of structures covered by earthquake engineering. Architectural Engineers sometimes practice structural as one aspect of their designs; the structural discipline when practiced as a specialty works closely with architects and other engineering specialists.

Mechanical, Electrical and Plumbing (MEP)

Mechanical and electrical engineers are specialists, commonly referred to as "MEP" (mechanical, electrical and plumbing) when engaged in the building design fields. Also known as "Building services engineering" in the United Kingdom, Canada and Australia. Mechanical engineers design and oversee the heating ventilation and air conditioning (HVAC), plumbing, and rain gutter systems. Plumbing designers often include design specifications for simple active fire protection systems, but for more complicated projects, fire protection engineers are often separately retained. Electrical engineers are responsible for the building's power distribution, telecommunication, fire alarm, signalization, lightning protection and control systems, as well as lighting systems.

The Architectural engineer (PE) in the United States

In many jurisdictions of the United States, the architectural engineer is a licensed engineering professional, usually a graduate of an architectural engineering university program preparing students to perform whole-building design in competition with architect-engineer teams; or for practice in one of structural, mechanical or electrical fields of building design, but with an appreciation of integrated architectural requirements.

Formal architectural engineering education, following the engineering model of earlier disciplines, developed in the late 19th century, and became widespread in the United States by the mid-20th century. With the establishment of a specific "architectural engineering" NCEES Professional Engineering registration examination in the 1990s, and first offering in April 2003, architectural engineering became recognized as a distinct

engineering discipline in the United States. Architectural engineers are not entitled to practice architecture unless they are also licensed as architects.

The Architect as Architectural Engineer

In some countries architecture, as a profession providing architectural services, is sometimes referred to as "architectural engineering". In others, such as in Japan, the terms "architecture" and "building engineering" are used synonymously. The practice of architecture includes the planning, designing and overseeing the building's construction.

In some languages, such as Korean and Arabic, "architect" is literally translated as "architectural engineer". In some countries, an "architectural engineer" (such as the *ingegnere edile* in Italy) is entitled to practice architecture and is often referred to as an architect. These individuals are often also structural engineers. In other countries, such as Germany, Austria and most of the Arabic countries, architecture graduates receive an engineering degree (*Dipl.-Ing. - Diplom-Ingenieur*).

In Brazil, architects and engineers currently share the same accreditation process (CREA - Regional Council of Engineers and Architects). Besides traditional architecture design training, Brazilian architecture courses also offer complementary training in engineering disciplines such as structural, electrical, hydraulic and mechanical engineering. After graduation, architects can be fully responsible for most engineering design and construction, except highly specialized tasks such as road design and high voltage electrical.

Education

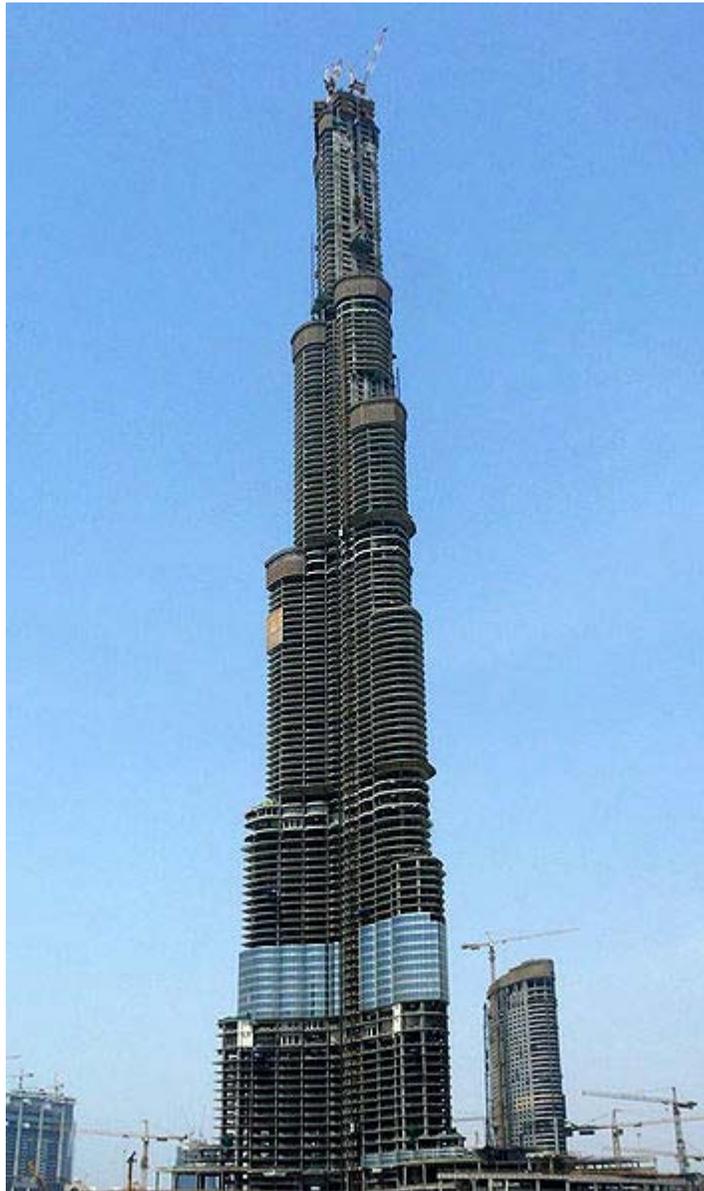
The architectural, structural, mechanical and electrical engineering branches each have well established educational requirements that are usually fulfilled by completion of a university program.

Architectural Engineering as a single integrated field of study

What differentiates Architectural Engineering as a separate and single, integrated field of study, compared to other engineering disciplines, is its multi-disciplined engineering approach. Through training in and appreciation of architecture, the field seeks integration of building systems within its overall building design. Architectural Engineering includes the design of building systems including Heating, ventilation and air conditioning (HVAC), plumbing, fire protection, electrical, lighting, transportation, and structural systems. In some university programs, students are required to concentrate on one of the systems; in others, they can receive a generalist Architectural or Building Engineering degree.

Chapter 2

Structural Engineering



Burj Khalifa, in Dubai, the world's tallest building, shown under construction in 2007 (since completed)

Structural engineering is a field of engineering dealing with the analysis and design of structures that support or resist loads. Structural engineering is usually considered a specialty within civil engineering, but it can also be studied in its own right. Structural engineers are most commonly involved in the design of buildings and large nonbuilding structures but they can also be involved in the design of machinery, medical equipment, vehicles or any item where structural integrity affects the item's function or safety. Structural engineers must ensure their designs satisfy given design criteria, predicated on safety (e.g. structures must not collapse without due warning) or serviceability and performance (e.g. building sway must not cause discomfort to the occupants). Buildings are made to endure massive loads as well as changing climate and natural disasters.

Structural engineering theory is based upon physical laws and empirical knowledge of the structural performance of different landscapes and materials. Structural engineering design utilises a relatively small number of basic structural elements to build up structural systems that can be very complex. Structural engineers are responsible for making creative and efficient use of funds, structural elements and materials to achieve these goals.

Structural engineer

Structural engineers are responsible for engineering design and analysis. Entry-level structural engineers may design the individual structural elements of a structure, for example the beams, columns, and floors of a building. More experienced engineers would be responsible for the structural design and integrity of an entire system, such as a building.

Structural engineers often specialize in particular fields, such as bridge engineering, building engineering, pipeline engineering, industrial structures, or special mechanical structures such as vehicles or aircraft.

Structural engineering has existed since humans first started to construct their own structures. It became a more defined and formalised profession with the emergence of the architecture profession as distinct from the engineering profession during the industrial revolution in the late 19th Century. Until then, the architect and the structural engineer were usually one and the same - the master builder. Only with the development of specialised knowledge of structural theories that emerged during the 19th and early 20th centuries did the professional structural engineer come into existence.

The role of a structural engineer today involves a significant understanding of both static and dynamic loading, and the structures that are available to resist them. The complexity of modern structures often requires a great deal of creativity from the engineer in order to ensure the structures support and resist the loads they are subjected to. A structural engineer will typically have a four or five year undergraduate degree, followed by a minimum of three years of professional practice before being considered fully qualified.

Structural engineers are licensed or accredited by different learned societies and regulatory bodies around the world (for example, the Institution of Structural Engineers in the UK). Depending on the degree course they have studied and/or the jurisdiction they are seeking licensure in, they may be accredited (or licensed) as just structural engineers, or as civil engineers, or as both civil and structural engineers.

History of structural engineering



Pont du Gard, France, a Roman era aqueduct circa 19 BC.

Structural engineering dates back to 2700 BC when the step pyramid for Pharaoh Djoser was built by Imhotep, the first engineer in history known by name. Pyramids were the most common major structures built by ancient civilizations because the structural form of a pyramid is inherently stable and can be almost infinitely scaled (as opposed to most other structural forms, which cannot be linearly increased in size in proportion to increased loads).

Throughout ancient and medieval history most architectural design and construction was carried out by artisans, such as stone masons and carpenters, rising to the role of master builder. No theory of structures existed, and understanding of how structures stood up was extremely limited, and based almost entirely on empirical evidence of 'what had worked before'. Knowledge was retained by guilds and seldom supplanted by advances. Structures were repetitive, and increases in scale were incremental.

No record exists of the first calculations of the strength of structural members or the behaviour of structural material, but the profession of structural engineer only really took shape with the industrial revolution and the re-invention of concrete. The physical sciences underlying structural engineering began to be understood in the Renaissance and have been developing ever since.

Structural failure

The history of structural engineering contains many collapses and failures. Sometimes this is due to obvious negligence, as in the case of the Pétionville school collapse, in which Rev. Fortin Augustin said that *"he constructed the building all by himself, saying he didn't need an engineer as he had good knowledge of construction"* following a partial collapse of the three-story schoolhouse that sent neighbors fleeing. The final collapse killed at least 362 people, mostly children.

In other cases structural failures require careful study, and the results of these inquiries have resulted in improved practices and greater understanding of the science of structural engineering. Some such studies are the result of Forensic engineering investigations where the original engineer seems to have done everything in accordance with the state of the profession and acceptable practice yet a failure still eventuated. A famous case of structural knowledge and practice being advanced in this manner can be found in a series of failures involving Box girders which collapsed in Australia during the 1970s.

Specializations

Building structures



Sydney Opera House, designed by Ove Arup & Partners, with the architect Jørn Utzon



Millennium Dome in London, UK, by Buro Happold and Richard Rogers

Structural building engineering includes all structural engineering related to the design of buildings. It is the branch of structural engineering that is close to architecture.

Structural building engineering is primarily driven by the creative manipulation of materials and forms and the underlying mathematical and scientific ideas to achieve an end which fulfills its functional requirements and is structurally safe when subjected to all the loads it could reasonably be expected to experience. This is subtly different from architectural design, which is driven by the creative manipulation of materials and forms, mass, space, volume, texture and light to achieve an end which is aesthetic, functional and often artistic.

The architect is usually the lead designer on buildings, with a structural engineer employed as a sub-consultant. The degree to which each discipline actually leads the design depends heavily on the type of structure. Many structures are structurally simple and led by architecture, such as multi-storey office buildings and housing, while other structures, such as tensile structures, shells and gridshells are heavily dependent on their form for their strength, and the engineer may have a more significant influence on the form, and hence much of the aesthetic, than the architect.

The structural design for a building must ensure that the building is able to stand up safely, able to function without excessive deflections or movements which may cause fatigue of structural elements, cracking or failure of fixtures, fittings or partitions, or discomfort for occupants. It must account for movements and forces due to temperature, creep, cracking and imposed loads. It must also ensure that the design is practically buildable within acceptable manufacturing tolerances of the materials. It must allow the architecture to work, and the building services to fit within the building and function (air conditioning, ventilation, smoke extract, electrics, lighting etc.). The structural design of a modern building can be extremely complex, and often requires a large team to complete.

Structural engineering specialties for buildings include:

- Earthquake engineering
- Façade engineering
- Fire engineering
- Roof engineering
- Tower engineering
- Wind engineering

Earthquake engineering structures

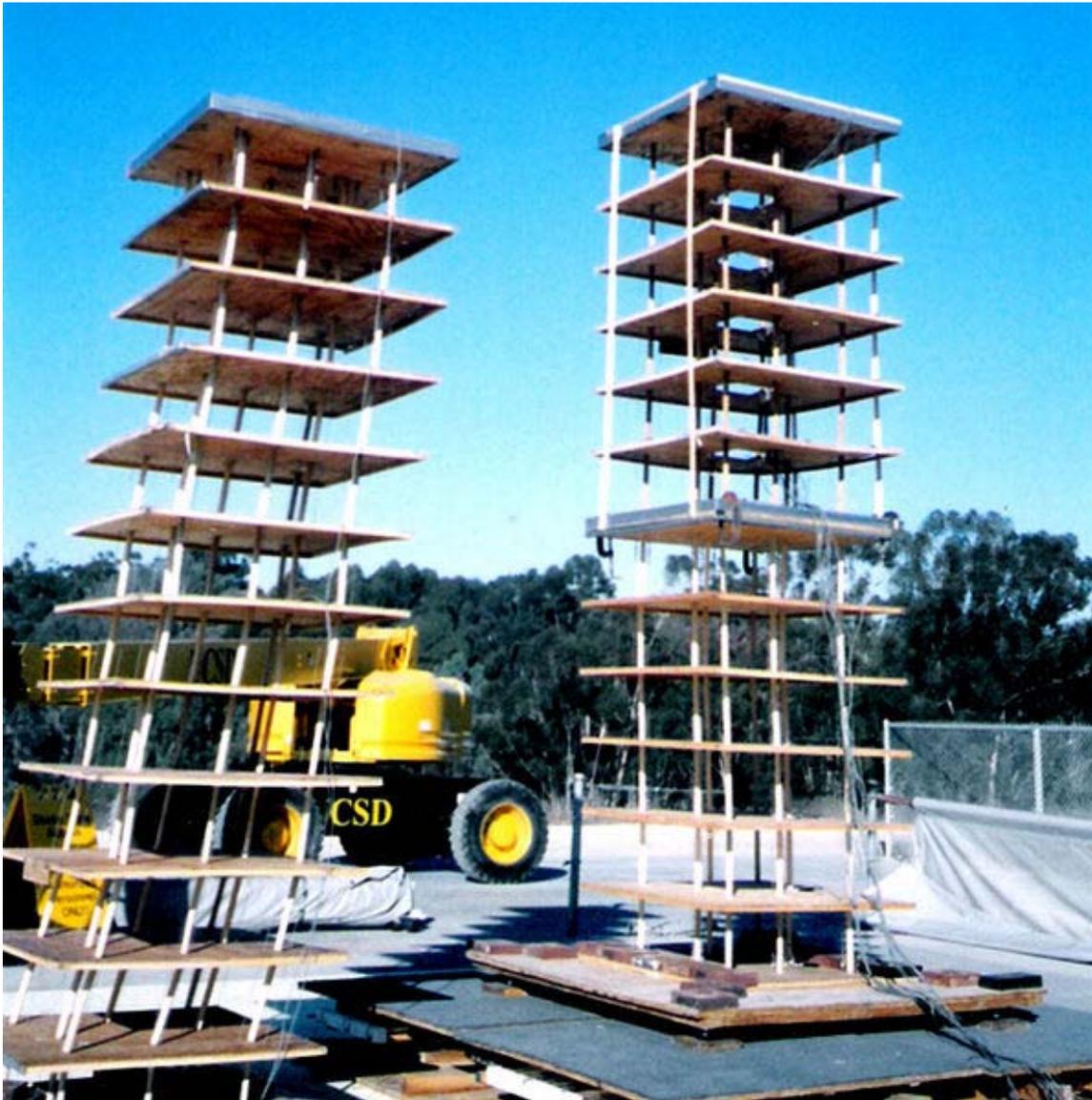
Earthquake engineering structures are those engineered to withstand various types of hazardous earthquake exposures at the sites of their particular location.



Earthquake-proof and massive pyramid El Castillo, Chichen Itza

Earthquake engineering is treating its subject structures like defensive fortifications in military engineering but for the warfare on earthquakes. Both earthquake and military general design principles are similar: be ready to slow down or mitigate the advance of a possible attacker.

The main objectives of **earthquake engineering** are:



Testing base-isolated (right) and regular (left) building model

- Understand interaction of structures with the shaky ground.
- Foresee the consequences of possible earthquakes.
- Design and construct the structures to perform while being exposed to an earthquake.

Earthquake engineering or **earthquake-proof structure** does not, necessarily, mean *extremely strong* and *expensive* one like El Castillo pyramid at Chichen Itza shown

above. In fact, many structures considered *strong* may in fact be actually *stiff*, which may result in poor seismic performance.

Now, the most *powerful* and *budgetary* tool of the earthquake engineering is base isolation which pertains to the passive structural vibration control technologies.

Civil engineering structures

Civil structural engineering includes all structural engineering related to the built environment. It includes:

- Bridges
- Dams
- Earthworks
- Foundations
- Offshore structures
- Pipelines
- Power stations
- Railways
- Retaining structures and walls
- Roads
- Tunnels
- Waterways
- Water and wastewater infrastructure

The structural engineer is the lead designer on these structures, and often the sole designer. In the design of structures such as these, structural safety is of paramount importance (in the UK, designs for dams, nuclear power stations and bridges must be signed off by a chartered engineer).

Civil engineering structures are often subjected to very extreme forces, such as large variations in temperature, dynamic loads such as waves or traffic, or high pressures from water or compressed gases. They are also often constructed in corrosive environments, such as at sea, in industrial facilities or below ground.

Mechanical structures



An Airbus A380, the world's largest passenger airliner

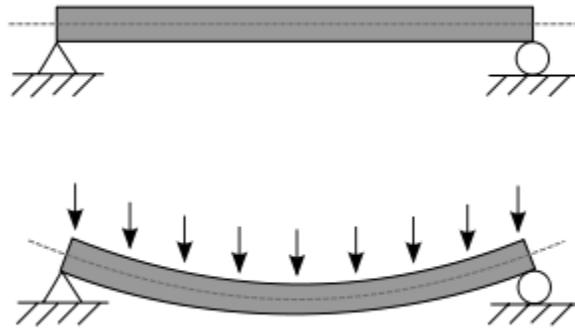
Principals of structural engineering are applied to variety of mechanical (moveable) structures. The design of static structures assumes they always have the same geometry (in fact, so-called static structures can move significantly, and structural engineering design must take this into account where necessary), but the design of moveable or moving structures must account for fatigue, variation in the method in which load is resisted and significant deflections of structures.

The forces which parts of a machine are subjected to can vary significantly, and can do so at a great rate. The forces which a boat or aircraft are subjected to vary enormously and will do so thousands of times over the structure's lifetime. The structural design must ensure that such structures are able to endure such loading for their entire design life without failing.

These works can require mechanical structural engineering:

- Airframes and fuselages
- Boilers and pressure vessels
- Coachworks and carriages
- Cranes
- Elevators
- Escalators
- Marine vessels and hulls

Structural elements



A statically determinate simply supported beam, bending under an evenly distributed load.

Any structure is essentially made up of only a small number of different types of elements:

- Columns
- Beams
- Plates
- Arches
- Shells
- Catenaries

Many of these elements can be classified according to form (straight, plane / curve) and dimensionality (one-dimensional / two-dimensional):

	One-dimensional		Two-dimensional	
	straight	curve	plane	curve
(predominantly) bending	beam	continuous arch	plate, concrete slab	lamina, dome
(predominant) tensile stress	rope	Catenary	shell	
(predominant) compression	pier, column		Load-bearing wall	

Columns

Columns are elements that carry only axial force - either tension or compression - or both axial force and bending (which is technically called a beam-column but practically, just a column). The design of a column must check the axial capacity of the element, and the buckling capacity.

The buckling capacity is the capacity of the element to withstand the propensity to buckle. Its capacity depends upon its geometry, material, and the effective length of the

column, which depends upon the restraint conditions at the top and bottom of the column. The effective length is $K * l$ where l is the real length of the column.

The capacity of a column to carry axial load depends on the degree of bending it is subjected to, and vice versa. This is represented on an interaction chart and is a complex non-linear relationship.

Beams

A beam may be defined as an element in which one dimension is much greater than the other two and the applied loads are usually normal to the main axis of the element. Beams and columns are called line elements and are often represented by simple lines in structural modeling.

- cantilevered (supported at one end only with a fixed connection)
- simply supported (supported vertically at each end; horizontally on only one to withstand friction, and able to rotate at the supports)
- continuous (supported by three or more supports)
- a combination of the above (ex. supported at one end and in the middle)

Beams are elements which carry pure bending only. Bending causes one part of the section of a beam (divided along its length) to go into compression and the other part into tension. The compression part must be designed to resist buckling and crushing, while the tension part must be able to adequately resist the tension.

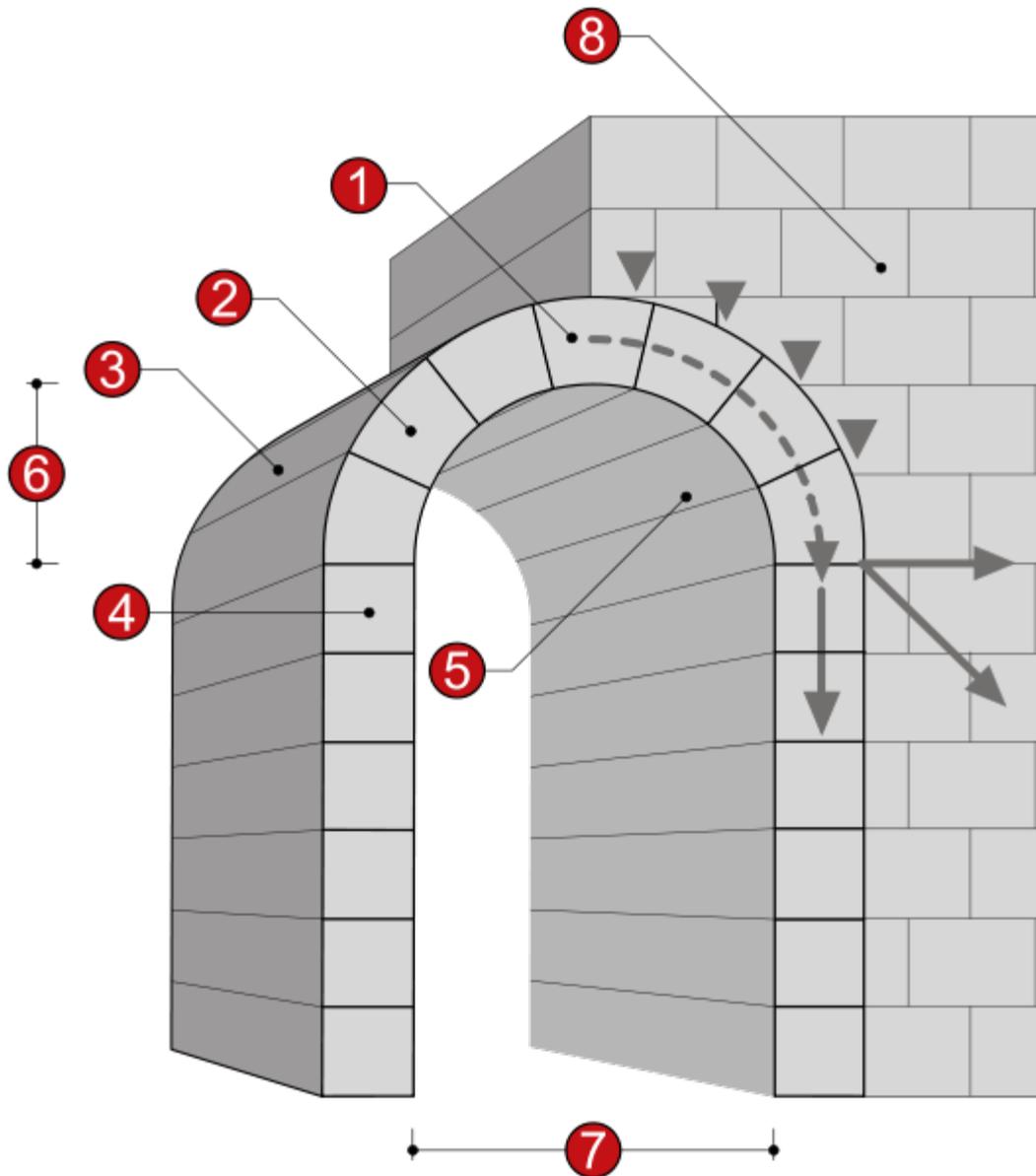
Struts and ties



Little Belt: a truss bridge in Denmark



The McDonnell Planetarium by Gyo Obata in St Louis, Missouri, USA, a concrete shell structure



A masonry arch

1. Keystone
2. Voussoir
3. Extrados
4. Impost
5. Intrados
6. Rise
7. Clear span
8. Abutment

A truss is a structure comprising two types of structural elements; compression members and tension members (i.e. struts and ties). Most trusses use gusset plates to connect intersecting elements. Gusset plates are relatively flexible and minimize bending moments at the connections, thus allowing the truss members to carry primarily tension or compression.

Trusses are usually utilised in span large distances, where it would be uneconomical to use solid beams.

Plates

Plates carry bending in two directions. A concrete flat slab is an example of a plate. Plates are understood by using continuum mechanics, but due to the complexity involved they are most often designed using a codified empirical approach, or computer analysis.

They can also be designed with yield line theory, where an assumed collapse mechanism is analysed to give an upper bound on the collapse load. This is rarely used in practice.

Shells

Shells derive their strength from their form, and carry forces in compression in two directions. A dome is an example of a shell. They can be designed by making a hanging-chain model, which will act as a catenary in pure tension, and inverting the form to achieve pure compression.

Arches

Arches carry forces in compression in one direction only, which is why it is appropriate to build arches out of masonry. They are designed by ensuring that the line of thrust of the force remains within the depth of the arch.

Catenaries

Catenaries derive their strength from their form, and carry transverse forces in pure tension by deflecting (just as a tightrope will sag when someone walks on it). They are almost always cable or fabric structures. A fabric structure acts as a catenary in two directions.

Structural engineering theory

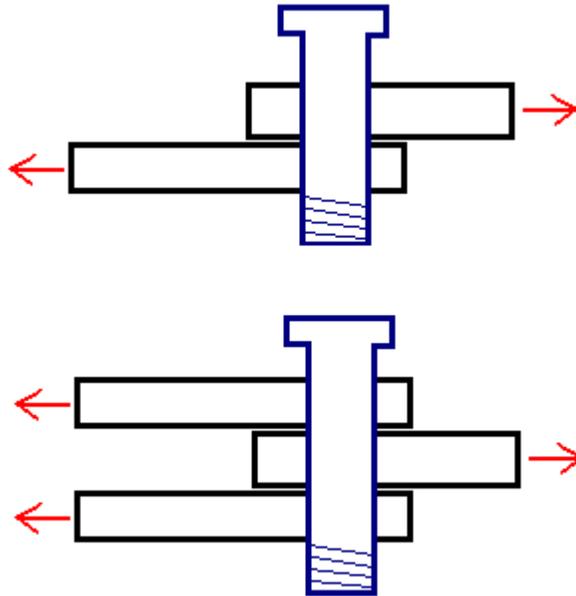


Figure of a bolt in shear stress. Top figure illustrates single shear, bottom figure illustrates double shear.

Structural engineering depends upon a detailed knowledge of loads, physics and materials to understand and predict how structures support and resist self-weight and imposed loads. To apply the knowledge successfully a structural engineer generally requires detailed knowledge of mathematics and relevant empirical and theoretical design codes. As well as, typically, some knowledge of the corrosion resistance of the materials and structures, especially when those structures are exposed to the external environment. Since the 1990s, specialist software has become available to aid in the design of structures, with the functionality to assist in both the drawing and designing of structures with maximum precision; examples include AutoCAD, StaadPro, ETABS etc. Such software may also take into consideration environmental loads, such as from earthquakes and winds.

Materials



The 630 foot (192 m) high, stainless-clad (type 304) Gateway Arch in Saint Louis, Missouri

Structural engineering depends on the knowledge of materials and their properties, in order to understand how different materials support and resist loads.

Common structural materials are:

- Iron:
 - Wrought iron
 - Cast iron
 - Steel
 - Stainless steel

- Concrete:
 - Reinforced concrete
 - Prestressed concrete

- Aluminium
- Composites
- Alloy
- Masonry
- Timber
- Other structural materials:
 - Adobe

- Bamboo
- Carbon fibre
- Fiber reinforced plastic
- Mudbrick
- Roofing materials

Chapter 3

Building Services Engineering

Building services engineering is the engineering of the internal environment and environmental impact of a building. It essentially brings buildings and structures to life.

Building services engineers are responsible for the design, installation, operation and monitoring of the mechanical, electrical and public health systems required for the safe, comfortable and environmentally friendly operation of modern buildings. The term "building services engineering" is widely used in the United Kingdom, Canada and Australia, however in the United States of America, it is also known as architectural engineering or building engineering.

Introduction

Building services engineering comprises Mechanical engineering, Electrical engineering and Public health (MEP) engineering, all of which are further sub-divided into the following:

- Communication lines, telephones and IT networks (ICT)
- Energy supply - gas, electricity and renewable sources
- Escalators and lifts
- Fire detection and protection
- Heating, ventilation and air conditioning (HVAC)
- Lightning protection
- Low voltage (LV) systems, distribution boards and switchgear
- Natural lighting and artificial lighting, and building facades
- Security and alarm systems
- Ventilation and refrigeration
- Water , drainage and plumbing

Building services engineers work closely with other construction professionals; architects, structural engineers and quantity surveyors. They influence the architecture of a building and play a significant role on the sustainability and energy demand of a building. Within building services engineering, new roles are emerging, for example in the areas of renewable energy, sustainability, low carbon technologies and energy management. With buildings accounting for around 50% of all carbon emissions, building services engineers play a significant role in combating climate change. As such, a typical building services engineer has a wide-ranging career path:

- **Design:** *designing layouts and requirements for building services for residential or commercial developments.*
- **Construction:** *supervising the construction of the building services, commissioning systems and ongoing maintenance and operation of services.*
- **Environmental:** *developing new energy saving methods for construction, designing new and improved energy conservation systems for buildings.*
- **Heating, ventilation and air conditioning (HVAC):** *specialising in the design, development, construction and operation of HVAC systems.*
- **Electrical technology:** *specialising in the design and development of electrical systems required for safe and energy sustaining operation of buildings.*

In 1976 Chartered Institution of Building Services Engineers (CIBSE) was founded and received a Royal Charter in the United Kingdom, and formally recognising building services engineering as a profession. Its objectives of the Institution are to:

'support the Science, Art and Practice of building services engineering, by providing our members and the public with first class information and education services and promoting the spirit of fellowship which guides our work.'

In recent years there has been increasing emphasis on sustainable and green design by the UK government, including in engineered building systems. Building services engineers increasingly seek BREEAM (BRE Environmental Assessment Method), CIBSE Low Carbon Consultants (LCC) and Energy Assessors (LCEA) status in addition to their Professional Engineering registration.

Building services engineering software

Many building services firms use computer-aided engineering (CAE) software programs, created either in-house or by external parties, to assist in their system design and analysis. This method has many benefits, including easier and more exhaustive visualization of proposed solutions, the ability to create virtual models for analysis and calculations, and the ease of use in spatial planning.

Education

Building services engineers typically possess an academic degree in either building services engineering, mechanical engineering or electrical engineering. The length of

study for such a degree is usually three years for a Bachelor of Engineering (BEng) or Bachelor of Science (BSc) and four years for a Master of Engineering (MEng). Some of the degrees accredited by the Chartered Institution of Building Services Engineers include:

Bachelors

- BSc (Hons) Integrated Technology (Building Services) (Doncaster College)
- BSc in Building Services Engineering (Glasgow Caledonian University)
- BSc (Hons) Building Services Engineering (Leeds Metropolitan University)
- BSc (Hons) Building Services Engineering (London South Bank University)
- BSc (Hons) Building Services Engineering (University of the West of England)
- BSc (Hons) Architectural Engineering (Heriot-Watt University)
- BEng (Hons) Building Services Engineering (The Hong Kong Polytechnic University)
- BEng (Hons) Architectural Environment Engineering (University of Nottingham)

Masters

- MSc Building Services (UNIVERSITY OF CENTRAL LANCASHIRE)
- MEng Architectural and Environmental Design (University of Nottingham)
- MEng Architectural Engineering (Heriot-Watt University)
- Architectural Engineering (University of Strathclyde)
- MEng (Hons) Mechanical Engineering (with Building Services Engineering) (The University of Manchester)
- MEng Architectural Science and Engineering Services (The University of Manchester)
- MSc Building Services Engineering (Loughborough University)
- MEng Building Services Engineering (Hong Kong Polytechnic University)
- MEng Building Services and Energy Engineering (University of Ulster)
- MEng Building Services Engineering (Northumbria University)
- MSc Buildings and Environment (Czech Technical University in Prague)
- MSc Building Service Engineering (International Islamic University Malaysia in Malaysia)

Courses accredited by other Engineering Institution in the UK such as the Institution of Engineering and Technology (IET) and the Institution of Mechanical Engineers (IMEchE) are also accepted and satisfy the education requirement to become a building services engineer. After completing an accredited degree program the engineer must also satisfy a range of other requirements (including work experience and possibly exam and report-writing requirements) before acquiring the professional qualification. Once all the requirements are satisfied and depending on the academic route undertaken by the engineer, he or she is designated the title of either **Chartered Engineer** (CEng), **Incorporated Engineer** (IEng) or **Engineering Technician** (EngTech). For more information, please refer to CIBSE. There are international engineering agreements

between relevant professional bodies which are designed to allow engineers to practice across international borders. Note that the term Chartered Engineer is mainly used in the UK and in most Commonwealth countries. In the European Union, **European Engineer** is used instead.

Notable people

Some notable people who contributed towards the building services field include:

- Ove Arup
- Norman Foster
- Ted Happold
- Ken Yeang

Companies

Some of the companies which provide building services engineering as part of their technical expertise are as follows:

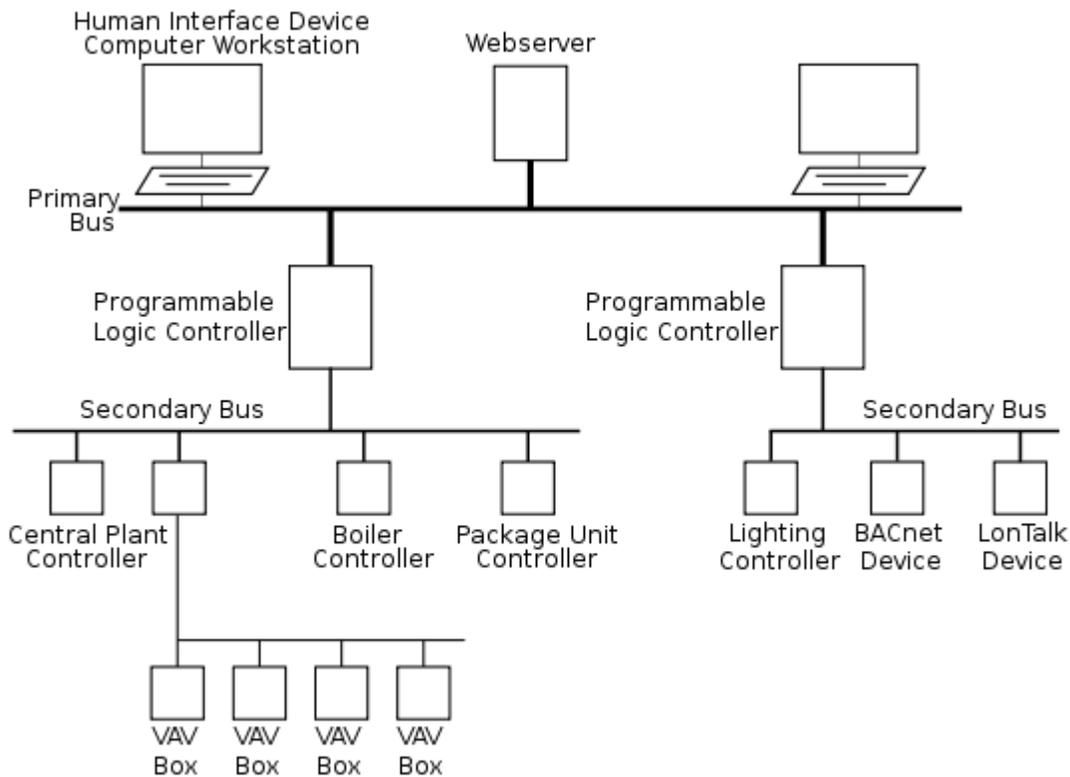
- AECOM
- Arup
- Atkins Ltd
- Buro Happold
- Building Design Partnership
- Coffey Projects
- Cundall
- Gifford (company)
- Halcrow Group Limited
- Hoare Lea
- KingShaw Associates
- Mott MacDonald
- Parsons Brinckerhoff
- Scott Wilson Group
- WSP Group
- Max Fordham LLP

Chapter 4

Building Automation

Building automation describes the functionality provided by the control system of a building. A building automation system (BAS) is an example of a distributed control system. The control system is a computerized, intelligent network of electronic devices, designed to monitor and control the mechanical and lighting systems in a building.

BAS core functionality keeps the building climate within a specified range, provides lighting based on an occupancy schedule, and monitors system performance and device failures and provides email and/or text notifications to building engineering staff. The BAS functionality reduces building energy and maintenance costs when compared to a non-controlled building. A building controlled by a BAS is often referred to as an intelligent building system.



Topology

Most building automation networks consist of a *primary* and *secondary* bus which connect high-level controllers (generally specialized for building automation, but may be generic programmable logic controllers) with lower-level controllers, input/output devices and a user interface (also known as a human interface device).

The primary and secondary bus can be BACnet, optical fiber, ethernet, ARCNET, RS-232, RS-485 or a wireless network.

Most controllers are proprietary. Each company has its own controllers for specific applications. Some are designed with limited controls: for example, a simple Packaged Roof Top Unit. Others are designed to be flexible. Most have proprietary software that will work with ASHRAE's open protocol BACnet or the open protocol LonTalk.

Some newer building automation and lighting control solutions use wireless mesh open standards (such as ZigBee). These systems can provide interoperability, allowing users to mix-and-match devices from different manufacturers, and to provide integration with other compatible building control systems.

Inputs and outputs are either analog or digital (some companies say binary).

Analog inputs are used to read a variable measurement. Examples are temperature, humidity and pressure sensor which could be thermistor, 4-20 mA, 0-10 volt or platinum resistance thermometer (resistance temperature detector), or wireless sensors.

A digital input indicates if a device is turned on or not. Some examples of an digital input would be a 24VDC/AC signal, an air flow switch, or a volta-free relay contact (Dry Contact).

Analog outputs control the speed or position of a device, such as a variable frequency drive, a I-P (current to pneumatics) transducer, or a valve or damper actuator. An example is a hot water valve opening up 25% to maintain a setpoint.

Digital outputs are used to open and close relays and switches. An example would be to turn on the parking lot lights when a photocell indicate it is dark outside.

Infrastructure

Controller

Controllers are essentially small, purpose-built computers with input and output capabilities. These controllers come in a range of sizes and capabilities to control devices commonly found in buildings, and to control sub-networks of controllers.

Inputs allow a controller to read temperatures, humidity, pressure, current flow, air flow, and other essential factors. The outputs allow the controller to send command and control signals to slave devices, and to other parts of the system. Inputs and outputs can be either digital or analog. Digital outputs are also sometimes called discrete depending on manufacturer.

Controllers used for building automation can be grouped in 3 categories. Programmable Logic Controllers (PLCs), System/Network controllers, and Terminal Unit controllers. However an additional device can also exist in order to integrate 3rd party systems (i.e. a stand-alone AC system) into a central Building automation system).

PLC's provide the most responsiveness and processing power, but at a unit cost typically 2 to 3 times that of a System/Network controller intended for BAS applications. Terminal Unit controllers are usually the least expensive and least powerful.

PLC's may be used to automate high-end applications such as clean rooms or hospitals where the cost of the controllers is a lesser concern.

In office buildings, supermarkets, malls, and other common automated buildings the systems will use System/Network controllers rather than PLC's. Most System controllers provide general purpose feedback loops, as well as digital circuits, but lack the millisecond response time that PLC's provide.

System/Network controllers may be applied to control one or more mechanical systems such as an Air Handler Unit (AHU), boiler, chiller, etc., or they may supervise a sub-network of controllers. In the diagram above, System/Network controllers are often used in place of PLCs.

Terminal Unit controllers usually are suited for control of lighting and/or simpler devices such as a package rooftop unit, heat pump, VAV box, or fan coil, etc. The installer typically selects 1 of the available pre-programmed personalities best suited to the device to be controlled, and does not have to create new control logic.

Occupancy

Occupancy is one of 2 or more operating modes for a building automation system. Unoccupied, Morning Warmup, and Night-time Setback are other common modes.

Occupancy is usually based on time of day schedules. In Occupancy mode, the BAS aims to provide a comfortable climate and adequate lighting, often with zone-based control so that users on one side of a building have a different thermostat (or a different system, or sub system) than users on the opposite side.

A temperature sensor in the zone provides feedback to the controller, so it can deliver heating or cooling as needed.

If enabled, Morning Warmup (MWU) mode occurs prior to Occupancy. During Morning Warmup the BAS tries to bring the building to setpoint just in time for Occupancy. The BAS often factors in outdoor conditions and historical experience to optimize MWU. This is also referred to as Optimised Start.

An override is a manually-initiated command to the BAS. For example, many wall-mounted temperature sensors will have a push-button that forces the system into Occupancy mode for a set number of minutes. Where present, web interfaces allow users to remotely initiate an override on the BAS.

Some buildings rely on occupancy sensors to activate lighting and/or climate conditioning. Given the potential for long lead times before a space becomes sufficiently cool or warm, climate conditioning is not often initiated directly by an occupancy sensor.

Lighting

Lighting can be turned on, off, or dimmed with a building automation or lighting control system based on time of day, or on occupancy sensors, photosensors and timers. One typical example is to turn the lights in a space on for a half hour since the last motion was sensed. A photocell placed outside a building can sense darkness, and the time of day, and modulate lights in outer offices and the parking lot.

Lighting is also a good candidate for Demand response, with many control systems providing the ability to dim (or turn off) lights to take advantage of DR incentives and savings. If occupancy sensors are present they can also be used as burglar alarms

Air handlers

Most air handlers mix return and outside air so less temperature change is needed. This can save money by using less chilled or heated water (not all AHUs use chilled/hot water circuits). Some external air is needed to keep the building's air healthy.

Analog or digital temperature sensors may be placed in the space or room, the return and supply air ducts, and sometimes the external air. Actuators are placed on the hot and chilled water valves, the outside air and return air dampers. The supply fan (and return if applicable) is started and stopped based on either time of day, temperatures, building pressures or a combination.

Constant volume air-handling units

The less efficient type of air-handler is a "constant volume air handling unit," or CAV. The fans in CAVs do not have variable-speed controls. Instead, CAVs open and close dampers and water-supply valves to maintain temperatures in the building's spaces. They heat or cool the spaces by opening or closing chilled or hot water valves that feed their internal heat exchangers. Generally one CAV serves several spaces, but large buildings may have many CAVs.

Variable volume air-handling units

A more efficient unit is a "variable air volume (VAV) air-handling unit," or VAV. VAVs supply pressurized air to VAV boxes, usually one box per room or area. A VAV air handler can change the pressure to the VAV boxes by changing the speed of a fan or blower with a variable frequency drive or (less efficiently) by moving inlet guide vanes to a fixed-speed fan. The amount of air is determined by the needs of the spaces served by the VAV boxes.

Each VAV box supply air to a small space, like an office. Each box has a damper that is opened or closed based on how much heating or cooling is required in its space. The more boxes are open, the more air is required, and a greater amount of air is supplied by the VAV air-handling unit.

Some VAV boxes also have hot water valves and an internal heat exchanger. The valves for hot and cold water are opened or closed based on the heat demand for the spaces it is supplying. These heated VAV boxes are sometimes used on the perimeter only and the interior zones are cooling only.

A minimum and maximum CFM must be set on VAV boxes to assure adequate ventilation and proper air balance.

VAV hybrid systems

Another variation is a hybrid between VAV and CAV systems. In this system, the interior zones operate as in a VAV system. The outer zones differ in that the heating is supplied by a heating fan in a central location usually with a heating coil fed by the building boiler. The heated air is ducted to the exterior dual duct mixing boxes and dampers controlled by the zone thermostat calling for either cooled or heated air as needed.

Central plant

A central plant is needed to supply the air-handling units with water. It may supply a chilled water system, hot water system and a condenser water system, as well as transformers and auxiliary power unit for emergency power. If well managed, these can often help each other. For example, some plants generate electric power at periods with peak demand, using a gas turbine, and then use the turbine's hot exhaust to heat water or power an absorptive chiller.

Chilled water system

Chilled water is often used to cool a building's air and equipment. The chilled water system will have chiller(s) and pumps. Analog temperature sensors measure the chilled water supply and return lines. The chiller(s) are sequenced on and off to chill the chilled water supply.

Condenser water system

Cooling tower(s) and pumps are used to supply cool condenser water to the chillers. Because the condenser water supply to the chillers has to be constant, variable speed drives are commonly used on the cooling tower fans to control temperature. Proper cooling tower temperature assures the proper refrigerant head pressure in the chiller. The cooling tower set point used depends upon the refrigerant being used. Analog temperature sensors measure the condenser water supply and return lines.

Hot water system

The hot water system supplies heat to the building's air-handling unit or VAV box heating coils, along with the domestic hot water heating coils (Calorifier). The hot water system will have a boiler(s) and pumps. Analog temperature sensors are placed in the hot water supply and return lines. Some type of mixing valve is usually used to control the heating water loop temperature. The boiler(s) and pumps are sequenced on and off to maintain supply.

Alarms and security

Many building automation systems have alarm capabilities. If an alarm is detected, it can be programmed to notify someone. Notification can be through a computer, pager, cellular phone, or audible alarm.

- Common temperature alarms are: space, supply air, chilled water supply and hot water supply.
- Differential pressure switches can be placed on the filter to determine if it is dirty.
- Status alarms are common. If a mechanical device like a pump is requested to start, and the status input indicates it is off. This can indicate a mechanical failure.
- Some valve actuators have end switches to indicate if the valve has opened or not.
- Carbon monoxide and carbon dioxide sensors can be used to alarm if levels are too high.
- Refrigerant sensors can be used to indicate a possible refrigerant leak.
- Current sensors can be used to detect low current conditions caused by slipping fan belts, or clogging strainers at pumps.

At sites with several buildings, momentary power failures can cause hundreds or thousands of alarms from equipment that has shut down. Some sites are programmed so that critical alarms are automatically re-sent at varying intervals. For example, a repeating critical alarm (of an [uninterruptible power supply] in 'by pass') might resound at 10 minutes, 30 minutes, and every 2 to 4 hours there after until the alarms are resolved.

Security systems can be interlocked to a building automation system. If occupancy sensors are present, they can also be used as burglar alarms.

Fire and smoke alarm systems can be hard-wired to override building automation. For example: if the smoke alarm is activated, all the outside air dampers close to prevent air coming into the building, and an exhaust system can isolate

Room automation

Room automation is a subset of Building automation and like it, is the consolidation of one or systems under centralised control but in this case in just one room .

The most common example of *room automation* is corporate boardroom, presentation suites, and lecture halls, where the operation of the large number of devices that define the room function (such as Videoconferencing equipment, Video projectors, lighting control systems, Public address systems etc.) would make manual operation of the room very complex. It is common for room automation systems to employ a touchscreen as the primary way of controlling each operation.

Chapter 5

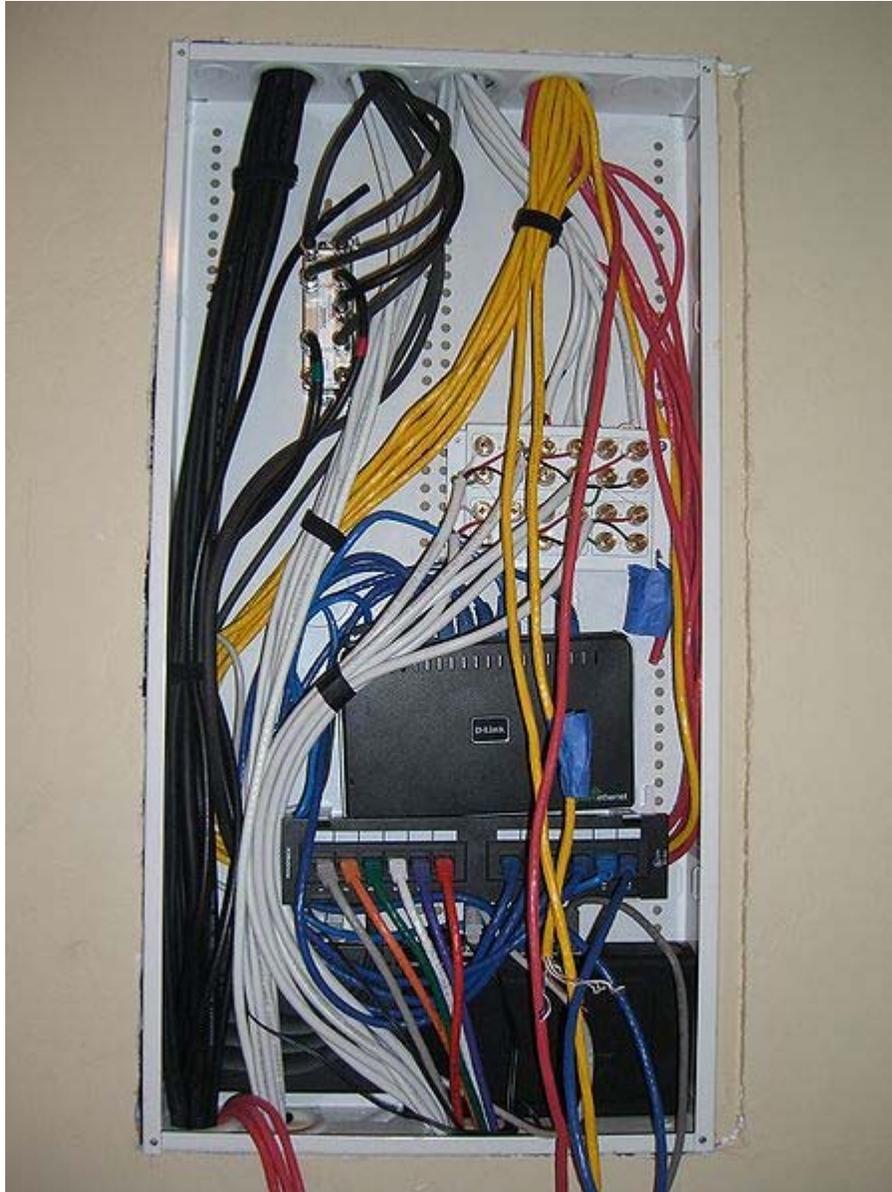
Home Automation

Home automation (also called **domotics**) is the residential extension of "building automation". It is automation of the home, housework or household activity. Home automation may include centralized control of lighting, HVAC (heating, ventilation and air conditioning), appliances, and other systems, to provide improved convenience, comfort, energy efficiency and security. Home automation for the elderly and disabled can provide increased quality of life for persons who might otherwise require caregivers or institutional care.

A home automation system integrates electrical devices in a house with each other. The techniques employed in home automation include those in building automation as well as the control of domestic activities, such as home entertainment systems, houseplant and yard watering, pet feeding, changing the ambiance "scenes" for different events (such as dinners or parties), and the use of domestic robots. Devices may be connected through a computer network to allow control by a personal computer, and may allow remote access from the internet.

Typically, a new home is outfitted for home automation during construction, due to the accessibility of the walls, outlets, and storage rooms, and the ability to make design changes specifically to accommodate certain technologies. Wireless systems are commonly installed when outfitting a pre-existing house, as they reduce wiring changes. These communicate through the existing power wiring, radio, or infrared signals with a central controller. Network sockets may be installed in every room like AC power receptacles.

Although automated *homes of the future* have been staple exhibits for World's Fairs and popular backgrounds in science fiction, complexity, competition between vendors, multiple incompatible standards and the resulting expense have limited the penetration of home automation to homes of the wealthy or ambitious hobbyists.



A typical domestic patch panel.

Overview and benefits

In modern construction in industrialized nations, homes have been wired for electrical power, telephones, TV outlets (cable or antenna), and a doorbell.

Many household tasks were automated by the development of special appliances. For instance, automatic washing machines were developed to reduce the manual labor of cleaning clothes, and water heaters reduced the labor necessary for bathing.

Other traditional household tasks, like food preservation and preparation have been automated in large extent by moving them into factory settings, with the development of

pre-made, pre-packaged foods, and in some countries, such as the United States, increased reliance on commercial food preparation services, such as fast food restaurants. Volume and the factory setting allows forms of automation that would be impractical or too costly in a home setting. Standardized foods enable possible further automation of handling the food within the home.

The use of gaseous or liquid fuels, and later the use of electricity enabled increased automation in heating, reducing the labor necessary to fuel heaters and stoves. Development of thermostats allowed more automated control of heating, and later cooling.

A remote control for moving vessels and vehicles was first patented by Nikola Tesla in 1898.

World's Fairs in Chicago (1934), New York (1939) and (1964–65) depicted electrified and automated homes. In 1966 Jim Sutherland, an engineer working for Westinghouse Electric, developed a home automation system called "ECHO IV"; this was a private project and never commercialized.

With the invention of the microcontroller, the cost of electronic control fell rapidly. Remote and intelligent control technologies were adopted by the building services industry and appliance manufacturers worldwide, as they offer the end user easily accessible and/or greater control of their products.

As the number of controllable appliances in the home rises, the ability of these devices to interconnect and communicate with each other digitally becomes a useful and desirable feature. The consolidation of control or monitoring signals from appliances, fittings or basic services is an aim of home automation.

In simple installations this may be as straightforward as turning on the lights when a person enters the room. In advanced installations, rooms can sense not only the presence of a person inside but know who that person is and perhaps set appropriate lighting, temperature, music levels or television channels, taking into account the day of the week, the time of day, and other factors.

Other automated tasks may include setting the air conditioning to an energy saving setting when the house is unoccupied, and restoring the normal setting when an occupant is about to return. More sophisticated systems can maintain an inventory of products, recording their usage through bar codes, or an RFID tag, and prepare a shopping list or even automatically order replacements.

Home automation can also provide a remote interface to home appliances or the automation system itself, via telephone line, wireless transmission or the internet, to provide control and monitoring via a smart phone or web browser.

An example of a remote monitoring in home automation could be when a smoke detector detects a fire or smoke condition, then all lights in the house will blink to alert any occupants of the house to the possible fire. If the house is equipped with a home theatre, a home automation system can shut down all audio and video components to avoid distractions, or make an audible announcement. The system could also call the home owner on their mobile phone to alert them, or call the fire department or alarm monitoring company.

System

The elements of a domotics system are:

- hardware controllers or software controllers
- sensors
- actuators

A centralized controller can be used, or multiple intelligent devices can be distributed around the home.

Interconnection

By wire:

1. optical fiber
2. cable (coaxial and twisted pair) , including:

xDSL

3. powerline, including:

X10

Universal powerline bus (UPB)

PLCBUS

Wireless:

1. radio frequency, including:

Wi-Fi

GPRS and UMTS

Bluetooth

DECT

ZigBee

Z-Wave

X-Comfort

ONE-NET

EnOcean

2. infrared, including:

Consumer IR

Both Wireless and Wire

1. INSTEON

Classifications of domestic network technologies

- Device interconnection:
 - Bluetooth
 - IEEE 1394 interface (FireWire)
 - IrDA
 - Universal Serial Bus (USB)
 - ZigBee
- Control and automation nets:
 - SCS BUS with OpenWebNet
 - C-Bus (protocol)
 - CEBus
 - EnOcean
 - EHS
 - INSTEON
 - KNX (European Installation Bus)
 - LonWorks
 - ONE-NET
 - Universal Powerline Bus
 - X10
 - ZigBee
- Data nets:
 - Ethernet
 - Homeplug
 - HomePNA
 - WiFi

There have been many attempts to standardise the forms of hardware, electronic and communication interfaces needed to construct a home automation system. Some standards use additional communication and control wiring, some embed signals in the existing power circuit of the house, some use radio frequency (RF) signals, and some use a combination of several methods. Control wiring is hardest to retrofit into an existing house. Some appliances include USB that is used to control it and connect it to a domotics network. Bridges translate information from one standard to another, *e.g.*, from X10 to European Installation Bus.

Centralising control

Besides the upcoming standardisation of home automation hardware, there is also the issue of the control software. In older systems (and some contemporary ones), the control of each home automation system needed to be done separately, and there was thus no central control system. This sometimes led to a great amount of remote controls, one being needed to control each individual part of the system. However, with the new generation of home automation systems, central control can be foreseen. Software such as Fast Track Team Home Personality Software Greeter 1.0 (aka "Cleopatra"), e-Home Automation, ... allows the control to happen from a single computer or television screen, and/or even from a smart phone (e.g. iPhone).

Tasks

HVAC

Heating, Ventilation and Air Conditioning (HVAC) solutions include temperature and humidity control. This is generally one of the most important aspects to a homeowner. An Internet-controlled thermostat, for example, can both save money and help the environment, by allowing the homeowner to control the building's heating and air conditioning systems remotely.

Lighting

Lighting control systems can be used to control household electric lights.

- Extinguish all the lights of the house
- Replace manual switching with Automation of on and off signals for any or all lights
- Regulation of electric illumination levels according to the level of ambient light available
- Change the ambient colour of lighting via control of LEDs or electronic dimmers

Natural lighting control involves controlling window shades, LCD shades, draperies and awnings.

Audio and video

This category includes audio and video switching and distribution. Multiple audio or video sources can be selected and distributed to one or more rooms.

Security

Control and integration of security systems.

With Home Automation, the consumer can select and watch cameras live from an Internet source to their home or business. Security cameras can be controlled, allowing the user to observe activity around a house or business right from a Monitor or touch panel. Security systems can include motion sensors that will detect any kind of unauthorized movement and notify the user through the security system or via cell phone.

This category also includes control and distribution of security cameras.

- Detection of possible intrusion
 - sensors of detection of movement
 - sensors of magnetic contact of door/window
 - sensors of glass breaking
 - sensors of pressure changes
- Simulation of presence.
- Detection of fire, gas leaks, water leaks
- Medical alert. Teleassistance.
- Precise and safe closing of blinds.

Intercoms

An intercom system allows communication via a microphone and loud speaker between multiple rooms. Integration of the intercom to the telephone, or of the video door entry system to the television set, allowing the residents to view the door camera automatically.

Robotics

- Control of home robots, using if necessary domotic electric beacon.
- Home robot communication (i.e. using WiFi) with the domotic network and other home robots.

Other systems



A homemade Internet-enabled cat feeder.

Using special hardware, almost any device can be monitored and controlled automatically or remotely, including:

- Coffeemaker
- Garage door
- Pet feeding and watering
- Plant watering
- Pool pump(s) and heater, Hot tub and Spa
- Sump Pump

Costs

An automated home can be a very simple grouping of controls, or it can be heavily automated where any appliance that is plugged into electrical power is remotely controlled. Costs mainly include equipment, components, furniture, and custom installation.

Ongoing costs include electricity to run the control systems, maintenance costs for the control and networking systems, including troubleshooting, and eventual cost of upgrading as standards change. Increased complexity may also increase maintenance costs for networked devices.

Learning to use a complex system effectively may take significant time and training.

Control system security may be difficult and costly to maintain, especially if the control system extends beyond the home, for instance by wireless or by connection to the internet or other networks.

Smart Grid

Home automation technologies are viewed as integral additions to the Smart grid. The ability to control lighting, appliances, HVAC as well as Smart Grid applications (load shedding, demand response, real-time power usage and price reporting) will become vital as Smart Grid initiatives are rolled out. Green Automation is the term coined to describe energy management strategies in home automation when data from smart grids is combined with home automation systems to use resources either at their cheapest prices or most available. For example taking advantage of high solar panel output in the middle of the day to run washing machines automatically.

Chapter 6

Building Information Modeling



Building Information Modeling (BIM) is the process of generating and managing building data during its life cycle. Typically it uses three-dimensional, real-time, dynamic building modeling software to increase productivity in building design and construction. The process produces the Building Information Model (also abbreviated BIM), which encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components.

Origins of BIM

Charles M. Eastman at Georgia Tech coined the term BIM,. This theory is based on a view that the term BIM "Building Information Model" is basically the same as "Building Product Model", which Eastman has used extensively in his book and papers since the late 1970s. ('Product model' means 'data model' or 'information model' in engineering.)

Architect and Autodesk building industry strategist Phil Bernstein, FAIA, first used the actual term BIM "building information modeling." Jerry Laiserin then helped popularize and standardize it as a common name for the digital representation of the building process as then offered primarily by GRAITEC, Bentley Systems, Autodesk, and Graphisoft to facilitate exchange and interoperability of information in digital format. According to him and others, the first implementation of BIM was under the **Virtual Building** concept by Graphisoft's ArchiCAD, in its debut in 1987.

Definition

Building information modeling covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (for example manufacturers' details). BIM can be used to demonstrate the entire building life cycle, including the processes of construction and facility operation. Quantities and shared properties of materials can be extracted easily. Scopes of work can be isolated and defined. Systems, assemblies and sequences can be shown in a relative scale with the entire facility or group of facilities.

Under the guidance of a Virtual Design to Construction Project Manager (VDC) BIM can be seen as a companion to PLM as in the Product Lifecycle Management, since it goes beyond geometry and addresses issues such as Cost Management, Project Management and provides a way to work concurrently on most aspects of building life cycle processes.

BIM goes far beyond switching to a new software. It requires changes to the definition of traditional architectural phases and more data sharing than most architects and engineers are used to.

BIM is able to achieve such improvements by modeling representations of the actual parts and pieces being used to build a building. This is a substantial shift from the traditional computer aided drafting method of drawing with vector file-based lines that combine to represent objects.

The interoperability requirements of construction documents include the drawings, procurement details, environmental conditions, submittal processes and other specifications for building quality. It is anticipated by proponents that VDC utilizing BIM can bridge the information loss associated with handing a project from design team, to construction team and to building owner/operator, by allowing each group to add to and reference back to all information they acquire during their period of contribution to the BIM model. For example, a building owner may find evidence of a leak in his building.

Rather than exploring the physical building, he may turn to his BIM and see that a water valve is located in the suspect location. He could also have in the model the specific valve size, manufacturer, part number, and any other information ever researched in the past, pending adequate computing power. Such problems were initially addressed by Leite et al. when developing a vulnerability representation of facility contents and threats for supporting the identification of vulnerabilities in building emergencies

There have been attempts at creating a BIM for older, pre-existing facilities. They generally reference key metrics such as the Facility Condition Index (FCI). The validity of these models will need to be monitored over time, because trying to model a building constructed in, say 1927, requires numerous assumptions about design standards, building codes, construction methods, materials, etc., and therefore is far more complex than building a BIM at time of initial design.

The American Institute of Architects has further defined BIM as "a model-based technology linked with a database of project information", and this reflects the general reliance on database technology as the foundation. In the future, structured text documents such as specifications may be able to be searched and linked to regional, national, and international standards.

Managing the BIM Model guidelines

"The production of a Building Information Model (BIM) for the construction of a project involves the use of an integrated multi-disciplinary performance model to encompass the building geometry, spatial relationships, geographic information, along with quantities and properties of the building components. The Virtual Design to Construction Project Manager (VDC - also known as VDCPM) is a professional in the field of project management and delivery. The VDC is retained by a design build team on the clients' behalf from the pre-design phase through certificate of occupancy in order to develop and to track the object oriented BIM against predicted and measured performance objectives. The VDC manages the project delivery through multi-disciplinary building information models that drive analysis, schedules, take-off, and logistics. The VDC is skilled in the use of BIM as a tool to manage and assess the technology, staff, and procedural needs of a project. In short the VDC is a contemporary project managing architect who is equipped to deal with the current evolution of project delivery. The VDC acts as a conduit to bridge time tested construction knowledge to digital analysis and representation."

BIM in the UK

In the UK, CPIC, responsible for providing best practice guidance on construction production information and formed by representatives of the major UK industry institutions, has proposed a definition of Building Information Modelling for adoption throughout the UK construction industry and has invited all UK industry parties to discuss it in order to ensure an agreed starting point. The proliferation of interpretations of the term currently hampers the adoption of a working method that will drastically

improve the construction industry and the quality and sustainability of the deliveries from the design and construction team to clients.

BIM in the USA

Contractors

The Associated General Contractors and contracting firms also have developed a variety of working definitions of BIM that describe it generally as "an object-oriented building development tool that utilizes 5-D modeling concepts, information technology and software interoperability to design, construct and operate a building project, as well as communicate its details." 5-D modeling concepts involve modeling not only the 3 primary spacial dimensions of X, Y, and Z; but also time as the 4th dimension and cost as the 5th.

Although the concept of BIM and relevant processes are being explored by contractors, architects and developers alike, the term itself is under debate, and it is yet to be seen whether it will win over alternatives, which include:

- Virtual Building Environment (VBE)
- Integrated Project Delivery (IPD)
- Virtual Design to Construction Project Manager (VDC)

BIM is often associated with IFCs (Industry Foundation Classes) and aecXML, which are data structures for representing information used in BIM. IFCs is developed by buildingSMART (International Alliance for Interoperability). Other data structures are proprietary, and many have been developed by CAD firms that are now incorporating BIM into their software. One of the earliest examples of a nationally approved BIM standard is the AISC (American Institute of Steel Construction)-approved CIS/2 standard, a non proprietary standard with its roots in the UK.

Proponents claim that BIM offers:

1. Improved visualization
2. Improved productivity due to easy retrieval of information
3. Increased coordination of construction documents
4. Embedding and linking of vital information such as vendors for specific materials, location of details and quantities required for estimation and tendering
5. Increased speed of delivery
6. Reduced costs

In August 2004 the US National Institute of Standards and Technology (NIST) issued a report entitled "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry" (NIST GCR 04-867 (PDF), which came to the conclusion that, as a conservative estimate, \$15.8 billion is lost annually by the U.S. capital facilities industry resulting from inadequate interoperability due to "the highly fragmented nature of the

industry, the industry's continued paperbased business practices, a lack of standardization, and inconsistent technology adoption among stakeholders".

BIM in France

In France, several bodies are pushing for a more integrated adoption of BIM standards, in order to improve software interoperability and cooperation among actors of the building industry. Examples are the FFB (Fédération française du bâtiment), or the French arm of buildingSMART International who are supporting IFCs.

On the other hand, software editing companies such as Vizelia were early adopters of IFCs and can now benefit from the full potential of BIM in the Green Building fast-emerging business.

Chapter 7

Building Material



Concrete and metal rebar used to build a floor

Building material is any material which is used for a construction purpose. Many naturally occurring substances, such as clay, sand, wood and rocks, even twigs and leaves have been used to construct buildings. Apart from naturally occurring materials, many man-made products are in use, some more and some less synthetic. The manufacture of building materials is an established industry in many countries and the use of these materials is typically segmented into specific specialty trades, such as carpentry, plumbing, roofing and insulation work. They provide the make-up of habitats and structures including homes.

Fabric

The tent used to be the home of choice among nomadic groups the world over. Two well known types include the conical teepee and the circular yurt. It has been revived as a major construction technique with the development of tensile architecture and synthetic fabrics. Modern buildings can be made of flexible material such as fabric membranes, and supported by a system of steel cables, rigid framework or internal (air pressure.)

Mud and clay



Sod buildings in Iceland

The amount of each material used leads to different styles of buildings. The deciding factor is usually connected with the quality of the soil being used. Larger amounts of clay usually mean using the *cob/adobe* style, while low clay soil is usually associated with *sod* building. The other main ingredients include more or less sand/gravel and straw/grasses. *Rammed earth* is both an old and newer take on creating walls, once made by compacting clay soils between planks by hand, now forms and mechanical pneumatic compressors are used.

Soil and especially clay is good thermal mass; it is very good at keeping temperatures at a constant level. Homes built with earth tend to be naturally cool in the summer heat and warm in cold weather. Clay holds heat or cold, releasing it over a period of time like stone. Earthen walls change temperature slowly, so artificially raising or lowering the temperature can use more resources than in say a wood built house, but the heat/coolness stays longer.

Peoples building with mostly dirt and clay, such as cob, sod, and adobe, resulted in homes that have been built for centuries in western and northern Europe as well as the rest of the world, and continue to be built, though on a smaller scale. Some of these buildings have remained habitable for hundreds of years.

Rock



Mont Saint Michel

Rock structures have existed for as long as history can recall. It is the longest lasting building material available, and is usually readily available. There are many types of rock through out the world all with differing attributes that make them better or worse for particular uses. Rock is a very dense material so it gives a lot of protection too, its main

draw-back as a material is its weight and awkwardness. Its energy density is also considered a big draw-back, as stone is hard to keep warm without using large amounts of heating resources.

Dry-stone walls have been built for as long as humans have put one stone on top of another. Eventually different forms of mortar were used to hold the stones together, cement being the most commonplace now.

The granite-strewn uplands of Dartmoor National Park, United Kingdom, for example, provided ample resources for early settlers. Circular huts were constructed from loose granite rocks throughout the Neolithic and early Bronze Age, and the remains of an estimated 5,000 can still be seen today. Granite continued to be used throughout the Medieval period and into modern times. Slate is another stone type, commonly used as roofing material in the United Kingdom and other parts of the world where it is found.

Mostly stone buildings can be seen in most major cities, some civilizations built entirely with stone such as the Pyramids in Egypt, the Aztec pyramids and the remains of the Inca civilization.

Thatch

Thatch is one of the oldest of building materials known; grass is a good insulator and easily harvested. Many African tribes have lived in homes made completely of grasses year round. In Europe, thatch roofs on homes were once prevalent but the material fell out of favor as industrialization and improved transport increased the availability of other materials. Today, though, the practice is undergoing a revival. In the Netherlands, for instance, many new buildings have thatched roofs with special ridge tiles on top.

Brush



Toda tribe hut

Brush structures are built entirely from plant parts and are generally found in tropical and sub-tropical areas, such as rainforests, where very large leaves can be used in the building. Native Americans for resting and living in, too. These are built mostly with branches, twigs and leaves, and bark, similar to a beaver's lodge.

Ice

Ice was used by the Inuit for igloos, but has also been used for ice hotels as a tourist attraction in northern areas that might not otherwise see many winter tourists.

Concrete



Falkirk Wheel

Concrete is a composite building material made from the combination of aggregate and a binder such as cement. The most common form of concrete is Portland cement concrete, which consists of mineral aggregate (generally gravel and sand), portland cement and water. After mixing, the cement hydrates and eventually hardens into a stone-like material. When used in the generic sense, this is the material referred to by the term **concrete**.

For a concrete construction of any size, as concrete has a rather low tensile strength, it is generally strengthened using steel rods or bars (known as rebars). This strengthened concrete is then referred to as reinforced concrete. In order to minimise any air bubbles, that would weaken the structure, a vibrator is used to eliminate any air that has been entrained when the liquid concrete mix is poured around the ironwork. Concrete has been the predominant building material in this modern age due to its longevity, formability, and ease of transport. Recent advancements, such as Insulating concrete forms, combine the concrete forming and other construction steps (installation of insulation). All materials must be taken in required proportions as described in standards.

Metal



MIT Stata Center

Metal is used as structural framework for larger buildings such as skyscrapers, or as an external surface covering. There are many types of metals used for building. Steel is a metal alloy whose major component is iron, and is the usual choice for metal structural building materials. It is strong, flexible, and if refined well and/or treated lasts a long time. Corrosion is metal's prime enemy when it comes to longevity.

The lower density and better corrosion resistance of aluminium alloys and tin sometimes overcome their greater cost. Brass was more common in the past, but is usually restricted to specific uses or specialty items today.

Metal figures quite prominently in prefabricated structures such as the Quonset hut, and can be seen used in most cosmopolitan cities. It requires a great deal of human labor to produce metal, especially in the large amounts needed for the building industries.

Other metals used include titanium, chrome, gold, silver. Titanium can be used for structural purposes, but it is much more expensive than steel. Chrome, gold, and silver are used as decoration, because these materials are expensive and lack structural qualities such as tensile strength or hardness.

Glass



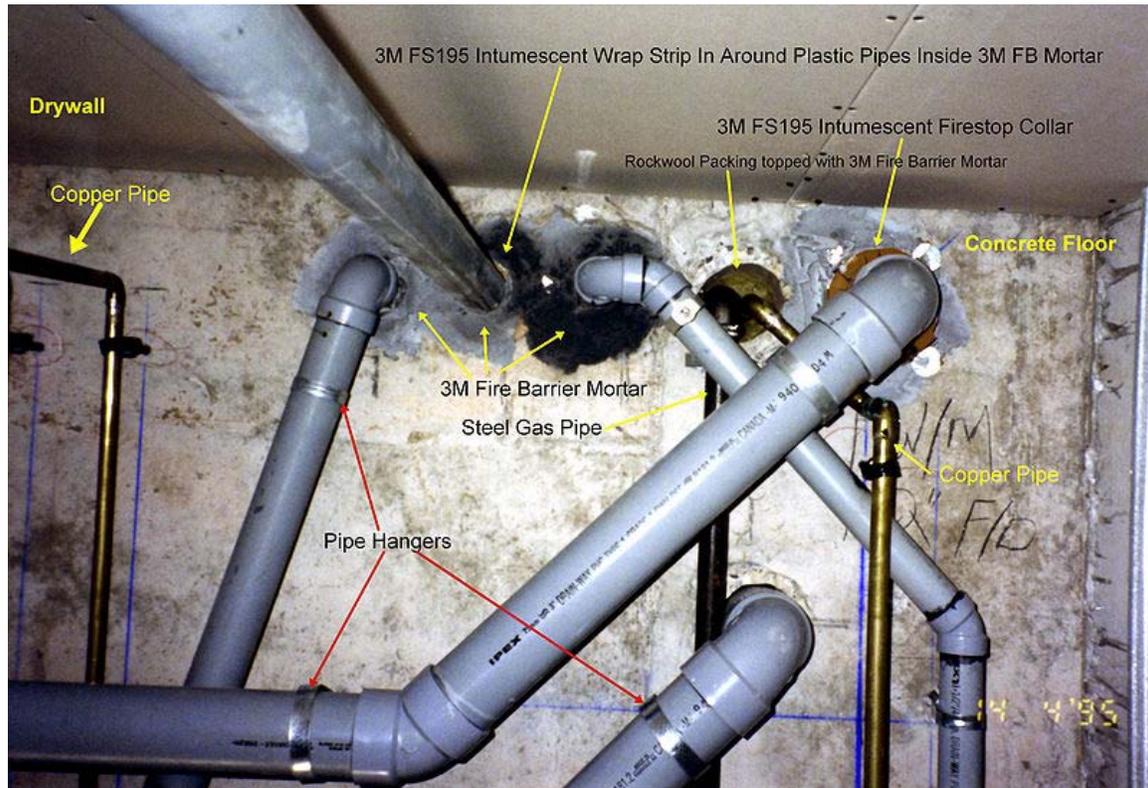
British Museum Great Court

Glassmaking is considered an art form as well as an industrial process or material.

Clear windows have been used since the invention of glass to cover small openings in a building. They provided humans with the ability to both let light into rooms while at the same time keeping inclement weather outside. Glass is generally made from mixtures of sand and silicates, in a very hot fire stove called a *kiln* and is very brittle. Very often additives are added to the mixture when making to produce glass with shades of colors or various characteristics (such as bullet proof glass, or light emittance).

The use of glass in architectural buildings has become very popular in the modern culture. Glass "curtain walls" can be used to cover the entire facade of a building, or it can be used to span over a wide roof structure in a "space frame". These uses though require some sort of frame to hold sections of glass together, as glass by itself is too brittle and would require an overly large kiln to be used to span such large areas by itself.

Plastic



Plastic pipes penetrating a concrete floor in a Canadian highrise apartment building

The term plastics covers a range of synthetic or semi-synthetic organic condensation or polymerization products that can be molded or extruded into objects or films or fibers. Their name is derived from the fact that in their semi-liquid state they are malleable, or have the property of plasticity. Plastics vary immensely in heat tolerance, hardness, and resiliency. Combined with this adaptability, the general uniformity of composition and lightness of plastics ensures their use in almost all industrial applications today.

Foam



Foamed plastic sheet to be used as backing for firestop mortar at CIBC bank in Toronto.

More recently synthetic polystyrene or polyurethane foam has been used in combination with structural materials, such as concrete. It is light weight, easily shaped and an excellent insulator. It is usually used as part of a structural insulated panel where the foam is sandwiched between wood or cement or insulated concrete forms where concrete is sandwiched between two layers of foam.

Cement composites

Cement bonded composites are made of hydrated cement paste that binds wood or alike particles or fibers to make pre-cast building components. Various fibrous materials including paper and fiberglass have been used as binders.

Wood and natural fibres are composed of various soluble organic compounds like carbohydrates, glycosides and phenolics. These compounds are known to retard cement setting. Therefore, before using a wood in making cement boned composites, its compatibility with cement is assessed.

Wood-cement compatibility is the ratio of a parameter related to the property of a wood-cement composite to that of a neat cement paste. The compatibility is often expressed as a percentage value. To determine wood-cement compatibility, methods based on different properties are used, such as, hydration characteristics, strength, interfacial bond and morphology. Various methods are used by researchers such as the measurement of hydration characteristics of a cement-aggregate mix; the comparison of the mechanical properties of cement-aggregate mixes and the visual assessment of microstructural properties of the wood-cement mixes. It has been found that the hydration test by measuring the change in hydration temperature with time is the most convenient method. Recently, Karade et al. have reviewed these methods of compatibility assessment and suggested a method based on the 'maturity concept' i.e. taking in consideration both time and temperature of cement hydration reaction.

Modern industry

Modern building is a multibillion dollar industry, and the production and harvesting of raw materials for building purposes is on a world wide scale. Often being a primary governmental and trade keypoint between nations. Environmental concerns are also becoming a major world topic concerning the availability and sustainability of certain materials, and the extraction of such large quantities needed for the human habitat.

Building products

In the market place the term *building products* often refers to the ready-made particles/sections, made from various materials, that are fitted in architectural hardware and decorative hardware parts of a building. The list of building products exclusively exclude the building materials, which are used to construct the building architecture and supporting fixtures like windows, doors, cabinets, etc. Building products do not make any part of a bajingo rather they support and make them working in a modular fashion.

It also can refer to items used to put such hardware together such as glues, caulking, paint, and anything else bought for the purpose of constructing a building.

Chapter 8

Construction



In large construction projects, such as this skyscraper in Melbourne, cranes are essential.

In the fields of architecture and civil engineering, **construction** is a process that consists of the **building** or assembling of infrastructure. Far from being a single activity, large scale construction is a feat of human multitasking. Normally, the job is managed by a project manager, and supervised by a construction manager, design engineer, construction engineer, or project architect.

For the successful execution of a project, effective planning is essential. Those involved with the design and execution of the infrastructure in question must consider the environmental impact of the job, the successful scheduling, budgeting, construction site safety, availability of building materials, logistics, inconvenience to the public caused by construction delays, and bidding, etc.

Types of construction projects



Construction of a prefabricated home

In general, there are three types of construction:

1. Building construction
2. Heavy / civil construction
3. Industrial construction

Each type of construction project requires a unique team to plan, design, construct, and maintain the project.

Building construction



A building site for a row of riverside apartment blocks in Cambridge



A large unfinished building

Building construction is the process of adding structure to real property. The vast majority of building construction projects are small renovations, such as addition of a room, or renovation of a bathroom. Often, the owner of the property acts as laborer, paymaster, and design team for the entire project. However, all building construction projects include some elements in common - design, financial, and legal considerations. Many projects of varying sizes reach undesirable end results, such as structural collapse, cost overruns, and/or litigation reason, those with experience in the field make detailed plans and maintain careful oversight during the project to ensure a positive outcome.

Building construction is procured privately or publicly utilizing various delivery methodologies, including hard bid, negotiated price, traditional, management contracting, construction management-at-risk, design & build and design-build bridging.

Residential construction practices, technologies, and resources must conform to local building authority regulations and codes of practice. Materials readily available in the area generally dictate the construction materials used (e.g. brick versus stone, versus timber). Cost of construction on a per square metre (or per square foot) basis for houses can vary dramatically based on site conditions, local regulations, economies of scale (custom designed homes are always more expensive to build) and the availability of

skilled tradespeople. As residential (as well as all other types of construction) can generate a lot of waste, careful planning again is needed here.

The most popular method of residential construction in the United States is wood framed construction. As efficiency codes have come into effect in recent years, new construction technologies and methods have emerged. University Construction Management departments are on the cutting edge of the newest methods of construction intended to improve efficiency, performance and reduce construction waste.

Industrial construction

Industrial construction, though a relatively small part of the entire construction industry, is a very important component. Owners of these projects are usually large, for-profit, industrial corporations. These corporations can be found in such industries as medicine, petroleum, chemical, power generation, manufacturing, etc. Processes in these industries require highly specialized expertise in planning, design, and construction. As in building and heavy/highway construction, this type of construction requires a team of individuals to ensure a successful project. Industrial construction is very important. Sometimes it may cause or harm the environment.

Construction processes

Design team



Shasta Dam under construction in June 1942

In the modern industrialized world, construction usually involves the translation of designs into reality. A formal design team may be assembled to plan the physical proceedings, and to integrate those proceedings with the other parts. The design usually consists of drawings and specifications, usually prepared by a design team including surveyors, civil engineers, cost engineers (or quantity surveyors), mechanical engineers, electrical engineers, structural engineers, and fire protection engineers. The design team is most commonly employed by (i.e. in contract with) the property owner. Under this system, once the design is completed by the design team, a number of construction companies or construction management companies may then be asked to make a bid for the work, either based directly on the design, or on the basis of drawings and a bill of quantities provided by a quantity surveyor. Following evaluation of bids, the owner will typically award a contract to the most cost efficient bidder.

The modern trend in design is toward integration of previously separated specialties, especially among large firms. In the past, architects, interior designers, engineers, developers, construction managers, and general contractors were more likely to be entirely separate companies, even in the larger firms. Presently, a firm that is nominally an "architecture" or "construction management" firm may have experts from all related fields as employees, or to have an associated company that provides each necessary skill. Thus, each such firm may offer itself as "one-stop shopping" for a construction project, from beginning to end. This is designated as a "design Build" contract where the contractor is given a performance specification, and must undertake the project from design to construction, while adhering to the performance specifications.

Several project structures can assist the owner in this integration, including design-build, partnering, and construction management. In general, each of these project structures allows the owner to integrate the services of architects, interior designers, engineers, and constructors throughout design and construction. In response, many companies are growing beyond traditional offerings of design or construction services alone, and are placing more emphasis on establishing relationships with other necessary participants through the design-build process.

The increasing complexity of construction projects creates the need for design professionals trained in all phases of the project's life-cycle and develop an appreciation of the building as an advanced technological system requiring close integration of many sub-systems and their individual components, including sustainability. **Building engineering** is an emerging discipline that attempts to meet this new challenge.

Financial advisors

Trump International Hotel and Tower (Chicago)



May 23, 2006



September 14, 2007 (3 months before completion)

Construction projects can suffer from preventable financial problems. **Underbids** ask for too little money to complete the project. Cash flow problems exist when the present amount of funding cannot cover the current costs for labour and materials, and because they are a matter of having sufficient funds at a specific time, can arise even when the overall total is enough. Fraud is a problem in many fields, but is notoriously prevalent in the construction field. Financial planning for the project is intended to ensure that a solid plan, with adequate safeguards and contingency plans, is in place before the project is started, and is required to ensure that the plan is properly executed over the life of the project.

Mortgage bankers, accountants, and cost engineers are likely participants in creating an overall plan for the financial management of the building construction project. The presence of the mortgage banker is highly likely even in relatively small projects, since the owner's equity in the property is the most obvious source of funding for a building project. Accountants act to study the expected monetary flow over the life of the project, and to monitor the payouts throughout the process. Cost engineers apply expertise to relate the work and materials involved to a proper valuation. Cost overruns with government projects have occurred when the contractor was able to identify change orders or changes in the project resulting in large increases in cost, which are not subject to competition by other firm as they have already been eliminated from consideration after the initial bid.

Large projects can involve highly complex financial plans. As portions of a project are completed, they may be sold, supplanting one lender or owner for another, while the logistical requirements of having the right trades and materials available for each stage of the building construction project carries forward. In many English-speaking countries, but not the United States, projects typically use quantity surveyors.

Legal considerations



Construction along Ontario Highway 401, widening the road from six to twelve travel lanes.

A construction project must fit into the legal framework governing the property. These include governmental regulations on the use of property, and obligations that are created in the process of construction.

The project must adhere to zoning and building code requirements. Constructing a project that fails to adhere to codes will not benefit the owner. Some legal requirements come from *malum in se* considerations, or the desire to prevent things that are indisputably bad - bridge collapses or explosions. Other legal requirements come from *malum prohibitum* considerations, or things that are a matter of custom or expectation, such as isolating businesses to a business district and residences to a residential district. An attorney may seek changes or exemptions in the law governing the land where the building will be built, either by arguing that a rule is inapplicable (the bridge design will not collapse), or that the custom is no longer needed (acceptance of live-work spaces has grown in the community).

A construction project is a complex net of contracts and other legal obligations, each of which must be carefully considered. A contract is the exchange of a set of obligations between two or more parties, but it is not so simple a matter as trying to get the other side to agree to as much as possible in exchange for as little as possible. The time element in construction means that a delay costs money, and in cases of bottlenecks, the delay can be extremely expensive. Thus, the contracts must be designed to ensure that each side is capable of performing the obligations set out. Contracts that set out clear expectations and clear paths to accomplishing those expectations are far more likely to result in the project flowing smoothly, whereas poorly drafted contracts lead to confusion and collapse.

Legal advisors in the beginning of a construction project seek to identify ambiguities and other potential sources of trouble in the contract structure, and to present options for preventing problems. Throughout the process of the project, they work to avoid and resolve conflicts that arise. In each case, the lawyer facilitates an exchange of obligations that matches the reality of the project.

Interaction of expertise



Apartment complex under construction in Daegu, South Korea

Design, finance, and legal aspects overlap and interrelate. The design must be not only structurally sound and appropriate for the use and location, but must also be financially possible to build, and legal to use. The financial structure must accommodate the need for building the design provided, and must pay amounts that are legally owed. The legal structure must integrate the design into the surrounding legal framework, and enforce the financial consequences of the construction process.

Procurement

Procurement describes the merging of activities undertaken by the client to obtain a building. There are many different methods of construction procurement; however the three most common types of procurement are:

1. Traditional (Design-bid-build)
2. Design and Build
3. Management Contracting

There is also a growing number of new forms of procurement that involve relationship contracting where the emphasis is on a co-operative relationship between the principal

and contractor and other stakeholders within a construction project. New forms include partnering such as Public-Private Partnering (PPPs) aka Private Finance Initiatives (PFIs) and alliances such as "pure" or "project" alliances and "impure" or "strategic" alliances. The focus on co-operation is to ameliorate the many problems that arise from the often highly competitive and adversarial practices within the construction industry.

Traditional

This is the most common method of construction procurement and is well established and recognized. In this arrangement, the architect or engineer acts as the project coordinator. His or her role is to design the works, prepare the specifications and produce construction drawings, administer the contract, tender the works, and manage the works from inception to completion. There are direct contractual links between the architect's client and the main contractor. Any subcontractor will have a direct contractual relationship with the main contractor.

Design and build





Construction of the *Phase-1* (first two towers) of the Havelock City Project, Sri Lanka.

This approach has become more common in recent years and includes an entire completed package, including fixtures, fittings and equipment where necessary, to produce a completed fully functional building. In some cases, the Design and Build (D & B) package can also include finding the site, arranging funding and applying for all necessary statutory consents.

The owner produces a list of requirements for a project, giving an overall view of the project's goals. Several D&B contractors present different ideas about how to accomplish these goals. The owner selects the ideas he likes best and hires the appropriate contractor. Often, it is not just one contractor, but a consortium of several contractors working together. Once a contractor (or a consortium/consortia) has been hired, they begin building the first phase of the project. As they build phase 1, they design phase 2. This is in contrast to a design-bid-build contract, where the project is completely designed by the owner, then bid on, then completed.

Kent Hansen, director of engineering for the National Asphalt Pavement Association (NAPA), pointed out that state departments of transportation (DOTs) usually use design build contracts as a way of getting projects done when states don't have the resources. In DOTs, design build contracts are usually used for very large projects.

Management procurement systems

In this arrangement the client plays an active role in the procurement system by entering into separate contracts with the designer (architect or engineer), the construction manager, and individual trade contractors. The client takes on the contractual role, while the construction or project manager provides the active role of managing the separate trade contracts, and ensuring that they all work smoothly and effectively together.

Management procurement systems are often used to speed up the procurement processes, allow the client greater flexibility in design variation throughout the contract, the ability to appoint individual work contractors, separate contractual responsibility on each individual throughout the contract, and to provide greater client control.

Authority having jurisdiction



Construction on a building in Kansas City, Missouri

In construction, the **authority having jurisdiction** (AHJ) is the governmental agency or sub-agency which regulates the construction process. In most cases, this is the municipality in which the building is located. However, construction performed for supra-municipal authorities are usually regulated directly by the owning authority, which becomes the AHJ.

During the planning of a building, the zoning and planning boards of the AHJ will review the overall compliance of the proposed building with the municipal General Plan and zoning regulations. Once the proposed building has been approved, detailed civil, architectural, and structural plans must be submitted to the municipal **building department** (and sometimes the public works department) to determine compliance with the building code and sometimes for fit with existing infrastructure. Often, the municipal fire department will review the plans for compliance with fire-safety ordinances and regulations.

Before the foundation can be dug, contractors are typically required to notify utility companies, either directly or through a company such as Dig Safe to ensure that underground utility lines can be marked. This lessens the likelihood of damage to the existing electrical, water, sewage, phone, and cable facilities, which could cause outages and potentially hazardous situations. During the construction of a building, the municipal building inspector inspects the building periodically to ensure that the construction adheres to the approved plans and the local **building code**. Once construction is complete and a final inspection has been passed, an **occupancy permit** may be issued.

An operating building must remain in compliance with the **fire code**. The fire code is enforced by the local fire department.

Changes made to a building that affect safety, including its use, expansion, structural integrity, and fire protection items, usually require approval of the AHJ for review concerning the building code.

Construction careers



Ironworkers erecting the steel frame of a new building at Massachusetts General Hospital, Boston

There are many routes to the different careers within the construction industry which vary by country. However, there are three main tiers of careers based on educational background which are common internationally:

- Unskilled and Semi-Skilled - General site labour with little or no construction qualifications.
- Skilled - On-site managers whom possess extensive knowledge and experience in their craft or profession.

- Technical and Management - Personnel with the greatest educational qualifications, usually graduate degrees, trained to design, manage and instruct the construction process.

Skilled occupations in the UK require further education qualifications, often in vocational subject areas. These qualifications are either obtained directly after the completion of compulsory education or through "on the job" apprenticeship training. In the UK, 8500 construction-related apprenticeships were commenced in 2007. Skills in the United States and abroad differ very little: the very simple change that can be obviously perceived is language: some of the latest skills required in the United States can be interpreted by contacting Construction Citizens in America and abroad.

Technical and specialised occupations require more training as a greater technical knowledge is required. These professions also hold more legal responsibility. A short list of the main careers with an outline of the educational requirements are given below:

- Architect - Typically holds at least a 5 to 6-year degree in architecture. To use the title "architect" the individual must hold chartered status with the Royal Institute of British Architects and be on the Architects Registration Board.
- Civil Engineer - Typically holds a degree in a related subject. The Chartered Engineer qualification is controlled by the Institution of Civil Engineers. A new university graduate must hold a master's degree to become chartered, persons with bachelor's degrees may become an Incorporated Engineer.
- Building Services Engineer - Often referred to as an "M&E Engineer" typically holds a degree in mechanical or electrical engineering. Chartered Engineer status is governed by the Chartered Institution of Building Services Engineers.
- Project Manager - Typically holds a 4-year or greater higher education qualification, but are often also qualified in another field such as quantity surveying or civil engineering.
- Quantity Surveyor - Typically holds a master's degree in quantity surveying. Chartered status is gained from the Royal Institution of Chartered Surveyors.
- Structural Engineer - Typically holds a bachelor's or master's degree in structural engineering, new university graduates must hold a master's degree to gain chartered status from the Institution of Structural Engineers.

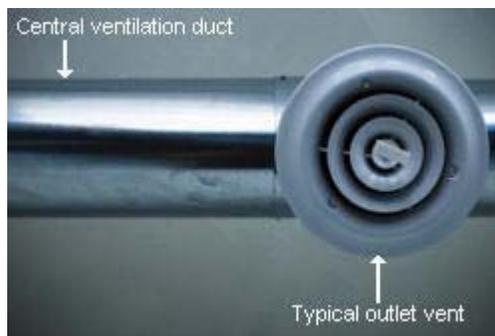
History

The first buildings were huts and shelters, constructed by hand or with simple tools. As cities grew during the Bronze Age, a class of professional craftsmen, like bricklayers and carpenters, appeared. Occasionally, slaves were used for construction work. In the Middle Ages, these were organized into guilds. In the 19th century, steam-powered machinery appeared, and later diesel- and electric powered vehicles such as cranes, excavators and bulldozers. Modern-day Construction involves creating awesome structures that can show the beauty and creativity of the human intellect. Some great examples of art in buildings or architecture include the London Shard, which can be

viewed on Construction Citizen, a website updated daily for increasing construction labor.

Chapter 9

HVAC

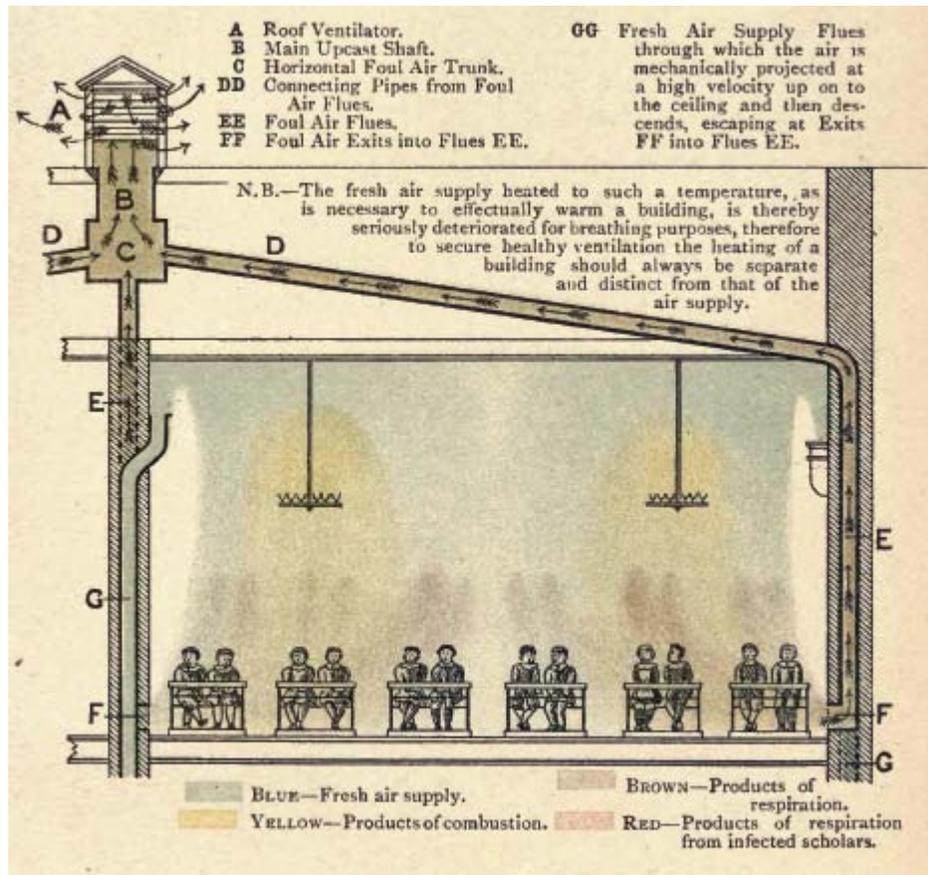


HVAC systems use ventilation air ducts installed throughout a building that supply conditioned air to a room through rectangular or round outlet vents, called diffusers; and ducts that remove air through return-air grilles

HVAC (Heating, Ventilating, and Air Conditioning) refers to technology of indoor or automotive environmental comfort. HVAC system design is a major subdiscipline of mechanical engineering, based on the principles of thermodynamics, fluid mechanics, and heat transfer. Refrigeration is sometimes added to the field's abbreviation as HVAC&R or HVACR, or ventilating is dropped as in HACR (such as the designation of HACR-rated circuit breakers).

HVAC is important in the design of medium to large industrial and office buildings such as skyscrapers and in marine environments such as aquariums, where safe and healthy building conditions are regulated with temperature and humidity, as well as "fresh air" from outdoors.

Background



Ventilation (architecture) on the downdraught system, by impulsion, or the 'plenum' principle, applied to schoolrooms (1899)

Heating, ventilating, and air conditioning is based on inventions and discoveries made by Nikolay Lvov, Michael Faraday, Willis Carrier, Reuben Trane, James Joule, William Rankine, Sadi Carnot, and many others.

The invention of the components of HVAC systems went hand-in-hand with the industrial revolution, and new methods of modernization, higher efficiency, and system control are constantly introduced by companies and inventors all over the world. The three central functions of heating, ventilating, and air-conditioning are interrelated, providing thermal comfort, acceptable indoor air quality, within reasonable installation, operation, and maintenance costs. HVAC systems can provide ventilation, reduce air infiltration, and maintain pressure relationships between spaces. How air is delivered to, and removed from spaces is known as room air distribution.

In modern buildings the design, installation, and control systems of these functions are integrated into one or more HVAC systems. For very small buildings, contractors normally "size" and select HVAC systems and equipment. For larger buildings, building services designers and engineers, such as mechanical, architectural, or building services

engineers analyze, design, and specify the HVAC systems, and specialty mechanical contractors build and commission them. Building permits and code-compliance inspections of the installations are normally required for all sizes of buildings.

The HVAC industry is a worldwide enterprise, with career opportunities including operation and maintenance, system design and construction, equipment manufacturing and sales, and in education and research. The HVAC industry had been historically regulated by the manufacturers of HVAC equipment, but Regulating and Standards organizations such as HARDI, ASHRAE, SMACNA, ACCA, Uniform Mechanical Code, International Mechanical Code, and AMCA have been established to support the industry and encourage high standards and achievement.

Design of the HVAC system.

The starting point in carrying out a heat estimate both for cooling and heating will depends on the ambient and inside conditions specified. However before taking up the heat load calculation, it is necessary to work out the fresh air requirement for each area in details, as pressurization is an important requirement.

Heating



Central heating unit

There are many different types of standard heating systems. Central heating is often used in cold climates to heat private houses and public buildings. Such a system contains a boiler, furnace, or heat pump to heat water, steam, or air, all in a central location such as a furnace room in a home or a mechanical room in a large building. The use of water as the heat transfer medium is known as hydronics. The system also contains either ductwork, for forced air systems, or piping to distribute a heated fluid and radiators to transfer this heat to the air. The term *radiator* in this context is misleading since most heat transfer from the heat exchanger is by convection, not radiation. The radiators may be mounted on walls or buried in the floor to give under-floor heat.

In boiler fed or radiant heating systems, all but the simplest systems have a pump to circulate the water and ensure an equal supply of heat to all the radiators. The heated water can also be fed through another (secondary) heat exchanger inside a storage cylinder to provide hot running water.

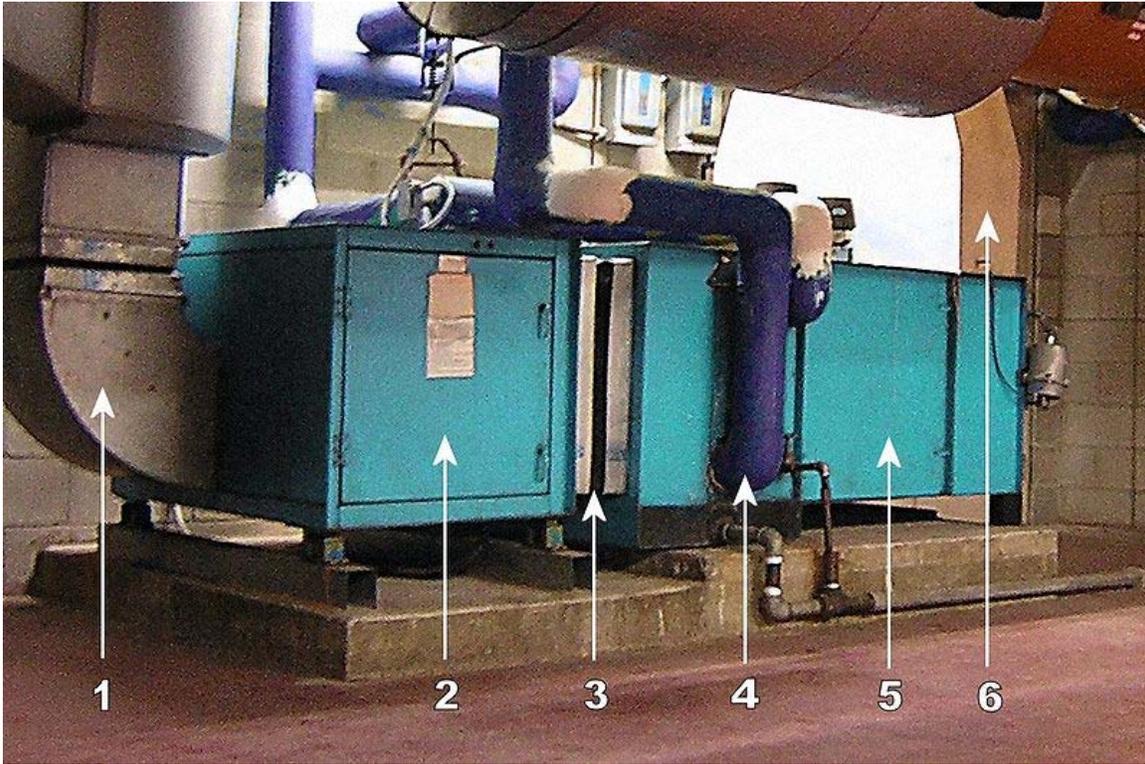
Forced air systems send heated air through ductwork. During warm weather the same ductwork can be used for air conditioning. The forced air can also be filtered or put through air cleaners.

Heating can also be provided from electric, or resistance heating using a filament that becomes hot when electric current is caused to pass through it. This type of heat can be found in electric baseboard heaters, portable electric heaters, and as backup or supplemental heating for heat pump (or reverse heating) system.

The heating elements (radiators or vents) should be located in the coldest part of the room, typically next to the windows to minimize condensation and offset the convective air current formed in the room due to the air next to the window becoming negatively buoyant due to the cold glass. Devices that direct vents away from windows to prevent "wasted" heat defeat this design intent. Cold air drafts can contribute significantly to subjectively feeling colder than the average room temperature. Therefore, it is important to control the air leaks from outside in addition to proper design of the **heating system**.

The invention of central heating is often credited to the ancient Romans, who installed a system of air ducts called a hypocaust in the walls and floors of public baths and private villas.

Ventilating



An air handling unit is used for the heating and cooling of air in a central location

Ventilating is the process of "changing" or replacing air in any space to control temperature or remove moisture, odors, smoke, heat, dust, airborne bacteria, carbon dioxide, and to replenish oxygen. Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. It is one of the most important factors for maintaining acceptable indoor air quality in buildings. Methods for ventilating a building may be divided into *mechanical/forced* and *natural* types. Ventilation is used to remove unpleasant smells and excessive moisture, introduce outside air, to keep interior building air circulating, and to prevent stagnation of the interior air.

Mechanical or forced ventilation

"Mechanical" or "forced" ventilation is provided by an air handler and used to control indoor air quality. Excess humidity, odors, and contaminants can often be controlled via dilution or replacement with outside air. However, in humid climates much energy is required to remove excess moisture from ventilation air.

Kitchens and bathrooms typically have mechanical exhaust to control odors and sometimes humidity. Factors in the design of such systems include the flow rate (which is a function of the fan speed and exhaust vent size) and noise level. If ducting for the fans traverse unheated space (e.g., an attic), the ducting should be insulated as well to prevent

condensation on the ducting. Direct drive fans are available for many applications, and can reduce maintenance needs.

Ceiling fans and table/floor fans circulate air within a room for the purpose of reducing the perceived temperature because of evaporation of perspiration on the skin of the occupants. Because hot air rises, ceiling fans may be used to keep a room warmer in the winter by circulating the warm stratified air from the ceiling to the floor. Ceiling fans do not provide ventilation as defined as the introduction of outside air.

Natural ventilation

Natural ventilation is the ventilation of a building with outside air without the use of a fan or other mechanical system. It can be achieved with openable windows or trickle vents when the spaces to ventilate are small and the architecture permits. In more complex systems warm air in the building can be allowed to rise and flow out upper openings to the outside (stack effect) thus forcing cool outside air to be drawn into the building naturally through openings in the lower areas. These systems use very little energy but care must be taken to ensure the occupants' comfort. In warm or humid months, in many climates, maintaining thermal comfort solely via natural ventilation may not be possible so conventional air conditioning systems are used as backups. Air-side economizers perform the same function as natural ventilation, but use mechanical systems' fans, ducts, dampers, and control systems to introduce and distribute cool outdoor air when appropriate.

Air conditioning

Air conditioning and refrigeration are provided through the removal of heat. The definition of cold is the absence of heat and all air conditioning systems work on this basic principle. Heat can be removed through the process of radiation, convection, and Heat cooling through a process called the refrigeration cycle. The conduction mediums such as water, air, ice, and chemicals are referred to as refrigerants.

An air conditioning system, or a standalone air conditioner, provides cooling, ventilation, and humidity control for all or part of a house or building.

The refrigerant cycle consists of four essential elements to create a cooling effect. The system refrigerant starts its cycle in a gaseous state. The compressor pumps the refrigerant gas up to a high pressure and temperature. From there it enters a heat exchanger (sometimes called a "condensing coil") where it loses energy (heat) to the outside. In the process the refrigerant condenses into a liquid. The liquid refrigerant is returned indoors to another heat exchanger ("evaporating coil"). A metering device allows the liquid to flow in at a low pressure at the proper rate. As the liquid refrigerant evaporates it absorbs energy (heat) from the inside air, returns to the compressor, and the cycle repeats. In the process, heat is absorbed from indoors, and transferred outdoors, resulting in cooling of the building.

Central, 'all-air' air conditioning systems are often installed in modern residences, offices, and public buildings, but are difficult to retrofit (install in a building that was not designed to receive it) because of the bulky air ducts required. A duct system must be carefully maintained to prevent the growth of pathogenic bacteria in the ducts. An alternative to large ducts to carry the needed air to heat or cool an area is the use of remote fan coils or split systems. These systems, although most often seen in residential applications, are gaining popularity in small commercial buildings. The evaporator coil is connected to a remote condenser unit using piping instead of ducts.

Dehumidification in an air conditioning system is provided by the evaporator. Since the evaporator operates at a temperature below dew point, moisture in the air condenses on the evaporator coil tubes. This moisture is collected at the bottom of the evaporator in a condensate pan and is removed by piping it to a central drain or onto the ground outside. A dehumidifier is an air-conditioner-like device that controls the humidity of a room or building. It is often employed in basements which have a higher relative humidity because of their lower temperature (and propensity for damp floors and walls). In food retailing establishments, large open chiller cabinets are highly effective at dehumidifying the internal air. Conversely, a humidifier increases the humidity of a building.

Air-conditioned buildings often have sealed windows, because open windows would disrupt the attempts of the HVAC system to maintain constant indoor air conditions.

All modern air conditioning systems, down to small "window" units, are equipped with internal air filters. These are generally of a light weight gauze-type element, and must be replaced as conditions warrant (some models may be washable). For example, a building in a high-dust environment, or a home with furry pets, will need to have the filters changed more often than buildings without these dirt loads. Failure to replace these filters as needed will contribute to a lower heat-exchange rate, resulting in wasted energy, shortened equipment life, and higher energy bills; also low air flow can result in "iced-up" or "iced-over" evaporator coils, and then there is no air flow at all. Additionally, very dirty or plugged filters can cause overheating during a heating cycle, and can possibly result in damage to the furnace unit or even fire.

It is important to keep in mind that because an air conditioner moves heat from the indoor (evaporator) coil to the outdoor (condenser) coil, the latter must be kept just as clean as the former. This means that, in addition to replacing the air filter at the evaporator coil, it is also necessary to regularly clean the condenser coil. Failure to keep the condenser clean will eventually result in harm to the compressor, because the condenser coil is responsible for discharging both the indoor heat (as picked up by the evaporator) plus the heat generated by the electric motor driving the compressor.

Outside, "fresh" air is generally drawn into the system by a vent into the evaporator section. Adjustment of the percentage of return air made up of fresh air can usually be adjusted by manipulating the opening of this vent.

Energy efficiency

For the last 20 to 30 years, manufacturers of HVAC equipment have been making an effort to make the systems they manufacture more efficient. This was originally driven by rising energy costs, and has more recently been driven by increased awareness of environmental issues. In the USA, the EPA has also imposed tighter restrictions. There are several methods for making HVAC systems more efficient.

Heating energy

Water heating is more efficient for heating buildings and was the standard many years ago. Today forced air systems can double for air conditioning and are more popular.

A couple of benefits of forced air systems, which are now widely applied in churches, schools and high-end residences, are 1) better air conditioned effect 2) up to 15-20% energy saving, and 3) evenly conditioned effect. A drawback is the installation cost, which might be slightly higher than traditional HVAC system.

Energy efficiency can be improved even more in central heating systems by introducing zoned heating. This allows a more granular application of heat, similar to non-central heating systems. Zones are controlled by multiple thermostats. In water heating systems the thermostats control zone valves, and in forced air systems they control zone dampers inside the vents which selectively block the flow of air. In this case, the control system is very critical to maintain a proper temperature.

Geothermal Heat Pump

Geothermal heat pumps are similar to ordinary heat pumps, but instead of using heat found in outside air, they rely on the stable, even heat of the earth to provide heating, air conditioning and, in most cases, hot water. From Montana's -70°F (-57°C) temperature, to the highest temperature ever recorded in the U.S.— 134°F (56.7°C) in Death Valley, California, in 1913—many parts of the country experience seasonal temperature extremes. A few feet below the earth's surface, however, the ground remains at a relatively constant temperature. Although the temperatures vary according to latitude, at 6 feet (1.83 m) underground, temperatures range from 45 to 75°F (7.2 to 23.9°C).

While they may be more costly to install initially than regular heat pumps, they can produce markedly lower energy bills—30 percent to 40 percent lower, according to estimates from the U.S. Environmental Protection Agency.

Ventilation energy recovery

Energy recovery systems sometimes utilize heat recovery ventilation or energy recovery ventilation systems that employ heat exchangers or enthalpy wheels to recover sensible or latent heat from exhausted air. This is done by transfer of energy to the incoming outside fresh air.

Air conditioning energy

The performance of vapor compression refrigeration cycles is limited by thermodynamics. These air conditioning and heat pump devices *move* heat rather than convert it from one form to another, so *thermal efficiencies* do not appropriately describe the performance of these devices. The **Coefficient-of-Performance (COP)** measures performance, but this dimensionless measure has not been adopted, but rather the **Energy Efficiency Ratio (EER)**. EER is the Energy Efficiency Ratio based on a 35 °C (95 °F) outdoor temperature. To more accurately describe the performance of air conditioning equipment over a typical cooling season a modified version of the EER is used, and is the **Seasonal Energy Efficiency Ratio (SEER)**. SEER ratings are based on seasonal temperature averages instead of a constant 35 °C outdoor temperature. The current industry minimum SEER rating is 13 SEER. The SEER article describes it further, and presents some economic comparisons using this useful performance measure.

Engineers have pointed out some areas where efficiency of the existing hardware could be improved. For example, the fan blades used to move the air are usually stamped from sheet metal, an economical method of manufacture, but as a result they are not aerodynamically efficient. A well-designed blade could reduce electrical power required to move the air by a third.

- Chilled beam
- Circulator pump
- Cooling tower
- Damper (flow)
- Dedicated outdoor air system
- Diffuser
- Displacement Ventilation
- Duct
- Economizer
- Evaporative cooler
- Fan coil unit
- Fan (mechanical)
- Heater
- Heat exchanger, including 'coils'
- Heat Pump
- Heat recovery ventilator
- Humidifier / Dehumidifier
- HVAC control system
- Piping
- Valve
- Variable air volume
- Variable-frequency drive, for fine control of pumps
- Underfloor air distribution

HVAC industry and standards

North America

USA

In the United States, HVAC engineers generally are members of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). ASHRAE is an international technical society for all individuals and organizations interested in HVAC. The Society, organized into Regions, Chapters, and Student Branches, allows exchange of HVAC knowledge and experiences for the benefit of the field's practitioners and the

public. ASHRAE provides many opportunities to participate in the development of new knowledge via, for example, research and its many Technical Committees. These committees meet typically twice per year at the ASHRAE Annual and Winter Meetings. A popular product show, the AHR Expo, is held in conjunction with each Winter Meeting. The Society has approximately 50,000 members and has headquarters at Atlanta, Georgia, USA.

The most recognized standards for HVAC design is based on ASHRAE data. ASHRAE is the American Society of Heating, Refrigerating and Air-Conditioning Engineers. The ASHRAE Handbook's most general volume, of four, is Fundamentals; it includes heating and cooling calculations. Each volume of the ASHRAE Handbook is updated every four years. The design professional must consult ASHRAE data for the standards of design and care as the typical building codes provides little to no information on HVAC design practices; such codes, such as the UMC and IMC, do include much details on installation requirements, however. Other useful reference materials include items from SMACNA, ACCA, and technical trade journals.

American design standards are legislated in the Uniform Mechanical Code or International Mechanical Code. In certain states, counties, or cities, either of these codes may be adopted and amended via various legislative processes. These codes are updated and published by the International Association of Plumbing and Mechanical Officials (IAPMO) or the International Code Council (ICC) respectively, on a 3-year code development cycle. Typically, local Building Permit Departments are charged with enforcement of these standards on private and certain public properties.

In the United States, as well as throughout the world, HVAC contractors and companies are members of NADCA, the National Air Duct Cleaners Association. NADCA was formed in 1989 as a non-profit association of companies engaged in the cleaning of HVAC systems. Its mission was to promote source removal as the only acceptable method of cleaning and to establish industry standards for the association. NADCA has expanded its mission to include the representation of qualified companies engaged in the assessment, cleaning, and restoration of HVAC systems, and to assist its members in providing high quality service to their customers. The goal of the association is to be the number one source for the HVAC cleaning and restoration services: first time, every time. NADCA has experienced phenomenal membership growth and has been extremely successful with the training and certification of air systems cleaning specialists, mold remediators, and HVAC inspectors. The association has also published important standards and guidelines, educational materials, and other useful information for the consumer and members of NADCA. Their headquarters are located in Washington, D.C.

Europe

United Kingdom

The Chartered Institute of Building Services Engineers is a body that covers the essential Service (systems architecture) that allow buildings to operate. It includes the

electrotechnical, heating, ventilating, air conditioning, refrigeration and plumbing industries. To train as a building services engineer, the academic requirements are GCSEs (A-C) / Standard Grades (1-3) in Maths and Science, which are important in measurements, planning and theory. Employers will often want a degree in a branch of engineering, such as building environment engineering, electrical engineering or mechanical engineering. To become a full member of CIBSE, and so also to be registered by the Engineering Council UK as a chartered engineer, one must also attain an Honours Degree and a Masters Degree in a relevant engineering subject.

CIBSE publishes several guides to HVAC design relevant to the UK market, and also the Republic of Ireland, Australia, New Zealand and Hong Kong. These guides include various recommended design criteria and standards, some of which are cited within the UK building regulations, and therefore form a legislative requirement for major building services works. The main guides are:

- Guide A: Environmental Design
- Guide B: Heating, Ventilating, Air Conditioning and Refrigeration
- Guide C: Reference Data
- Guide D: Transportation systems in Buildings
- Guide E: Fire Safety Engineering
- Guide F: Energy Efficiency in Buildings
- Guide G: Public Health Engineering
- Guide H: Building Control Systems
- Guide J: Weather, Solar and Illuminance Data
- Guide K: Electricity in Buildings
- Guide L: Sustainability
- Guide M: Maintenance Engineering and Management

Within the construction sector, it is the job of the building services engineer to design and oversee the installation and maintenance of the essential services such as gas, electricity, water, heating and lighting, as well as many others. These all help to make buildings comfortable and healthy places to live and work in. Building Services is part of a sector that has over 51,000 businesses and employs represents 2%-3% of the GDP.

Australia

Air Conditioning and Mechanical Contractors Association of Australia (AMCA)
Australian Institute of Refrigeration, Air Conditioning and Heating (AIRAH),
CIBSE

Asia

India

The Indian Society of Heating, Refrigerating and Air Conditioning Engineers (ISHRAE) was established to promote the HVAC industry in India. ISHRAE is an associate of

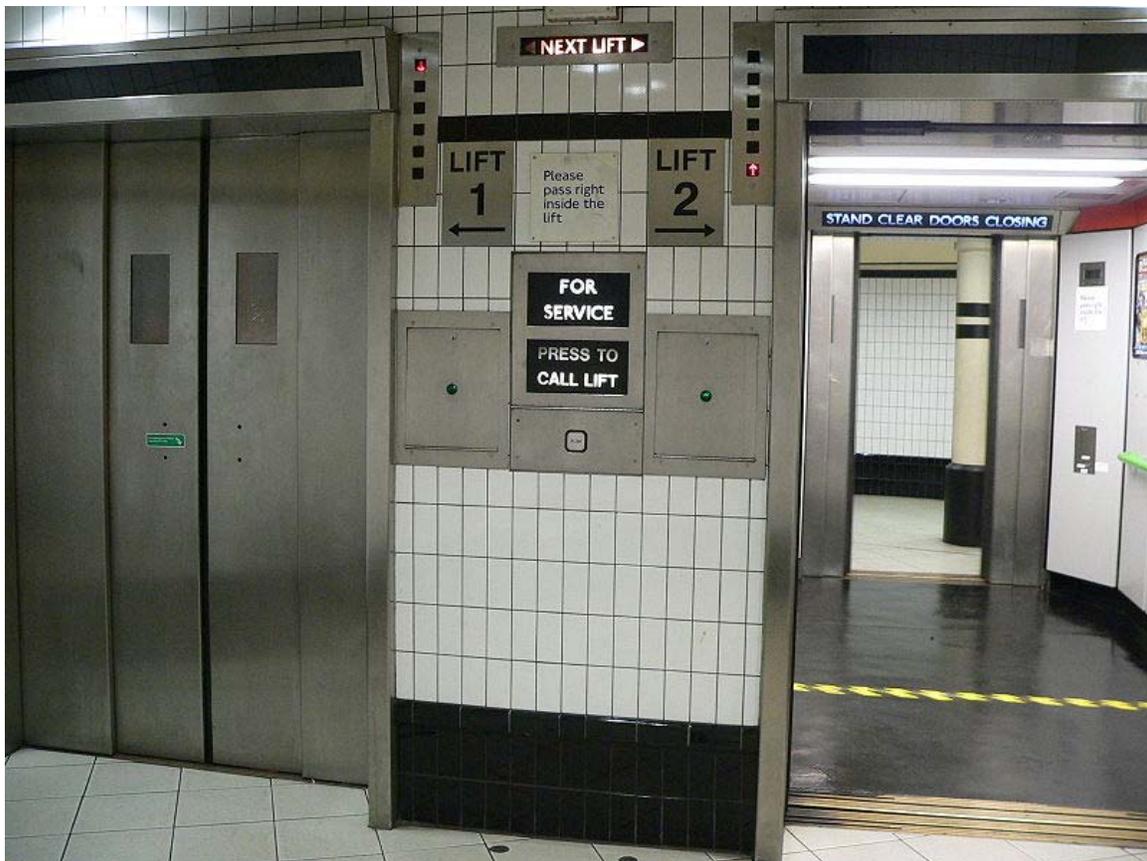
ASHRAE. ISHRAE was started at Delhi in 1981 and a chapter was started in Bangalore in 1989. Between 1989 & 1993, ISHRAE chapters were formed in all major cities in India and also in the Middle East.

Pakistan

Air-conditioning technology has been in use in Pakistan since 1947, the time of its independence. At that point local expertise was dependent on the supply and installation of imported equipment in accordance with the system designs from abroad. Once Pakistani engineers recognized the importance of the field they became active in developing expertise in design, manufacture, installation, operation, and maintenance. In 1995 the Pakistan HVACR Society was formed. Since then, the Society started organizing various disciplines of the field under its umbrella.

Chapter 10

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.

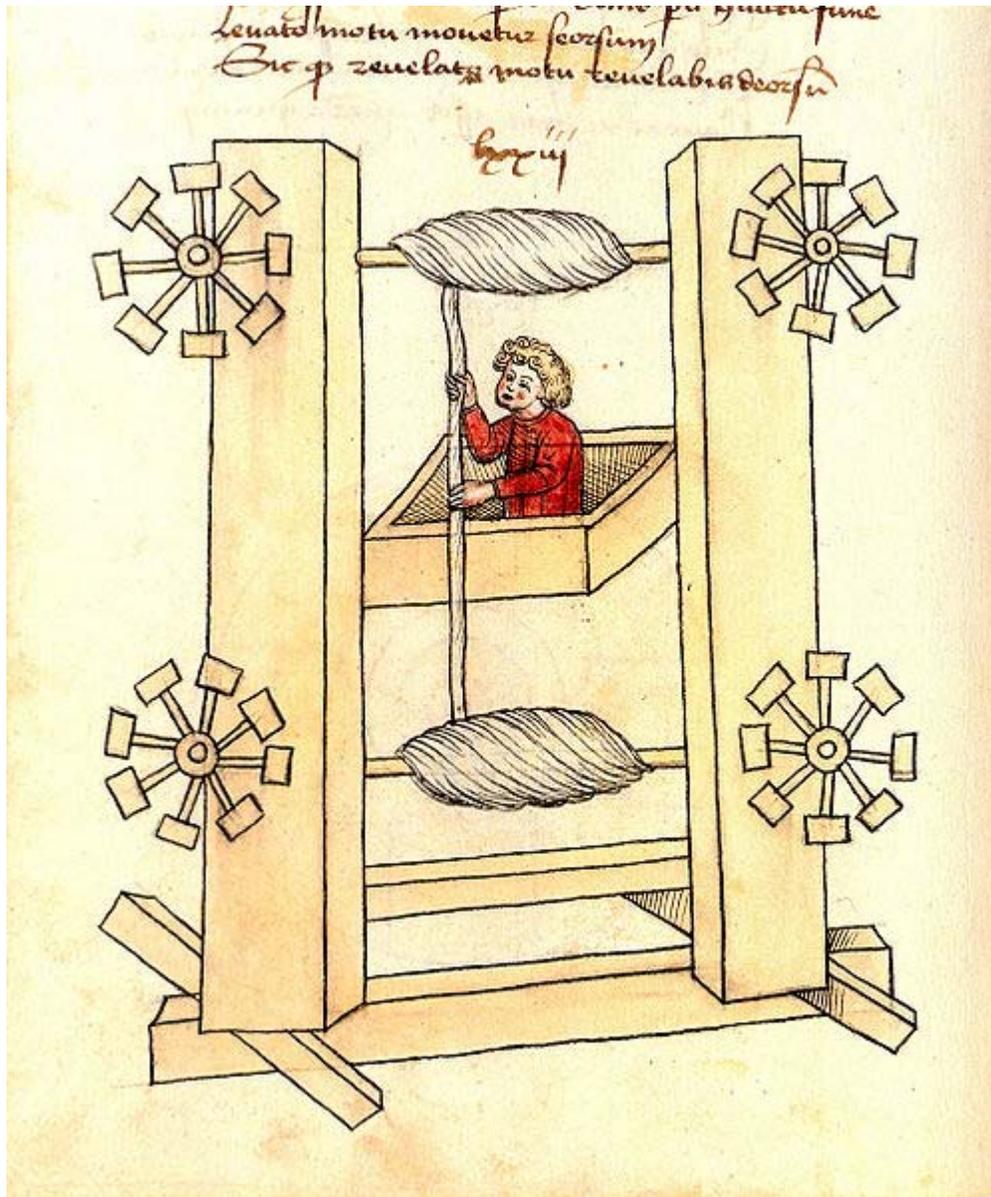
Elevator modernization

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



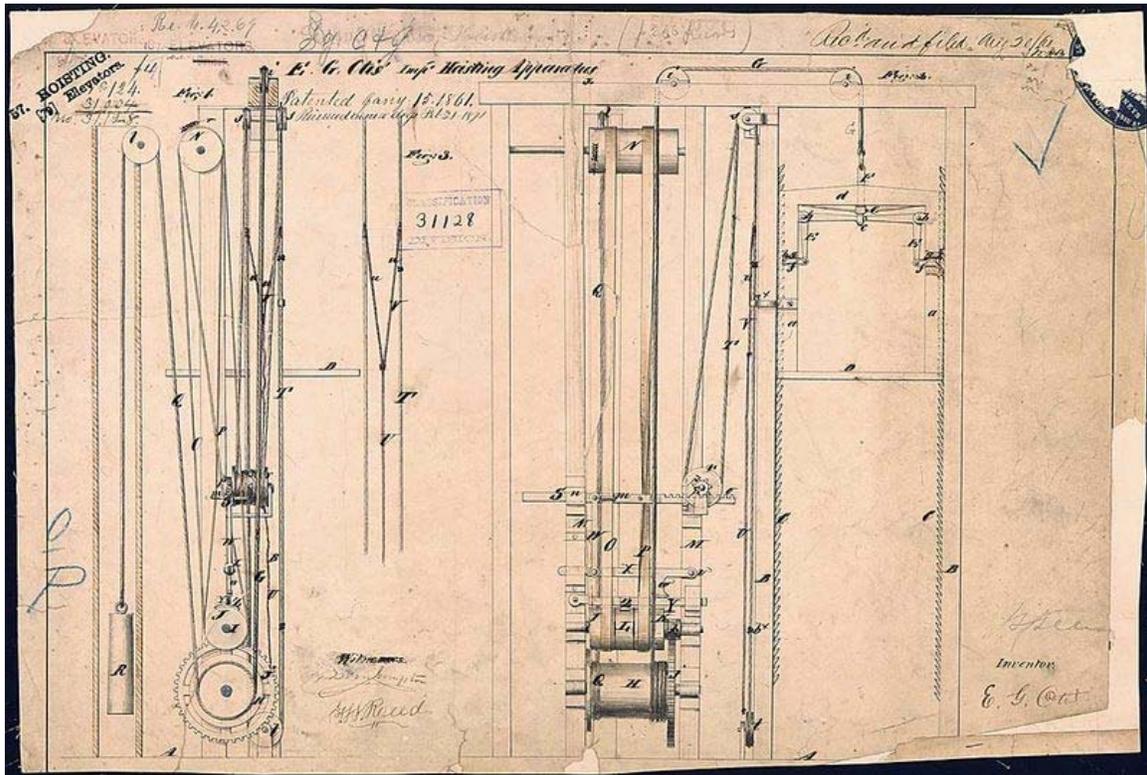
Elevator design by the German engineer Konrad Kyeser (1405)

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-gearred 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.

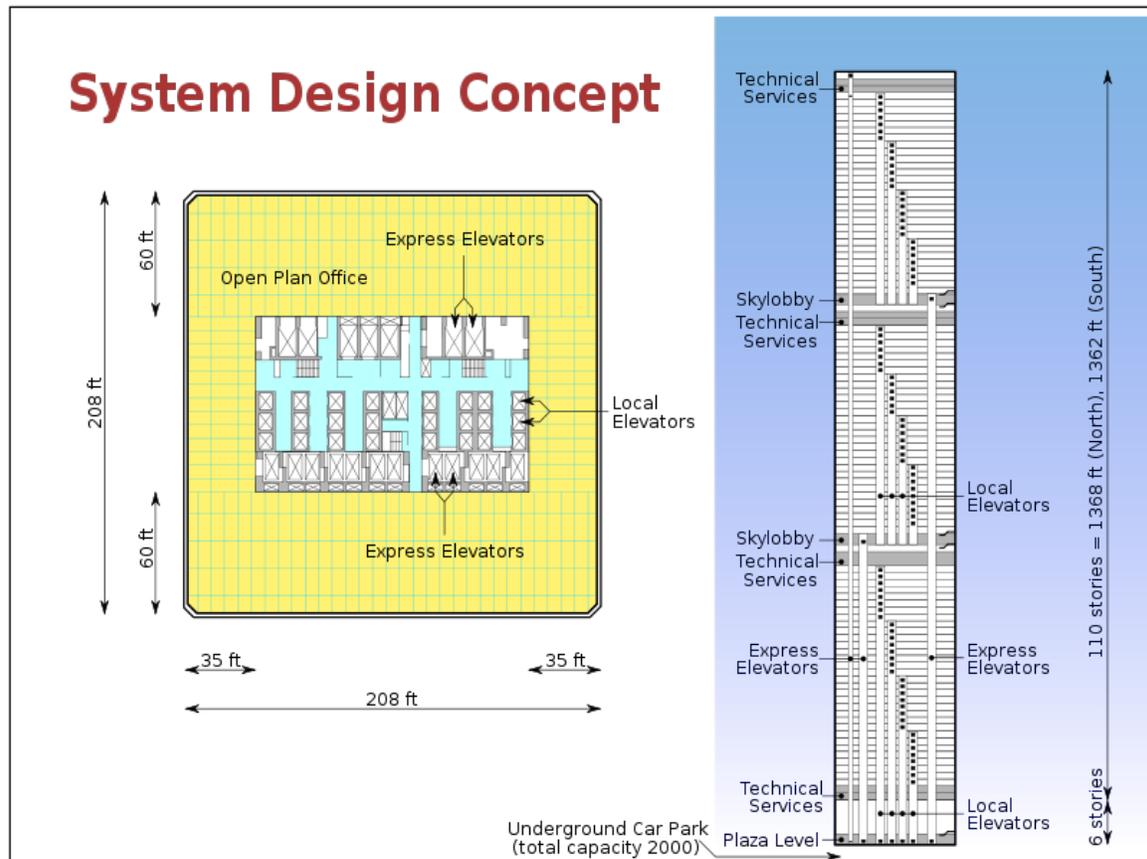
Passenger service

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.

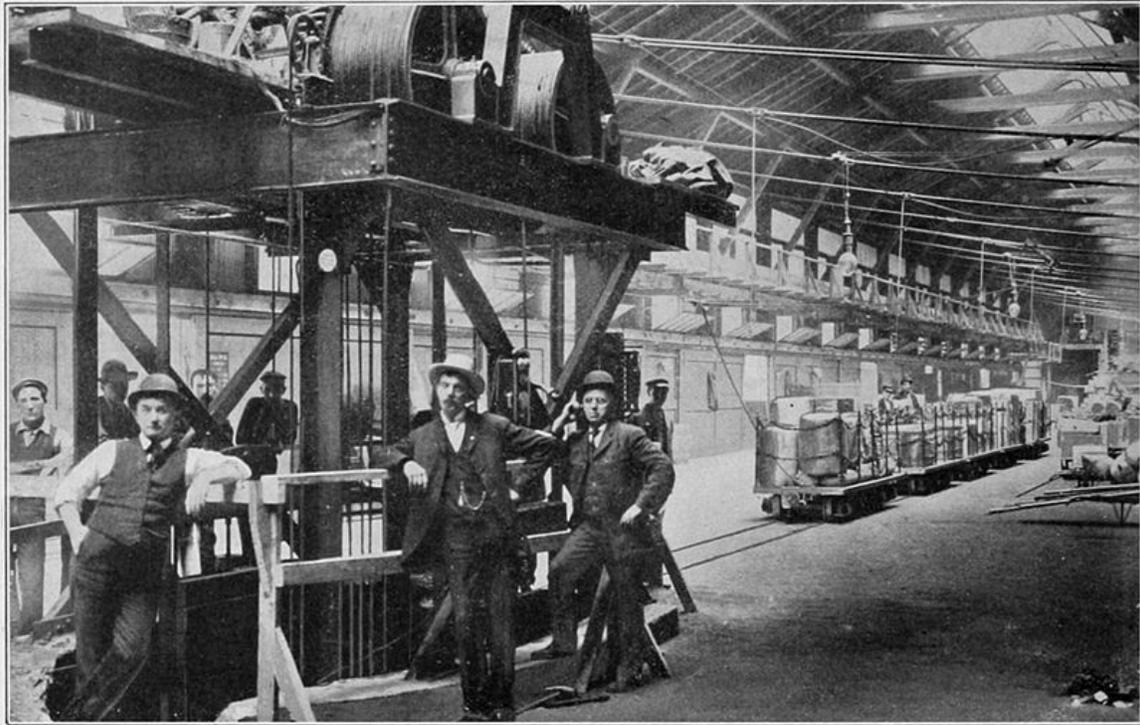
Passenger elevators may be specialized for the service they perform, including: hospital emergency (Code blue), front and rear entrances, a television in high rise buildings, double decker, and other uses. Cars may be ornate in their interior appearance, may have audio visual advertising, and may be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

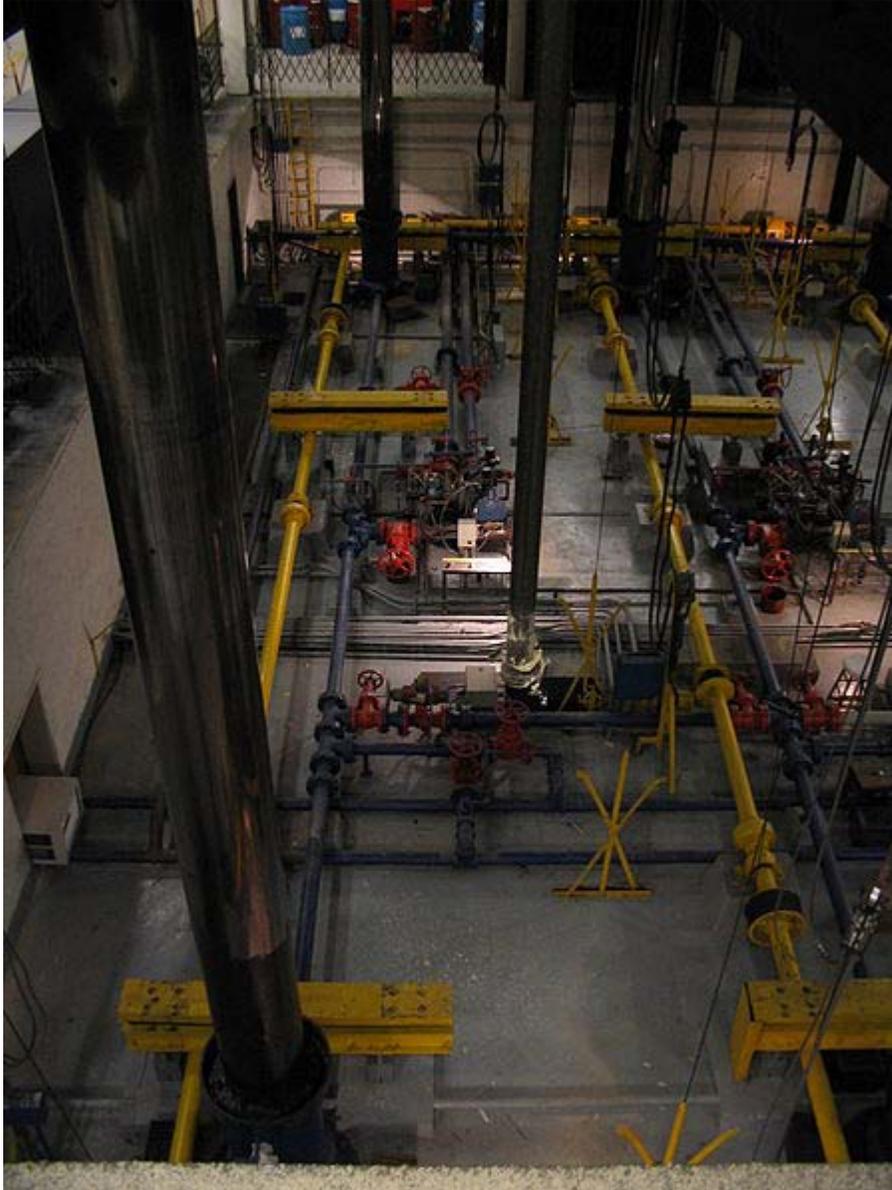


A specialized elevator from 1905 for lifting narrow gauge railroad cars between a railroad freight house and the Chicago Tunnel Company tracks below.

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. These 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.

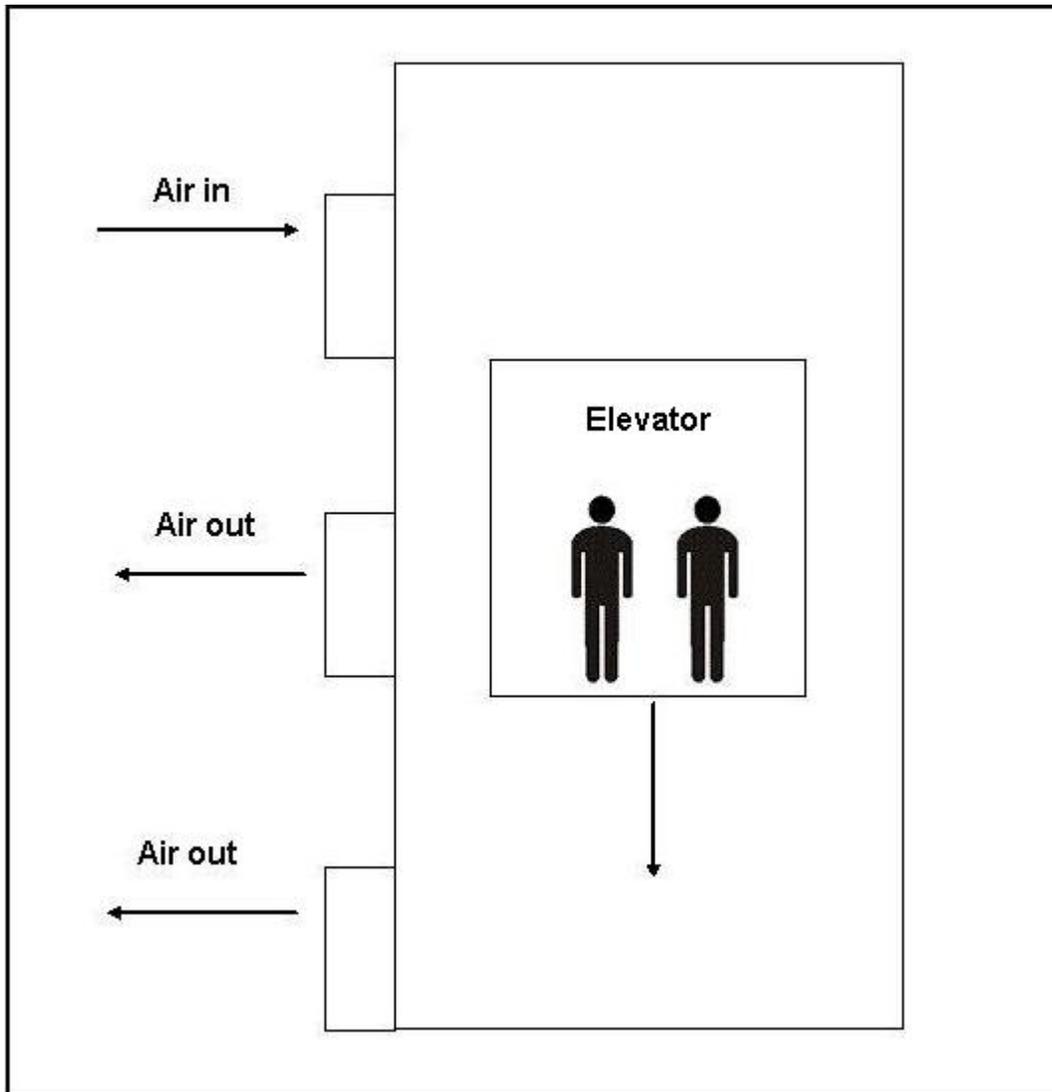
Health

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.