12 Architectural sub-systems organization

Each architectural sub-system performs a [possibly] necessary role in the actualization/materialization of a designed architectural unit (or, architectural object in the habitat service system).

The architecture-based subsystem categories are as follows:

1. **Structural systems** - a structure is some-thing that holds, supports static and dynamic (internal and external) loads/forces:
   A. **Fixed structure** (i.e., immovable building foundation).
   B. **Movable structure** (e.g., collapsible awning support).
2. **Fluid systems** - a fluid is some-thing that flows:
   A. **Water sub-system** (i.e., hydraulics; water storage, processing, and distribution).
   B. **Atmospheric sub-system** (i.e., heating, ventilation and air conditioning, atmospheric processing).
   C. **Combustible gas and oil sub-system** (i.e., combustible power-source distribution piping).
   D. **Other liquids and gas sub-system** (i.e., specialized liquids and gas storage and piping).
3. **ElectroMagnetic (EM) systems** (a.k.a., EM torsion systems) - electromagnetics (a.k.a., EM torsion) is some-thing that torques atoms.
   A. **Electrical torsion sub-system** (i.e., electricity production and distribution).
   B. **Illumination torsion sub-system** (e.g., lighting placement).
4. **Surface systems** - a surface is some-thing that humans interface with through sight and/or touch, and has some function:
   A. **Human interface category:**
      1. **Touch** (e.g., leather, cotton fabric, clickable, holdable, etc.) and/or,
      2. **Vision** (e.g., paint, stone arrangement, colored plastic, natural setting, etc.).
   B. **Societal function service category:**
      1. **Technology** (i.e., engineered functional assembly, e.g., furniture, keyboard) and/or,
      2. **Aesthetic** (i.e., natural beauty; plant arrangements and specific configurations of architecture).
   C. **Planetary ecological service category:**
      1. **Human [planetary resource] harnessing assembly** - where humans construct technologies that use and cycle biospheric/ planetary resources to assemble humans and human service support systems (i.e., cities, human habitats).
      2. **Wild [nature resource] planetary/biospheric cycling** - where nature does its own cycling of resources using living and non-living assemblies of materials (i.e., wild nature, the planetary biosphere, wild ecological habitats).
5. **Technology systems** (an assembly of some-thing that has a function other than being a surface; e.g., furniture):
   A. **Furnishings sub-system** are functional technical units that are placed in a room to support the functional service system(s) present in the room.

The hierarchical sub-layout of these systems is as follows:

1. **Standards:**
   A. Documentation.
   B. Requirements.
   C. Hazards.
2. **Conception of System:**
   A. System's primary sub-types.
3. **Conception of Sub-System(s):**
   A. Sub-system's primary sub-types.
4. **Objects in System.**
   A. Fixture objects.
   B. Fitting objects.
   C. Appliance objects.
5. **Engineering calculations for system.**
   A. Mathematical mechanics.
6. **Installation of System**
   A. Installation mechanics.
7. **Operation of System:**
   A. Load demands on system.

In order to install a system, that system must have had (in the past), all engineering calculations certifiably (traceably) performed on it. These calculations ensure that in the operational phase of the system, that it is capable of safely and optimally meeting [user] load demands.

All architectural sub-systems are all organized categorically in the same way:

1. **The standards:** There are standards that define how the system is to be understood and integrated into the whole architectural system.
   A. Standards are documented somewhere.
   B. Standards are designed to meet requirements.
   C. There are hazards in the design of systems.
2. **The definition and conceptualization [of the function] of the system's sub-systems:** Each system is composed of sub-systems with specific functions relative to the whole system.

3. **The objects in the system**: Because each system is composed of physical matter in the form of objects. The components of each sub-system are:
   A. Fixtures (fixtures list).
   B. Fittings (fittings list).
   C. Appliances (appliances list).
   D. Map of components (positioned in architectural views). These components are visualized in a map.
4. **The routing rules (if applicable):** The sub-systems can be interconnected [optimally] given a set of protocols governing implementation.
   A. Drawings (positioned in architectural views).
   B. Reasoning (written explanation of decision).
5. **The mathematical calculation of the system:** The systems can be assured to operate as expected given engineering calculations.
   A. Load demands.
   B. Structural engineering calculations on load demands.

Architectural systems can be optimized, given physical understandings related to:

1. **Thermal energy** design optimization.
2. **Insulation** design optimization (including, thermal, acoustic, etc.).
3. **Accessway and security** design optimization.
4. **Automation** design optimization.
5. **Safe access** design optimization.
6. **Fire and contaminant protection** design and optimization.
7. **Pest control** design optimization.
8. **Modularity** design optimization.

Architecture is a service, and hence, as a service, it has a set of operational plans and manuals. These plans include, but are not limited to:

1. Maintenance plans and operations.
2. Fire plans and operations.
3. Water plans and operations.
4. Weather plans and operations.
   A. Snow removal plan.
   B. Vegetation removal plan.
   C. Storm-readying plan.
5. Daily readiness and daily shut-down plans and operations.
6. Safety/security plans and operations.
7. Waste removal plans and operations.
8. Signage plans and operations.

13 Architecture structure sub-system

A.k.a., Structural engineering.

Structural systems are those elements of construction that are designed to form part of an architectural structure, either to support the entire architectural system (e.g., building or bridge), or just a part of it. Fundamentally, a structure is responsible for maintaining the shape and form under the influence of subjected forces. A structure is a system to channel loads from one place to another, and to equalize forces (either locally, i.e., load bearing, or over a distance, i.e., non-load bearing). Effectively, an architectural structure is the part of an architectural system that resists the loads that are imposed on it. In concern to most buildings, an architectural structure is anything that is constructed or built from interrelated parts with a fixed (relatively) location on the ground. Note that the common definition of structure within the built environment is, anything that is constructed or built from interrelated parts with a fixed location on the ground. This includes buildings, but can refer to any body that is designed to bear loads (internal and/or external), even if it is not intended to be occupied by people or fixed to the ground:

1. Building structures (i.e., buildings are generally fixed, or rest on, the ground).
2. Non-building structures (e.g., bridges, tunnels, etc.).
3. Other architectural structures (e.g., vehicles, cultivation architecture, doors, windows, etc.; note that although clothing is architecture, it is not considered load bearing).

Structural form is mathematically based, it seeks the greatest efficiency, economy of resources, and simplicity that the engineer can create [given a set of architectural requirements, which may or may not be flexible].

Most built structures are assemblies of large numbers of elements and the performance of the complete structure depends principally on the types of element which it contains and on the ways in which these are connected together. Every structure is a designed and engineered system. To achieve an ideal structural system, architectural design must factor between all of the following:

1. Function.
2. Form (look, aesthetics).
3. Availability of materials.
4. Availability of construction technologies.
5. Physical principals.

Physical principals and laws must be evaluated critically so that structural designs are stable and the elements that make them up are in equilibrium. Each element that makes up an architectural structure must be in balance or equilibrium with every other structural element in the structure so that it stays together and remains stable. The elements and the structures that make them up must be resistant to the forces that act on them.

The function of a structure is to supply the strength and rigidity which are required to prevent a system from collapsing. More precisely, it is the part of an architectural system that conducts the loads that are imposed on it from the points where they connect to the ground underneath the system, where they can ultimately be resisted.

A **structural support** is a part of a building or structure that provides the necessary stiffness and strength in order to resist various forces. In an architectural structural system there are two categories of structure depending on load transfer type:

1. **Load bearing structural support (a.k.a., the structural force-resisting support framework)** - structural components that are capable of transferring loads.
   A. **Piles** (a.k.a., foundation piles, physical foundation feet and platform, fixed feet and platform) - the physical foundation feet and platform that are fixed into the ground. Piles are structural elements driven or installed into the ground to transfer the loads of a building or structure to deeper, more stable soil or rock layers below the surface. Piles can reach down to the bedrock to be most stable, or they can rely on friction to hold stability, and present greater risk to leaning (because they are not anchored to bedrock):
      1. **End-bearing piles (a.k.a., bedrock piles, point-bearing piles, bearing piles, reach bedrock piles) -** are designed to transfer structural loads through the upper, softer layers of soil or weak strata to reach and rest upon a harder, load-bearing layer, which could be bedrock or a stronger soil layer below the weaker strata. These piles derive their support primarily from the resistance or bearing capacity of the underlying firm stratum or bedrock.
      2. **Friction pies (a.k.a., cohesion piles, floating piles)** - are piles that do not reach bedrock. Instead, they rely on the frictional resistance generated along the sides of the pile shaft when driven into softer or looser soil layers. These piles transfer structural loads by utilizing the adhesion or friction between the pile surface and the surrounding soil, distributing the load through skin friction along the pile's length.
   B. **Beams** - are horizontal load bearing structural supports.
   C. **Columns** - are vertical load bearing structural supports.
   D. **Braces** - are angled load bearing structural supports.
   E. **Walls** - walls can be used as structural support.
2. **Non-load bearing structural support** - structural components that are not capable or intended to transfer loads, and may need to hold themselves us against gravity and vibration. These are often called "space dividing" structures. Non-load bearing elements often fill-in the gaps between the structural frame. The components that fill in such gaps have many names, including but not limited to: facade, infill, non-load bearing walls ("curtain walls"), sheeting, etc.

IMPORTANT: *Unlike the other architectural sub-systems, there are no fixtures and fittings for the structural system. Instead, the structural system is divided by load and non-load bearing elements*

It is important to note here that not all structure is considered load bearing structure. Non-load-bearing architectural [surface] elements are not part of the structural support framework for a building system, but they are part of the total structure. Non-load bearing walls, however, do hold themselves up, and hence, are part of the structure. Structural frameworks can contain non-load bearing elements, such as non load bearing partitions in a building, or redundant members in a framework. So by that logic, a non load bearing wall in a building would only support its own weight and play no part in the distribution of loads imposed by other building elements such as the roof or intermediate floors. Conversely, a load-bearing wall is part of the structure of the building, used to support floors, ceiling, roof, and other walls.

All building and non-building architecture contains a structure, because there is always the necessity to resist force. Note, however, that there is a continuum here. Some buildings are almost entirely structure, whereas others have very little structure. It is possible to produce a building which consists of little other than structure. And, it is possible to produce a building with minimal structure.

Load-bearing structure (ak.a., structural supports) can be applied in two ways:

1. Enclosed inside the architecture.
   A. The location of the structure within a building is not always obvious because the structure can be integrated with the non-structural parts in various ways.
2. Visible (exposed) and contribute to the aesthetics of the building.

The most common types of structural support systems include, but are not limited to:

1. Continuous structures.
2. Framed structures.
3. Shell structures.
4. Tensile structures.
5. Arches.
6. Barrel vaults.
7. Cantilevers.
8. Domes.
9. Shell and core.
10. Space frame.
11. Trussed rafters.
12. Portal frame.

The most common elements of a structural support are:

1. Frame: A member that forms part of the structural frame of a building (Read: architectural system), or any other beam or column.
2. Load bearing wall: A load bearing wall or load bearing part of a wall.
3. Floor: A floor.
4. Gallery: A gallery (but not a loading gallery, fly gallery, stage grid, lighting bridge, or any gallery provided for similar purposes or for maintenance and repair).
5. External wall: An external wall.
6. Compartment wall: A compartment wall (including a wall that is common to two or more buildings).

13.1 Structural standards

A.k.a., Structural engineering standards.

In structural engineering, standards (and codes) are the factors needed to make the design structurally safe and effective ("sound"). Different jurisdictional regions have different structural engineering design standards and codes (for various reasons, sometimes political).

Structural design criteria categories for safety, include, but are not limited to:

1. Seismic analysis reference standards/code.
2. Concrete design standards/codes.
3. Minimum load design requirements (standards/code).
4. Material type standards codes (and, material reinforcement)

13.1.1 Standard structural documentation

A.k.a., Structural system specification and drawings.

Structures are documented via specifications and drawings.

1. Structural drawings illustrate the system that will support loads and other forces, transfer loads, and support other services.
2. Structural specifications include all written content, reasoning for decisions, and calculations.

13.1.1.1 Structural system plan

The structural plan is a plan view that shows the complete structural system. The structural plan shows the following parameters for all units of structure:

1. Material composition of structure.
2. Amount of material.
3. Method of construction (and destruction) of structure.
4. Positional mapping of structure and all structural elements.
5. Calculation of all structure.
6. Type of equipment for de-/construction.
7. Calculation to determine optimal equipment type.

The structural plan includes standards for safety and structural engineering quality for all buildings. It also covers requirements for the prevention of collapse and other hazards.

13.1.2 Standard structural requirements

What is required for a viable structural production-distribution system is:

1. **For architecture** - structure production proportionate to environmental disturbances (e.g., gravity and other environmental forces) as well as human and machine demand [via a load].
   A. Herein, a load means the amount of motion produced at a specific temperature required by a building to support without breaking.
2. **For economic calculation** - Data sheet about structural configuration and loads (weights and moving weights) to produce optimization calculation.
3. **For life support demand** - structure proportionate to human demand.
4. **For technology and exploratory demand** - structure proportionate to human demand.

13.1.3 Standard structural hazards

A.k.a., Structural risks.

The primary structural risks include, but may not be limited to:

1. **Collapse** - improperly engineered structures that fail existing conditions.

2. **Water and humidity/moisture control** - moisture from the ground can degrade structural materials rapidly. This is particularly the case with foundations -- foundations must be protected from water and moisture ("damp"). Moisture control in walls, floors, and roofs may also be significantly important.
   A. Waterproof impermeable membrane.
   B. Permeable membrane (a.k.a., vapor or humidity membrane, vapor barrier).
3. **Rain** - that is water from clouds in the higher atmosphere, especially when wind-driven, can cause moisture problems in walls (and as well as roofs, etc.). Rain leaks through exterior walls are usually a result of improper installation of:
   A. Siding materials.
   B. Poor quality flashing.
   C. Impermeabilization layers.
   D. Weatherstripping or caulking around joints in the building exterior (such as windows, doors, and bottom plates).
4. **Flooding** - liquids pooling in areas where they are not intended to pool.
5. **Earth movement** - including earth movements including earth slides (erosion) and earth quakes.
6. **Thermal expansion and contraction** - as structures expand and contract due to changes in temperature they can weaken and/or become loose.
7. **Thermal bridging** - are sinks of thermal (heat) energy that transfer it to undesirable and/or unintended locations. These unintended thermal connections will heat or cool additional surfaces that are not intended to be heated or cooled. The thermal energy generally comes from the outside environment, such as the sun when heating and snow (or cold wind) when cooling.
8. **Vibration (uncontrolled oscillations)** - usage occupancy leads to uncontrolled oscillations that damage the structure.
9. **Construction risks** - These are risks associated with the construction of he structure. Structures necessarily involve material objects of sufficient weight to seriously harm humans.

13.2 Conception of the structural service system

A structural system specification will include all the different types of structures used in the system.

13.2.3.1 Types of structure

Structures can be classified in a number of ways:

1. **By type:**
   A. Composite.
   B. Frame.
   C. Liquid.
   D. Membrane.
   E. Shell.
   F. Solid.
2. **By structural system:**
   A. Bending.
   B. Composite.
   C. Compressive.
   D. Shear.
   E. Tensile.
3. **By application:**
   A. Aqueducts and viaducts.
   B. Building.
   C. Bridges.
   D. Canals.
   E. Cooling towers and chimneys.
   F. Dams.
   G. Railways.
   H. Roads.
   I. Retaining walls.
   J. Tunnels.
   K. Coastal defences.
4. **By form:**
   A. One-dimensional (e.g., ropes, cables, struts, columns, beams, arches).
   B. Two-dimensional (e.g., membranes, plates, slabs, shells, vaults, domes, synclastic, anticlastic).
   C. Three-dimensional (e.g., solid masses).
   D. Composite. A combination of the above.

   NOTE: *A three-dimensional structure can be expressed in terms of geometric principles such as spatial limits and shapes.*

5. **By material:**
   A. Adobe.
   B. Composite
   C. Concrete.
   D. Glass.
   E. Masonry (e.g., brick, block, stone, etc.).
   F. Metal (e.g., steel, aluminium, etc.).
   G. Timber.
   H. Etc.
6. **By element:**
   A. Substructure.
   B. Superstructure.
   C. Foundation.
   D. Roof.
   E. Shell and core.
   F. Structural frame.
   G. Floor.

H. Wall: load-bearing walls, compartment walls, external walls, retaining walls, as well as non-load bearing walls.

7. **By overall building form:**
   A. By number of openings into enclosed volumes.
   B. By number of floors.
      1. Low-rise.
      2. Multi-storey.
      3. Mid-rise.
      4. High rise.
      5. Groundscraper.
      6. Skyscraper.
      7. Supertall.
      8. Megatall.
      9. Super-slender
      10. Megastructure.
   C. By shape:
      1. Anticlastic.
      2. Synclastic.
      3. Hyperbolic paraboloid.
      4. Conoid.
      5. Tower.
      6. Dome.

13.2.3.2 Superstructure and substructure

The most broad definition of superstructure includes all works above ground level; however, this is an ambiguous definition. A more complete definition of superstructures includes, but may not be limited to the following elements:

1. Frame: The load-bearing framework, including main floor and roof beams, ties and roof trusses of framed buildings; casing to stanchions and beams for structural or protective purposes.
2. Upper floors: Floors suspended over, or in basements, service floors, balconies, sloping floors, walkways and top landings, where part of the floor rather than part of the staircase.
3. Roof: the roof structure, roof coverings, roof drainage, roof lights and roof features.
4. Stairs and ramps: Construction of ramps, stairs, ladders, etc. connecting floors at different levels.
5. External walls: External enclosing walls including walls to basements but excluding walls to basements designed as retaining walls.
6. Windows, doors and openings in external walls (e.k.a., fenestration). Internal walls, partitions, balustrades, moveable room dividers, cubicles and the like.
7. Doors, hatches and other openings in internal walls and partitions.

NOTE: *This definition excludes; the substructure, finishes, fittings, furnishings, equipment and services.*

The most broad definition of substructure includes all works below ground level; however, this is an ambiguous definition. A more complete definition of substructures is, all work below the underside of a screed (Read: first leveled layer of material) or, where no screed exists, the underside of lowest floor finishes including damp-proof membrane, together with relevant excavations and foundations (includes walls to basements designed as retaining walls). In this sense, the function of the substructure is to,transfer the load of the building (or non-building structure) to the ground and to isolate it horizontally from the ground.

A narrow definition of substructure includes (while excluding finishes, basement walls not in contact with earthwork, retaining walls not providing external walls, etc.):

1. Foundations up to and including the damp proof course.
2. Lowest floor assembly below the underside of the screed or the lowest floor finish.
3. Basement excavation.
4. Basement retaining walls up to and including the damp proof course.

13.3 Conception of the structural support system

A.k.a., , Structural lading system, structural members, structural loading members.

A structural support system is generally classified in two ways:

1. **By material composition** - types of structural supports by material.
2. **By component position** - types of structural supports by component position.

13.3.1 Types of structural supports by material

There are many different types of support structures, including but not limited to:

1. Metal based structures.
2. Metal and concrete based structures.
3. 3D printed concrete (or similar material) structures.
4. Etc.

13.3.1.1 Metal-based structuring (metallic structure)

Metal frame that some other material (e.g., blocks of concrete) are fitted into. The metal frame can be prefabricated with approximate location conduits and connectors connected together.

13.3.1.2 Metal- and concrete-based structuring

One of the ways found to improve the concrete's strength and durability is to incorporate tensioned steel tendons before casting (e.g., reinforced steal, rebar, or wire framing).

13.3.2 Types of structural supports by position

There are two primary positions for structural supports:

1. **Horizontal** (a.k.a., horizontal inter-connectors, horizontal supports).
2. **Vertical** (a.k.a., vertical inter-connectors, vertical supports).
3. **Combination** (e.g., archway).

It is relevant to note here that in the case of 3D printing, the interconnections (3D printed structure) may also act as a vertical and horizontal support structure, whereupon additional horizontal and vertical supports are not necessary.

13.3.2.3 Horizontal supports as beams

A.k.a., Beaming.

A beam is a horizontal structural element that withstand vertical loads, shear forces and bending moments. The loads applied to the beam result in reaction forces at the support points of the beam. The total effect of all the forces acting on the beam is to produce shear forces and bending moment within the beam, that in turn induce internal stresses, strains and deflections of the beam. They transfer loads imposed along their length to their end points where the loads are transferred to columns or any other supporting structural elements.

Types of loads on beams are (includes a requirement for calculation of each):

1. Self-weight of the beam.
2. Dead load includes point load for instance column constructed on beam, distributed load for example setting slabs on a beam.
3. Live load.
4. Torsional load.

13.3.2.4 Horizontal support inter-connectors as floors

The floors are both structural and space-dividing elements. Some floors (Read: those not on the ground) have ceilings suspended underneath them.

13.3.2.5 Horizontal support inter-connectors as slabs

A.k.a., Slabbing.

A slab is an important structural element which is constructed to create flat and useful surfaces such as floors, roofs, and ceilings. It is a horizontal structural component, with top and bottom surfaces parallel or near so. Commonly, slabs are supported by beams, columns (concrete or steel), walls, or the ground. The depth of a concrete slab floor is very small compared to its span. The primary function of slabs is to safely control loads. Slabs can have additional functions, and are sub-classified thereby.

Types of loads acting on a slab are (includes a requirement for calculation of each):

1. Dead load of the slab.
2. Live load.
3. Floor finish load.
4. Snow load in the case of roof slab.
5. Earthquake loads.

Slabs can be sub-classified by:

1. Composition.
2. Size and dimensions.
3. Secondary functions (primary function is always loading):
   A. Has installation inside?
   B. Has open spaces inside?
      1. Has conduits space(s)?

13.3.2.6 Vertical supports as columns

A.k.a., Columning.

Column is a vertical structural member that carry loads mainly in compression. It is assumed to be the most crucial structural member of a building because the safety of a building rest on the column strength.
Columns transfer vertical loads from a ceiling, floor or roof slab or from a beam, to a floor or foundation. They also carry bending moments about one or both of the cross-section axes.

Types of loads on columns are (includes a requirement for calculation of each):

1. Self-weight of the column multiplies by number of floors.
2. Self-weight of beams per running meter.
3. Load of walls per running meter.
4. Total Load of slab (Dead load + Live load + Self weight).

Columns are purely structural, although they do punctuate the interior spaces and are space-dividing elements, to some extent.

13.3.2.7 Horizontal support inter-connectors as walls

Load-bearing (bearing) walls support the weight of a floor or roof structure above and are so named because they can support a significant amount of load. Load bearing walls are both active structural elements and space-dividing elements. Load bearing walls are designed differently (in concern to their non-surface elements) than non-load-bearing walls.

13.3.2.8 Foundational supports

A.k.a., Footing, platforming, etc.

Footings are structural elements that transmit load of entire superstructure to the underlying soil below the structure. Footings are designed to transmit these loads to the soil without exceeding its safe bearing capacity. Thus, prevent excessive settlement of the structure to a tolerable limit, to minimize differential settlement, and to prevent sliding and overturning. All building structures are built on a foundational support. A foundation is generally concrete in or on dirt, or packed dirt itself.

Types of loads on footings are (includes a requirement for calculation of each):

1. Dead load.
   A. Self-Weight of the elements.
   B. Superimposed loads such as finishes, partitions, block work, services.
2. Live load.
3. Impact load.
4. Snow load.
5. Wind load.
6. Earthquake force.
7. Soil pressure.
8. Rain loads.
9. Fluid loads.

Soil is the root support of the footing. All the forces that come in contact with the footings will be transferred to the soil. The soil shall bear these loads by the aspect known as bearing capacity. The bearing capacity changes from one type of soil to another and it is the key factor in estimating the size of footings.

The calculations for the foundation depend on soil conditions. These calculations are completed after calculating for the structure of the building itself.

13.4 Conception of the in-fill sub-system

Whereas the structural support system transfers loads, the structural in-fill system is non-load bearing. The most common element in a structural in-fill system is the non-load bearing wall.

Types of non-load bearing walls include, but are not limited to (based on the wall unit specifics):

1. Hollow concrete block wall - are semi-hollow blocks of concrete formed into an immovable block or wall.
2. Facade bricks wall - are bricks positioned to create a facade on a pre-existing wall.
3. Hollow bricks wall - are semi-hollow bricks formed into an immovable block or wall made of bricks.
4. Brick walls - are made of an immovable block or wall made of brick.

5. Sub-system objects (a.k.a., fittings, fittings, and appliances).
6. Sub-system installation of objects (construction and maintenance).
7. Sub-system operation of objects (production and usage; supply and demand).
8. Sub-system engineering calculations.

13.5 Objects in the structural system: fixtures, fittings, and appliances

A.k.a., Structure-based technologies.

Structural fixtures and fittings are equipment that interface with the water in a building:

1. **Structural load bearing fixtures** - are structural elements designed to bear structural supporting loads. The most common fixtures include, but may not be limited to:
   A. Columns.
   B. Beams.
   C. Foundations.
   D. Floors (and sometimes roofs)
   E. Load bearing walls.
2. **Structural non-load bearing *solid* fixtures** - are structural elements not designed to bear structural supporting loads. The most common fixtures include, but may not be limited to:
   A. Non-load bearing walls.
   B. Roofs (if not load bearing).
   C. Infill (whatever material goes in between structural supports; e.g., bricks).
   D. Bollards and similar barriers.
   E. Railings and similar barriers.
   F. Doors (accessway and insulation).
   G. Windows (illumination and insulation).
   H. Staircase (accessway).
   I. Ramps (accessway).
   J. Escalators, moving walkways, and elevators (transportation).
3. **Structural non-load bearing *void* fixtures** - are gaps in the whole structure designed to contain doors and windows.
   A. Door void.
   B. Window void.
   C. Space void (is a void not filled with any solid object).

4. **Structural fitting** - a device designed to control or connect non-load bearing structures. The most common fittings include, but may not be limited to:
   A. Mechanisms (e.g., locks).
   B. Levers (e.g., handles).
5. **Structural appliances** - appliance devices that change structural elements, the most common of which include:
   A. Garage door machine (for opening and closing garage door).
   B. Automated door opener.
   C. Automated window opener.

13.5.1 Doors and windows

A.k.a., Frames, fenestrations, openings in the building envelope, etc.

Doors and windows are structural non-load bearing solid fixtures:

1. A door is a moving structure used to block off, and allow access to a separated area, such as a building. Doors normally consist of a panel that swings on hinges on the edge or a motor that retracts and extends. Typically, doors have an interior side that faces the inside of a space and an exterior side that faces the outside of that space.
   A. A lintel (lintol) is a type of beam (a horizontal structural element) that spans openings, such as doors, windows, and fireplaces.
2. A window is an opening in the structural enclosure (e.g., wall, door or roof) that allows the passage of light and/or air. Modern windows are usually glazed or covered in some transparent or translucent material. Generally, windows are held in place by frames.

NOTE: *In phases of construction, frames (doors and windows are a separate construction phase from the infrastructure as well as superstructure construction.*

13.6 Specialized openings

There are a number of specialized openings into various forms of architecture. The most common of these specialized openings are manholes. Manholes (and manhole covers) are one example of a specialized opening into sewer (waste water transport) architecture. The "modern" manhole cover allowed for easier access to the underground sewer network. Specifically, manhole covers are also used as access points to septic tanks, electrical controls, and wiring.

13.7 Construction of a structural system

A.k.a., Structural construction.

There are many ways to construct structures, using many different types of tools and even more techniques.

13.8 Operation of a structural system

In general, there are no significant operational characteristics to structures. In some cases, non-load bearing walls can be made to be movable (e.g., rotated). The movement of such walls would be considered part of the operation of a structure.

13.8.1 Structural load demands

A.ka., Structural loading.

Structure loads are measured in several ways, most notably:

1. Mass,
2. Gravity,
3. Vibration, and
4. Surface temperature.

In order to resist, structural systems are split into load transfer bearing and non-load transfer bearing:

1. Load transferring system:
   A. Energy absorbed by structure.
      1. Permanent load (a.k.a., static load, dead load) - are essentially constant during the life of the structure and normally consist of the weight of the structural elements. The structure first of all carries the dead load, which includes its own weight, the weight of any permanent non-structural partitions, built-in cupboards, floor surfacing materials and other finishes. It can be worked out precisely from the known weights of the materials and the dimensions on the working drawings. Although the dead load can be accurately determined, it is wise to make a conservative estimate to allow for changes in occupancy; for example, the next owner might wish to demolish some of the fixed partitions and erect others elsewhere.
      2. Dynamic load (a.k.a., live load) - All the movable objects in a building, and usually vary greatly. The weight of occupants, snow and vehicles, and the forces induced by wind or earthquakes are examples of live loads.
         i. Wind loads
         ii. Snow loads
         iii. Earthquake loads
         iv. Thermal loads
         v. Settlement loads
         vi. Dynamic loads
      3. Most structural loads are measured in weights of mass. Often, the weight expressed as

[amount of possible motion in]:
 i. Newtons per meter squared (N/m^2)
2. A structural service system:
 A. Structural volume - is volume of area consumed by a structure:
  1. Meters cubed per liter (m^3/L)
 B. Structural materials - the material resources that are occupied by the structure.
  1. Quantities of material units.
 C. Temperature transfer is measured in kelvins or Celsius (or Fahrenheit in imperial).
3. Non-usage, but presence, will still equate to system service usage.
 - If a usage has no demand in the form of a structure factor of zero the user would consume NO usage per minute (i.e., no usage), but the land would still occupy, and the supplier would still have to maintain the structure. Structural factor is the relationship (phase) of volume and material in a structural support system.

13.9 Structural engineering calculations

A.k.a., Structural analysis, structural engineering.

Structural analysis is concerned with mechanical science, which is concerned with statics, equilibrium and the properties of materials; it includes all structural principles (i.e., force, load, materials, and components). Structural analysis is primarily concerned with finding the structural response to given [set of] forces and loads (internal and/or external) composed of a set of materials and fabricated into a component(s). Structural analysis is used to analyze and calculate the effects of the forces and loads acting on any component of the structure, and on the structure overall. A structural model is what is analyzed, and only after analysis is the model accepted for construction.

Structural analysis calculations for a building include:

1. Structural analysis (with specific materials)
 A. Engineering calculations for building alone.
 B. Engineering calculations for foundation, including building and soil/terrain.

Engineering in architecture involves (at least) the following components and their inclusion in calculations for the building:

1. Weight (gravity) distribution calculation.
 A. Material specifics (or, combined material specifics).
 B. Volume relative.
2. Vertical structural support(s).
3. Horizontal structural support(s).
4. Walls.
5. Windows.
6. Doors (if heavy).
7. Floors.
8. Ceilings.
9. Conduits.

13.9.1.1 Entry-level formulae for structural analysis

Use the following formulas for entry type calculations on ideally simple structures:

1. Shape Formulae
 - Circle A = π r2
 - Triangle A = ½ bh
 - Rectangle A = bh
2. Formula for pressure on a column
 - Pressure (P) = Force (F) / Area (A)
 - P = F / A

13.9.1.2 Bearing capacity calculation

Bearing capacity refers to the capacity of soil to support applied loads that are acting on it. This typically relates to the capacity of soil to support architectural foundations, in which case, the bearing capacity can be calculated from the maximum average contact pressure between the foundation and the soil that would not produce shear failure.

Three modes of failure limit bearing capacity:

1. General shear failure.
2. Local shear failure.
3. Punching shear failure.

The ultimate bearing capacity of soil (qu) is the maximum pressure which can be supported without failure occurring.

The net ultimate bearing capacity (qnu) does not take into consideration the over-burden pressure and can be calculated as:

- qnu = qu - Ydf
- Where,
 - Y = unit weight of soil
 - Df = foundation depth

The net safe bearing capacity (qns) considers only shear failure, and can be calculated as:

- qns = qnu / F
- Where
- F = factor of safety.

The allowable bearing capacity (qs) is the ultimate bearing capacity divided by a factor of safety, and can be written as:

- qs = qu / F

Note that on particularly soft soil, significant settlement can occur without shear failure. In such instances, the maximum allowable settlement is used as the allowable capacity.

13.9.2 Engineering calculations for structure

Structural design and calculation is based on structural engineering principles.

The four categories of structural principles are:

1. **Forces** - interactions that changes the motion of an object when it is unopposed.
2. **Loads** - a type of force.
3. **Materials** - physical composition.
4. **Structural elements (structural members)** - constructed system.

13.9.2.1 Forces (impact on structure)

Forces are interactions that changes the motion of an object when it is unopposed.

The two broad categories of forces between objects are:

1. **Contact forces** - occur when the two interacting objects physically connect with one another.
   A. **Friction** - the force that resists the relative motion of solid objects, surfaces, fluid layers and material elements sliding against one another.
   B. **Tension** - the force transmitted through a string, rope, cable or wire when pulled tight by oppositional forces.
   C. **Normal force** - the support force exerted upon an object that is in contact with another stable object. For example, an object on the surface of a table is supported by an upward force being exerted by the table surface.
   D. **Air resistance** - the frictional force air exerts against a moving object. This is also known as 'drag'.
   E. **Applied force** - a force applied to an object by a person or another object.
   F. **Spring force** - a restoring force exerted by a spring, which acts to restore a spring towards equilibrium.
2. **Forces that result from action-at-a-distance** - occur when two interacting objects are not in physical contact with one another but still exert a push or pull.
   A. **Gravitational force** - the phenomenon by which all things with mass are brought toward one another.
   B. **Electrical force** - the attractive or repulsive interaction between any two charged objects.
   C. **Magnetic force** - the attraction or repulsion that arises between electrically charged particles due to their motion.

The three properties of forces are:

1. **Magnitude:** The size of the force.
2. **Direction:** The direction in which the force is acting.
3. **Position:** The position on which the force acts.

The three laws of motion that act on a structure are:

1. **Inertia (first law):** An object will remain at rest or in uniform motion unless compelled to do otherwise by some external force acting on it.
2. **Force = mass * acceleration (F = ma; Second law):** A force is caused by an acceleration acting on an object.
3. **Action and reaction (Third law):** Action and reaction are equal and opposite.

In concern to a building, one of the main structural principles is that elements such as the roof, floor and walls must remain stationary. For this to happen, there needs to be an equilibrium of forces – when the forces acting on them are equal and opposite. Under loading, some deflection and deformation – in the form of bending and buckling – may occur, and if this movement is not allowed for then structural failure may be the result. Therefore, a principle of structures is that they be designed to maintain a state of equilibrium; resisting external loads without moving.

The study of the causes and effects of stationary forces acting on rigid objects is 'statics'. When a structure is stationary or in equilibrium, it is a 'static body'. For a structure to remain static, three basic equations must hold true:

1. Sum of all vertical forces must be zero.
2. Sum of all horizontal forces must be zero.
3. Sum of all bending forces, or moments, must be zero.

Elements in architectural structures are subjected, principally, to one of the following:

1. Axial internal force .
2. Bending-type internal force.
3. A combination.

Axial internal force can be resisted more efficiently than bending-type internal force. The type of internal force which occurs in an element depends on the relationship between the direction of its principal axis (its longitudinal axis) and the direction of the load which is applied to it (Macdonald, 2001:37)

13.9.2.2 Force factors

The two force factors created by a given application of a load are:

1. The type of internal force.
2. The magnitude of the internal force.

The shapes of structural elements determine the types of internal force which occur within them and influence the magnitudes of these forces.

13.9.2.3 Loads (impact on structure)

In structural design, a load is a weight or mass (force) applied to a component of a structure or to the structure as a unit. A structural load or structural action is a force, deformation, or acceleration applied to structural elements. A 'load' is a force that a building (structure) needs to be able to resist. Loads cause stresses and deformations. The effects of loads on physical structures are determined through structural analysis, which is one of the tasks of structural engineering. The surfaces that form the architecture (or, architectural envelope; e.g., walls, floors, roof, etc.) are subjected to various types of loads. For example, external surfaces are exposed to the climatic loads of snow, wind and rain; floors are subjected to the gravitational loads of the occupants and equipment and their combined effects; and most of the surfaces also have to carry their own weight. A load causes stress, deformation, and displacement in a structure. Structural analysis, a discipline in engineering, analyzes the effects loads on structures and structural elements. Examples of load-bearing structures include, but are not limited to:

1. Buildings
2. Aircrafts
3. Dams
4. Bridges

> **NOTE:** *A load-bearing wall is part of the structure of the building, used to support floors, ceiling, roof, and other walls. A non load-bearing wall, also called a partition is used to divide rooms but does not hold anything up apart from its own weight.*

To perform its function of supporting an architectural system in response to loads applied to it, a structure must possess three required properties (Macdonald, 2001):

1. **It must be capable of achieving a state of equilibrium** - Structures must be capable of achieving a state of equilibrium under the action of applied load. This requires that the internal configuration of the structure together with the means by which it is connected to its foundations must be such that all applied loads are balanced exactly by reactions generated at its foundations. Architectural structures must be capable of achieving equilibrium under all directions of load.
2. **It must be stable** - Geometric stability is the property which preserves the geometry of a structure and allows its elements to act together to resist load. The fundamental issue of stability is that stable systems revert to their original state following a slight disturbance, whereas unstable systems progress to an entirely new state. The fundamental requirements for the geometric stability of any arrangement of elements is that it must be capable of resisting loads from orthogonal directions (two orthogonal directions for plane arrangements and three for three-dimensional arrangements). In other words, an arrangement must be capable of achieving a state of equilibrium in response to forces from three orthogonal directions (x, y, and z). If an arrangement is not capable of resisting load from three orthogonal directions then it will be unstable in service even though the load which it is designed to resist will be applied from only one direction. Note that It frequently occurs in architectural design that a structural geometry that is potentially unstable must be adopted in order that other architectural design requirements can be satisfied. In such cases, additional components are added to the structural geometry. These additional components (Read: bracing elements) are often problematic in that they use additional materials, complicate space planning, and change the buildings appearance. Optimized architectural-engineering arrangements do not generally require bracing elements, either because they are fundamentally stable or because stability is provided by rigid joints, are said to be self-bracing. Note that when bracing elements are included it is common practice to include more bracing elements than the minimum number required so as to improve the resistance of three-dimensional frameworks to horizontal load.
3. **It must have adequate strength and rigidity** - The application of load to a structure generates internal forces in the elements as well as external reacting forces at the foundations, and the elements and foundations must have sufficient strength and rigidity to resist these. The structure must not rupture when the peak load is applied; neither must the deflection resulting from the peak load be excessive. The requirement for adequate strength is satisfied by ensuring that the levels of stress which occur in the various elements of a structure, when the peak loads are applied, are within acceptable limits. Structural calculations allow the strength and rigidity of structures to be controlled precisely. The calculations can be considered to be divisible into two parts, but

carried out together:

A. **The structural analysis (a.k.a., load assessment)** - the evaluation of the internal forces which occur in the elements of the structure. The assessment of the loads which will act on a structure involves the prediction of all the different circumstances which will cause load to be applied to a building in its lifetime and the estimation of the greatest magnitudes of these loads. The purpose of structural analysis is to determine the magnitudes of all of the forces, internal and external, which occur on and in a structure when the most unfavourable load conditions occur. The engineer must anticipate all of these possibilities and also investigate all likely combinations of them. The maximum load could occur when:
    1. The building is full of people.
    2. Particularly heavy items of equipment are installed.
    3. It is exposed to the force of exceptionally high winds.
    4. It is exposed to moving earth.
    5. Or, as a result of many other eventualities.
B. **The element-sizing calculations** - carried out to ensure that they will have sufficient strength and rigidity to resist the internal forces which the loads will cause. The size of a cross-section for a structural element must provide adequate strength and adequate rigidity. In other words, the size of a cross-section must allow the internal forces (determined in the load analysis) to be carried without overloading the structural material and without the occurrence of excessive deflection. These calculations involve the use of the concepts of stress and strain.

Most buildings (structures) are polyhedrons. A polyhedron is a three-dimensional form whose surfaces are polygons. A polygon is a closed plane figure with at least three sides. The sides intersect only at their endpoints and no adjacent sides lie on the same plane (colinear). The polygons are faces of the polyhedron.

Table 4. *Types of polygons with their associated number of sizes.*

Polygon	Number of sides
Triangle	3
Quadrilateral	4
Pentagon	5
Hexagon	6
Heptagon	7
Octagon	8

The main types of load which a structure must be able to resist are:

1. **Dead loads** (e.g., fixtures and structural elements).
2. **Live loads** (e.g., occupants, furniture, traffic).
3. **Environmental loads** (e.g., wind, snow, earthquake, settlement).

Factors that need to be considered when considering loads on structures include:

1. Magnitude.
2. Frequency of occurrence.
3. Distribution.
4. Nature/type (static/dynamic).

Based on the way in which deformation occurs to an element, five different modes of load transfer can be identified:

1. Load transfer by compression--when the resistance of a body to a load tends to decrease one of its dimensions.
2. Load transfer by tension--when the resistance of a body to a load tends to increase one of its dimensions.
3. Load transfer by bending--when the resistance of a body to a load tends to curve it.
4. Load transfer by shear--when the resistance of a body to a load tend to change the angle.
5. Load transfer by torsion--when the resistance of a body to a load tends to twist it.

It is important to note that a one-dimensional linear element may transfer loads only by compression or tension. Only two-dimensional surfaces are able to transfer loads by bending or by shear. Load bearing elements can be classified according to how they respond to stress and forces because of a particular geometric form:

1. **Surface forms** - one whose two dimensions are clearly larger than the third. Curved surface forms include shells, folded plates, and membranes. Flat surface forms include slabs, walls, and disk-like shapes.
2. **Linear forms** - are defined as forms that have a minimal cross-section. Load transfer takes place linearly, along the axis of the element. For this reason, only tensile and compression stresses can develop within this type of bearing element.
3. **Beam** - a linear surface element that acts on bending and shear; crucially important in determining the way in which the form operates as a bearing element. Beams in buildings are subject to forces of compression and tension because they have to support weight across a span.
4. **Column/pillar** - a linear element that transfers loads to the base of a structure.
5. Composite forms - these forms incorporate straight,

polygonal, or curved bearing elements with a statical function. They include nets, trusses, space frames, and various kinds of geodesic domes.
6. Forms with a mass statical function - are those forms with a three-dimensional load bearing function in which all three dimensions are involved in the load transfer.

13.9.2.4 Materials (impact on structure)

The effectiveness of a structure depends on the mechanical properties of the materials from which it is constructed. These properties include:
Strength.

1. **Strength** - the stress that something can endure before failing.
2. **Toughness** - a measure of the energy required to break a material. Toughness measures the ability of a material to resist crack propagation.
3. **Elasticity (elastic limit)** - a measure of the maximum stress per unit area it can withstand before there is permanent deformation.
4. **Plasticity (plastic deformation)** - a measure of the capacity to resist plastic deformation (dislocation movement).
5. **Ductility** - the amount of tensile stress a material can take before enduring deformation.
6. **Malleability** - measure of a material's ability to be rolled or hammered into some form (e.g., thin sheets).
7. **Brittleness** - a measure of how easily broken, damaged, disrupted, cracked, and/or snapped.
8. **Hardness** - a measurement of the strength of a material (its ability to resist plastic deformation).
9. **Stiffness** - the extent to which an element is able to resist deformation or deflection under the action of an applied force.
10. **Flexibility (pliability)** - a measure of how flexible a component is (i.e. the less stiff it is, the more flexible it is).
11. **Durability** - a measure of how long a material will last under usage and environmental conditions.

13.9.2.5 Structural members (impact on structure)

Structural members are the primary load bearing components of a building, and each have their own structural properties which need to be considered. Structural members include, but are not limited to:

1. Beams - horizontal members which transfer loads to supports.
2. Columns - vertical members which transfer compressive loads to the ground.
3. Bracing - members that interconnect and stiffen columns and beams.
4. Roof trusses - load-bearing frames constructed of connected triangular shapes.
5. Retaining walls - support soil where a sloping site requires excavation.
6. Concrete slabs - span horizontally between supports, used as floors and sometimes as roof systems.
7. Footings - transfer load from the structure to the foundations.

Simplistically, the three main structural load bearing elements are:

1. Structural frames.
2. Floors (note: roofs, unless they serve the function of a floor, are not treated as elements of a support structure).
3. Load bearing walls.

13.9.3 Standard structural efficiencies

There are three standard ways of optimizing efficiency in structural design:

1. Resources used (in unit quantity).
2. Energy used (in kWh) in transportation.
3. Energy used (in kWh) in construction.
4. Fabrication data (from pre-fab to localized).

13.10 Retaining walls

A.k.a., Structural earth retainment.

he four main types of retaining wall are:

1. Gravity retaining walls.
2. Cantilever retaining walls.
3. Embedded retaining walls.
4. Reinforced soil retaining walls.

14 Architecture surface sub-system

A.k.a., Surfacing, coating, etc.

In most buildings, there are additional surfaces and/or specialized surface processing added to base architectural surfaces.

14.1 Surface standards

Just like other subsystem services (e.g., plumbing, electrical, etc.), there are surface standards. Surface standards must specify:

1. Surface material (surface assembly).
2. Surface duration:
   A. Between cleanings.
   B. Until replacing.
3. Surface-environmental interaction -- how does the surface interact with external elements:
   A. Rain, snow, and ice.
   B. Ocean spray.
   C. Sunlight.
   D. Wind.
   E. Sand.
   F. Humidity.
   G. Other (non-human) animals.
4. Surfacing technique -- how was the surface material applied.

14.1.1 Standard surface documentation

Surface systems are documented via specifications and drawings.

1. Surface drawings (a.k.a., surface schematics, surface drawings) illustrate the system that will support illumination.
2. Surface specifications include all written content, reasoning for decisions, and calculations.

Buildings may have the following architectural surface diagrams:

1. Surface tiling diagram.
2. Painting diagram.
3. Baseboard and crowning diagram.
4. Trim diagram.
5. Surface processing diagram (e.g., polishing concrete, lacquer, etc.).

NOTE: *Surface diagrams are generally applicable to all structures, including but not limited to walls, floors, ceilings, roofs, doors, windows, etc.*

14.1.2 Standard surface requirements

What is required for a viable surface system is:

1. **For architecture** - Surfaces appropriate for:
   A. Aesthetics (surface for aesthetics).
   B. Function (surface for function).
      1. Impermeability (surface for impermeability to elements, such as: mold, fire, light, earth, etc.).
2. **For walking and transportation** - Surfaces designed proportionate to motion and surface composition, including the maintenance (cleaning) of the surface.
   A. **For transport** - Surfaces proportionate to motion and safety.
   B. **For walking** - Surfaces proportionate to motion and safety.
3. **For economic calculation** - Data sheet about surface composition, usage, and safety to produce optimization calculation.
4. **For life support demand** - Surfaces proportionate to human demand.
5. **For technology and exploratory demand** - Surfaces proportionate to human demand.
6. **For dwellings** - Surfaces proportionate to human demand.
7. **For working areas** - Surfaces proportionate to human and production demand.

14.1.2.1 Standard surface efficiencies

Surfaces can be made more efficient by reducing:

1. The amount of materials used.
2. The labor associated with the production of the surface.
3. The labor associated with the installation of the surface.
4. The necessity to maintain/clean the surface.

14.1.3 Functions of the surface system

A surfacing system can have one or more of the following functions:

1. Aesthetics (for beauty).
2. Tactile (for touch).
3. Acoustic (for sound absorption).
4. Thermal (for temperature-based properties).
5. Illumination (to reduce or allow).
6. Protective (for protective properties).

14.1.4 Hazards with the surface system

Common hazards with the surface system include, but may not be limited to:

1. Off-gassing (a.k.a., out-gassing) of harmful

chemicals.
2. Abrasion or chemical reaction (e.g., lacquer).
3. Cleaning.
4. Contamination (as the surface degrades and falls off).
5. Slip (when surfaces are not designed appropriate to speed of motion).

14.2 Objects in the surface system: fixtures, fittings, and appliances

Surface fixtures and fittings are equipment that interface with the electrical-illumination in a building:

1. **Surface fixtures** - systems and material layers for producing [physical] surfaces. Something which is fixed or affixed to the structure. The most common fixtures include, but may not be limited to:
    A. **Windows:** Window surfaces are a light permittance surfaces, and can be part of construction and/or installation. These surfaces can be more or less insulated. These surfaces can let different amounts of frequencies of light through.
    B. **Shades (blinds):** Are light permittance surfaces that reduce or eliminate light (and possibly, rain). Blinds and other shades are part of the surfacing system, except where they also act as structural barriers to physical force, wherein they are also classified as part of the structure.
    C. **Screens (mesh covering openings):** Are object permittance surfaces that reduces the permittance of insects and animals from outside to in (or reverse), and also, restrict the movement of pets through openings. Screens allow atmosphere to transfer, and will reduce light transfer to some relative degree (because, the physical areas of the screen will block out light). Screens can be used to protect the indoor occupants from insects.
    D. **Flooring fixtures** - systems that become the floor of a built environment.
        1. **Tile and plank flooring:** An added material layer of flooring usually shaped into a tile and/or plank formation. These may be added by several means:
            i. Surface added by physical connectors and interconnection. The tiles and planks are interconnected and kept on the surface by physical interconnectors (and not, adhesive). Of course, adhesive and physical connectors can be combined.
                1. **Floating floor systems**: A type of flooring installation system where the flooring is not secured to the subfloor by means of glue, nails, or staples. It actually lays on top of the subfloor and each panel or plank is secured to each other by a locking system or adhesive and simply "floats".
            ii. Surface fixed by gravity and surface interconnection: The tiles and/or planks are interconnected and kept on the surface by gravity (no adhesive necessary, because of weight of tiles/plants.
            iii. Tiles and planks are added by means of an adhesive. Adhesive is the “glue” that secures the tiles to another surface (e.g., floor, wall, ceiling, etc.). Adhesive types range from simple glues to specialized cements and pastes, affecting the durability and appearance of the flooring.
                1. The added individual tiles and planks come together with some space between them wherein only adhesive is present on the surface. These gaps (spaces) are known as grout lines. The spaces between tiles/planks where adhesive is applied. The visibility of grout lines can be minimized with larger tiles and precise installation. Larger tiles and more effective adhesive (e.g., cement, paste, mucilage, etc.) allows for smaller exposure of adhesive in the form of "grout lines" per area.
                2. The alignment of tiles/planks to have greater parallelity can reduce the visibility of grout lines, achieving a more seamless look. Note that degree of parallelity of individual tiles and planks also affects the environmental exposure of the adhesive; wherein, more tile proximity and more tile parallelity reduces the presence of exposure, if non-exposure (i.e., less grout exposed) is an objective.
            iv. Types of tile and plant flooring:
                1. Ceramic and porcelain tiles: Hard, durable tiles for floors and walls, available in a wide range of colors and designs.
                2. Natural stone tiles: Includes marble, granite, quartzite, limestone, and slate, offering unique textures and colors.
                3. Organic tiles and planks: Typically, cut wood and compressed bamboo; plywood.
                4. Composite mineral powder and resin

tiles: a composite mix of ground minerals and a resin.
5. Vinyl tiles and planks: Provide a water-resistant and durable flooring option with various patterns, including realistic wood and stone looks.
6. Laminate flooring: Mimics the look of hardwood or stone with a photographic layer under a clear protective layer.
7. Engineered wood flooring: Consists of a real wood top layer bonded to multiple layers of plywood or fiberboard.

E. **Facade cladding** - an added material layer to a surface, typically walls.
F. **Lacquer** - is a clear or coloured wood finish that dries by solvent evaporation or a curing process that produces a hard, durable finish. This finish can be of any sheen level from ultra matte to high gloss, and it can be further polished as required. It is also used for "lacquer paint", which is a paint that typically dries better on a hard and smooth surface. lacquers produce very hard, durable finishes that are both beautiful and very resistant to damage by water, acid, alkali or abrasion.
G. **Paint** - an added material layer of thin material by hydrodynamic, adhesive, and chemical mechanisms. Paint adheres to the surface of the material to which it is being applied. A paint is composed of pigments, solvents, resins, and various additives. The pigments give the paint color; solvents make it easier to apply; resins help it dry; and additives serve as everything from fillers to anti-fungicidal agents. There are both natural and synthetic pigments.
H. **Baseboards and crowns:** are fixtures attached to floors, walls, and ceilings. These are usually fixed to the surface, and can be decorative and/ functional *(see "surface appliances" below)*.
I. **Water membranes:** are waterproofing impermeable membrane and moisture/ vapor membranes (e.g.., house waterproofing membrane, rubberized roofing, ice-dam) protect the building from water damage.

2. **Surface fittings** - a device designed to attach in some way one surface to another. The most common fittings include, but may not be limited to:
   A. Attaching connectors (i.e., hooks).
   B. Winds (e.g., winding up and down blinds).
   C. Locks.
      1. Physical.
      2. Digital magnetic.
3. **Surface appliances** - appliances and objects that change the surface, the most common of which include:
   A. Decor.
      1. Paintings.
      2. Limited area added textural materials.
      3. Decorative trim.
      4. Baseboards(and crowns as decorative trim.
   B. Functional.
      1. Televisions.
      2. White board.
      3. Baseboards and crowns as functional wall (or, other surface) protectors.
      4. Mirrors.

IMPORTANT: *All fixtures, fittings, and appliances must be specified with the right connection type for their placement.*

14.2.1 Facade cladding

Facade cladding maintains the following characteristics:

1. Appropriately selected texture can make an area more aesthetic.
   A. The following critical question must always be asked, why does the area need facade cladding to make it look more aesthetic?
   B. Note that many structures have an exterior and interior facade to improve insulation, improve impermeability, provide surface protection, provide aesthetics, improve surface usage characteristics (e.g., hanging, outleting, etc.).
2. Uses more material.
   A. Why are more materials necessary?
3. Some facade is impossible to effectively clean without pressure washing and pressure washing can sometimes damage the facade.
   A. How will the facade be cleaned, and will it ever need cleaning?
4. Some facades, particularly those outdoors can create breeding grounds for insects, especially spiders.
   A. Is a breeding ground for insects a concern in context?
5. Facades can serve a dual purpose, as texture and protection and/or conduiting for cables and pipes.
   A. Is the facade only necessary to aesthetically cover infrastructure (Read: cables and pipes), if so, why?
6. Buildings and other architectural surfaces can be designed with and without facade, some designs are likely to make façades more, and others less, necessary.
   A. Is the facade a necessary use of materials for the given time period?

14.3 Installation of surface system

There are many ways to install surfaces. Surfaces are generally installed over top of (Read: on top of) structure.

14.4 Operation of surface system

In concern to surfaces, most significant operational activities are associated with cleaning.

14.4.1 Surface load demands

A.ka., Surface loading.

Surface loads are measured in several ways::

1. Gravity: When individual objects compose a surface (e.g., tiles), then gravity is a surface load demand.
   A. Weight (and mass) capacity as amount of weight a surface can sustain and remain viable.
   B. Stability: Likelihood of overturning (or, becoming unstable) given accidental pressure on the surface.
2. Resistance to damage and failure from:
   A. The elements and contact with other [accounted for] materials.
   B. Repeated cleaning.
   C. Thermal bridging and thermal capacity.
3. Electricity (electrical power) to do the work of motion in dynamic surface systems.

14.4.2 Surface thermal properties

The color and texture of a surface can change the thermal properties of the surface. A black painted wall will absorb light and heat more than a white painted wall. Conversely, a white pained wall will absorb less light and heat less than a black painted wall. When painting something black (or any color, but particularly black), make sure it is not a toxic paint that will not degrade in high heat and release VOCs or other toxic chemicals.

Architectural structures, because they are outside and exposed to the sun, often use specific surface materials to interface with the sun in specific ways, either for emittence or insulation. For instance,

1. Reflective or cool roofs: Cool roofing materials, designed to reflect sunlight and absorb less heat, help reduce urban heat island effects and lower building cooling costs.
2. Absorbing walls: Heat absorbing materials can be affixed to the surface of walls and roofs to absorb more heat.

14.4.3 Surface cleaning

Necessarily, buildings have surface cleaning services and procedures. Surfaces can be cleaned in a number of different ways, including but not limited to:

1. Water-based:
   A. Hand washing.
   B. Scrubbing-washing (can be by hand or machine).
   C. Pressure washing. Pressure washers are rated in terms of their PSI. More powerful pressure washers can remove paint, and less powerful ones can be used to clean paint (and other surfaces).
2. Air-based:
   A. Air pressurizers (e.g., air sprayer).
   B. Suction (e.g., vacuums).
3. Thermal temperature accounting:
   A. Steam-based (e.g., steam floor cleaners).
   B. Warmth-based (e.g., hot water).
4. Automaticity accounting:
   A. Higher manualization, lower automation.
   B. Lower manualization, higher automation.

15 Architecture water sub-system

A.k.a., Architectural hydrological system, plumbing system, plumbing network, hydraulics system, hydraulics network, hydraulics engineering, hydronic network, hydronic system, water engineering, plumbing engineering, hydraulics engineering, hydronic engineering.

A complete water-based service system for architecture provides adequate supply of water and removes waste, while meeting user service requirements. The principal parts of an architectural water service system are categorizable under the conception of a plumbing network (a.k.a., plumbing systems):

1. Piping throughout (piping network).
2. Water supply sub-system.
3. Water and waste removal sub-system.
4. Plumbing fixtures and fittings (integrated into plumbing network.

Plumbing is any system that conveys fluids for a wide range of applications. Plumbing uses pipes, valves, plumbing fixtures, tanks, and other apparatuses to convey fluids. Heating and cooling, waste removal, and potable water delivery are among the most common uses for plumbing, but it is not limited to these applications. Note that there are many distribution configuration methods for a plumbing network.

TERMINOLOGICAL CLARIFICATION: *The word "plumbing" means lead-work. Historically, pipes that transport water were made of lead. A more accurate term for a water and drainage system/ network might be, hydraulics, or just, water system. However, a plumbing network can be used to transport more than just water. There are specialized plumbing system for vacuum, gas, etc.*

All plumbing systems transport materials (most often, fluids) via pipes. Piping systems for a plumbing system/ network include, but may not be limited to:

1. Water supply piping:
   A. Hot water.
   B. Hot water recirculating.
   C. Cold water.
   D. Tempered water.
2. Sanitary piping:
   A. Lipid-inclusive sanitary (oil interception).
   B. Soap inclusive sanitary (soap interception).
   C. Wastewater.
   D. Rainwater/stormwater (environmental interception).
3. Vent piping - A pipe that goes through the wall and up to the roof to vent to the outside environment.
4. Hydronics piping (hydronic piping) - Hydronics (hydro- meaning "water") is the use of liquid water or gaseous water (steam) or a water solution (usually glycol with water) as heat-transfer medium in heating and cooling systems (e.g., chiller plants, HVAC systems, etc.)
   A. Hydronic supply.
   B. Hydronic return.
5. Drainage piping:
   A. Area drainage (part of sanitary system).
   B. Landscape and foundation drainage.
   C. Storm drain.
6. Fire protection piping:
   A. Fire protection dry.
   B. Fire protection other.
   C. Fire protection pre-action.
   D. Fire protection wet.
7. Special systems piping:
   A. Vacuum.
   B. Fuel gas.
   C. Carbon dioxide.
   D. Compressed air.
   E. Natural gas.
   F. Nitrogen.
   G. Nitrous oxide.

Herein, an optimized water system is designed to account for water availability, water demand, and ecological needs.

15.1 Plumbing standards

A.k.a., Hydraulic standards, hydrologic standards.

The design of a plumbing system is greatly influenced by your applicable codes. The most common plumbing codes are the:

1. International Plumbing Code (IPC) [codes.iccsafe.org]
2. Uniform Plumbing Code (UPC)
3. Unified Facilities Criteria Plumbing Systems (UFC) 3-420-01 Plumbing Systems.

National standards include, but may not be limited to.

- National plumbing standard (NPS) is the North American standard today.

There are many different plumbing related water sub-system standards, such as:

1. Supply standards require and facilitate that adequate supply is provided.
2. Drainage standards requires that adequate drainage is provided. Often, these standards also deals with pollution prevention, sewage

infrastructure, and maintenance. Technical design standards for drainage cover sanitary pipework, foul drainage, rainwater drainage and disposal, wastewater treatment, discharges, and cesspools.

15.1.1 Standard plumbing documentation

A.k.a., Plumbing system specification and drawings, plumbing and pipe drawings, plumbing and pipe diagram, plumbing schematics, hydraulics schematics.

Plumbing is documented via specifications and drawings:

1. Plumbing drawings illustrate the system that will bring water in, transfer water around the building, and take waste out. It typically includes water supply lines, drains, vent pipes, valves, and fixtures (e.g., toilets and sinks). Some diagrams also show fittings. There are diagrams for every sub-system in the plumbing system, including but not limited to:
    A. Riser diagrams are used as supplementary details on working drawings in order to show more clearly how the plumbing system is to be installed. Riser diagrams of plumbing systems can be shown in both orthographic and isometric views. A riser diagram is generally not drawn to scale, but should be correctly proportioned.
    B. Drain diagrams.
    C. Supply diagrams.
    D. Sanitary piping diagrams.
    E. Etc.
2. Plumbing specifications include all written content, reasoning for decisions, and calculations.

15.1.1.1 Plumbing system plan

The plumbing plan is a plan view that shows the complete plumbing system. The plumbing plan shows the following parameters for all units of plumbing equipment:

1. Source of supply.
2. Transportation of supply.
3. Location of process and/or use.
4. Size of usage system.
5. Type of equipment for de-/construction.

The plumbing plan should include the following (where applicable):

1. Water supply lines.
2. Drains.
3. Vent pipes.
4. Waste lines and vent stacks.
5. Valves.
6. Plumbing fixture.
7. Size and type of pipe to be used.
8. A plumbing fixture schedule.
9. Symbols legend.
10. General notes.

The plumbing plan includes standards for safety and water quality for all buildings. It also covers requirements for the prevention of floods and other hazards.

15.1.2 Standard plumbing requirements

What is required for a viable plumbing production-distribution system is:

1. **For architecture** - plumbing production proportionate to water-usage electrical power and liquid (water) demand [via a load].
    - Herein, a load means the amount of water at a specific temperature required by a building.
2. **For economic calculation** - Data sheet about loads (water fixtures) to produce optimization calculation.
3. **For life support demand** - water proportionate to human demand.
4. **For technology and exploratory demand** - water proportionate to human demand.

15.1.3 Hazards with the water system

A.k.a., Plumbing risks, hydraulics risks.

The primary plumbing risks include, but may not be limited to:

1. **Blockages** - the partial or complete blockage of some element in the system.
2. **Leaks** - a leak from one or more elements in the system. Water leak testing consists of capping all system openings and filling the system with water, and pumping a static head into the system at around 100 psi for at least 2 hours. This test is often conducted prior to sterilization.
3. **Frozen pipes** - liquids freezing within the pipe due to extreme cold.
4. **Thermal expansion and contraction** - as pipes expand and contract due to changes in temperature they can weaken and/or become loose.
5. **Water vapor and humidity** - the presence of water in the atmosphere.
6. **Noise ("banging")** - water moving through pipes, particularly pipes that are too large and pipes that change diameter, can create unwanted noise and vibration. Most noise comes from pipes going through holes that are not large enough so that when the pipe expands from the [hot] water there is creaking.
7. **Sterility** - the water system should be cleaned and disinfected. Disinfection is usually conducted with

chlorine. It is injected into the system through a service cock, near the entrance into the building. Once the disinfectant is injected into the system at the correct concentration, it is then held in the system for a set period of time. After the retention, the concentrations are checked and if they are satisfactory, the system is flushed.

8. **Hydraulic shock (water hammer)** - is the term used to describe the pounding noise and vibrations in a piping system when a volume of liquid flowing is abruptly stopped. A pressure wave is started at the point of fluid stoppage and is reflected back and forth from this point to a point downstream. This wave is slowly dissipated after a period of time. Water hammer arrestors can be provided at every branch to multiple fixtures and on every floor for both hot and cold water.
9. **Rupture** - due to the buildup of energy. For example, most boilers have heat-purge controls.

15.1.3.1 Water vapor and humidity

Water vapor is a colorless, odorless gas that is always present in the air. Water vapor can create problems if it condenses on interfaces with unintended building components. Condensation occurs when moist air is cooled below its dew point temperature, by either mixing with colder air or contacting cold surfaces. Condensation can cause frosting and fogging of the surfaces of materials altering the function and/or components. It can saturate insulating materials in structure, and render them ineffective. It can create drips, puddles, water stains, fungal growth, and corrosion inside a building. When water penetrates building materials, it can cause some materials to weaken and disintegrate. It can blister and rupture paint coatings and membranes on the outside of a building.

There are many potential sources of water vapor within a building, including the unique category of and human metabolic activity such as respiration and sweating. In a new building, water vapor may also come from wood, concrete, plaster, and other materials that are still giving off excess moisture. For standard human occupation, a good optimum interior relative humidity is between 40 and 60 percent. In warm, humid locations, interior air pressure should be slightly higher than outside to reduce the inflow of humid air. A building's atmospheric mechanical system (e.g., HVAC) is often designed to reduce the amount of water vapor inside a building by ventilation, by dehumidifying the air with an air-conditioning system, or both.

15.1.3.1 Vapor/humidity control

Whether or not mechanical systems are installed, there are four precautions we take in detailing to avoid water vapor problems in a building (Allen, 2016):

1. Use thermal insulation, multiple glazing, and thermal breaks to keep interior surfaces at temperatures above the dew point of the air.
2. Use a warm-side vapor/moisture retarder (object or surface coat/alteration) to keep air and water vapor from reaching surfaces and spaces that are cool enough to cause condensation to occur.
3. During assembly, ventilate the portion that lies on the cold side of a vapor retarder, to be sure that no moisture is trapped there.
4. Where condensation is likely to occur despite any such precautions, we provide a gravity-driven system to catch and remove condensate before it can create problems.

15.2 Conception of the plumbing service system

There are plumbing systems that are, and are not, water based. All water-based plumbing systems use two separate subsystem networks made of pipes. One brings freshwater inside, and the other transports wastewater/sanitary away. The following are the most common types of water systems/networks associated with most architecture:

1. **Water supply (inflow)** - water supplied to the architecture from a specific source (i.e., water entering the architecture).
   A. **By source:**
      1. Municipal sourced.
      2. Well or nature sourced (other than rainwater).
      3. Rain sourced.
   B. **By temperature:**
      1. Cold water.
      2. Hot water.
   C. **By purity:**
      1. Municipal water (from the municipal source).
      2. Fresh water (freshwater) from nature.
      3. Drinkable (purified) water.
2. **Sanitary water (outflow)** - water leaving the architecture (i.e., water exiting the architecture).
   A. Rainwater (but, may also be a supply source).
   B. Gray water.
      1. Water with fat.
      2. Water with soap.
   C. Blackwater.

The three basic (normally used, considered fundamental) types of pipe systems for a water-based plumbing system/network are:

1. **Cold water piping (water supply cold)** - has pressure. Pressurized water pipes can go in a straight horizontal line. To supply clean cold water.
2. **Hot water piping (water supply hot)** - has

pressure. Pressurized water pipes can go in a straight horizontal line. To supply clean hot water.
3. **Sanitary piping** - has no pressure, and requires a downward sloping pipe at a country specific graded angle (often, 2%). Non-pressurized pipes require a gravity slope to move. These remove black and grey water.

A refrigerant hydronic system may be considered a type of plumbing system that is not water-based. There are also plumbing systems for other types of liquid materials.

15.3 Conception of the water supply sub-system

A.k.a., Water supply infrastructure.

Water supply is the provision of water by utilities organisations, typically using a pump and pipe system. The main components of a water supply system for an architectural construction are:

1. **Plumbing network (a.k.a., water network, hydraulics network)** - the interconnect of pipes through which water flows within and without an architectural structure.
2. **Building supply** or **water service** – a large water supply pipe that carries potable water from the water district or city water system or other water source to the building.
   A. **Cold water supply line** - a supply line that provides cold water. All municipalities supply architectural constructions with a cold water supply.
   B. **Hot water supply line** - some municipalities supply architectural constructions with a hot water supply also. These municipalities supply hot water from a series of water heating plants throughout the city, not from basement boilers.
3. **Building main line** – a large pipe that serves as the principal artery of the water supply system. It carries water through the building to the furthest riser. The building main is typically run (located) in a basement, in a ceiling, in a crawl space, or below the concrete floor slab.
   A. **Cold water building main line** - all buildings supplied with water have a cold water building main line. The cold water building main line often maintains a branch point where water splits off into the cold water supply and hot water heating system.
   B. **Hot water building main line** - a main line for hot water.
4. **Riser** - a water supply pipe that extends vertically in the building at least one story and carries water to fixture branches. It is typically connected to the building main and runs vertically in the walls or pipe chases.
5. **Fixture branch** – a water supply pipe that runs from the riser or main to the fixture being connected. In a water supply system, it is any part of a piping system other than a riser or main pipe. Fixture branch pipes supply the individual plumbing fixtures. A fixture branch is usually run in the floor or in the wall behind the fixtures.
6. **Fixture connection** - a fixture connection runs from the fixture branch to the fixture, the terminal point of use in a plumbing system.
7. **Shut-off valve** - for the entire system, as well as for specific areas, let people turn off the water flow while they fix problems. These are typically located in the hot and cold-water supply at the fixture connection.
   A. **Main water shut-off valve** - shuts off [main line] water to the whole building.
   B. **Fixture specific shut-off valves** - shuts off water to specific areas and/or fixtures.
8. **Water meter** – used to measure and record the amount of water used. It may be placed in a meter box located in the ground near the street or inside the building. In the market-State, this device allows a local water district to calculate the bill for water usage for a building.

15.3.1 Water supply equipment

General water supply equipment includes, but is not limited to, the following equipment:

1. Pipes.
2. Water heaters.
3. Pressure booster systems.
4. Pressure regulating valves.
5. Circulating pumps.
6. Back flow preventers.
7. Balancing valves Isolation valves.
8. Hangers and supports.
9. Thermal insulation.

15.3.2 Water supply for different categories of building

All plumbing systems must use equipment to maintain adequate pressure and flow in all parts of the system. Different categories of buildings have different arrangements of plumbing:

1. House system - derive pressure from either, or some combination of the following:
   A. Municipal pressure.
   B. Water tank on top floor or roof.

   C. Separate pump.
2. Apartment systems:
   A. Multi-story systems (high-rise systems) - refers to those buildings that are too tall to use pressure from the municipal water supply to reach the entire building. These taller, vertical buildings need systems that can reach each unit. The pressure options include:
      1. Gravity-based roof tanks - wherein, water is pump up from storage tanks on the ground floor or in the basement. The water reaches the roof tank, where gravity helps it flow down to every unit.
      2. Booster pumps - that adds the pressure needed to move water from the storage tanks or straight up from the municipal water supply. These pumps add to the system's existing pressure.
      3. Hydro-pneumatic storage tanks - water moves from the municipal supply or the storage tanks into these hydro-pneumatic storage tanks, where air pressure helps push the water to where it is needed.
      4. Note that these systems need control valves for each unit. This reduces the risk of cross-contamination between units. It also lets the water supply to an individual unit be shut off if repairs are needed or the unit isn't occupied.
   B. Multiple dwellings - have separate units but don't have the same water pressure issues. Multiple dwelling apartments can use plumbing systems like those in a house system, except that the pipes branch out more to provide water to each unit. As the water comes into a multiple dwelling apartment from the municipal supply, a system of pipes, faucets and valves makes sure water gets where it's needed. The drain-waste-vent (DWV) system carries wastewater out of each unit in the apartment building.

15.3.3 Hot water supply specifics

The US General Services Administration maintains the following guidelines in concern to domestic hot water supply (Plumbing systems, 2021):

1. Domestic hot water supply temperature is often generated at 60°C (140°F), and is tempered to 49°C (120°F) using a three-way mixing valve, before supplying to all plumbing fixtures.
2. Hot water supply to dishwashers shall be at 82°C (180°F), and the temperature shall be boosted from 60°C (140ºF) to 82°C (180°F).
3. Circulation systems or temperature maintenance systems may need to be included.
4. Hot water shall be available at the furthest fixture from the heating source within 15 seconds of the time of operation.

15.4 Conception of the water piping sub-system

A.k.a., The piping network, water piping infrastructure.

Water distribution uses a piping system/network. Piping is the process of selecting and routing a piping network. The process of piping involves:

1. **Pipes (piping types)** - pipe material based (may include function; e.g., PVC cold water; copper hot water, etc.).
   A. Material based (i.e., the physical/material composition of the pipes).
   B. May also include system-type (e.g., water). But, this is not necessary; all that is necessary (often appropriate) is material type.
   C. Contains routing preferences.
2. **Piping systems** - piping system categories (a system of classification by piping system function; e.g., hot water, cold water, oxygen, vacuum, etc.).
   A. Customizable potentially by:
      1. Materials.
      2. Mechanical calculations.
      3. Fluid type.
      4. Temperature.
      5. Fluid viscosity.
      6. Fluid density.
      7. Flow conversion method (references International Plumbing Code by applying a demand factor to the plumbing fixtures).
   B. Reference to system classification.
3. **Plumbing fixtures (or, piping fixtures)** - endpoint or processing points for the contents transported in the piping system (e.g., lavatory, sink, etc.).

15.4.1 Piping routing rules and parameters

A.k.a., Plumbing pipe running rules, pipe layout and design rules.

Routing preferences (a.k.a., piping interconnection rules) refers to the rules ("preferences") for connecting (routing) pipes over distance.

Pipe routing preferences/rules are based on one or a combination of the following:

1. Pipe material (material types).
2. Pipe connection type (pipe geometry, geometry

types).
3. Flange types

The parameters to consider when creating pipes in software include:

1. Pipe type (generally, material composition)
2. System type (generally, function)
3. Diameter type
4. Slope

Common pipe routing best practices include, but may not be limited to:

1. In general, pipes do not pass vertically directly through floors; instead, they pass through the space between a floor, wall, and ceiling.

15.4.2 Plumbing pipes

> **NOTE:** *Pipes are made of materials (and they conduit the transportation of materials).*

Pipes may be classified by (note: this content is usually defined in a set of piping standards):

1. Type of material (i.e., material composition of pipe).
2. Function of pipe network (e.g., to provide cold water, hot water, etc.)
3. Specific pipe elements:
   A. Types of physical interconnection between pipe elements (e.g., glue, screw, etc.).
   B. Geometric function of pipe elements (e.g., segment, curve, etc.).
   C. Conduit shape (e.g., square, round, oval.)
4. Sizes (relative to region)
   A. United States, Canada, and Brazil
   B. Europe
   C. Australia
   D. Russia
   E. China
   F. Others

Categories of connection for piping include, but may not be limited to:

1. By geometric function of element:
   A. Straight connector
   B. 90 degree bend
   C. Other degree bends.
   D. T connector
   E. Cross connector
   F. Size adapter
2. By physical interconnection type:
   A. Compression connection
   B. Welded (solder connection)
   C. Threaded (screw connection)
      1. With plumbing this often necessitates another tape like material that is first twisted around the part to be screwed.
   D. Flanged connection
   E. Glued connection
3. By conduit shape:
   A. Round

15.4.2.1 Types of pipes by function

Other piping elements include, but may not be limited to:

1. Supply pipes.
   A. Water supply line pipes.
   B. Cold water pipes
   C. Hot water pipes
2. Drain pipes.
   A. Drop pipes (drop tubes, plumbing drops) - sanitary pipes that drop sanitary water down an elevation(s).
   B. Soil sack - vertical pipe that carries waste away from sanitary units (blackwater).
   C. Waste sack - a vertical pipe that carries graywater.
3. Vent pipes:
   A. Stack vent.
   B. Loop vent.
   C. Roof vent.
4. Trap pipes.

15.4.2.1 Types of pipes by geometry

A.k.a., Types of pipe interconnections.

Piping elements include:

> **NOTE:** *Pipe connectors are sometimes called pipe fittings.*

1. **Pipe segment** - straight, horizontal segment of pipe.
2. **Elbow** - curved piece that joins two pipes.
   A. 90 degree.
   B. 45 degree.
   C. Etc.
3. **Junction**
   A. Tee - shaped like a T; connects 3 pipe segments.
   B. Tap.
4. **Cross** - connects 4 pipe segments.
5. **Transition** - adapter element for changing pipe sizes.
6. **Union** - connector of 2 pipe segments.
7. **Flange** - connects piping and components in a piping system by use of bolted connections and gaskets.
8. **Cap** - closes (seals off) end of a pipe.

Note: The above types of [pipe] fittings (unions, interconnections) can be set for routing a pipe.

15.4.2.2 Types of pipe fittings and connectors

NOTE: *All pipe connectors are also called fittings. Hence, the term 'fitting' can be appended onto the end of each of these connectors (e.g., Tee fitting, mini ball fitting, etc.*

Piping connectors include, but may not be limited to:

1. Connectors and couplings
   A. Tee
   B. 90 degree
   C. 45 degree
   D. Compression
   E. QickTight
   F. Insert
   G. Small tube push fit
   H. Sharkbite
   I. Bulkhead
   J. Flare
   K. Radiant heat
   L. Cleanout plugs
   M. ABS
   N. Hose adapters
   O. Barbed
   P. QwikRepair
   Q. Full flow quick
   R. Left/right
2. Couplings
   A. No-hub coupling
   B. Flexible pipe connector
3. Valves
   A. Sharkbite
   B. Push to fit
   C. Kitz
   D. Aquamix tempering
   E. Blackwater
   F. Slice gate
   G. Add-A-Line
   H. PVC check
   I. PVC ball
   J. Straight and angle style
   K. Needle
   L. Gas ball
   M. Mini ball
   N. Isolation
   O. Zone
   P. Purge
4. Adapters
   A. Quick Tee
   B. Quick connect
5. Flanges
6. Supply hoses
   A. Flexible water connectors
   B. High-flow water connectors
   C. Gas connectors
   D. Commercial gas connectors
   E. Gas connectors with valves

NOTE: *Some pipe connectors are for potable water, and others are not. In other words, some fittings on these pages may be suitable for use in potable water systems, while others may not.*

15.4.2.3 Types of piping tools

The most common types of piping tools include, but may not be limited to:

1. Pipe and tubing index.
2. Thread seal tape (PTFE tape, teflon tape, plumbers tape).
3. Pipe freeze kits.
4. Pipe threaders.
5. PVC/ABS reamers.
6. Pip fitting removers.
7. Nipple extractors.
8. Pip repair clamps.
9. Pipe hangers.
10. J-hook hangers.
11. Pipe brackets.
12. Pipe taps.
13. Hose clamps.
14. "Bunny box" nipple case.
15. Plumbers saw.
16. Pipe wrench.
17. Pipe cleanout brush.

15.4.2.4 Pipe categorization specifics

In general, pipes are categorized by the following specifics:

1. Material(s).
2. Purity of material(s).
3. Pipe diameter (pipe bore).
4. Wall thickness (pipe schedule).
5. Rigidity.

Hence, different pipe networks will need different:

1. Types of material.
2. Sizes of pipe.
3. Rigidities of pipe.

15.4.2.5 Types of piping materials

The most common materials for pipes are:

1. **Metal**
   A. **Cast iron** - mostly in use before 1960; used for drain/waste/vent (DWV) lines.
   B. **Steel (galvanized pipe)** - common in older

homes; lasts only about 50 years.

C. **Stainless steel**
D. **Chrome** (note: chrome plated brass fittings can contain lead)
E. **Brass** (note: must be lead free. Older brass fittings, valves, and faucets can contain lead).
F. **Copper** - commonly used in water lines and some drain lines; resists corrosion, lasts a long time. Not that some types of copper piping are available in both rigid and flexible varieties. Copper pipes are categorized by their purity, size (wall thickness and diameter), and rigidity:
    1. **Flexible copper tubing (a.k.a., soft copper tubing, coil tubing)** - often used with appliances lines (e.g., dishwasher, refrigerator, icemaker) and rolled out for under slab installations. These are generally called, type K copper plumbing pipes.
    2. **Rigid copper.**
        i. **Rigid copper distribution pipe** — comes in three thickness's: type M (thinnest), type L (thicker), type K (thickest).
        ii. **Rigid copper drain pipe** — comes in one thickness marked drain-waste-vent (DWV) and is thinner walled than type M.

2. **Plastic** - used since mid-1970s; two types:
    A. **ABS (acrylonitrile-butadiene-styrene)** - black color; first to be used in residential homes, though some areas restrict their use in new construction.
    B. **PVC (polyvinyl-chloride)** - white or cream color; rating and diameter are stamped on the pipe. PVC is commonly used for drains. The two most common forms of PVC are:
        1. **Schedule 40 PVC** is strong enough for drain lines and cold-water lines, but local code will determine applicability. When used for cold-water lines, it is generally not allowed for use inside a building.
        2. **Schedule 80 PVC** is often used for cold water lines, but isn't allowed for use inside a building in some areas because it isn't suitable for hot water.
    C. **CPVC (chlorinated polyvinyl chloride)** - as strong as PVC but is heat-resistant, which makes it acceptable in most areas for interior [hot water] supply lines. It is most commonly measured with CTS standards (which is important when considering fittings for existing pipe; for example, a 2" fitting will not always fit on a 2" CTS pipe, but it will always fit on a 2" nominal size PVC pipe).
        1. Schedule 40 and 80 CPVC pipe and schedule 80 CPVC fittings are available and generally used in industrial applications.

3. **PEX (cross-linked polyethylene)** - newest pipe for residential water supply (cold and hot supply lines) use. In general, PEX is primarily used for supply lines. However, PEX can also sometimes be used for cold and hot water drains. PEX is also sometimes used in radiant hot water heating. PEX is an option for plumbing as well as radiant and hydronic systems in both residential and larger plumbing applications. Note that PEX is not intended for compressed air applications. PEX type piping can use compression fittings or push on fittings, more permanent connections require crimp style fittings and a crimping tool (Read: PEX pipes can use crimp, clamp, and press connectors -- necessitating these types of tools). PEX pipes do not require glue or cement, and can simply be joined with push-to-connect fittings, metal insert fittings, or plastic insert fittings for a watertight seal. PEX pipe is not approved for outdoor applications and is not approved for continuous UV exposure. PEX pipe should not be stored in direct sunlight.
    A. The disadvantages of PEX piping include:
        1. Almost all PEX used for pipe and tubing is made from high-density polyethylene (HDPE). PEX will likely leach toxic chemicals (e.g., VOCs). Different brands cause different odors and leach different chemicals. There are 3 types of PEX (A, B, and C); the type B is claimed to have the least significant leaching problem (note, this needs to be confirmed). The pipes may either have to be outgased through flushing over an extended prior of time, or a sufficiently capable water filter may need to be installed at usage endpoints
        2. PEX is extremely sensitive to all sources of UV light. Most manufacturers recommend a limited amount of sunlight exposure, which is important to note during the installation process, and others recommend total darkness.
        3. PEX can be damaged by chlorine and other oxidizing chemicals. PEX pipe is vulnerable in concern to contact with such solutions as petroleum products and oxygen.
        4. PEX can be damaged by pests. Some pest control companies argue against installing PEX because it is highly susceptible to pest damage. Since PEX is plastic, it's more sensitive than copper and other metal pipes. Rodents can chew threw the pipe. Note here that this is more of a rodent problem than a PEX problem.
        5. PEX can't be installed in extremely high heat

areas. The max temperature a PEX pipe can hold before damage is approximately 82C (180F).

6. PEX is semi-permeable, which means liquid can enter the pipe. When it comes to safety, PEX isn't antibacterial. This is one reason people don't choose PEX in the PEX vs. copper decision. The plastic material also allows water to enter the tube, which could cause contamination.
7. PEX should not be used if there are hot water lines that are pinched by small holes. This situation can result in squeaking when hot water flows cause the line to expand slightly.

B. The benefits of PEX piping include:
   1. Easy to install (Read: easier install than rigid pipe).
   2. Cuts easily.
   3. Is flexible and can be navigated around obstacles.
   4. Available in long coils that can eliminate the need for extra fittings.
   5. Freeze damage resistant. PEX pipe will expand if frozen and contract to its original shape when thawed. PEX pipe is not freeze-proof. Normal standard insulation precautions should be taken PEX piping to help prevent freezing.
   6. When installed correctly, PEX is generally not associated with noise complaints.

15.4.2.6 Drain-waste-vent piping

A.k.a., Plumbing vent pipe, vent stack.

In modern plumbing, a drain-waste-vent (or DWV) is part of a system that allows air to enter a plumbing system to maintain proper air pressure to enable the removal of sewage and greywater from a dwelling. The plumbing vent, also known as a vent stack, helps regulate the air pressure in your plumbing system. The plumbing vent pipe removes gas and odors. It also allows fresh air into the plumbing system to help water flow smoothly through the drain pipes. However, no water runs through the plumbing vent pipe. It is a vertical pipe attached to a drain line and runs through the roof of your home. The vent stack is the pipe leading to the main roof vent. It channels the exhaust gases to the vent and helps maintain proper atmospheric pressure in the waste system.

15.4.2.7 Piping insulation

Domestic cold and hot water distribution systems should be insulated per ASHRAE 90. and all exposed piping should have PVC jacketing.

15.4.2.8 Vertical and sloped piping

Types of sloped and vertical pipes include, but may not be limited to:

1. Vent pipes - might run level, although some codes call for a slight slope toward the main drain. A vent system that allows air in to equalize pressure and let sewer gases escape up the stack to the outside.
2. Drain pipes - all drain lines must be sloped.
3. Riser pipes - A pipe that extends vertically from one floor level (or, elevation) to the next for the purpose of carrying or distributing water, steam, etc. Generally made from durable metal or plastic. Metal risers last longer than plastic ones.
   A. Vent riser - a riser that vents. Vent risers often start from the last plumbing fixture on the top most level of the plumbing network.
   B. Wet riser- The pipes are kept permanently charged with water.
   C. Dry risers - A pipe is maintained empty of water is called a dry riser. This is found in fire suppression equipment. Dry risers have pipes that are dry. These pipes are capable of being charged with water to extinguish fire.
   D. Sprinkling riser - This riser used in the garden or in commercial buildings and kitchens to sprinkle water on detection of smoke. For proper functioning of the riser pipes it is important to get a servicing done for the riser pipes because:

WARNING: *Leaking from a wet riser could cause substantial damage.*

15.4.3 Hot water piping

There are two types of hot water piping:

1. **Domestic hot water (DHW) piping** - is hot water piping for a building.
2. **District hot water piping (a.k.a., municipal hot water piping, heat networks, teleheating, etc.)** - is a piping system that distributes generates and distributes heated water from a centralized location through a system of insulated pipes. This heated water is produced centrally and distributed to many buildings.

Hot water distribution networks can be made to recirculate the hot water with a hot water recirculation system. Using a recirculating pump, the hot water from your furthest plumbing fixture will circulate back to the water heater through the domestic hot water piping. Installing such a system is likely to save energy. These circulation systems come in two types:

1. Constant (continuous) circulation.

2. On-demand circulation. This system is optimal because the pump is not overused and distribution losses are decreased drastically, leading to more energy conservation.

It is important to note that material selection and pipe insulation play a significant role in the efficacy of a hot water distribution system. Cold water supply lines dot not have to withstand maximum water temperature and can be made out of different types of material. Hot water supply lines are generally composed one of the following types of material: copper, polybutylene (PB), chlorinated polyvinylchloride (CPVC), random polypropylene (PP-R) and cross-linked polyethylene (PEX).

15.5 Conception of the sanitary water sub-system

A.k.a., The water sanitation subsystem, sanitary septic subsystem, water and waste removal subsystem, water sanitary infrastructure.

Used water and other wastes are carried to the sanitary sewer or septic tank/biodigester through a waste removal system. The sanitary drainage system is not under pressure and depends on gravity (and pre-existing water pressure) to carry the waste.

15.5.1 Sanitary piping

The sanitary system is isolated from the water supply system and must be sized for sufficient capacity, have proper slope and venting, and have provisions for cleanout (and inspection).

1. Typically, it is practical to drain as many fixtures as possible into a single drain.
2. Sanitary pipes never go 90 deg into a [main] pipe, they always have to be attached at 135 or 45 deg. Bends at 90 degrees can easily result in blockages. A 45 degree bend between two sanitary pipes is optimal. Blockages in sanitary pipes can easily occur be because of lack of pressure within the pipe; such pipes mostly use gravity to move the water.

Sanitary piping network generally includes:

1. **Stack pipes** - vertical drain pipes. All stacks extend into ground and empty into a house drain.
    A. **Soil stack pipe** - a vertical drain pipe that collects waste from one or more fixtures (Read: sanitary units; e.g., toilets). Soil stacks move water away from fixtures like urinals or toilets.
    B. **Waste stack pipe** - a vertical drain that doesn't carry soil from a sanitary fixture (e.g., sink). Waste stacks move water away from "clean water fixtures" like showers and sinks.
    C. **Main stack pipe** - a soil stacks that drain water closets. Every multi-story building must have at least one main stack. And, every bathroom must have a main stack.
    D. **Secondary stack pipe** - stacks that do not drain water closets. These are usually a smaller diameter than the diameter of main stacks.
    E. **Vent stacks** (*see: vent stack pipe*) - only support the system with airflow – they don't actually move water.
2. **Cleanout fitting** - is a pipe with a removable plug that is found a waste system. It is designed to help keep the pipe clear of any debris that could cause any type of stoppage in the water drain lines. Cleanouts are usually placed at the connection point between the sewer lines and the drain lines where the base is located of a vertical stack and at all places where the pipe direction changes at 90 degrees. Cleanouts are required at the base of all stacks.
3. **Branch main pipe** - pipes that connect fixtures to the stack.
4. **House drain pipe** - receives all waste and water discharged by the soil stacks and waste lines. It drains waste water toward the outside of the house and is directly connected to the house sewer. The house drain is laid from a point just outside the building foundation wall, where it connects to the house sewer.
5. **House sewer pipe** - the house drain becomes the house sewer once it is outside the house. The house sewer empties into the city sanitary sewer or private septic/biodigester system.
6. **Vent stack pipe (vent pipe)** - gases from the system dissipate through the vent stack, which rises above the roof. To prevent the siphonage of a trap seal in fixture traps and allow gravity flow of drainage, it is essential to let atmospheric air from outside the building into the piping system to the outlet (or discharge) end of the trap. The air is supplied through pipes called 'vents'. This air provides pressure on the outlet end of the seal equal to pressure on the inlet end. Since the air supplied by the vent to the outlet end provides a pressure equal to that at the inlet end of the trap, the trap seal cannot escape through siphonage. Note that the term main soil vent, wast vent, and soil stack vent, refer to the portion of the stack pipe extending above the highest fixture branch; these vent pipes are an extension of the main soil and waste stack.
    A. **Main vent (vent stack)** - the principal pipe of the venting system
    B. **Vent branches** - pipes connected to the main

vent and run undiminished in size as directly as possible from the building drain to the open air above the roof.
   C. **Individual vent** - a vent that connects the main vent with the individual trap underneath or behind a fixture.
7. **Trap pipes** - installed bellow each fixture to prevent gases from entering the house. The trap is always filled with water. Water closets have a built-in trap.
   A. **Fixture trap pipes** - most, if not all, fixtures have their own trap.
   B. **House trap pipe** - should be provided with a cleanout and a relief vent or fresh air intake on the inlet side of the trap. Relief vents or fresh air intakes shall be carried above grade and shall be terminated in a screened outlet located outside the building. The size of the relief vent or fresh air intake shall not be less than one-half the diameter of the drain to which the relief vent or air intake connects.
8. **Drain fixtures** - fixtures, generally on the floor, into which waste water flows.
9. **Sewage ejector fixtures** - should only be used where gravity drainage is not possible. If they are required, only the lowest floors of the building should be connected to the sewage ejector; fixtures on upper floors should use gravity flow to the public sewer. Sewage ejectors should generally be non-clog, screenless duplex pumps, with each discharge not less than 100 mm (4 inches) in diameter. They should be connected to the emergency power system.

15.5.1.1 Vents

Vents in the wastewater system let air in so the water more easily flows out.

15.5.1.2 Sealing valves and pipes

A.k.a., Trap pipes, trap seal valves, trap seal pipes, unwanted flow pipes, p pipes, hepvo valves, hepvo trap, etc.

Traps seal the drainage system so nothing can move back up once it drains away. Traps are required because they prevent sewer gases from entering the building and causing serious illness or death. The term 'trap seal' refers to the water being held in the bent portion of the fixture trap. The trap seal forms a seal against the passage of sewer gases through the trap and into the building. There are several types of sealing traps:

1. The trap most commonly used with plumbing fixtures is the P-trap. The P-trap gets its name because of it is shaped similar to the letter P. P-traps trap a bit of water, thus prevent gas flow. In very cold conditions, the water in these valves can freeze, possibly causing the trap housing to break. Certainly, the trap will not work when the water inside is frozen. P-pipes need space beneath the drain to contain the water trap.
2. Alternatively, a hepvo valve incorporates a self-sealing silicone valve that allows water flow one way and seals the tube shape when there is no water flow. Hepvo traps work in very cold conditions and do not need so much depth of volume beneath the drain because they can extend off quickly at a near 90 degree, horizontal, angle from the drain.

15.5.1.3 Floor drains

The following are best practices for floor drains:

1. Floor drains should be provided in multitoilet fixture restrooms, kitchen areas, mechanical equipment rooms, locations where condensate from equipment collects, and parking garages and ramps.
   A. Floor drains shall be cast iron body type with 6 inch diameter nickel-bronze strainers for public toilets, kitchen areas and other public areas.
   B. Equipment room areas will require large diameter cast iron strainers and parking garages will require large diameter tractor grates.
   C. Drainage for ramps will require either trench drains or roadway inlets when exposed to rainfall.
2. Single fixture toilet rooms do not require floor drains.
3. Trap primers shall be provided for all floor drains where drainage is not routinely expected from spillage, cleaning, or rainwater.
4. Specific drains in kitchen areas shall discharge into a grease interceptor before connecting into the sanitary sewer.
5. Floor drains and/or trench drains in garage locations are to discharge into sand/oil interceptors.

15.5.2 Drain fixture units

Drain fixture unit (DFU) is a relative measure of the drain wastewater flow or load for various plumbing fixtures. A drain fixture unit is a unit of measure, based on the rate of discharge, time of operation and frequency of use of a fixture, that expresses the hydraulic load imposed by that fixture on the sanitary plumbing installation. A fixture unit is equal to 0.028m^3 (1 cubic foot) of water drained in an 32mm (1+1⁄4 inches) diameter pipe over one minute.

15.5.3 Water-based biotreatment

A.k.a., Water-based bio-management

(biomanagement).

The biotreatment system is a process for conversion of water-based organic waste and its transformation into energy (gas), fertilizer, and aquifer directed water .

The elements in a water-based biotreatment system are:

1. Supply tank.
2. Pre-treatment.
3. Biodigester.
4. Stabilized organic matter storage tank.
5. Biogas purification unit (filters).
6. Motor and generator set.

Processes responsible for the degradation of organic matter include:

1. Anaerobic microorganisms.
2. Anaerobic degradation:
   A. Hydrolysis.
   B. Acidogenesis.
   C. Acetogenesis.
   D. Methanogenesis.

Waste characterization factors include, but may not be limited to:

1. Composition of each waste.
2. Hydraulic detention time (TDH).
3. Only biodegradable organic waste.

Other parameters for the proper functioning of the biodigesters:

1. Inflow into the system
2. Organic load applied
3. PH
4. Temperature
5. Carbon Nitrogen Ratio
6. Chemical Oxygen Demand Ratio (COD)
7. Biochemical Oxygen Demand (BOD)
8. Monitoring

15.5.4 Septic system elements

A septic system elements (specification) include, but may not be limited to:

1. Septic design diagram.
   A. Local sewage system.
   B. Septic tank.
      1. Septic filtration - In places where there is no public network, sanitary sewage must be retained and the residual water must be treated before being discharged back into nature. The septic tank retains waste and transforms into less aggressive material to nature. By retaining this waste at the bottom of the tank, odorless liquids called effluents are formed. A septic tank consists of a tank. Sewage remains for a few hours inside, which allows the sedimentation of solid particles on its bottom that form a slime rich in microorganisms. This biomass is responsible for the decomposition of organic matter present in the liquid.
   C. Septic filtration with anaerobic filter.
   D. Septic tank - 1st stage of the Bio-digestive process. Waste is retained at the bottom of the tank.
   E. Anaerobic filter - 2nd stage of the Bio-Digestive process with a false bottom and Gneiss gravel, which provides the ideal environment for the formation of Zogleias (bacterial colonies), the final stage of the Bio-Digestive process. The efficiency of the system is increased by directing the effluent to the biodigestion zone, located at the bottom of the tanks, where the process of self - destruction of the bacteria causes all the sludge deposited at the bottom to be in constant motion.
   F. Fat box (a.k.a., fat trap, lipid trap) - Used to separate fat (lipids). Water fat separator by decanting process. Water from the kitchen cannot be directly discharged into the pit (nor can it be discharged directly into the public sewer system), as the fat on contact with the water solidifies and can obstruct the pipes. When cooling, the fats form a thick layer above the water surface (float). The solids, being heavier, settle to the bottom of the box. These systems must be cleaned out (maintained) at a regular cycle. The fat residue put into compost.
      1. Brazil NBR Standard: NBR 8160/1999.
   G. Soap box - soap is separate from the water.
   H. Graded box - Block solid waste. Solid residues can also clog the pipes and must be retained in the grid.
2. Biodigestive septic tank (biodigester).
   A. Sptetic tank.
   B. Anaerobic filter.
   C. Sinkhole (sink-hole).

NOTE: *The volume and flow of these systems must be appropriate for the system.*

15.5.4.1 Biodigester location

As a general rule, the biodigester should be located near the source of material. The direct advantage of this is that the waste can then be easily mixed and fed to the biodigester unit without having to travel long distances, which might require pressure and increase the likelihood over time of blockages.

The following three main factors for site selection should be taken into consideration:

1. Proximity to source of materials.
2. Areas prone to flooding should be avoided.
3. The pit should be located on the lower side of the site (source of material) for easy flow (by gravity) into the biodigester.

15.6 Conception of the rainwater sub-system

A.k.a., Water rainwater infrastructure, gutters, rainwater conduits.

A rainwater design diagram for an architectural object and the surrounding site includes, but may not be limited to:

1. Rainwater directing.
   A. Rainwater gutters, pipes, and conduits (a.k.a., rainwater continuous guttering.)
   B. Guttering covers.
   C. Guttering cleaning.
2. Rainwater catchment.
3. Rainwater storage tank.
   A. Tank.
   B. Purification (e.g., ozonation).
4. Rainwater filter/filtration.
5. Rainwater drains in architecture.
6. Rainwater drainage around architecture.
7. Rainwater pool overflow.

15.6.1 Rainwater drainage

Proper drainage around all architectural structures is essential. The more surface area covered by architecture, the larger the amount of water the ground must absorb or be channelled away for storage, evaporation, ground drainage. Paths can be built that actually allow water to drain through them as opposed to "pool" off to the side. For paths that do not allow for immediate drainage there must be conduits for channelling the water to locations where it could either be:

1. Used.
2. Stored for usage or evaporation.
3. Drained.

Pipes and fittings for rainwater drainage should be sized based upon local rainfall intensity.

15.6.1.1 Roof drainage

Adequate provision must be made for rainwater to be carried from the roof of buildings and away from the buildings' foundation. To achieve this, roofs must be designed with a suitable fall towards either a surface water collection channel or gutter that conveys surface water to vertical rainwater pipes, which in turn connect the discharge to the drainage system.

Drainage from roofs is generally provided by internal rainwater outlets and downpipes, or by external guttering systems or hoppers. It is recommended that there are at least two drainage points, even if the roof is small, to mitigate against one of them becoming blocked.

The type of roof covering used determines the required fall of the roof. Minimum recommended falls are typically (Designing Buildings: Drainage, 2021):

1. Aluminium - 1:60.
2. Lead - 1:120.
3. Copper - 1:60.
4. Roofing felts - 1:60.
5. Mastic asphalt - 1:80.
6. Flat roofs - should have a designed minimum fall of 1:40 (2.5cm), so that an actual finished fall of 1:80 (1.25cm) is achieved, allowing some room for error in the construction.

The discharge from a building downpipe can be:

1. Directed some distance away from the building and allowed to soak into the ground.
2. Directly connected to a drain discharging and into a soakaway.
3. Directly connected to a drain discharging and into a surface water sewer.
4. Indirectly connected to a drain via a trapped gully if the drain discharges into a combined sewer.

Roof drain can have a separate overflow drain located adjacent to it. Overflow drains will be the same drains as the roof drains except that a damming weir extension will be included.

15.6.1.2 Pathway drainage

Pathway areas on and around architecture are provided with some method of surface water drainage, including but not limited to (Designing Buildings: Drainage, 2021):

1. **Drains and gutters** - channel the water away from the architecture.
2. **Permeable pavement** - allows the water to percolate downward into the ground.
3. **Other methods detailed** in Transportation Service System: Drainage subsystem.

15.6.2 Rainwater gutter

A.k.a., Rain gutter, rain conduit, rain channel, eavestrough, eaves-shoot, eaves channel, surface water collection channel.

A rain gutter is a component of a water collection and discharge system for a building. Gutters can be separate conduits or embedded within the structure of a building. Fundamentally, gutters prevent water ingress into a the building by channelling the rainwater away from the exterior walls and foundations.

It is necessary to prevent water standing as well as dripping or flowing off roofs in an uncontrolled manner for several reasons:

1. To prevent standing water. In the case of a flat roof, removal of water is essential to prevent water ingress and to prevent a build-up of excessive weight.
2. To prevent it damaging the walls, drenching persons standing below or entering the building.
3. To direct the water to a suitable disposal site where it will not damage the foundations of the building.

Note that a roof must be designed with a suitable fall to allow the rainwater to discharge.

A rain gutter may be a:

1. Integrated roof profile - make the external surface profile of the building behave like a water gutter, directing water to flow in specific ways.
2. Roof trough - trough positioned along the lower edge of the roof slope which is fashioned from the roof covering and flashing materials.
3. Discrete trough of metal, or other material that is suspended beyond the roof edge and below the projected slope of the roof.
4. Wall integral structure beneath the roof edge, traditionally constructed of masonry, fashioned as the crowning element of a wall.[

15.6.3 Concrete profiling for a rainwater distribution system

The roof of the welling surface shall have a water distribution network integrated into its surface profile. The top of the building should channel water to distribution points along the veranda that channel water to hung pots (with plants), or runoff water appropriately if no plants.

Requirements for guttering a roof include:

1. Allow for distribution to hanging (or otherwise located) plants.
2. Allow for excess water to be transported appropriately.
3. Leaves and other natural material should not easily block the flow of water.
4. Excess water should be transported down the remaining structure and away from the structure of the house.
    1. Transport of water not connected to plants.
    2. Transport of water connected to plants.
        i. Could use lightweight chains to direct the water and those chains could have vines growing on them.
5. The veranda must drain water or allow water to flow off the veranda evenly.
6. The ground foundation should have appropriate drainage around the foundation and building pad.

15.6.4 Rainwater reservoir

A rainwater reservoir is often exclusively for rainwater; however, in limited cases this reservoir may also be connected to other water sources.

There are several ways to implement a rainwater reservoir system:

1. Each architectural structure can have its own reservoir.
2. A number of architectural structures can share a reservoir system.

Placement of rainwater reservoir systems:

1. Above ground-level - use gravity to access the water. May require a pump to pump water up to the reservoir. Can have an electrical generator attached to the plumbing to produce electricity as the water falls.
2. At ground-level - requires a pump to access the water.
3. Below ground-level - requires a pump to access the water.

15.7 Conception of the drainage water sub-system

A.k.a., Water drainage infrastructure.

Drainage is the directed removal of water, both surface and sub-surface water. Drained water may either be:

1. Recycled for reuse in (or around/on) the architecture.
2. Used on the landscape.
3. Discharged into a body of water (Read: effluent).

Herein, 'effluent' is an outflowing of water or gas to a natural body of water, from a structure. Typically, effluent is conveyed by drains to sewers, and from sewers to a suitable outfall or treatment plant, before being discharged to a water body.

In architectural drainage terms, drained water can refer to the following:

1. **Subsoil water (ground water)** - This is water collected from the earth to lower the subsoil's water table. Subsoil water is considered to be clean and can be discharged into an approved watercourse (e.g. river or lake), or soakaway without treatment.
2. **Surface water** - This is collected from surfaces such as roofs and paved areas. Surface water is considered to be clean and can be discharged into an approved watercourse (e.g. river or lake), or soakaway without treatment. Surface water is a type of sanitary water.
   A. Roof drainage.
   B. Paved area drainage (path drainage).
   C. Road drainage.
3. **Greywater (foul water) and blackwater (soil water)** - This is effluent contaminated by domestic or manufacturing waste. Foul and soil water must be conveyed, often by sewer, to a treatment location before being discharged into a watercourse. Foul and soil water are a type of sanitary water. Surface water is a type of sanitary water.
   A. **Greywater (a.k.a., foul water, waste water)** - effluent from sinks and basins which does not contain excreta.
   B. **Blackwater (a.k.a., soil water)** - effluent from water closets, toilets and urinals which does.

15.7.5 Groundwater control

A.k.a. Groundwater drainage control.

Groundwater control encompasses the range of temporary works techniques used to allow below-ground construction projects to be carried out in dry and stable conditions. The most common groundwater control methods are:

1. Subsoil drainage.
2. Groundwater pumping.
3. Low permeable cut-off walls.
4. Grout barriers.
5. Artificial ground freezing.

15.7.5.1 Subsoil drainage

Subsoil drainage can be used to improve ground stability, to lower the moisture content of a site, to enhance horticultural properties for landscaping and so on. It can be required to drain the whole site or to protect a particular part. Subsoil drainage generally involves the use of pipes that are porous to allow subsoil water to pass through the pipe body, or pipes that are perforated with a series of holes in the lower half to allow subsoil water to rise into the pipe. This type of groundwater control is only feasible up to a depth of 1.5 m, and any further lowering of the water table should be achieved by other methods.

When subsoil drainage is used to protect an architectural substructure, a cut off drain is generally installed that intercepts the flow of water and diverts it away from the site.

15.7.5.2 Groundwater pumping (dewatering)

Groundwater pumping is a groundwater control method that involves pumping groundwater from an array of wells or sumps around a site. The objective is to lower groundwater levels. Examples of this group of techniques include sump pumping, wellpoints, deepwells and ejector wells.

15.7.5.3 Low permeable cut-off walls

Low permeable cut-off walls are installed into the ground around the perimeter of the site. These walls act as barriers to groundwater flow, and effectively exclude groundwater from the site. The requirement to pump groundwater is limited to pumping out water trapped within the area enclosed by the cut-off walls. Examples of the techniques used to form cut-off walls include steel sheet-piling, concrete diaphragm walls, concrete bored piles and bentonite slurry walls.

15.7.5.4 Grout barriers

Grout barriers are formed after fluid grouts are injected into the ground and set or solidify in soil pores and rock fissures. The solidified grout blocks the pathways for groundwater flow and can produce a continuous zone of treated soil or rock around the site that is of lower permeability than the native material. This reduces groundwater inflow in a similar way to cut-off walls. The most commonly used grouts are based on suspensions of cement in water.

15.7.5.5 Artificial ground freezing

Artificial ground freezing uses a very low temperature refrigerant (either calcium chloride brine or liquid nitrogen) that is circulated through a series of closely-spaced boreholes drilled into the ground. The ground around the boreholes is chilled and ultimately frozen. Frozen soil or rock has a very low permeability, and will significantly reduce groundwater inflow into the site.

15.8 Objects in the water system: fixtures, fittings, and appliances

A.k.a., Water-based technologies, including appliances.

Plumbing fixtures and fittings are equipment that interface with the water in a building:

1. **Plumbing fixture** - A device for receiving water and/or waste matter that directs these substances into a sanitary drainage system. Note that the

term is used erroneously in common vernacular to describe "fittings". The most common fixtures include, but may not be limited to:
   A. Toilets (water closets).
   B. Sinks.
   C. Bathtubs.
   D. Shower receptors.
   E. Filters and inceptors (i.e., filter boxes; e.g., chemical feeder).
   F. Junction boxes (i.e., multi-inceptors, junction chambers) - combines the effluent from several sources.
   G. Inspection chambers.
   H. Drain fixtures:
      1. Static open drain fixtures.
      2. Open/closed drain fixtures.
   I. Heat recovery systems
   J. Gutters.
   K. Pumps.
   L. Water meters.
   M. Water sensors.
   N. Hot water fixtures:
      1. Water heaters.
      2. Radiators (hot water radiators).
2. **Plumbing fitting** - a device designed to control and guide the flow of water. Note that some people call these "fixtures," but that term means something different in plumbing. The differing usage of "fitting vs. fixtures" can lead to unintended consequences, such as when legislation calls for changes in fixtures, although the true intent involves changes in fittings. The most common fittings include, but may not be limited to:
   A. Pipe conduits.
   B. Pipe fittings (note: all pipe connectors are also called pipe fittings).
   C. Drains.
   D. Faucets (hot, cold, or mixed).
   E. Shower heads.
   F. Shutoff valves (resistor valves).
   G. Shower valves.
   H. Retaining valves - prevent the backflow of effluent, prevents insects and rodents.
   I. Sealing valves (e.g., p-pipe, p-trap, etc.).
   J. Drinking fountain spouts.
3. **Plumbing appliances** - appliance devices that use water, the most common of which include:
   A. Refrigerators (only those with a water hookup).
   B. Washing machines.
      1. Fabric washing (e.g., clothes washer).
      2. Ceramics washing (e.g., dish washer).
   C. Dish washing machine (including, instrument washing machine).
   D. Waste disposal unit (under kitchen sink).

IMPORTANT: *All fixtures, fittings, and appliances must be specified with the right capacity for their placement.*

15.8.1 Pump fixtures

Building installations do not have a constant demand for water, and the flow provided by pumping systems must be adjusted to match demand. There are three main ways to achieve demand matching:

1. **Flow restriction [control]** - uses a control valve at the pump outlet to restrict flow.
2. **Flow recirculation [control]** - uses a recirculation valve to send the unused water flow back to the pump inlet.
3. **Variable speed [control]** - uses a variable speed pump (with a variable speed impeller) to adjust flow and match usage demand.

Variable speed control is the most efficient option because the other two waste pumping power:

1. Flow restriction [control] wastes power because the pump consumes power to compensate the pressure loss across the control valve.
2. Flow recirculation [control] wastes power since the unused water flow represents wasted power.

15.8.1.1 Variable speed pumps

Variable speed pumping systems are often used to boost the pressure of the local water supply, especially in high multi-story constructions. Variable speed pumping systems can adjust the rotating speed of the impeller to modulate water flow. This method is significantly more efficient than using valves. Flow restriction and flow recirculation both represent a waste of pumping power, driving up electricity expenses. Only variable speed pumping systems can optimize their operating efficiency, consuming just the necessary power to establish the required water flow. (Variable speed, 2021)

Here, speed control is achieved by designing the pump's motor system with a variable frequency drive (VFD). A VFD modulates the voltage and frequency of the power supply, and the rotational speed of the pump changes accordingly. If the demand for water is below the rated flow of the pump, the VFD slows it down until the flow provided matches demand. (Variable speed, 2021)

Note that when variable speed pumping systems are deployed as part of an HVAC installation, the design process must consider the entire installation and not only the hydronic piping. To take advantage of a variable speed pumping system, HVAC installations must also be capable of adjusting the air supplied by ventilation systems, and the cooling output of chillers and boilers.

Variable speed pumping systems provide an excellent opportunity to save energy in applications where large amounts of water are used. However, the benefits can only be achieved if the system is designed correctly and compliant with local codes. Professional design services from MEP engineers are strongly recommended.

NOTE: *When deploying speed controls for a pumping systems, it is important to have reliable electrical protections.*

15.8.1.2 Well pumps

A.k.a., Water pumps.

A well pump is installed after drilling or digging a well. Its purpose is to pump water from the well into a plumbing system. An electric motor drives an impeller or centrifugal pump, which pushes water from the well through a jet or pipe. Well/water pumps supply the pressure needed to pressurize a plumbing system or fill a water tank with water from an underground (Read: well) source. (Ultimate guide, 2021)

There are three primary types of well pumps:

1. **Centrifugal pumps** - rotate an internal fan to create suction. Unlike other well pumps, centrifugal pumps sit in a mechanical housing next to the well instead of inside it, making maintenance less of a hassle. Centrifugal pumps are generally used for shallow wells as they do not have enough power for deep wells.
2. **Submersible pumps** - are practical for virtually any well, no matter how shallow or deep it is. Submersible pumps are placed underwater, inside the well. The motor powers impellers that push water up the pipe. Turning on the pressure switch causes the impellers to spin, which will push water to the surface. These pumps are watertight, generally last a long time and rarely need repairs. However, repairs involve pulling the pump out of the well and up to the surface. These pumps will not function unless they are entirely submerged under water. A submersible pump has a cylindrical shape, and the bottom half consists of a sealed pump motor that attaches to an aboveground power source. The motor powers impellers, which in turn drive the water upward. Turning on the pressure switch causes impellers to spin, thereby sucking water into the pump. The water gets pushed through the body of the pump, then (typically) into a storage tank on the ground's surface. Even though a submersible pump can deliver water more efficiently than a jet pump with a similarly sized motor, any motor issues could require removing the entire unit from the well casing. Fortunately, most submersible pumps tends to be highly reliable and can operate at peak performance for as long as 25 years before needing maintenance.
3. **Jet pumps** - provide the most power and can deliver more water faster than other type of pump. Jet pumps work in wells at all depths. Jet pumps create pressure via impellers. The impellers move water (drive water), through a small orifice mounted in the housing located in front of the impeller. Doing so increases the water's speed. When the water leaves the jet, a vacuum will suck more water from the well. This water will combine with the drive water and discharge into the plumbing at high pressures. There are two types of jet pump:
   A. **Single-drop** - best for shallow wells. These are placed inside a building or in an outbuilding.
   B. **Double-drop** - suitable for deep wells. These require a split installation. The jet assembly is in the well, and the motor must stay above ground.

NOTE: *That the upfront costs for submersible pumps are often higher, they are generally lower maintenance, and often a lower cost long-term investment. Unlike aboveground well pumps, which are vulnerable to mechanical failure, submersible pumps tend to have fewer problems. Because submersible pumps are underwater, they don't lose prime, an issue commonly experienced by aboveground pumps. Cavitation, an occurrence when gas or air makes its way into a pump's mechanical parts, is generally not an issue for a submersible pump because the pump sits far below the water's surface and can always access water.*

When choosing the right pump for a well sourced system, the most important factor is the well's depth (i.e., how far the water must travel to get to the surface of the ground):

1. If the well is less than 8 meters (25ft) deep (Read: shallow well), use a shallow well jet pump. A submersible pump can be used for wells as shallow as 8 meters.
2. If the depth of the well is between 8 to 33 meters (25ft to 110ft), use a deep well jet pump. Alternatively, a submersible pump can be used here.
3. If the depth of the well is between 33 to 121 meters (110ft to 400ft), use an appropriately sized submersible pump. Remember, you can also use a submersible pump for wells as shallow as 25 feet.

If the well is a shallow (up to 8m), then a single-drop jet pump is recommended. These pumps come with one-way check valves, which serve to keep the pumps primed. The single-drop jet pump sits aboveground and draws water up through one inlet pipe. This pump sits over the well and draws up water via suction. The distance it can suck up the water depends on the air pressure. While air pressure changes with elevation, jet pumps generally are not ideal for wells more than 25 feet deep. A jet pump generates pressure via its impeller, which pushes the drive water through a small orifice or a jet inside housing located in front of the impeller. The jet's constriction increases the moving water's speed. As the water exits the jet, a vacuum will then suck more water out of the well. When this extra water comes together with the drive water, it will discharge into the plumbing at high pressure.

If the well is up to 33m deep, then a double-drop jet pump is recommended. Deep-well jet pumps are positioned above ground. They draw water by using two pipes. One pipe draws water out of the well, while the other pushes the water up. A deep well jet pump sucks up water from depths as great as 33m, and hence, uses a foot valve for priming the pipe as well as prevents water drainage from the pipes. The impeller is responsible for driving water into the body of the jet, whereas the jet delivers the water back to the pump. A deep well jet pump uses suction at the jet for bringing water into the system. It also uses pressure to lift water up the well and deliver it. Some models come with a tailpipe, which prevents users from pumping the well dry (Read: overpumping). When the water level dips below the jet's housing, the tailpipe will ensure nobody can pump the well dry. The higher the jet sits above the level of the water, the more efficiently it will pump. Just like with a shallow-well system, a deep-well system also requires priming with water.

If the well is up to 121m deep, then a submersible pump is recommended. Deep-well submersible pumps use pressure tanks to suction water via one pipe that connects to the plumbing system. While a jet pump can work with wells several hundred feet deep, they are generally not as effective for deeper wells as submersible pumps.

15.8.1.3 Pool pumps

Pool pumps are the source of water circulation for a pool system. Pool pumps primarily pull water from the pool through a skimmer and main drain, pushing it through a filter, and returning it to the pool through the main returns. This allows chemicals (if present) to circulate evenly throughout the pool, as well as filter out debris by circulating water through a filter system. Without the water moving around regularly, algae may start to form in your pool water. Some pool pumps can also add and/or remove water from the pool -- add in the case of water shortage and remove in the case of excess water, such as from excess rain. These pumps use electricity.

There are three common types of pool pumps:

1. **Single-speed pumps** - pump the swimming pool's water through the system at one constant speed. The pump runs at the same speed all the time and can increase power usage.
2. **Two-speed pumps** - run at two fixed speeds – high and low. The higher speed is equipped to handle pool cleaners while lower speeds are best for general circulation.
3. **Variable-speed pumps** - adjust their speed based on the task they are performing.

15.8.1.4 Pool system fixtures

Most pool systems consist of the following elements:

1. A basin.
2. A motorized pump.
3. A water filter.
4. A chemical feeder.
5. Drains.
6. Returns.
7. PVC plastic plumbing connecting all of these elements.

Every pool system has two general sides to the system (as well as a filtration system):

1. **The suction side** - draws water from the pool to the pump. This is the part that begins the circulation process. This side generally consists of the following elements:
   A. **Skimmer outlet** - pulls water from the pool's surface into the filtration system. These are usually positioned on the side of the pool. Debris goes through a flapping door ("weir") and goes into the skimmer basket that traps the material. The skimmer basket will need to be emptied periodically to keep it from clogging.
   B. **Main drain outlet** - located at the bottom of the pool and pulls debris that has fallen to the base.
   C. **Suction lines** - run to the pump. These lines are generally a flexible or rigid set of PVC pipes that run from the skimmer to the pump system. Depending on the type of pool, the suction lines can be found above ground or underground. Suction lines can leak, causing problems with the system. If the suction lines are above ground, the leak is easier to find and therefore fix.
2. **The pressure side** - provides pressure to move water through various pool fixtures and back into the pool basin.
   A. Pump - pushes the water through the filter, heater, and chemical feeder.
   B. Filter - filter debris and particle matter from the pool. Note that the 'filter system' consists of the pump and the filter. Filters include, but may not be limited to:
      1. Sand filters.

2. Cartridge filters.
3. Diatomaceous earth filters.
4. Biological filter (for natural pools).

C. Heater (heat exchanger).

D. Chemical feeder - introduction and circulation element for chemicals. Chemicals may include, but are not limited to:
1. Ozonator.
2. Chlorinator.
3. Salt.
4. Etc.

E. Return lines - carry the water from the circulation system to the return jets.

F. Return jets - are positioned in the pool basin (generally), and return water into the pool. Some return jets are movable to control the circulation of the water. Pointing them down helps with better chemical and temperature distribution as well as overall filtration.

NOTE: *The only difference between a standard chlorine pools and a salt water pool is that in the salt pool the chlorine is not poured into the water, but is produced by electrolysis from common salt dissolved in the pool. The effect is the same - it is still a chlorine pool.*

In 'natural pools' no additional chemicals are required due to biological self-cleaning processes. Technology is used to support and enhance the natural processes. A natural pool will function as it should if the regeneration area is designed correctly and the underwater plants are used properly. The pool is fortified with zooplankton (including: water fleas, rotifers, paramecia, etc.), which play an important role in keeping the water clean on a continual basis. In natural pools, the separation of the pool into two water circuits allows the system to operate economically and with minimal use of space. The first circuit is responsible for cleaning the surface of the water and removing floating particles. Its pump runs throughout the day. The purpose of the second circuit is to eliminate organic compounds. Its pump runs continually during the swimming season. Features like rock fountains, waterfalls or curtain fountains can be integrated into either or both of the circuits.

Note that some pools also contain a pool cover to protect the pool and/or nearby persons. Pool cover types include, but may not be limited to:

1. Winter cover - is the most common and least expensive of the pool covers. It is usually made of a tarp-like material but does the job of keeping debris out of the pool. Note that these covers usually only lasts two winters.
2. Security cover - is a sturdier and more costly cover than the standard winter cover. The security cover is made to keep debris, children and pets out of the pool when covered.
3. Automatic pool cover - rolls out over the pool with the touch of a button.
4. Solar pool cover – is intended to extend the pool's usage season. It can warm up the water earlier in spring and keep it warmer longer later in the fall.

15.8.2 Mixed cold and hot water fixtures

The most common dual water fixtures are:

1. Sinks.
2. Showers.

15.8.3 Cold water fixtures

The most common cold water fixtures are:

1. Toilets.
2. Bidet spray (is a small shower head with a relatively short hose often connected to the wall near the toilet).
3. Hosepipe (a.k.a., garden hose tap).

15.8.3.1 Toilets

Toilets are a collection receptacle for human urine and faeces. Some toilets use water. The size and type of toilet receptacle can vary from place to place, depending on culture, availability, and purpose. Water-using toilets can differ in the following ways:

1. Size, shape, and purpose:
   A. The squat floor toilet.
   B. The standard sitting bowl toilet.
   C. The urinal.
   D. The handicapped toilet.
   E. The bidet.
   F. The standard sitting toilet with integrated bidet.
2. Trigger mechanism for flushing:
   A. Some toilets have a single handle for flushing.
   B. Some have a pull chain.
   C. Some have a push button (Read: flush valve).
   D. Hands-free automatic flushing.
3. Flushing quantity type:
   A. Single flush system - In a single flush system, the toilet user can only use the same amount of water whether flushing liquids or solids. These toilet systems mostly use a trip lever handle mounted on the side or the front of the tank. The toilet handle is connected to a lift chain which is in turn connected to a flapper. When you push the toilet handle down, the chain lifts the flapper off the flush valve opening allowing water to flow down to the bowl for flushing to happen.
   B. Dual flush system (a.k.a., flush valve systems) - has two different buttons/handles that offer

lower and higher water pressure, depending on the amount of waste. This conserves water. A dual flush valve assembly is mounted on top of the flush valve. When any of the buttons are pressed, the valve seal lifts off allowing water to flow down to the bowl. The amount of water depends on the button you pressed. These systems can be designed to let users push a handle/button in one direction for liquid waste and another direction/button for solid waste.

4. Flushing hydrodynamics type:
   A. Gravity flush system (a.k.a., gravity-powered flush, tank-based, cistern-based) - water flows from the tank which is mounted on top of the bowl and move to the bowl via gravity creating a force inside the bowl that causes the toilet trap to siphon out the waste. These toilets have a cistern that fills and stores water until flushing occurs solely by gravity. After flushing, the water supply once again fills the cistern for the next flush. Water that sits in the toilet tank for long periods of time can become unsanitary.
   B. Pressure-assisted flush system (a.k.a., gravity with compressed air flush) - combines the gravity flushing system with compressed air. This system is used to create a powerful flush in toilets where gravity flush system on its own would not be sufficient like in rear-discharge and upflush toilets. A pressure-assisted toilet has secondary plastic tank inside the main tank called a pressure vessel. Incoming water from the water supply line mixes with the air in the pressure vessel therefore becoming pressurized. When you flush the tank, the water leaves the tank forcefully and powerfully flushes the toilet. Pressure-assisted flushing systems are louder than gravity flush systems which might be uncomfortable for some people. Because of this gravity-powered flush assistance, tank toilets can function on a water pressure as low as 10 pounds per square inch (psi).
   C. Tankless flush system (a.k.a., flushometer, fully pressurized flush) - are connected directly to the pressurized plumbing network without an in-between tank. Some plumbing networks have enough water pressure to power the flush of a tankless toilet without any sort of mechanical assistance. Tankless toilets use approximately the same amount of water as a tank-type toilet, but the water enters the fixture at a greater pressure. Tankless flush systems usually need at least 15 to 20 psi of water pressure to function properly, sometimes more. Urinals are an exception. Urinals generally operate using the same basic principles as regular flush valve toilets, but they require less water pressure because of the nature of the material being flushed (liquid versus solid waste). For this reason, urinals can run on much smaller water supply lines. They also require much less water to complete a flush.
   D. "Tornado" and "double-cyclone" system: The double cyclone system uses tank that passes water into bowl through 2 nozzles located at the top of the bowl facing sideways. As a result, the water swirls in the bowl like cyclone which is very effective in cleaning, rinsing and flushing the toilet. The "cyclone" is created due to the direction in which the water enters the bowl. The nozzles which face sideways allow the water to strike the surface of the bowl thereby creating a vortex which is what cleans the bowl. The tornado system is an improved version of the double-cyclone flush system. Instead of 2 nozzles, the tornado flush system lets the water in to the bowl through 3 jets positioned sideways around the top of the bowl. As the water enters the bowl, it swirls around the like a "tornado" which is very effective in cleaning the bowl. It also has more quiet flush. With a tornado flush system, the toilet bowl does have a rim which eliminates bleeding ground for germs. It is also easier to clean.
   E. Tower style flush system (a.k.a., canister flush system) - uses a canister toilet flapper which is normally mounted in the middle of the tank and connected to the flush handle.
   F. Double vortex flush system - Water enters the bowl via 2 nozzles at the top of the bowl which face sideways which creates a whirlpool in the bowl. Although most of the water comes through the 2 nozzles, some of the water is directed straight to the trapway simultaneously with the double-vortex action.

Most flush toilets operate using a siphon, which is a tube at the bottom of the bowl fixture. Water coming into the toilet must do so fast enough to fill the siphon tube, allowing the water and whatever else is in the bowl to be sucked through and pulled down the drain. Some water supply lines don't allow water to enter a toilet fast enough to trigger the siphon effect.

NOTE: *In many places on the central and south American continent, plumbing/sewage systems are not capable, due to their design, to handle large amounts (or, any at all) of toilet paper. Flushing toilet paper causes clogs and plumbing issues. That said, toilet paper is designed to be* *flushed; it breaks apart in the water and can form a movable sludge. Pipe networks must have enough pressure and appropriate pipes to move such sludge effectively. Municipal water pressure in some areas of the world isn't strong enough (or, the pipes are not designed) to handle the sludge. Most spetic systems can handle toilet paper.*

15.8.4 Hot water fixtures

Common hot water fixtures include:

1. **Fixtures that produce hot water (water heating fixtures):** Normally, cold water comes out of the taps automatically. To get hot water, cold water moves through a heater to raise its temperature. Hot water can be generated by heaters utilizing natural gas, electricity or steam as an energy source. 'Water heater' is a generic term for a device that heats water.
   A. **Instantaneous hot water (a.k.a., on-demand water heaters, demand-type water heaters, tankless water heaters)** - make hot water on demand without the presence of a tank.
      1. Powered by natural gas.
      2. Powered by electricity.
   B. **Boiler (a.k.a., boiler, tank storage water heater, hot water tank)** - make and hold hot water inside a tank. This type uses hot water storage.
      1. Powered by natural gas.
      2. Powered by electricity.
2. **Fixtures that use hot water:**
   A. **Heat radiating fixtures (a.k.a., hot water radiators)** - radiate heat from pre-heated water.
   B. **Heat recovery fixtures (a.k.a., power pipes)** - recover heat from heated water in drains.

There are many different sub-types of water heater, which can be electric or gas, and can be tank-based or tankless. These include, but are not limited to:

1. Whole house water heaters.
2. Bathroom water heaters.
3. Under sink and over sink water heaters.
4. Shower head water heaters.

Hot water heaters are generally powered by either:

1. Electricity.
2. Natural gas.
3. Propane.

15.8.4.1 On-demand water heater

A.k.a., Tankless water heater, instantaneous water heater, instant hot water heater.

On-demand water heaters provide hot water only as it is needed (i.e., on-demand). In other words, these systems work from demand, not from [tank] capacity. These systems use high-powered heaters (or burners) to rapidly heat water as it runs through a heat exchanger, and is then, delivered directly to endpoints without storing it in a tank. These systems usually take a minute or less to heat the water and distribute to the usage point, after a hot water tap has been turned on.

The advantages and disadvantages include, but are not necessarily limited to:

1. On-demand water heaters occupy less space than boilers.
2. On-demand water heaters need to be selected to provide sufficient hot water for all expected endpoint uses when providing hot water simultaneously.
3. Save energy over time.
4. Cannot be used to supply radiators with hot water.

15.8.4.2 Tankless coil (furnace and boiler) water heater

A tankless coil water heater provides hot water on demand without a tank. When a hot water faucet is turned on, water is heated as it flows through a heating coil or heat exchanger installed in a main furnace or boiler. Tankless coil water heaters are most efficient during cold months when the heating system is used regularly but can be an inefficient choice for many homes, especially for those in warmer climates.

15.8.4.3 Tank-based water heater

A.k.a., Boiler, reservoir water heater, hot water tank, conventional water storage water heaters.

Boilers provide hot water by heating the water in a tank (reservoir), either through electricity or gas. These systems use an insulated tank with a fixed storage capacity that heats and stores the water until it is needed. These systems continuously use energy to maintain a hot water supply [in a tank]. A pipe emerges from the top to deliver hot water to endpoints.

Natural gas storage-tank water heaters use almost 50 percent less energy to operate than the electric variety. However, they cost more than electric models. Natural gas systems also feature a temperature and pressure-release valve that opens when either temperature or pressure exceeds preset levels.

The advantages and disadvantages include, but are not necessarily limited to:

1. Boilers occupy more space than on-demand water heaters.
2. Smaller boilers (relative) can run out of water prior to the user desiring the water running out.

3. Can be used to supply radiators with hot water.

The greater the demand for water, the higher the requirement for capacity (tank size).

15.8.4.4 Indirect (furnace and boiler) water heaters

Indirect water heaters require a storage tank. An indirect water heater uses the main furnace or boiler to heat a fluid that's circulated through a heat exchanger in the storage tank. The system is "indirect", because the furnace or boiler is the location where a separate fluid is heated, which passes through a heat exchange coil [hot] water tank. It is the heat exchange coil in the tank that makes the water therein hot. The boiler/furnace that heats the coil is separated from the hot water tank. The energy stored by the water tank allows the furnace to turn on and off less often, which saves energy. An indirect water heater, if used with a high-efficiency boiler and well-insulated tank, can be the least expensive means of providing hot water, particularly if the heat source boiler is set to "cold start."

15.8.4.5 Heat pump water heater

Heat pump water heaters use electricity to move heat from one place to another instead of generating heat directly. To move the heat, heat pumps work like a refrigerator in reverse. Heat pump water heaters require installation in locations that remain in the 4.4º–32.2ºC (40º–90ºF) range year-round and provide at least 28.3 cubic meters (1,000 cubic feet) of air space around the water heater. Air passing over the evaporator can be exhausted to the room or outdoors. Heat pump water heaters will not operate efficiently in a cold space since they tend to cool the space they are in. Installing them in a space with excess heat, such as a furnace room, will increase their efficiency. Newer type heat pump water heaters pull heat energy from the air around them to heat water. When the air around the device is too cold, these devices often switch to a standard electric-type water heater to keep the water hot.

> **NOTE:** *Heat pumps can be used to transfer thermal energy between different materials. There are heat pumps that combine heating, cooling, and water heating.*

Table 61 Heat pump water heaters.

Brand	Name	Efficiency
Rheem	ProTerra	Up to 4.0 UEF

15.8.4.6 Solar boiler (a.k.a., solar water heater)

A solar boiler is a type of tank-based water heater. Solar boilers use sunlight to heat. Light from the sun strikes a solar collector and heats the black metal sunstrip absorber underneath the glass cover. This heat is transferred to a non-toxic anti-freeze solution (e.g., propylene glycol and water) that is pumped through the collector and returns to the solar boiler. In many cases, a solar boiler is paired with a conventional heating system. In this case, cold water enters the solar boiler for initial heating, and is then delivered to the backup or conventional heating system for final heating as required. Conventional energy requirements can be reduced substantially by using the Solar Boiler, and on many days the Solar Boiler will provide ample hot water without the backup (conventional) heater turning on.

15.8.4.7 Drain water heat recovery (DWHR) unit

> *A.k.a., Hot water heat recovery system, power-pipes.*

A hot water heat recovery unit works by using outgoing warm drain water to pre-heat cold water going to the water heater. A DWHR is generally a double-wall, vented heat exchanger system can be used to supply fresh, pre-heated water to the water heater. The system features multiple coils wrapped in parallel around a central drainpipe. DWHR systems are based on a fundamental physical principle called the “falling film” effect. This means water falling down a vertical pipe does not run down the center of that pipe, but clings to its inside wall.

15.8.4.8 Hot water radiator

> *A.k.a., Hydronic radiator.*

Hot water radiators work by drawing heat from water or steam and use that heat to warm up surrounding air. Hydronic heat is one of the most effective ways to warm a building. It is highly controllable, silent and maintains a much steadier ambient temperature than central air systems. Hot water radiators can be positioned either within a room itself, or under the floor.

Area-base hot water radiators have piping that allows hot water to enter the radiator through a control valve and exits through a lockshield. On initial fill, air is vented through the bleed valve to ensure the radiator is completely full of water. The control valve allows water into the radiator. It can be manual or thermostatic. A thermostatic radiator valve (TRV) adds control and increased energy efficiency.

15.8.5 Inspection chambers

Inspection chambers are part of a drainage system. They are locations where inspection of the water and piping can occur, and blockages can be removed. Inspection-type chambers include, but may not be limited to:

1. **Manholes** - allows the physical whole-human access to the blockage in the underground pipes.
2. **Inspection chambers** - small boxes/chambers, which allow only hands, arms, and cameras (and other devices) to inspect and test the drainage and flow of water through the pipes. Note that any type of water network can have one or more inspection chambers, such as
   A. **Sewer inspection chambers (caixa de inspecao de esgoto)** - allows for inspection of

sewer water.

B. **Soap water chambers (caixa de sabao)** - this is a box/chamber where water with soap enters can be inspected.

15.8.6 Outlet fixtures

A.k.a., Taps, faucets.

Human use water switches are designed to be as precise, simple, and helpful as possible. Faucets have three primary functional designs:

1. **No handle** design (i.e., automatic sensor, touch interface, or other).
2. **Single handle** design allow the user to turn on and off the tap with one hand. Users of single handle designs are less likely to leave the water on than users of a two handle design. Also, with a single handle design the user can set the temperature of the water more easily than with **two handles**.
   A. **Single handle with one temperature** of water.
   B. **Single handle with two temperature** inputs of water.
3. **Two handle** design allows for adjustment of cold and hot water inputs simultaneously.

15.8.7 Plumbing filtration and inceptor fixtures

Plumbing filtration fixtures include:

1. **Water supply filtration** - a filter that purifies the source of water so it is fit for various purposes, most often, drinking.
   A. Carbon-type filters.
   B. Reverse osmosis filters.
   C. Etc.
2. **Sanitary water filtration** - a filter that filters out material from the sanitary water system so it doesn't contaminate its final destination.
   A. **Lipids (FOG) filters (a.k.a., fat interceptors, lipid interceptors, caixa de gordura)** - FOG refers specifically to fats, oils and grease entering the sewer system when poured down drains in homes, apartments, restaurants, industry and public facilities. FOG is generally a product of cooking. When poured down the drain (sink or floor), FOG can build up, blocking sanitary sewer lines. This accumulation not only reduces the capacity of the wastewater collection system, but it also alters its effectiveness, and can lead to complete blockages. In severe cases, blockage can lead to: Sewage backups into homes and businesses and Sewers that overflow onto roadways and property, eventually flow into local waterways, causing contamination. The easiest way to solve the grease problem and help prevent overflows of raw sewage is to keep this material out of the sewer system. Through education and by adopting certain habits, it is easy to minimize FOG sources at home. FOG buildup also increases the cost and resources usage of maintaining a wastewater treatment system. Grease traps and interceptors are devices designed to keep fats, oils and grease (FOG) from entering building and public sewer lines. They can be located inside or outside of your kitchen, depending on the application. In general, they are designed to retain FOG-laden discharge long enough for grease in the water to cool, solidify and separate from the remaining waste. Once the grease has separated, it can be disposed of properly.
   B. **Sand/oil interceptors** - generally contain one to four compartments (basins) where oil separates and floats to the surface, while sand and grit settle to the bottom sludge.

15.9 Installation of plumbing system

A.k.a., Plumbing installation.

There are many ways to install plumbing. These systems are usually embedded into structure.

15.10 Operation of plumbing system

A.k.a., Plumbing operation.

Most significant operational activities are located on the supply side because of the requirement for static pressure given dynamic demand. Some demand-side specialized water systems, such as pools and ponds, may have significant operational activities.

15.10.1 Plumbing load demands

A.ka., Water loading.

Water loads are measured in several ways, most notably, energy consumed to produce:

1. Conditioned water flow, and
2. Surface temperature.

In order to do work, plumbing systems are split into a power usage system and an water flow and temperature changing service system:

1. **A power usage system:**
   A. **Energy consumed** may be by electricity or combustion of fuel.

1. Most plumbing electrical loads are measured in watts [of electrical] power. Often, the kilowatt hour (kW.h)
2. Heating and cooling systems can be measured in BTU [of heating or cooling] power

2. **A water-flow conditioning (production and distribution) system:**
   A. **Water flow volume** is water flow rate, or quantity of water being moved, which is measured in:
      1. L^3/sec (cubic liters per second) or
      2. cubic gallons per minute (CGPM).

   B. **Water flow velocity** (Read: distance travelled per unit of time) is measured by sensing the pressure that is produced through the movement of the water. Velocity is also related to water density with assumed constants of 70° F and 29.92 in Hg. Water velocity is generally measured using flow meters, which are one of the most effective instruments for measuring water flow, or the speed of the water. It is possible to measure the velocity at different points in a pipe and find the average velocity in the pipe. The most common measuring units for velocity are:
      1. Meters per second (m/s, m/sec)
      2. Feet per minute (FPM)

   C. **Temperature** production is measured in kelvins or Celsius (or Fahrenheit in imperial).

   D. **Static pressure**, as it applies to water, is the water pressure within a system when no faucet or valve is on, i.e. the water is static or not flowing. Static and dynamic pressure can be tested for with a standard water pressure test gauge for a outlet. By connecting the gauge to a spigot and turning the valve on while nothing is on within the plumbing system. Readings need to be taken at the proximal and distal a mains. It is an important design consideration to have these openings built into the design so that post installation construction to drill holes is not required. The most common measuring units for pressure are:
      1. kPa
      2. psi
      3. H2O

3. **The conduit pipes** (piping, transmission lines) and filters are another type of load.
   A. Friction causes losses in conduit lines and filters.

4. **Non-usage**, but presence, will still equate to system service usage.
   A. If a usage circuit has no load in the form of a power factor of zero the user would consume NO liters per minute (i.e., no usage), but the supplier would still have to send static pressure to them and incur real energy losses in lines, pumps, and filters. Power factor is the relationship (phase) of volume and velocity in a water production-distribution system.

15.11 Engineering calculations for plumbing

In order to achieve optimally configured plumbing systems, the selection of sub-systems be must account for:

1. Identify demand requirements (load).
   A. Identify demand fixture units.
2. Identify supply parameters for demand requirements.
   A. Identify supply fixture sizes and first hour rating.
      1. Tankless-based water heaters: Flow rating in liters/minute at specific temperatures.
      2. Tank-based water storage: volume of stored fluid possible.
3. Identify thermal heating and cooling requirements.
4. Identify fuel/power type.
5. Identify fuel/power availability.
6. Identify fuel/power financial cost (market only).
7. Calculate energy efficiency (energy factor, EF).
8. Overall resource and financial costs (budget).
   A. Acquisition.
   B. Installation.
   C. Operation.
   D. Maintenance.
   E. Replacement.
   F. State tax.

15.11.1.1 Water heating sub-system calculations

It is possible to calculate the energy efficiency of water heating systems, including storage tanks, tankless or demand-type water heater, or heat pump water heater. The energy factor (EF) indicates a water heater's overall energy efficiency based on the amount of hot water produced per unit of fuel/power consumed over a typical day. This includes the following:

1. **Recovery efficiency** – how efficiently the heat from the energy source is transferred to the water
2. **Standby losses** – the percentage of heat loss per hour from the stored water compared to the heat content of the water (water heaters with storage tanks)
3. **Cycling losses** – the loss of heat as the water circulates through a water heater tank, and/or inlet and outlet pipes.

The higher the energy factor, the more efficient the water heater. However, higher energy factor values don't always mean lower annual operating costs, especially when you compare fuel sources. Product literature from a manufacturer usually provides a water heater model's energy factor. Don't choose a water heater model based solely on its energy factor. When selecting a water heater, it's also important to consider size and first hour rating, fuel type, and overall cost.

15.11.1.2 Water supply calculations

The proper design of a water distribution system within and between buildings necessitates calculations on the supply side.

The water is system is calculated in the following ways:

1. Estimate demand (water supply fixture units, WSFU).
2. Calculating pipe sizes for the whole building supply (cold and hot water) system.
3. Calculating pipe sizes for the whole building drainage system
4. Calculating friction pressure drops or losses in cold and hot water pipes, as well as drainage pipes.

15.11.1.1 Estimate demand with water supply fixture units (WSFU)

A.k.a., Water supply units.

Water supply fixture units (WSFU) is the standard method for estimating the water demand for a building. WSFU is is defined by the American Uniform Plumbing Code (UPC) and is used to calculate the demand in water supply systems. This system assigns an value called a WSFU to each fixture in a building, based on the amount of water required and the frequency of use. The water supply fixture units are distinguished between cold, hot or both. If a plumbing line serves only the cold water side of a fixture, then the corresponding value should be used. For example, a main line may serve the both cold and hot water, but then a branch line may go to the hot water heater. The branch line would only use the hot water value.

The international plumbing code (IPC) maintains a water supply fixture unit table. If a plumbing fixture is not available in the table, then a fixture unit value can be assigned by the designer or engineer. Typically, a similar plumbing fixture that has a similar maximum flow rate and frequency of use will be selected. If the plumbing fixture will be on for long periods of time, then the volumetric flow rate can be inserted into the domestic water piping calculator.

Note that a fixture unit (FU) is used in plumbing design for both water supply and waste water. Different fixtures have different flow requirements.

One WSFU is equal to one gallon per minute = 3.785 L/m = 1 WSFU. The relationship between liters per minute (LPM; or gallons per minute, gpm) and fixture units is not constant, but varies with the number of fixture units.

Fixture units are used in order to determine the required size of pipe. Fixture unit values can be determined using charts from the International Plumbing Code or similar codes in local jurisdictions.

Additionally, there are situations where a design provides for more FUs being discharged than being supplied. This occurs in situations where liquids may infiltrate or are added to a draining system, such as might happen in a large sports venue. Examples of how this could occur include rain water infiltration.

Table 5. *Example table of water-supply fixture units for common plumbing fixtures.*

Type of fixture or group of fixtures	Water-supply fixture unit value		
	Hot	Cold	Combined
Bathtub	1.0	1.0	1.4
Lavatory	0.5	0.5	0.7
Kitchen sink	.8	.8	1.2

Table 6. *Example table of water-supply fixture units for common plumbing fixtures. Not that for SI: 1 gallon per minute = 3.785 L/m, 1 cubic foot per minute = 0.4719 L/s.*

Supply systems predominantly for flush tanks			Supply systems predominantly for flushometer valves		
Load	**Demand**		**Load**	**Demand**	
Water supply fixture units	**Gallons per minute**	**Cubic feet per minute**	**Water supply fixture units**	**Gallons per minute**	**Cubic feet per minute**
1	4.0	0.051	-	-	-
2	4.0	0.0485	—	—	—
3	3.2	0.58730	—	—	—
4	7.0	1.0494	—	—	—
5	3.1	.73653	5	15.0	2.00
...					

Table 7. *Example of fixture units for fixture models in relation to community access-types.*

Appliance or fixture	Fixture unit value			Number of fixtures and appliances	Total (Col 1, 2, or 3) x 4 = Total)
	Personal	Common	Team		
Model 389	1	1	1	25	2
Model 49	x	x	x	x	x
Model 342	x	x	x	x	x
Model 45	x	x	x	x	x
Model 53	x	x	x	x	x

Table 8. *Table estimating peak hour demand/first hour rating for a set of plumbing fixtures. Example values given.*

Fixture use *(machine specific)*	Average liters per usage	x	Times used during one hour	=	Liters used in one hour (or, gallons)
Shower	20	x	3	=	60
Dish washing	1	x	1	=	1
Manual dish washing	2	x	1	=	2
Automatic dish washing	3	x	1	=	3
Clothes washing	25	x	1	=	25
Drinking	.5	x	2	=	1
			Total peak hour demand	=	92

15.11.2 Standard plumbing efficiencies

A.k.a., Plumbing control and automation.

It is possible to attach meters to fixtures to measure incoming and outgoing water. Some plumbing system context lend themselves easier to automation, such as pool plumbing. In a pool, for example, plumbing can be automated in the following ways:

1. Refill the pool when the fill is low.
2. Automatically overflow the pool when over filled.
3. Automatically filter pool.
4. Automatically clean and replace filter.
5. Etc.

In non-industrial situations, plumbing is considered pre-automated. In other words, it is a static system that is designed to meet a demand, and there isn't significant need for dynamic motion on the usage side. Conversely, at the size of a utility providing water pressure to many buildings and/or storeys, there are degrees of automation. Sensors, which may not need to be on continuously, can provide a valuable source of information on the status of the system. Monitoring instruments can be continuous or temporary.

16 Architecture atmospheric sub-system

A.k.a., Atmospherics engineering, climactic design, HVAC engineering, ventilation engineering, refrigeration engineering, mechanical atmospheric system.

Atmospheric thermal conditions can be changed with energy from several sources, including:

1. Natural ventilation.
2. Electrical ventilation.
3. Electricity (refrigeration or direct heating).
4. Combustion (hydrocarbons or carbon).
5. The underground earth.

An atmospheric system must account for at least the following characteristic factors of air (atmosphere is the object) and its movement (as a set of concepts):

1. Atmosphere (and machine objects that interface with the atmosphere object).
2. Air temperature (concept).
3. Air velocity (concept).
4. Air humidity (concept).
5. Environmental illumination (vision).

Healthy ventilation is crucial for keeping indoor air free from not only infectious pathogens but also from harmful contaminants, which come in particulate and gaseous form. Healthy illumination is essential for safely moving in an enclosed environment.

16.1 Atmospheric standards

Atmospheric/HVAC standards include, but are not limited to:

1. ANSI/ASHRAE Standard 180-2018 - Standard Practice for Inspection and Maintenance of Commercial Building HVAC Systems.
   A. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).
2. Air Conditioning Contractors of America (ACCA).
3. Air Conditioning and Refrigeration Institute (ARI).
4. National Fire Protection Association (NFPA).
5. Sheet Metal & Air Conditioning Contractors National Association (SMACNA).

16.1.1 Standard atmospheric documentation

A.k.a., Atmospheric system specification and drawings.

Atmospheric systems are documented via specifications and drawings.

1. Atmospheric drawings (a.k.a., HVAC schematics, atmospheric schematics) illustrate the system that will support airflow and transfer thermal energy. Atmospheric (HVAC) drawings illustrates the atmospheric system.
2. Atmospheric specifications include all written content, reasoning for decisions, and calculations.

16.1.2 Atmospheric system planning

Firstly, an atmosphere (i.e., climactic, ventilation) modifying systems can be:

1. **Passive (a.k.a., natural ventilation, bioclimactic ventilation)** - is an approach to architectural design that relies on natural environmental factors and building elements to regulate indoor air quality and temperature. The primary passive ventilation strategies include:
   A. Site Orientation: Properly aligning the building on the site to maximize exposure to prevailing winds and optimize solar gain for natural heating and cooling.
   B. Materials Selection: Using construction materials and finishes that have thermal properties and insulation characteristics that contribute to passive temperature control.
   C. Openings Area: Designing the building with strategically placed windows, vents, and openings to facilitate cross-ventilation and the circulation of fresh air.
2. **Active (a.k.a., mechanical ventilation)** - relies on mechanical systems that require electricity to manage indoor air quality and temperature. This category encompasses various powered HVAC (Heating, Ventilation, and Air Conditioning) systems, including:
   A. Forced air heating and cooling systems.
   B. Ventilation systems with fans and ductwork.
   C. Air conditioning units.
   D. Heat pumps.
   E. Exhaust fans.
   F. Climate control systems that regulate temperature and humidity electronically.

An atmospheric plan covers the following elements:

1. System concept.
2. Load calculation.
3. System zoning.
4. Air distribution.
5. Equipment selection.
6. Duct size calculation.
7. Adjustment, testing and balance.

The atmospheric plan includes standards for ventilation and air quality for all buildings. It also covers requirements for the prevention of condensation and other hazards.

16.1.3 Climate specific planning

In cold weather, it is also important to recycle thermal energy so the heat carried by the outgoing air is not totally lost to the ambient environment. Mechanical ventilation systems recycle heat (or enthalpy) using one of two methods:

1. Cleaning the return air and mixing it with outdoor air before conditioning it and recirculating it indoors.
2. Using heat exchangers, putting the incoming and outgoing streams in close thermal contact without mixing them, so that heat recovery occurs.

It is possible to recover heat using passive methods also through buoyancy ventilation and appropriate space configurations. (Halepaska, et al., 2023)

16.1.4 Standard atmospheric requirements

What is required for a viable atmospheric production-distribution system is:

1. **For architecture** - heating, ventilation, and air cooling (HVAC) production proportionate to electrical/combustion power and air demand [via a load].
   A. Herein, a load means the amount of heating or cooling required by a building.].
2. **For economic calculation** - Data sheet about loads (HVAC appliances) to produce optimization calculation.
3. **For life support demand** - HVAC proportionate to human demand.
4. **For technology and exploratory demand** - HVAC proportionate to human demand.

16.2 Conception of the atmospheric service system

An atmospheric system specification may include:

1. Ventilation system:
   A. Ventilation points.
   B. Conduits.
   C. Fans.
   D. Filtration.
2. Types of ventilation:
   A. Mechanical ventilation.
   B. Natural ventilation.
3. Types of atmospheric movement (atmospheric pressure-driven conduit types):

   A. Positive pressure conduits and vents.
      1. Outlet vents.
   B. Negative pressure conduits and vents.
      1. Inlet vents
      2. Suction (vacuum) conduits and vents.
4. Types of air processing:
   A. Temperature:
      1. Heat removers (coolers).
      2. Heat adders (heaters).
   B. Mechanical:
      1. Particulate modifiers.
         i. Mechanical filters (e.g., HEPA).
   C. Electrical:
      1. Ionic filters (using negatively charged metal plates).
   D. Chemical:
      1. Electrical ozone production (a type of electrical modification).
      2. Other chemical types (e.g., added oxygen or CO_2).
5. Types of piping:
   A. Hydronic water piping.
   B. Refrigerant fluid piping.
   C. Water drain piping.
   D. Ducting for atmosphere transfer.
6. Temperature adjustment:
   A. Types of heating:
      1. Centralized.
         i. Vented atmospheric heating (by means of centralized ducting).
         ii. Centralized under-floor heating (centralized by means of heated water or electricity).
         iii. Centralized wall-attached heating (centralized by means of heated water or electricity).
      2. Distributed.
         i. Localized under-floor heating (by means of one water heater or one electric distribution point).
         ii. Localized wall-attached heating (by means of one water heater or one electric distribution point).
         iii. Localized air circulation heating (e.g., mini-split heat pumps).
   B. Types of cooling:
      1. Centralized.
         i. Vented atmospheric cooling (by means of centralized ducting).
      2. Distributed.
         i. Localized circulation cooling (e.g.. mini-split heat pumps and air conditioners).

16.3 Conception of the atmospheric control sub-system

An atmospheric control system is the system of controls that change atmospheric and surface (thermal) parameters over time. Such a system incorporates communication between various system inputs and outputs related to the atmosphere and surface temperatures. Atmospheric control may be more automated ("intelligent") or more manual.

An atmospheric control system may have any of the following functions:

1. **On/Off switch** that turns the atmospheric system (and sub-systems) on and off.
2. **Volume and velocity control** that makes the system cycle or output more air.
3. **Thermal control (a.k.a., temperature control)** that makes the system change the output temperature.

Atmospherics can be regulated through the following methods:

1. Atmospheric processing and cycling can be set with timers.
2. Heaters and coolers can be put on timers.
3. Atmospherics can be connected to motion sensors.
4. Atmospherics can be connected to electromagnetic sensors (i.e., sensors that detect sunlight).
5. Atmospherics can be connected to particle sensors (i.e., presence of dust, contaminant, etc.).
6. Atmospherics can be connected to alarms.

16.3.1 Thermostat

A.k.a.,, Thermostatic regulator, thermostatic controller.

A thermostat is a device that turns the HVAC unit on and off to maintain the temperature at the thermostat close to the specified setting. Simplistically, it is a device that monitors the indoor temperature and automatically adjusts the heating and/or cooling system to maintain the desired level. A thermostat is wired to a heating and/or cooling unit and acts as a thermometer, switch, and temperature controller. It is typically mounted on an interior wall and, alone, cannot measure temperature throughout the house – only near the thermostat.

Most thermostat modules should be placed:

1. So that it is easily accessible.
2. Possibly in a central location in the structure.
3. At eye-level for adults, or possibly lower for children.
4. Away from sunlight (and other temperature extremes.

Thermostats have a basic task - to maintain the temperature of an area (as in, some configuration of floor, wall, ceiling, room volume area. If the temperature falls below the set-point, or desired temperature, the thermostat enable the heating system, or cooling system in the sense of rising above the set-point. Once the temperature reaches the setpoint, the system either disable the heating/cooling system or maintains the area with less power. A programmable thermostat has [at least] two inputs: the setpoint and the current temperature. In most cases, the user programs the setpoint at various activities and/or times of day for each day of some calendar cycle (e.g., week). The thermostat then monitors and compares the current temperature to the desired setpoint and acts accordingly. The Nest learning thermostat also allows the user to set a schedule, but has a few more inputs, such as occupancy and manual overrides. If the schedule says 23 Celsius, but the thermostatic system doesn't sense anyone is in the area (e.g., home), then it will lower the temperature automatically. These systems can be designed to "learn" users' atmospheric habits. For example, imagine a case where every morning someone set the thermostat to 20 Celsius, the intelligent thermostat would remember and predict, and thus, adjust the schedule over time to mirror your preferences.

16.4 Conception of the atmospheric processing sub-system

A.k.a., Atmospheric processing and distribution systems.

An atmospheric processing system is a machine or technology that is used to change the material characteristics of the atmosphere, and/or its direction of flow.

Atmospheric processing systems can perform the following functions:

1. Temperature control - regulated by a thermostat (Read: temperature controller):
   A. Cooling of interior area:
      1. Central cooling.
      2. Space cooling.
   B. Cooling of limited interior space:
      1. Refrigerator (cooling without freezing).
      2. Freezer (deep refrigeration).
   C. Heating of interior area:
      1. Central heating.
      2. Space heating.
2. Air direction control:
   A. Air circulation (fans and ducts; e.g., air handler).
3. Area air-water control:
   A. Humidification (humidificator).
   B. Dehumidification (de-humidificator).
4. Localized drying control:
   A. Dryer (for drying of fabrics).
5. Air purity control:
   A. Purification (purificator).

16.5 Conception of the heating, ventilation, and air conditioning (HVAC) sub-systems

A.k.a., Heating and cooling atmospheric processing systems, heating and cooling atmospheric fixtures.

Heating, ventilation, and air conditioning (HVAC) systems can be classified according to:

1. Atmospheric processing type.
2. Distribution type.

The required atmospheric processes for an HVAC system include:

1. The heating process.
2. The cooling process.
3. The ventilation process.

Other atmospheric processes can be added, such as:

1. Ventilation fans.
2. Humidification.
3. Dehumidification.
4. Filtration.

In concern to distribution type, HVAC systems come in two general types depending upon whether they have venting to the exterior environment as well as venting throughout the interior environment (Seyam, 2018):

1. Exterior environmental venting?
   A. Has venting to the exterior environment.
      1. Ducted (vented, central, centralized).
   B. Does not have venting to the exterior environment
      1. Ductless (non-vented, local, mini-split, mini-split).
2. Interior area venting?
   A. Has venting throughout the interior environment.
      1. Ducted (vented, central, centralized).
   B. Does not have venting throughout the interior environment.
      1. Ductless (non-vented, local, mini-split, mini-split).

The same information could alternatively be displayed as follows:

1. Ducted (vented, central, centralized):
    A. Has venting to the exterior environment.
    B. Has venting throughout the interior environment.
2. Ductless (non-vented, local, mini-split, minisplit):
    A. Does not have venting to the exterior environment
    B. Does not have venting throughout the interior environment.

Central HVAC systems (ducted HVAC systems) are located in a central equipment room and deliver the air by a delivery ductwork system. Central HVAC systems can be all-air, air-water, or all-water systems. Numerous air quality products integrate easily with whole-building, ducted systems. These include humidifiers, dehumidifiers, and air purifiers.

A ductless indoor unit blows conditioned air and/or heats directly into one living space without ducts. Ductless systems can be configured with either one or multiple indoor units.

16.5.1 HVAC components

Basic (generalized) components of an HVAC system include, but are not limited to:

1. Mixed-air plenum and outdoor air control.
2. Air filter.
3. Supply fan.
4. Exhaust or relief fans and an air outlet.
5. Outdoor air intake.
6. Ducts (ventilation conduits)
7. Terminal devices.
8. Return air system.
9. Heating and cooling coils.
10. Self-contained heating or cooling unit.
11. Cooling tower.
12. Boiler.
13. Water chiller.
14. Humidification and dehumidification equipment.
15. Control.

HVAC systems commonly include the following equipment:

1. Primary equipment:
    A. Heating equipment.
    B. Cooling equipment.
    C. Air delivery equipment (i.e., air handlers).
2. Space requirements:
    A. Equipment rooms.
    B. HVAC systems.
    C. Fan rooms.
    D. Conduits.
    E. Equipment access.
3. Atmospheric distribution:
    A. Terminal units.
    B. Ductwork.
4. Hydronic piping (fluid conduiting):
    A. System piping (supply and return).
    B. Delivery piping.

Horizontal hierarchy representation of the main types of central HVAC systems:

1. All air systems:
    A. Single zone.
    B. Multi zone.
    C. Terminal reheat.
    D. Dual duct.
    E. Variable air volume.
2. Air-Water systems:
    A. Fan coil units.
    B. Induction units.
3. All water systems.
    A. Fan-coil units.
4. Water-source heat pumps.
5. Ground-source heat pumps (geothermal).
6. Heating and cooling panels.

Table 9. *Table shows the difference between central and decentralized HVAC systems based upon a set of criteria.*

Criteria	Central system	Decentralized system
Temperature, humidity, and space pressure requirements	Fulfilling any or all of the design parameters	Fulfilling any or all of the design parameters
Capacity requirements	Considering HVAC diversity factors to reduce the installed equipment capacity Significant first cost and operating cost	Maximum capacity is required for each equipment Equipment sizing diversity is limited
Redundancy	Standby equipment is accommodated for troubleshooting and maintenance	No backup or standby equipment
Special requirements	An equipment room is located outside the conditioned area, or adjacent to or remote from the building Installing secondary equipment for the air and water distribution which requires additional cost	Possible of no equipment room is needed Equipment may be located on the roof and the ground adjacent to the building
First cost	High capital cost Considering longer equipment services life to compensate the high capital cost	Affordable capital cost

Criteria	Central system	Decentralized system
Operating cost	More significant energy efficient primary equipment A proposed operating system which saves operating cost	Less energy efficient primary equipment Various energy peaks due to occupants' preference Higher operating cost
Maintenance cost	Accessible to the equipment room for maintenance and saving equipment in excellent condition, which saves maintenance cost	Accessible to equipment to be located in the basement or the living space. However, it is difficult for roof location due to bad weather
Reliability	Central system equipment can be an attractive benefit when considering its long service life	Reliable equipment, although the estimated equipment service life may be less
Flexibility	Selecting standby equipment to provide an alternative source of HVAC or backup	Placed in numerous locations to be more flexible

16.5.2 HVAC Zoning

Zoning allows for the creation of customized temperature zones throughout a building, which allows for greater temperature preference control and efficiency. This process allows the user(s) to set the conditions independently for each section of a building. Depending upon the specific type of HVAC machine, both split-type systems and central ducted systems have the capacity for single and multi-zoning.

16.5.2.1 Ducted HVAC zoning

Here, a zoned system is a single HVAC system serving two or more zones, rather than two separate HVAC systems. A ducted zoning system (a.k.a., zoned HVAC) is a system that uses dampers in the ductwork to regulate and redirect processed air to specific areas of a building. In this case, HVAC zoning utilizes a series of dampers that are installed either in the ducts or at the air vents. These dampers can open or close mechanically as needed to deliver airflow.

Ducted systems can be zoned in two ways. First, these systems can be zoned manually with each zone having its own thermostat. Secondly, these systems can be zoned centrally by an intelligent central controller that allows for adjustment of all zones from one central location.

If multiple ducts or air registers serve a particular part of the building, multiple dampers will move at once. Note that an air register is the same thing as a grille (vent), but with adjustable dampers in it. In other words, a register is a grille with moving parts, capable of being opened and closed and the air flow directed

16.5.2.2 Ductless HVAC zoning

Ductless zoning, unlike ducted zoning, requires more than one air handling unit. Ductless systems can be zoned in two ways. Firstly, these systems can be zoned manually, wherein multiple thermostats are located in various areas of the building to turn on/off and set the temperature of specific units in those areas. Secondly, these systems can be zoned centrally by an intelligent central controller that turns individual units on/off and sets their temperature.

16.6 Conception of the admospheric ducting sub-system

A.k.a., HVAC ducting.

Ducting is the process of selecting and routing a ducting network. The process of ducting involves:

1. **Ducts (ducting types)** - duct material based (may include function):
   A. Material based (i.e., the physical/material composition of the ducts).
   B. May also include system-type (e.g., atmosphere type). But, this is not necessary; all that is necessary (often appropriate) is material type).
   C. Contains routing preferences.
2. **Ducting systems** - ducting system categories (a system of classification by ducting system function; e.g., hot air, cold air, purified air, vacuum, etc.).
   A. Customizable potentially by:
      1. Materials.
      2. Mechanical calculations.
      3. Atmosphere/gas type.
      4. Temperature.
      5. Atmospheric density.
      6. Flow conversion method.

TERMINOLOGICAL CLARIFICATION: *A forced air system is essentially any HVAC system that delivers temperature-controlled air into your home via ducts and vents. Hence, a central air conditioning system uses the forced-air system to deliver cooled air, making use of the vents, plenums, and ducts to provide conditioned air. A central heating system does the same.*

It is important to note that having a ductless system may be more efficient, in that there is usually energy lost in duct work. The length, size, texture, configuration of ductwork can dramatically reduce energy efficiency.

16.6.1 Ducting system types by function

Ducting system types by function include:

1. Type of materials the that travel through ducts:

A. Used in ducting and connectors.
2. Type of atmosphere, including, but not necessary limited to:
   A. Hot air.
   B. Cool air.
   C. Vented air.
   D. Moist/humid air.
   E. Special systems:
      1. Vacuum.
      2. Toxic and/or other gases.

16.6.2 Ducting routing rules and parameters

The following measurement characteristics are used to design a ducting system to meet requirements (Bhatia, 2021):

1. Duct size
2. Fan size.
3. Duct shape.
4. Airflow volume.
5. Airflow pressure.
6. Air intake ducting.
7. Air outlet ducting.

16.6.2.1 The measurement of airflow through ducts

Air pressure is understood in the following ways:

1. **Mass:** Air has mass. The density of dry air is:
   A. 1.225 kg/m^3
   B. 0.0765 lb/ft^3.
2. **Atmospheric pressure** - Pressure of the atmosphere at the earth's surface NIST standard atmospheric pressure = 1.01325 bar.
   A. **BAR** - unit of pressure (or stress).
      1. 1 bar = 750.07 mm of mercury at 0°C, at 45°.
3. **Gauge pressure** - is pressure measured relative to ambient atmospheric pressure. Quantified in pounds per square inch-gauge (PSI-G).
4. **Absolute pressure** - is the total of the indicated gauge pressure plus atmospheric pressure. The zero reference in absolute pressure is a perfect vacuum, which has no atmospheric pressure at all. Pressure measured relative to full vacuum. Referred to as pounds per square inch-absolute (PSI-A).
   A. Absolute pressure = gauge pressure + atmospheric pressure

The pressure of airflow through ducts maintains three possible measurement values:

1. **Static pressure** - is the air pressure in the duct, which is used for fan selection. It is the pressure that causes air in the duct to flow. Static pressure is the outward push of air against duct surfaces and is a measure of resistance when air moves through an object like duct work. Measured in pascals per meters or inches of water column (in-wc). It acts equally in all directions and is independent of velocity.
   A. **External static pressure (ESP)** - is the static pressure created downstream of the AHU and it includes all the duct losses from the fan until it reaches the discharge point. This could include a negative static pressure on the pull side of the fan and a positive pressure on the push side, or any combination of pressures the fan must overcome. It is estimated by the HVAC design engineer as he lays out the ductwork, diffusers, and terminal devices.
   B. **Internal static pressure (ISP)** - is pressure as it pertains to the HVAC AHU, is the static pressure loss across the filters, coils, louvers, dampers, and twists and turns inside the AHU casing. ISP is usually provided by the supplier, but for custom designs, the HVAC design engineer estimates the pressure loss across the various components of the AHU
   C. **Total static pressure (TSP)** - is the sum of the external static pressure (ESP) and internal static pressure (ISP).
      1. TSP = ESP + ISP
2. **Velocity pressure** - is the pressure generated by the velocity and weight of the air, which is used for measuring the flow (m^3/s or cfm) in a system. Velocity pressure is the pressure caused by air in motion. It is equal to the product of air density and the square of the velocity divided by 2.
   A. VP = 0.5 x ρ x v2
   B. Using standard air, the relationship between V and VP is given by:
      1. $VP = (v / 4005)^2$
      2. VP will only be exerted in the direction of air flow and is always positive.
3. **Total pressure** - is used to find velocity pressure. Total Pressure determines the actual mechanical energy that must be supplied to the system. Total pressure equals static pressure plus velocity pressure. In other words, total pressure is the algebraic sum of velocity pressure and static pressure:
   A. TP = VP + SP
   B. TP = Total Pressure
   C. VP = Velocity Pressure
   D. SP = Static Pressure

Air flow is measured in the following ways and by the following units:

1. **Air volume of air flow (volumetric flow rate)** - determined by how many metric cubes per second (or, cubic feet per minute) of air pass by a stationary point.
   A. m^3/s - meters cubed / second.
   B. cfm - cubic feet/minute.
      1. Air volume in cfm can be calculated by multiplying the air velocity by the cross-sectional area of the duct in square feet or cubed millimeters:
         - cfm = fpm x area
         - Area = cfm/fpm
2. **Air velocity of air flow:**
   A. m/s - meters / second.
   B. fpm - feet / minute.
      - fpm = cfm/area
      - Area = cfm/fpm
3. **Duct shape size:**
   A. Diameter in metric or imperial.
   B. Length x height in metric or imperial.
4. **Friction loss.**
   A. Pa/100m - pascals / 100 meters
   B. H2O/100 ft - water / 100 feet

System capacity is directly affected by changes in air flow. As air is heated or humidified, its specific volume increases and its density decreases. If the air density is low, more air volume (in m^3/s or cfm) is required to keep the mass flow rate the same.

16.6.2.1 Best practice ducting routing rules

Some best practice ducting routing rules include, buy are not limited to (Bhatia, 2021):

1. **Configure the network appropriately:** Ducts should be designed so that the length of each run (each section of ductwork) is short enough to provide proper control of air flow and stability of construction. Radial or trunk-and-branch configurations have shorter runs and generally work best. Wherever possible, ducts should be located within the conditioned space. Do not twist or block ducts and do not position them so they may collapse in the future.
2. **Straightness is optimal:** this is the most important rule of all; reduce the number of bends and turns to an absolute minimum. From an energy perspective, air wants to go straight and will lose energy if it bends. From a cost perspective, straight ducts costs less than fittings. Fittings are more costly because they must be hand assembled even if the pieces are automatically cut by plasma cutters.
3. **Appropriately size the ducts:** Ductwork that's too small won't be able to carry enough air to heat or cool a building. Ducts that are too large can lose both air and energy, cutting system efficiency. Use industry standards and procedures, such as those published by ASHRAE, to size ducts.
4. **Calculate for sufficiency for sufficiency of return ducts:** Supply ducts carry conditioned air to the building, but the system also requires enough return ducts to bring expended air back to the HVAC unit to be conditioned again. Each room that receives heating or cooling should have at least one return duct (in a centralized system). As a rule of thumb, use 2 cfm for each sq.-inch of return air opening; for example, 20" x 20" grille equals 400 sq.-in. gross area of grille, which means 800 cfm of recommended air flow.
5. **Preferentially pass ducts through conditioned spaces:** Ducts placed in conditioned spaces are more efficient than those placed in unconditioned spaces. If located within conditioned space, conductive and radiative losses, leakage losses, and equipment cabinet losses are reduced or regained into the building space. If it is not feasible to locate ductwork within conditioned spaces, the ducts should be properly sealed and insulated. The trunk ducts are usually located above corridors in the cavity above the ceiling to minimize noise transmission to the conditioned zones and allow easy access without disturbing the building occupants.
6. **Appropriately design for thermal zoning:** Zoning is a practice of dividing a building into distinct thermal zones, which have similar heating and cooling requirements. In practice the corner rooms and the perimetric spaces of the building have variations in load as compared to the interior core areas. If zones have special temperature and/or humidity requirements, they should be served by independent air distribution systems separate from variable zones. The idea is to permit independent control of temperature and humidity in similar zones. Where it is not possible, consider use of VAV systems and/or supplementary controls. Some locations will have highly variable occupancy loads that must be accounted for so as not to waste energy and provide sufficient HVAC when occupied (e.g., conference rooms). Building are usually divided into two major zones:
   A. **Exterior zone:** This is the area inward from the outside wall (usually 12 to 18 feet, if rooms do not line the outside wall). The exterior zone is directly affected by outdoor conditions during summer and winter and has variable thermal loads.
   B. **Interior zone:** This is the area contained by the

external zone. The interior zone is only slightly affected by outdoor conditions and usually has a uniform and steady cooling load throughout.

7. **Seal and insulate sufficiently:** Make sure all ductwork sections fit together tightly. Connections can be mechanically sealed with sheet metal screws or other fasteners to improve connection strength. Seal connections with mastic or metal tape. Cover the ductwork with insulation, such as rigid fiber board or standard blanket-type insulation.
8. **Efficiency and effectiveness accounting rules:**
   A. **Account for attenuation over distance:** For supply ducts longer than 10 feet, the air is reduced in that run by 10% for every 5 feet over 10 feet. For example, a 30 foot run yields a reduction of 40% (30-10=20, 20÷5=4, 4×10=40%). Minimize length and restrictions. Keep the supply duct length as close to 10 feet as possible but never less than 6 feet. Use the fewest number of bends as possible.
   B. **Account for structural rigidity:** Use at least 24 inches of straight plenum before any fitting, such as an elbow, tee, or takeoff. Electric duct heaters require 48 inches. Avoid elbows directly off units. The maximum total plenum length should be restricted to 150 ft. For the plenum, maximize length and minimize restrictions.
   C. **Account for the degree of split of a tee connector:** When using a tee, split the flow as close to 50/50 as possible, no more than 60/40. Here, always use a turning vane.
   D. **Account for the degree of branch off a tee connector:** Turn the tee 90° to make a side branch with no more than 30 percent of the air. Do not use a turning vane.
   E. **Account for distance between takeoffs:** Maintain distance between takeoffs as evenly as possible. Space the takeoffs at least 6 inches apart and 12 inches from the end cap.
   F. **Use radiused over mitered fittings:** Use long and radiused duct fittings instead of short or mitered fittings wherever possible. Mitered (edged) fittings are less efficient (due to friction loss) than radiused (rounded) fittings.

16.6.2.1 Air flow characteristics in ducts

Air flow in ducts has the following characteristics (Bhatia, 2021, p.9-10):

1. At any point, the total pressure is equal to the sum of the static and velocity pressures.
2. The exertion of pressure is different for static pressure and velocity pressure.
   A. Static pressure (SP) is exerted equally in all directions. Static pressure is typically used for fan selection.
   B. Velocity pressure (VP) is exerted only in the direction of air flow. Velocity pressure is used for measuring cfm in a system.
   - This makes it difficult to directly measure velocity pressure in a duct; because, static pressure is also pushing in the direction of air flow, you can never measure just velocity pressure. Practically, velocity pressure is calculated by measuring pressure perpendicular to the air flow (Static Pressure) and also measuring pressure parallel to the air flow (Total Pressure). Once values for the two pressures are available, it is possible to subtract static pressure from the total pressure and derive the velocity pressure.
     - VP = TP - SP
3. Static and velocity pressure are mutually convertible. The magnitude of each is dependent on the local duct cross-section which determines the flow velocity. The following pressure changes are affected in the ducts:
   A. Constant cross-sectional areas: Total and static losses are equal.
   B. Diverging sections (increase in duct size): Velocity pressure decreases, total pressure decreases, and static pressure may increase (static regain).
   C. Converging sections (decrease in duct size): Velocity pressure increases in the direction of flow, total and static pressure decrease.
4. The total pressure generally drops along the air flow because of frictional and turbulence losses.

16.6.2.2 Types of ducting

A.k.a., HVAC ducts, duct fittings.

Ducts may be classified by (note: this content is usually defined in a set of piping standards):

1. Type of material (i.e., material composition of duct).
2. Function of duct network (e.g., to provide filtered air, cool and/or hot air, etc.).
3. Specific duct elements:
   A. Types of physical interconnection between duct elements (e.g., glue, screw, flange, etc.).
   B. Geometric function of duct elements (e.g., segment, curve, flexible, etc.).
   C. Conduit shape (e.g., square, round, oval.).
4. Sizes:
   A. United States, Canada, and Brazil.
   B. Europe.
   C. Australia.
   D. Russia..
   E. China.

F. Others

16.6.2.3 Types of duct by function

The air distribution system will have a designation depending on the function of the duct. There are five general designations of ducts by function:

1. **Supply air ductwork** - supplies conditioned air from the air handling unit to the conditioned area.
2. **Return air ductwork** - removes air from the conditioned building spaces and returns the air to the air handling unit, which reconditions the air. In some cases, part of the return air in this ductwork is exhausted to the building exterior.
3. **Fresh air ductwork** - supplies outdoor air to the air handling unit. Outdoor air is used for ventilating the occupied building space.
4. **Exhaust (relief) air ductwork** - carries and discharges air to the outdoors. Exhaust air is taken from toilets, kitchen, laboratories and other areas requiring ventilation.
5. **Mixed air ductwork** - mixes air from the outdoor air and the return air then supplies this mixed air to the air handling unit.

16.6.2.4 Components of a ducting system

The primary components of ducting system are:

1. **Plenum or Main Trunk** - is the main part of the supply and return duct system that goes directly from the air handler to the "Trunk Duct".
2. **Trunk duct** - when a duct is split into more than one duct, it is called a "trunk". Ducts that are on the end of a trunk and terminate in a register are called branches.
3. **Take off** - Branch ducts are fastened to the main trunk by a takeoff-fitting. The takeoff encourages the air moving the duct to enter the takeoff to the branch duct.
4. **Air terminals** - are the supply air outlets and return or exhaust air inlets. For supply, diffusers are most common, but grilles and registers are also used.
   A. **A diffuser** - is an outlet device discharging supply air in a direction radially to the axis of entry.
   B. **A register** - is a grille equipped with a volume control damper.
   C. **A grille** - is a register without a damper.

16.6.2.5 Types of ducting material

The primary types of metal material used in ducting include, but may not be limited to (Bhatia, 2021):

1. **Galvanized steel** - is used commonly for heat pumps and air conditioners.
   A. The specifications for galvanized steel sheet are ASTM A653, coating G90.
2. **Aluminium** - is widely used in clean room applications. These are also preferred systems for moisture laden air, special exhaust systems and ornamental duct systems.
   A. The specifications for Aluminium sheet are ASTM B209, alloy 1100, 3003 or 5052.
3. **Stainless steel** - is used in duct systems for kitchen exhaust, moisture laden air, and fume exhaust.
   A. The specifications for stainless steel sheet are ASTM A167, Class 302 or 304, Condition A (annealed) Finish No. 4 for exposed ducts and Finish No. 2B for concealed duct.
4. **Carbon steel (black iron)** - is widely used in applications involving flues, stacks, hoods, other high temperature and special coating requirements for industrial use.
5. **Copper** - is mainly used for certain chemical exhaust and ornamental ductwork.

The primary types of non-metal material used in ducting include, but may not be limited to (Bhatia, 2021):

1. **Fibreglass reinforced plastic (FRP)** - is used mainly for chemical exhaust, scrubbers, and underground duct systems. Advantages are resistance to corrosion, self-insulation, excellent sound attenuation and high quality sealing. Limiting characteristics include cost, weight, range of chemical and physical properties, and code acceptance.
2. **Polyvinyl chloride (PVC)** - is used for exhaust systems for chemical fumes and underground duct systems. Advantages include resistance to corrosion, light weight, and ease of modification. Limiting characteristics include cost, fabrication, code acceptance, thermal shock, and weight.
3. **Fabric (a.k.a., textile ducts)** - is usually made of special permeable polyester material and is normally used where even air distribution is essential. Due to the nature or the air distribution, textile ducts are not usually concealed within false ceilings. Condensation is not a concern with fabric ducts and therefore these can be used where air is to be supplied below the dew point without insulation.
4. **Flex duct** - consists of a duct inner liner supported on the inside by a helix wire coil and covered by blanket insulation with a flexible vapor barrier jacket on the outside. Flex ducts are often used for runouts, as wellas with metal collars used to connect the flexible ducts to supply plenums, trunks and branches constructed from sheet metal or duct board. Flex ducts provide convenience of

installation as these can be easily adapted to avoid clashes but has certain disadvantages. These have more friction loss inside them than metal ducting. Flex duct runs should be as short as possible (1.5-1.8m or 5-6ft max.), and should be stretched as tight as possible.

NOTE: *Pressure in the air conditioning ducts is small, so materials with a great deal of strength are not needed. The thickness of the material depends on the dimensions of the duct, the length of the individual sections, and the cross-sectional area of the duct.*

16.6.2.6 Ducts classified by velocity and pressure

Ducts are classified into 3 basic categories in terms of velocity (Bhatia, 2021):

1. **Low velocity systems** - are characterized by air velocities up to 2000 fpm.
2. **Medium velocity systems** - are characterized by air velocities in the range of 2,000 to 2,500 fpm.
3. **High velocity systems** - are characterized by air velocities greater than 2,500 fpm.

DESIGN RELATIONSHIP CONSIDERATION:
Duct velocity influences noise, vibration, friction losses and fan power.

High duct velocities result in lower initial costs but require increased fan static pressures; therefore, resulting in increased energy usage. Often these need additional noise attenuation (use of noise silencers) and are not suitable for comfort applications. Generally, high-velocity systems are applicable to large multi-story buildings, primarily because the advantage of savings in duct shafts and floor-to-floor heights is more substantial. Small two- and three-story buildings are normally low velocity. A velocity of 1,000 to 1,500 fpm for main ducts and a velocity of 700 to 1,000 fpm for the branch take offs are recommended.

Ducts are classified into 3 basic categories in terms of pressure (Bhatia, 2021):

1. **Low pressure** - applies to systems with fan static pressures less than 3 inches WC. Generally, duct velocities are less than 1,500 fpm.
2. **Medium pressure** - applies to systems with fan static pressures between 3 to 6 inches WC. Generally, duct velocities are less than or equal to 2,500 fpm.
3. **High pressure** - applies to systems with fan static pressures between 6 to 10 inches WC. Usually the static pressure is limited to a maximum of 7 inches WC, and duct velocities are limited to 4,000 fpm. Systems requiring pressures more than 7 inches WC are normally unwarranted and could result in very high operating costs.

DESIGN RELATIONSHIP CONSIDERATION:
Duct pressure influences the duct strength, deflection and air leakage.

Good engineering practices for duct pressurization are:

1. Use of medium pressure classification for primary air ductwork (fan connections, risers, and main distribution ducts).
2. Use of low pressure classification for secondary air ductwork (runouts/branches from main to terminal boxes and distribution devices).

16.6.2.7 Types of duct sizes

Different ducting networks will need different sizes of duct.

The current practice is to determine duct size through the following:

1. Nominal diameter.
2. Outside diameter.
3. Inside diameter.
4. The duct schedule (or wall thickness).

16.6.2.8 Types of duct shape

Different ducting networks will need different shapes of duct.

Ducts typically come in three types, each with advantages and disadvantages:

1. **Round** - is the most efficient (offers the least resistance) in conveying moving air is a round duct, because it has the greatest cross-sectional area and a minimum contact surface. In other words, it uses less material compared to square or rectangular ducts for the same volume of air handled. Some of the advantages of round ductwork include:
    A. Round shape results in lower pressure drops, thereby requiring less fan horsepower to move the air and, consequently, smaller equipment.
    B. Round shape also has less surface area and requires less insulation when externally wrapped.
    C. Round ducts are available in longer lengths than rectangular ducts, thereby eliminating costly field joints. Spiral lock-seams add rigidity; therefore, spiral ducts can be fabricated using lighter gauges than longitudinal seam ducts. Spiral ducts leak less and can be more easily sealed compared to rectangular ducts.
    D. The acoustic performance of round and oval ducts is superior because their curved surfaces

allow less breakout noise. The low-frequency sound is well contained in round ducts.
   E. Round ducts can help promote healthier indoor environments. Less surface area, no corners and better air flow reduce the chance of dirt and grime accumulating inside the duct and, therefore, becoming a breeding ground for bacterial growth.
2. **Rectangular** - fit above ceilings and into walls, and they are often easier to install between joists and studs. Disadvantages of rectangular ducts are as follows:
   A. They create higher pressure drop.
   B. They use more pounds of material for the same air-flow rate as round ducts.
   C. Their joint length is limited to the sheet widths stocked by the contractor.
   D. Their joints are more difficult to seal.
   E. Ducts with a high aspect ratio can transmit excessive noise if not properly supported.
3. **Oval** - have smaller height requirements than round ducts and retain most of the advantages of the round ducts. However, fittings for flat oval ducts are difficult to fabricate or modify in the field. Other disadvantages include:
   A. Difficulty of handling and shipping larger sizes.
   B. Tendency of these ducts to become more round under pressure.
   C. In large aspect ratios, difficulties of assembling oval slip joints.

16.6.2.9 Types of ducting interconnections

Connectors for ducting include, but may not be limited to:

1. By geometric function of element:
   A. Straight connector.
   B. 90 degree bend.
   C. Other degree bends.
   D. T connector.
   E. Cross connector.
   F. Size adapter.
2. By physical interconnection:
   A. Compression connection.
   B. Welded (solder connection).
   C. Threaded (screw connection).
      1. With plumbing this often necessitates another tape like material that is first twisted around the part to be screwed.
   D. Flanged connection.
   E. Glued connection.
3. By conduit shape:
   A. Rectangular.
   B. Round.
   C. Oval.

16.6.2.10 Types of ducting elements

Ducting elements include:

1. **Pipe segment** - straight, horizontal segment of pipe.
2. **Elbow** - curved piece that joins two pipes.
   A. 90 degree.
   B. 45 degree.
   C. Etc.
3. **Junction**
   A. Tee - shaped like a T; connects 3 pipe segments.
   B. Tap.
4. **Cross** - connects 4 pipe segments.
5. **Transition** - adapter element for changing pipe sizes.
6. **Union** - connector of 2 pipe segments.
7. **Flange** - connects piping and components in a piping system by use of bolted connections and gaskets.
8. **Cap** - closes (seals off) end of a pipe.

Note: The above types of [duct] fittings (unions, interconnections) can be set for routing a duct.

16.6.2.11 Fan selection

The fan must be selected to deliver a specific volumetric flow rate and generate static pressure to overcome the pressure losses due to ducts (length and dimensions), fitting, and the components of an air handling unit (AHU).

16.7 Objects in the atmospheric system: fixtures, fittings, and appliances

Atmospheric fixtures and fittings are equipment that interface with the atmosphere in a building:

1. **Atmospheric fixtures** - a device for processing air. The most common fixtures include, but may not be limited to:
   A. Heating, ventilation, and air conditioning (HVAC) systems.
      1. Ventilation exchange systems.
      2. Air conditioner machines.
      3. Heat pump machines.
      4. Underfloor heating system.
      5. Furnace system.
      6. Etc.
   B. Exhaust fans:
      1. Humidity exhaust fans.
      2. Kitchen exhaust fans.
      3. Hazardous chemical exhaust fans.
2. **Atmospheric fittings** - a device designed to control and guide the flow of atmosphere. The most common fittings include, but may not be limited to:
   A. Vents.

B. Air intakes.
C. Thermostats.
D. Duct airflow monitoring devices (e.g., anemometer and manometer).
E. Drain (e.g., for heat pumps and air conditioners).
F. Etc.

3. **Atmospheric appliances** - appliance devices that change the atmosphere, the most common of which include:
    A. Drying machine.
    B. Air purifier (portable).
    C. De-/humidifier (portable).
    D. Refrigerator
    E. Freezer
    F. Vacuum (a type of atmospheric filter; can be central or portable)

IMPORTANT: *All fixtures, fittings, and appliances must be specified with the right capacity for their placement.*

16.7.1 Ventilator exchange systems (VES)

A.k.a., Ventilation recovery systems, air exchange solutions, ventilation renewal systems, air circulation systems, fresh air exchange (FAE) systems.

A ventilator exchange system, also known as an air exchange system or ventilation system, serves to improve indoor air quality by replacing stale or polluted indoor air with fresh, outdoor air. Its primary functions include:

1. Intake - brings in air from the outside surrounding environment.
2. Air circulation - circulates air throughout a building or enclosed space, ensuring a constant flow of fresh air.
3. Filtration: incorporate air filtration to remove contaminants such as dust, allergens, and pollutants from the incoming and circulating air.
4. Temperature control: regulates indoor temperatures by pre-conditioning incoming air to ensure it is comfortable for occupants and objects.
5. Humidity control: uses control mechanisms to maintain optimal indoor humidity levels, by increasing or decreasing humidity as required.
6. Exhaust: expels stale or contaminated indoor air, preventing the buildup of pollutants and maintaining a healthy indoor environment.

Ventilator exchange systems include, but are not limited to:

1. Energy recovery ventilator (ERV).
2. Heat recovery ventilator.
3. Fresh air exchange system.

16.7.2 Air handling systems

A.k.a., Air circulation systems, air handling fixtures, air circulation fixtures, air handling unit (AHU).

Air handlers are a complementary component of space heating and air conditioning equipment that distribute air within building interiors. Air handlers also provide filtering, and they ensure a constant supply of outdoor air. Air handlers sustain the airflow required to deliver heating or cooling for indoor areas. In the air handler, the air supply is blown through a heating and/or cooling element before circulating through the indoor area. Air handlers are generally equipped with filters. The filter is normally placed at the air handler intake to protect internal components from dust and other polluting particles. Filtering requirements change depending on the application; for example, medical facilities and some manufacturing processes require highly purified air quality. (Air Handlers, 2021)

There are two general types of air handlers:

1. Localized air handler - are included in small air conditioners and packaged units within which air handlers are built-in.
2. Central air handlers - are used in large HVAC systems where hydronic piping connects to air handlers with chillers and/or boilers.

Based on their connection two a duct system, there are two types of air handlers:

1. Air handling units designed for connection to a duct system, where the airflow in each area is controlled with dampers. Central air handlers generally use ducts.
2. Air handler units that discharge air directly into indoor spaces, without ducts. Localized air handlers generally do not use ducting.

Based on their physical construction and applications, air handlers may be classified as follows:

1. Fan coil units - compact air handlers with a simple construction. Their basic components are a fan, a filter, and a heating or cooling coil.
2. Make-up air units - larger air handlers designed to condition outdoor air and deliver it to indoor spaces. These air handlers do not recirculate indoor air.
3. Rooftop package units - are used in larger HVAC systems and designed for exterior installation within a rooftop HVAC system configuration.

Heat exchangers are a fundamental component of air handlers. Depending on how heat is delivered or removed, these heat exchangers are classified as:

1. Direct heat exchange air handlers - move air directly through heating or cooling elements. For example, air is blown through electrical resistance units or gas burners in heating applications, or through AC evaporator units when cooling is required. Air handlers can also be integrated with heat pumps to provide heating and cooling with the same device.
2. Indirect heat exchange air handlers - do not move air through the heating or cooling unit. Instead, another substance is used to supply or remove heat. Water is the most common option, since it can be used for either heating or cooling, by circulating it through a boiler or chiller. Steam and refrigerant fluids are other options.

Air handlers with separate heating and cooling coils can provide dehumidification. Air is cooled below the required temperature to remove humidity by condensation. Since this process cools the air excessively, the heating coil is then used to raise temperature back to a comfortable level. (Air Handlers, 2021)

Air handlers are applied to provide sufficient airflow when the building is at full occupancy. Demand-controlled ventilation (DCV) involves the adjustment of airflow according to occupancy, with the purpose of conserving power. It is possible to monitor occupancy, and this information is used to decrease airflow when the full capacity is not required. When deploying demand-controlled ventilation, the speed of fans can be adjusted with variable frequency drives (VFD), which reduce fan power in cubic proportion to fan speed. For example, if a VFD reduces fan speed to some lower percentage of its rated RPM, then power consumption is also reduced by some percentage. The performance of air handlers can also be increased with heat recovery systems, which exchange heat between the outdoor air supply and the exhaust of a ventilation system. During summer, a heat recovery system uses the exhaust air to remove heat from the outdoor air supply. Since the outdoor air reaches air handlers at a lower temperature, the cooling load is reduced. The opposite process applies during winter, where the exhaust air is used to preheat the outdoor air supply. In this case, the heating load is reduced. (Air Handlers, 2021)

Noise and vibration are common issues when air handlers are not designed or installed properly, or when maintenance has been lacking. Oversized fans and inadequate air handler supports are two common causes of noise and vibration issues.

The internal mechanical components will wear down over time, and rotating elements of motors and fans can start experiencing unbalance and misalignment, producing more noise and vibration. A certain degree of noise and vibration is unavoidable when using air handlers, especially when dealing with a large unit. (Air Handlers, 2021)

16.7.2.1 Positioning of interior air handlers

Interior air handlers are generally placed on the wall near the ceiling and oriented in a manner that is unlikely to blow air on occupants.

16.7.3 Heat pump atmospheric processing systems

A.k.a., Combined heating and cooling atmospheric processing systems.

A heat pump is a device that transfers heat between the inside of a building space and the outside environment. It is an atmospheric processing system that transfers thermal energy from a cooler location to a warmer location using the refrigeration cycle, being the opposite direction in which heat transfer would take place without the application of external power. A heat pump works similarly to a refrigerator or air conditioner -- it uses electricity and a refrigerant to “pump” or move heat from one location to another by using a compressor and a circulating structure of liquid or gas refrigerant. In a heat pump, electricity is used by the compressor to send refrigerant around the system, capturing heat from outside, or inside, and bringing it to the opposite side of the split system. A pure heat pump does not generate heat by electrifying metal (e.g., light bulb) or oxidizing organics (e.g., furnace).

NOTE: *Heat pumps can be used to transfer thermal energy between different materials. There are heat pumps that combine heating, cooling, and water heating.*

There are two general variants of heat pumps categorized by the direction of thermal energy transfer:

1. **Reversible heat pumps (two-way heat pumps)** - work in both directions to keep both the heat and the cold-regulated. A reversible heat pump is essentially an all-in-one air conditioning and heating system that works year-round. These systems conduct heat from the outdoors to the indoors during times of cold (i.e., in winter). When it is hot outside (i.e., in summer), these pumps convect heat out from inside a building, keeping the inside cool. Reversible simply means that the flow of refrigerant can be reversed, and is therefore able to draw ambient heat from outside to provide indoor heating. By means of a reversing valve in the outdoor unit, a heat pump can absorb heat energy from outside air, even in cold temperatures, and transfer the heat inside the building. In other words, these systems use a reversing valve to reverse the flow of refrigerant from the compressor through the condenser and

evaporation coils. Reversible heat pumps are more effective throughout the whole year than irreversible heat pumps.

A. In heating mode, a heat pump collects heat from the air, water, or ground outside a structure, then concentrates it and transfers it for use inside. During the heating cycle, the outdoor coil is the evaporator, and the indoor one functionings as the condenser. Here, heat pumps are three to four times more effective at heating than simple electrical resistance heaters using the same amount of electricity; they can have coefficient of performance (COP) = 4.

B. In cooling mode, the heat pump collects thermal energy from air inside the structure and transfers it outside. In other words, they use a refrigerant to absorb heat from the air inside a building and transport it outside. During the cooling cycle, the outdoor coil is the condenser, and the inside one the evaporator. The COP for cooling mode is less than for heating mode, because the work done by compressor is utilized only during the heating mode.

2. **Irreversible heat pumps (one way heat pumps)** - heat pumps that can only transfer heat one way.
   A. **Heating mode only irreversible heat pumps** - can only transfer heat from outside to the inside and will have no effect in the summer (when it is hot outside). A separate cooling system will need to be installed for when it is hot outside.
   B. **Cooling mode only irreversible heat pumps (a.k.a., air conditioner, AC, air con, air-con, etc.)** - can only transfer heat from the inside to the outside. An air conditioner (AC) is basically a one way heat pump; an irreversible heap pump is generally called an "air conditioner". It can cool, but cannot heat. All air conditioners work on the heat pump principle that they draw heat out of an area.

Reversible heat pumps are machines that are capable of producing both heating and cooling [within a single device] for an environment. A reversible heat pump can heat and cool. It is important to note here that although a reversible heat pump can heat a structure, when outside temperatures drop below freezing, the efficiency of a heat pump is significantly affected. Typical reversible heat pump systems have an auxiliary heater added to the indoor unit to add supplemental heat when outdoor temperatures drop below freezing.

TERMINOLOGICAL CLARIFICATION: *The term heat pump is usually reserved for a device that transfers heat from outside to inside to heat a building. However, in the United States, the term, heat pump, generally refers to the reversible version of the heat pump (i.e., a two-way heat transfer heat pump that can cool and heat).*

There are three main types of heat pumps (note: all three of these operate on the same principles, except they gather heat from different sources:

NOTE: *These are all split atmospheric processing machine with a part of the machine interior to the building and another part of the machine exterior to the building.*

1. **Air source heat pump (a.k.a., air-to-air heat pump):**
   A. Air source heat pumps extracts heat from outdoor air and transfers it into the building. The system is comprised of an indoor and outdoor unit and works by extracting heat from the outdoor air and transferring it into the building. This is one of the easiest and cheapest heat pumps to install and takes up little space. It is also the most common type of heat pump.
2. **Ground source heat pump (a.k.a., geothermal):**
   A. A ground source heat pump extracts the heat energy from the ground and soil around a building's foundation and transfers it into the building. Ground source heat pumps move heat through a series of pipes that are buried in loops outdoors
   B. The ground temperature is almost always warmer than the air in the winter, which is why ground source heat pumps are more efficient than air source heat pumps, especially in the winter months. In other words, ground-sourced heat pumps are typically more efficient than air-sourced because the ground has a higher density and heat capacity compared to air.
   C. A geothermal heat pump is also more reliable and quieter than an air source system. The main reason geothermal heat pumps haven’t become more widespread is due to the high cost of installation. For the system to work correctly, excavation is needed to insert long runs of tubing underneath or near the building. A newer system called “direct-injection” aims to make this process more affordable, but still requires more time, effort and money than air source.
   D. This type of heat pump requires earthwork excavation. For new builds, the cost can be incorporated within construction. The underground pipes that form the exterior part of the system extract some number of Watts per meter of pipe underground.
3. **Water source heat pump** (note: sometimes considered a sub-classification of geothermal heat pumps)**:**

A. Water sourced heat pumps are only viable if there is a body of water close to the building, such as a pond or river. Water sourced heat pumps can be of two types related to the water source they are connected to: closed loop (lake) or open loop (river). A water source heat pump extracts heat energy from water by pumping the water from the source directly through the heat pump. This method provides a more constant input temperature than an air source pump and is much cheaper to install than a ground source pump. Water source heat pumps require a constant flow of water and during the heart of the winter months, a second heat source may be needed as back-up.
B. If the refrigerant in the heat pump system leaks into a closed source water environment (and even into an open sourced water environment) it could kill fish and other aquatic life therein.
C. A non-reversing water source heat pump is one without a reversing valve, but where the flow of water can change direction instead of the refrigerant.

4. **Exhaust air heat pump (EAHP):**
   A. An exhaust air heat pump (EAHP) extracts heat from the exhaust air of a building and transfers the heat to the supply air, hot tap water and/or hydronic heating system (underfloor heating, radiators).
5. **Grey water heat recovery heat pump:**
   A. This type of heat pump is rare and is designed to recover heat from grey water plumbing.

Heat pumps can also be categorized based on how they heat and cool building interiors. The classification above describes where they exchange heat with the, but not how the heating or cooling effect reaches indoor spaces:

1. **Liquid-to-air heat pumps** - that heat or cool indoor air directly (similar to rooftop air conditioners). After being cooled or warmed, the air is circulated through indoor spaces using air-handling units and ductwork.
2. **Liquid-to-water** - heat pumps are similar to chilled water systems, wherein the heat pump is used to heat or cool water, which is then circulated through the building. The water then heats or cools indoor air as it circulates through fan-coils.

16.7.3.1 Geothermal systems (a.k.a., ground-source heat pumps, GSHP)

Geothermal heat pumps draw heat from the ground during the winter and transfer it indoors, and from the indoor air during the summer and transfer it into the ground. Geothermal systems can deliver atmospheric heating and cooling (as well as water heating). For water heating, it is possible to add a desuperheater to a geothermal heat pump system. A desuperheater is a small, auxiliary heat exchanger that uses superheated gases from the heat pump's compressor to heat water. Desuperheaters are also available for tankless or demand-type water heaters. Desuperheaters operate best in summer, when the compressor has more frequent operation. During the fall, winter, and spring, when the desuperheater isn't producing as much excess heat, the building will rely more on its storage or demand water heater.

Depending on region, the underground environment is an effective heat source during winter and an effective heat sink during summer. These systems pump heat between a building interior and the underground. Heat is extracted from the building and released underground during summer, and the opposite process is carried out during winter. A geothermal heat pump exchanges heat with the ground at relatively low depth in comparison to a geothermal power plant.

Geothermal systems can be classified into three main types, based on how they exchange heat with the underground:

1. **Direct exchange (DX)** - exchange heat using refrigerant lines that are buried in direct contact with the ground or groundwater, as implied by their name. This is the oldest type of geothermal system. Because heat is exchanged directly with the ground as refrigerant travels through buried piping, these systems have a higher efficiency and a lower installation cost than other geothermal heat pumps. Direct exchange heat exchangers are susceptible to refrigerant leakage and pipe corrosion, and they must be designed to withstand both conditions. Even a slight opening in refrigerant lines can cause a serious refrigerant leak and lead to groundwater contamination.
2. **Closed loop systems** - use water to exchange heat between the refrigerant and underground. Refrigerant never travels underground as a result. Water circulates through a series of buried loops before returning to the heat pump, releasing or gathering heat depending on the operating mode. Closed loop geothermal systems use a mixture of water and antifreeze in the underground piping loop. Leaks in closed loop systems are less serious because the refrigerant evaporates rapidly when exposed to the atmosphere.
3. **Open loop systems** - use water to exchange heat with the underground, but groundwater is pumped directly to the heat pump. The main drawback of open loop systems is that groundwater cannot be treated easily before circulating through the heat

pump, exposing the system to corrosive substances or abrasive particles. Open loop geothermal systems are a viable option when groundwater conditions are suitable.

When a geothermal system is installed closed to a large body of water such as a lake, the piping that normally travels underwater can simply be submerged. This provides a simpler and less expensive installation, but it is only possible if the property has access to a large body of water.

Geothermal systems can be configured in either a liquid-to-air or liquid-to-water configuration. In the liquid-to-water configuration with a closed-loop or open-loop geothermal system, it is important to remember that the water circulating underground is completely isolated from the water circulating through the building.

16.7.3.2 Variable refrigerant flow systems

Variable refrigerant flow (VRF), also known as variable refrigerant volume (VRV), is an HVAC technology characterized by using refrigerant lines directly to move heat, similar to how a mini-split air conditioner works, but without the use of air ducts or hydronic piping. In general, VRF systems have a large outdoor unit connected to several indoor units with refrigerant lines. The outdoor unit has one or more variable speed condensers, adjusting its continuous output according to the total heating or cooling demand of indoor units. This continuous configuration is significantly more efficient than using an ON/OFF control to run the condenser intermittently; and, equipment lasts longer by avoiding the mechanical wear of frequent starts and stops. (Variable Refrigerant, 2021) A variable refrigerant system allows for the usage of zones, allowing the system to turn off at times when certain zones do not require heating or cooling. Additionally, these systems can be designed for simultaneous heating and cooling in different zones, and heat recovery from one zone to another.

Variable refrigerant flow systems may be designed to operate as heat pumps, allowing reversible operation between heating and cooling modes. Some VRF designs are designed for cooling only; these systems are best suited for tropical weather.

Variable refrigerant flow systems are available in two-pipe and three-pipe configurations, and each option offers different performance features:

1. **Two-pipe VRF systems** - have a supply line and a return line between the outdoor unit and the multiple indoor units. This layout is simpler and less expensive than a three-pipe configuration, but it also comes with a limitation: the system cannot deliver simultaneous heating and cooling for different building, and all indoor units must operate in the same mode.
   A. Branch controllers: Some devices include branch controllers that allow simultaneous heating and cooling with a two-pipe VRF system. A branch controller uses the heat removed by units in cooling mode and delivers it to areas that require heating. The outdoor unit only provides balancing between heating and cooling loads.
2. **Three-pipe VRF systems** - involve two supply lines, one for heating and one for cooling, and a common return line. Indoor units are connected to all three refrigerant lines, and they have a branch selector that switches between the heating and cooling lines as needed.

Each option has advantages and disadvantages, and the best selection depends on project conditions:

1. Two-pipe VRF systems with branch controllers offer the most flexible configuration for future expansions. All refrigerant lines are connected to a common hub, and you can simply add more as required by new indoor units.
2. Three-pipe VRF systems allow a higher energy efficiency. However, they are less flexible for future expansions, since it is necessary to modify the existing refrigerant lines.

16.7.3.3 Heat pump operation

To provide cooling inside when it is hot outside, heat pumps have the following stages (note that the exact same steps occur in reverse to provide heat inside when it is cold outside):

1. Refrigerant enters the compressor (outdoor unit) of the heat pump system as a hot low-pressure gas and is compressed into a high-pressure gas.
2. Next a hot high-pressure gas, the refrigerant enters the condenser where it is condensed into a liquid. During the condensation process, the liquid refrigerant gives up its heat, which is radiated to the outside air.
3. Next a cold, pressurized liquid, the refrigerant moves into the expansion valve, which restricts the flow of the liquid. Upon exiting the expansion valve, the pressure lets up.
4. The cold, low-pressure liquid now moves into the evaporator, where it absorbs heat from air blown over the evaporator coils and turns into a gas.
5. Next a hot low-pressure gas once again, the cycle starts over. The cycle repeats until the temperature of the air in your home matches that set by the thermostat.

In colder temperatures a heat pump will run almost all the time to maintain warmer internal temperatures. A heat pump that runs all year round (HVAC system) will have more wear and tear. However, in contrast to a conventional furnace, the heat pump will generally heat more evenly. In extremely cold temperatures, heat pumps are not highly efficient. Also, the outdoor units should never be covered in snow. Although a heat pump can heat a home, when outside temperatures drop below freezing, the efficiency of a heat pump is affected as the unit requires more energy to maintain warm temperatures inside the home. Typical heat pump systems have an auxiliary electric heater added to the indoor or outdoor unit to add supplemental heat when outdoor temperatures drop below a specifically set degree. In specific setups, if outside heat is insufficient, the heat pump may have an attached electric heater that will supplement the outdoor environment with additional heat to meet the inside heat requirements. However, because electric auxiliary heating Is not very efficient, the addition of a furnace can be a solution to this problem, creating a system that relies on the heat pump as the primary heat source but automatically switches to the furnace when appropriate. The discharge temperatures of a heat pump will be significantly less than that of a furnace. However, during non-extreme temperatures, an efficient heat pump may use four times less electricity than a resistance heater.

Note that some heat pumps have a defrost mode. Different heat pumps have different ways of determining when to go into defrost. On a call for defrost, the reversing valve is energized, switching the system into the air conditioning mode. The outdoor evaporator becomes the condenser but at the same time the outdoor fan shuts off. This allows the high pressure refrigerant circulating through the outdoor coil to get very warm, melting the ice.

16.7.3.4 Heat pumps combined with other atmospheric and water processing systems

In addition to the main types of heat pumps (i.e., air, water, and geothermal), there are also several sub-types, including but not limited to:

1. **Hybrid heat pumps (a.k.a., dual fuel heat pump** or **add-on heat pump)** - uses both an electric heat pump and/or a fossil fuel gas furnace (natural or propane gas). In other words, a dual fuel system is a system with the ability to heat with a gas furnace and/or heat pump. Herein, the air-source heat pump uses a gas furnace for auxiliary or backup heating rather than the electric heating element (within the heat pump system). When the outside temperature drops too low (typically below the -1C to -3C (30F to 25F) the furnace will do most of the heating. Additionally, if the economic conditions change and either electricity or gas becomes more expensive or more abundant, then the least expensive option within the system can be chosen for a period of time.
2. **Solar heat pumps** - uses a solar powered boiler to increase the initial temperature of the water. This warm water then feeds into the heat pump evaporator for final processing, thereby reducing the overall amount of electricity consumed to produce hot water.
3. **Absorption heat pumps (AHP)** - is an air-source heat pump driven not by electricity, but by a thermal energy (heat) source, such as combustion of natural gas, steam solar-heated water, air, or geothermal-heated water. These heat pumps are driven by heat as opposed to normal heat pumps that use electricity and mechanical energy. Absorption heat pumps can be used in situations where both heating and cooling is required. The principle of operation of an absorption heat pump is based on absorption and evaporation of a refrigerant.
4. **Gas-fired absorption heat pumps (a.k.a., gas engine heat pump)** - uses a generator, and an absorber, which combined is called a thermal compressor. This replaces the electric compressor, which is standard in air conditioning and heat pump systems. Note that there are also absorption (or gas-fired) coolers available that work on the same principle.

NOTE: *The heat transfer from a heat pump (or, heat pump combination) can heat water for radiators, or even circulate it under floors for heating.*

Most air conditioning units have a heat pump version. In other words, there are air conditioners that put out heat (i.e., they are heat pumps), however, they are sold on the market as air conditioning systems (even though they are heat pumps). In warm weather, a heat pump and an air conditioner are the exact same thing (i.e., perform the same function similarly). During the phase where the heat pump is cooling the interior environment it is using the same mechanisms as an air conditioner to do so. They both equally cool the interior environment. The difference is that an air conditioner can't heat the interior air significantly during winter. And, a heat pump can be used to create and/or support interior heating. In the case of cold temperatures outside, the external part of the heat pump absorbs heat from outside and brings the heat to the inside. However, the heat provided by a heat pump is less than that provided by conventional combustion furnaces and burners. An air conditioner and air-sourced heat pump look identical from inside and outside the building.

16.7.3.5 Heat pump limitations

Every heat pump is engineered to achieve its optimal efficiency within a specific range of temperatures. Outside of that specific temperature range, the efficiency drops. Heat pumps are sized and configured for what the temperature is most likely to be. Heat pumps that may run intermittently within normal temperature ranges are likely to run continuously in order to produce reasonably expected atmospheric conditions. The more the temperatures exceed the expected range, the less efficient the machine will be. Additionally, for most heat pumps, if the outside temperature is below or above some limit, it may be best not to turn the heat pump on. If heat pumps are turned on under extreme conditions, the consequences may be:

1. In cases of extreme heat:
   A. Overheating that damages equipment.
2. In cases of extreme cold:
   A. The unit's inner coils will freeze.
   B. The fluids will thicken.

16.7.3.6 Heat pump installation configuration options

There are a few different ways to install heat pump systems based on the positioning of the system and whether or not it uses ducts:

1. **Ductless heat pump (a.k.a., split-ductless** or **mini-split)** - is used in buildings without ducts. They include two units: an outdoor compressor and indoor handlers (usually, a maximum of four). These systems do not require ductwork. These systems circulate refrigerant through the tubing that connects the indoor and outdoor units.
   A. **Single zone ductless heat pump** - consist of one outdoor unit and one indoor unit.
   B. **Multi-zone ductless heat pumps** - consist of one outdoor unit and two or more indoor units. Multi-zone units can be more cost-effective, because they have a cheaper upfront cost compared to installing multiple single zone heat pumps.
2. **Package ducted heat pump (a.k.a., packaged heat pump)** - wherein, all the mechanical components are housed in a relatively large, single, outdoor unit. Only the ductwork is found inside the building. This outdoor unit may be mounted on a concrete pad outside or even on the roof. Sometimes, a packaged unit also includes electric heating coils or a gas furnace, which supplements the heat pump to deliver warm air indoors during extremely cold weather conditions.
3. **Split ducted heat pump (a.k.a., ducted mini split)** - wherein, an indoor evaporative unit is placed in the attic, basement, or closet, while the condenser and compressor unit is located outside in a large metal box. Ducting is connected to the indoor unit and transfers air throughout the building.

16.7.3.7 Decisioning selection of a heat pump

Generally, heat pumps range from 1.2kW to over 10kW. Here are some factors to consider when choosing the size and type of a heat pump:

1. Does the system need to provide hot air, cool air, hot water, or some combination?
2. Will it need to be combined with other atmospheric and/or water processing systems?
3. What is the local climate, including the average seasonal high and low temperatures?
4. What is the level of insulation in the building?
5. What is the size of the building(s) and the number of occupants?
6. Is there ducting, or will there be ducting? If not then a ductless system is necessary.
7. Is there access to a lake or river? If not, then a water-sourced heat-pump is unavailable.
8. Is an air-sourced, ground-sourced, or water sourced heat pump the best option given the conditions and constraints?

16.7.4 Heating only atmospheric processing systems

A.k.a., Heating machines, heating specific atmospheric fixtures, environmental heating mechanisms, heaters, heating fixtures.

Heaters are machines that produce significant heat for an environment. A heater is really just a catch all term for a device that heats up an environment. There are several types of machines used to generate heat for an environment. The following systems only produce heat.

Firstly, heat for a building can either be produced centrally or by area:

1. **Central heating units** - have a central location for the heating device, be it in a machine room or attic or basement, where the heat is created and distributed throughout the building. These systems are generally part of an HVAC system. These systems are quite common in most houses, apartment complexes, and commercial buildings. Modern central heating systems are efficient enough that they typically won't require additional energy-wasting localized or space heaters. A furnace or boiler is the mechanism that produces the heat that a central heating system will then distribute to keep the internal environment warm. Modern central heating units, produce high amounts of heat, which is then distributed, generally, by forced-air through ductwork, by hot water circulating through pipes, or by steam fed through pipes. A central heating system uses some form of energy combustion (e.g., gas) and/or electricity.
2. **Space heaters (a.k.a., portable heaters, panel**

heaters, area heaters, etc.) - are portable units that lack the ability to transfer heat to another location. These heaters heat a limited area. These systems are generally electric. If they use any form of combustion, then [generally] they should only be used outdoors.

Area heaters are generally installed under windows and on perimeter walls of the building. This allows them to counteract the cold air radiating off the window glass, as well as the areas where the building's greatest heat loss tends to happen.

16.7.4.1 Combustion furnace ("fire box")

Furnaces get their name from the Greek word "fornax," which means oven. A furnace generates heat by burning a fuel source (gas, oil, or biomass). Sometimes furnaces are designed to only heat the local environment, but more often, furnaces produce hot air and force it throughout a building via a series of ducts.

> **NOTE:** *Many furnaces share the same interior cabinet space, ductwork and thermostat with the central air conditioner.*

The first furnaces were stone or clay structures that used coal and/or wood to create intense heat. The combustion source for a modern furnace could be:

1. Biomass (e.g., wood, wood chips, or wood pellets).
2. Bio and/or natural gas (most common).
3. Coal hydrocarbon.
4. Oil hydrocarbon.

The combustion chamber is the part of the furnace where some combustible element (fuel) is burnt to create the heat that enters into a heat exchanger. There are many types of combustion furnace.

Natural gas furnaces are environmentally friendlier and more energy efficient than oil furnaces. Natural gas also costs less than oil. Not all locations have access to all fuel sources. There are many similarities, but each type has its own unique features, as well as pros and cons for different buildings. Natural gas furnaces are environmentally friendlier and more energy efficient than oil furnaces. Natural gas also costs less than oil. There must be a supply of natural gas in the area for this type of furnace to be installed. Oil furnaces are less expensive up front than natural gas, but the fuel costs will depend on the highly volatile oil market. Oil is also less eco-friendly than natural gas. Oil furnaces require more cleaning due to the buildup of soot and debris. However, oil furnaces can be installed in areas where there is no natural gas.

One of the biggest benefits of a furnace is its reliability. Though modern heat pumps work pretty well in temperatures that dip below freezing, they still have to source heat from somewhere. If a region experiences long, cold winters, it's generally best to choose a furnace, which generates its own heat. Another benefit is that furnaces tend to last longer than heat pumps. Since they are used only during the heating season, they generally require less maintenance and sustain less wear and tear. While the average useful life of a heat pump is just 10 to 15 years, both gas and oil furnaces can easily last 20 to 30 years with proper care.

There are several types of furnaces used in HVAC systems, including but not limited to:

1. **A sealed combustion furnace (a.k.a., sealed combustion heater)** - draws on air from outside the house to use for burning fuel (i.e. combusting fuel). The jets of the burners in a gas furnace must have air to mix with the gas. A sealed combustion furnace, however, isn't open to the house. It's closed-off and draws air through a plastic PVC pipe that connects it to the outside. A second pipe attached to the combustion chamber sends out the exhaust. The combustion process is entirely isolated from the air in a house. Sealed combustion furnaces do not remove air from indoors, and this can be help in keeping humidity balanced inside in winter.
2. **An atmospheric furnace** - uses air from within the building. The combustion chamber in the furnace is exposed to the space around it so the furnace can draw air directly inside. An atmospheric combustion chamber draws air from inside the house as it runs, causing an air deficit. Air from the outside,. which is usually drier in the winter, then rushes in to replace it; thus, creating a drier atmosphere.

16.7.4.2 Electric furnace heater

A.k.a., Electric furnace, electric resistance heater.

Electric furnaces are a type of furnace that runs off electricity producing heat by heating metals. The source of power for an electric furnace is electricity. A fan is used to circulate the heated air.

16.7.4.3 Steam water heaters

Steam heat is created by converting water from a boiler into steam. Steam is an efficient source of heat for large buildings; because, on the basis of unit mass, steam can hold a significant amount of energy. It ranges from approximately 2326 to 2908 kJ/kg (1000 to 1250 BTU/lb), which can be converted into mechanical operations as heat or using a turbine. In other words, steam-based heaters can be used for more than one purpose; they can be used for heating [water] (to provide thermal warmth) as well as generating electricity.

Most of the heat content in steam is latent heat; therefore, it can be transported at the same temperature. Some of the major advantages associated with using steam systems include the high capacity for heat, low toxicity, high efficiency, and low cost as compared to other alternatives.

Note here that steam heaters can be very dangerous. If a steam pipes breaks around animal occupants, the steam can seriously harm and even kill. Steam systems need to be inspected regularly (often, annually).

16.7.4.4 Boilers (boiler plants)

A boiler is a device that heats water. Most boilers supply hot water below the boiling point, which is then distributed through hydronic piping to provide space heating. Some boilers use a steam-based heating and distribution system. Here, water is turned into steam, which is denser than air and lighter than water. Air doesn't hold heat well, and water is difficult to move, so steam is a good medium for transferring heat to where it is needed. In most instances, a furnace or other heating device is attached to the boiler. The hot water or steam is distributed through a series of hot water pipes and/or ducts that make up a central heating system.

Some boilers provide both hot water and hot water atmospheric heating, which can eliminate the need to have a separated central heating system and hot water heater. This does, however, require hot water piping throughout the architecture in a closed loop (primarily) cycle that recycles back into water to be heated again.

These systems generally use hydrocarbon combustion to provide sufficient heat, however, smaller systems may use electricity only. The source of power for a boiler could be:

1. Fuel combustion - tends to be the most economic option.
   A. Wood (biomass).
   B. Natural gas (most common).
   C. Propane.
   D. Coal.
2. Electricity - these boilers have a much higher operating cost than combustion-based boilers, which limits their usefulness in buildings.

The boiler plant must be designed so that building occupants are not exposed to components at high temperature, and it must be properly vented to prevent the accumulation of combustion gases. Steam-based hot water distribution systems can be very dangerous if a pipe bursts. In such case, they are likely to kill occupants in rooms where the steam (or very hot water) enters.

16.7.4.5 Water-based space heater

Integrated or combination water and space heating systems usually cost more than a separate water heater and furnace or boiler, but installation and maintenance costs may be less. For example, you won't need multiple utility hook-ups since there's one source of heat. There also aren't as many moving parts to maintain or service. Some of these high efficiency systems may also provide power savings, and hence, lower utility costs (market only). The sizing of a combination system involves several different calculations than those used for sizing a separate water heating or space heating system.

To determine the energy efficiency of a combination water and space heating system, use its combined appliance efficiency rating (CAE). The higher the number, the more energy efficient. Combination appliance efficiency ratings vary from 0.59 to 0.90. The higher the number, the more energy efficient model.

16.7.4.6 Water-based radiant floor heater

Water-based radiant floor heating systems are fuelled by either natural gas, propane gas, or oil. These system do not “boil” the water, rather they heat it to below boiling. This hot water is then pumped to radiant floor tubes, to radiators, or it is run through a heat exchanger.

16.7.4.7 Furnace and boiler combination

A system that produces hot air and produces hot water. These systems are generally gas, but may be electric. The water from a boiler system can be circulated, like an air ducted vent system, to heat the interior.

16.7.4.8 Electricity-based radiant floor heater

Electricity-based radiant floor heating systems use electricity to heat metal under the floor.

16.7.4.9 Portable electric space heaters

A.k.a., Electric space heater, portable space heater, portable electric heater, portable heater.

Electric heaters use electricity to heat metals, and include a fan to blow and circulate the heated air.

16.7.5 Cooling only atmospheric processing systems

A.k.a., Cooling machines, cooling specific atmospheric fixtures.

The following systems only provide cooling (i.e., reduce heat).

16.7.5.1 Air conditioning machines

A.k.a., AirCon, AC, A/C, air cooling machine.

It is important to note here that an air conditioning system cannot provide significant heating to an interior environment; an air conditioner is only capable of cooling. This means that it extracts heat from the indoor air and transfers the heat outside. Note that some air conditioning systems are sold as air conditioners, but are actually reversible heat pumps (i.e., because they are actually heat pumps, they can provide heating). An air conditioner is typically paired with a heating system (e.g., electric heater or furnace) to provide heat when it is cold outside. The components used in an air conditioner are also similar to a heat pump, consisting of an outdoor unit housing a condenser, compressor, and fan. The indoor unit includes an evaporator coil (a.k.a., evaporator core) and a fan. The evaporator coil is the part of the system where the refrigerant absorbs heat. That is, it's where the cold air comes from. The evaporator coil is located inside or near the air handler where the blower fan is. Evaporator coils are made from copper, steel, or aluminum because these metals conduct heat easily. A refrigerant circulates through the condenser and evaporator, absorbing heat from indoor air and transferring it outdoors. While the evaporator coil picks up heat from indoor air, the condenser coil releases heat into outdoor air. The resulting cold air moves through the ducts using the fan and cools the indoors. Functionally, an air conditioner has two connected coils with continuous flowing refrigerant fluid inside of them. The two coils form the two primary processes the machine performs. The coil inside the build is called the evaporator. The coil exterior the building is called the condenser (condenser). The fundamental engineering principle is to keep the evaporator (inside part) colder than the room temperature, and the condenser hotter than the surroundings. With this material configurations making this conditions where the continuously flowing fluid absorbs hear from the room and ejects it out to the exterior surroundings. To achieve this engineering objective, the machine also requires a compressor (mechanism) and an expansion value (mechanism). The compressor mechanism sits near to the condenser, and the expansion valve sits near to the evaporator. The compressor increases the pressure on the refrigerant fluid. By compressing the fluid, the compressor dramatically increases its temperature. Turning it into a hot gas that can be ejected exterior coil (condenser coil). A fan in the condenser unit makes this task more efficient. During the heat ejection phase, the gas turns back into a liquid. An expansion valve fitted at the exit of the condenser coil restricts the refrigeration flow, thus reducing the pressure on the refrigerant fluid. The low pressure refrigerant should be at a temperature lower than the interior's temperature.

By passing the air of the interior environment the machines cools (reduces the temperature) of the interior atmospheric (and possibly, the whole interior material) environment. The refrigerant gets converted to vapor during this heat absorption process. There is one significant issue with this design - near to the evaporator coils, the air temperature will be low, which will lead to water condensation on the evaporator coils. Therefore, a pipe is required to remove this water condensate.

Note that compressors can be damaged if the input refrigerant is not in gaseous form. A more advanced expansion mechanism (which may also use its own internal refrigerant) may be used to tightly control the output of the compressor system. These more complex compression mechanisms have a variable/dynamic restriction flow system. These mechanisms ensure that the compressor receives the refrigerant in pure vapor form. Herein, the refrigerant flow rate and the room temperature are actually controlled by the speed of the compressor.

Modern air conditioners dehumidify as they cool; this can be seen by the water that drains away from the machine. However, this dehumidification is incidental to their main job of controlling temperature. In general, they cannot independently control both temperature and humidity.

The refrigeration cycle in a typical AC works as follows:

1. Using electricity as its power source, the refrigerant flows through a closed system of refrigeration lines between the indoor unit and the outside unit.
2. Warm air from the inside of the building is pulled into ductwork by a motorized fan.
3. The refrigerant is pumped from the exterior compressor coil to the interior evaporator coil, where it absorbs the heat from the air.
4. This cooled air is then pushed through connecting ducts to vents throughout the home, lowering the interior temperature.

There are two primary types of air conditioning systems as categorized by the presence of ducting as well as installation configuration:

> *Note: These are all split atmospheric processing machine with a part of the machine interior to the structure and another part of the machine exterior to the structure. Both the interior and exterior parts need ambient air (i.e., do not box or close them in). If they are confined, then recirculation will occur and lead to high inefficiency.*

1. **Ducted (vented, central, centralized) air conditioner systems** - a centralized air conditioning system uses one centrally located indoor unit, with an exterior fanned compressor (a.k.a., condenser unit, heat pump), that delivers cool air throughout the building through a series of ducts and vents. In other words, a central A/C system generates cold air at a single point inside the building and distributes it via ducts throughout the building. This unit is generally placed on the roof, or on a concrete slab next to the building. The unit is connected with the supply and return ducts installed along the walls of a building. The inside part of the machine is heat absorbing when cooling (or, heat emitting if a heat pump in heating mode). The outside unit will release heat to the exterior environment. In a cooling arrangement, a condensing unit is located outside and contains the condenser coils, a compressor, and the compressor fan motor. The evaporator

coils (cooling coils) are located inside the building. Note that in a heating and cooling configuration with an air handling furnace, the inside evaporator coils are located on top of an air handling furnace. The air handling furnace uses a blower fan motor to draw air through the return vent, blow it past the evaporator coils, and force the air through the structure's venting network. The return air is then drawn back through the return vents, cycling the air. Once the room has reached a set temperature, the thermostat turns the condensing unit off until the room temperature moves outside set parameters. Central air conditioners usually include a large particle filter (not small particle filter, such as, HEPA filter). These filters should be checked monthly and replaced ever couple of months (as needed). A typical central air conditioning system is a two-part or split system that includes:

A. The outdoor unit contains the condenser coil, compressor, electrical components and a fan.
B. The evaporator coil, which is usually installed on top of the gas furnace inside the home.
C. A series of pipes, or refrigeration lines, connecting the inside and outside equipment.
D. Refrigerant, the substance in the refrigeration lines that circulates through the indoor and outdoor unit.
E. Ducts that serve as air tunnels to the various spaces inside your home.

2. **Ductless (non-vented, local, mini-split, minisplit) air conditioner systems** - do not require ductwork for air supply. The cold air blows through a slim indoor unit mounted on the wall. These units are powered by a single exterior compressor, and connected by refrigerant tubing and electrical wiring. Using electricity as its power source, the refrigerant flows through a closed loop system of refrigeration lines between the indoor unit and the outside unit. Ductless mini-splits offer zoned temperature controls, meaning that it is possible to set each zone to a different temperature. These systems generally have lower quality air filtration. The following are types of ductless systems (which apply to heat pumps as well as an air conditioner).
   A. **Single-split ductless system** - uses refrigeration technology to transfer thermal energy from one outdoor unit to one indoor unit.
   B. **Multi-split ductless system** - uses refrigeration technology to transfer thermal energy from one outdoor unit to many indoor units.
   C. **Window air conditioner systems** - are devices that fit within a window port.
   D. **Portable air conditioner systems** - are portable air conditioning devices.

There are two primary types of air conditioning systems as categorized by the presence of motor speed controller:

Note: These are all split atmospheric processing machine with a part of the machine interior to the structure and another part of the machine exterior to the structure.

1. **Inverter** - An inverter is energy saving technology that eliminates wasted operation in air conditioners by efficiently controlling motor speed. In inverter type air conditioners, temperature is adjusted by changing motor speed without turning the motor 'on' and 'off'; instead, the compressor runs on different power modes. An inverter air conditioner can regulate the speed of its compressor motor. This type of system will reduce temperature fluctuations in the environment. With inverter technology, both the temperature and the humidity will remain constant. Simply by adjusting the speed of the motor(s), the compressor speed, flow rate, cooling capacity, and temperature can all be controlled accurately. The advantages of inverter systems include:
   A. Less electricity consumption.
   B. Constant air temperature.
2. **Non-inverter** - A non-inverter air conditioner cannot regulate the speed of its compressor motor. The motor runs at full speed, but turns off once room temperature drops to the desired level. Non-inverter systems cycle off the [exterior] compressor once the set temperature is 1-2 degrees approximate the temperature set by the user. The compressor turns back on once the temperature is 1-2 degrees outside the set temperature. This change will cause an ~4 degree continuous temperature and humidity fluctuations in the environment. The disadvantages of an non-inverter system include:
   A. More electricity consumption.
   B. Environmental variable fluctuations (e.g., fluctuations in temperature and humidity).

Air conditioners (of the type: wall units, cassettes, ducted units) are generally fitted at higher levels on the walls of a room in order to produce quick cooling in the room. As air is cooled, it contracts, become denser and sinking. Warmer air at the bottom is displaced, and due to it being less dense, it rises. This process continues and sets up a convection current that will allow thermal transfer to occur, wherein warmer air rises, is taken in by air conditioner, and cooler air is output in a horizontal or downward direction. Since cold air is emitted from the A/C unit blowers, the unit has to be placed at the top of a room to allow a convection current to form. Note that there are some A/C units that "throw" the cool air upwards to generate this convection current; however, the bulk of A/Cs available are situated at the top

16.7.5.2 Chiller plants (water-based)

A.k.a., Water-based and centralized air cooling system, water-based and centralized air conditioning system.

Chiller plants use chilled (Read: cooled) water to remove heat from a building. Chiller plants are commonly used for air conditioning in large and/or integrated facilities. In manufacturing applications, they also play an important role in process cooling. Chiller plants use chilled (cold) water to remove heat from indoor spaces. Chiller plant systems cool large amounts of water in a central location, and then pump the cool water to distal air handlers that circulate and cool the local air. The temperature of chilled water increases as it captures building heat within each air handler, and is then returned to the chiller plant to be cooled again. Chiller plants provide a high cooling output and have a much higher efficiency than unitary air conditioners. Additionally, hydronic piping requires less space than air ducts, since water can hold more heat than air in a given volume. (Chiller Plants, 2021)

A chiller plant systems consists of the following primary elements:

1. **Large refrigeration condenser:** Chillers are larger versions of air conditioning condensers, with cooling capacities often reaching several hundred tons of refrigeration.
2. **Pump and hydronic piping:** A pump system that distributes chilled water throughout the building, and the piping used for this purpose is called hydronic piping.
3. **Cooling coils and fans (air handlers):** Chilled water is delivered to cooling coils in air-handling units, where fans blow air through the coil to reduce its temperature.

All chiller systems use water to remove heat from buildings, but they differ in the method used to release the heat to the exterior environment:

1. **Air-cooled chillers** - are exposed directly to outdoor air, just like the condenser units of smaller air conditioning systems. A fan is used to establish airflow through the chiller, and the condenser is constantly releasing heat outdoors.
2. **Water-cooled chillers** - are not in contact with outdoor air, and instead they use a secondary water loop reject heat. This water loop connects to an outdoor cooling tower where heat is released, and water is then returned to the chiller to remove more heat.

Note that air-cooled chillers have a simpler configuration because they are only connected to one hydronic piping circuit, while water-cooled chillers use another loop to reject their own heat. However, water-cooled chillers typically offer a higher efficiency than their air-cooled counterparts.

Most chiller compressors can be classified in the following ways:

1. **Reciprocating compressors** - use pistons to compress refrigerant. These resemble the engine of a car. Depending on how the chiller is designed, the compressor and its motor may share the same housing, or they can have separate housings. Reciprocating compressors are the most affordable, and it is possible to use multiple units together to serve variable loads. However, reciprocating compressors are disadvantaged by their low efficiency. Additionally, their piston mechanisms require more maintenance.
2. **Centrifugal compressors** - are similar to centrifugal pumps, since a rotating impeller is used to increase pressure. Their cooling output is controlled with inlet valves that regulate the flow of refrigerant in to the compressor. Centrifugal compressors are the most efficient type when operating at rated capacity. They are also very compact, and available in a wide range of sizes. The main disadvantage of centrifugal compressors is their sharp drop in efficiency when operating under part-load conditions.
3. **Rotary-screw compressors** - have two matching helical screws that rotate at high speed, and refrigerant is compressed in the space between them. The cooling output is controlled with a special valve that adjusts the volume ratio.

Although a centrifugal compressor is more efficient at full load, rotary-screw compressors offer the highest efficiency under part-load conditions. Since buildings do not require the full cooling output all the time, these compressors normally have the lowest running costs. The main disadvantage of rotary-screw compressors is their higher price, compared with reciprocating and centrifugal units of the same capacity. They are only recommended in applications that benefit from their high efficiency at part load.

Note that chiller plants can be equipped with ice storage tanks to increase their energy performance.

16.7.5.3 Water-based cooling towers

Water can absorb large amounts of heat when it evaporates; hence, cooling towers normally use that physical principle to expel heat from a building. Cooling tower systems that use water evaporation to achieve their cooling effect are classified as either (Cooling

Towers, 2021):

1. **Open circuit cooling towers** - discharge water carrying the building's heat directly on the upper side of the unit. Water falls against an upward flow of air, which is established by a fan above the cooling tower. With the combination of forced airflow and water evaporation, the unit releases a large amount of heat in a relatively compact volume.
   A. The water is exposed directly to the atmosphere before it returns to the chiller, heat pump or process being cooled. Therefore, it must be treated constantly to prevent contamination with particles or bacteria.
   B. Since some water evaporates as it falls through the cooling tower, it must be replenished constantly to sustain the required flow through the HVAC unit or process being cooled.
2. **Open circuit contamination prevention cooling towers** - this system operate similarly to the prior system, but In this case, the water stream from the chiller or process does not reach the cooling tower directly, and instead it cools down in a heat exchanger connected to the cooling tower.
   A. This configuration requires an extra water loop and pump, but it prevents contamination with bacteria or particles.
3. **Closed circuit cooling towers (adiabatic cooling towers)** - operate similarly to open circuits, but do not expose water to the atmosphere, and instead, circulate it through a coil inside the unit.
   A. This system uses a fan to establish an upward airflow, but water is sprinkled from a separate source. As a result, the water that flows through the chiller plant or cooled processes is never exposed to the atmosphere.
   B. These systems save water.
   C. Also, by deactivating the sprinklers when airflow from the fan can provide enough cooling by itself.

Cooling towers normally complement a major air conditioning system such as a chiller or a large heat pump in the following three ways:

1. While the compressor units in heat pumps and chiller plants gather heat from indoor spaces, cooling towers are used to remove the heat from the compressors themselves.
2. Since large HVAC units are often found indoors, while cooling towers are installed outdoors, both devices are normally connected with a water loop. The piping loop is equipped with a pump to keep the water in circulation.
3. There are special applications where a cooling tower can provide direct heat removal, without being connected to a chiller or heat pump.

There are two methods to increase the energy efficiency of a cooling tower:

1. By using high-efficiency motors to drive the pump and fan in the cooling tower system.
2. By adding speed control capabilities to these motors. These speech control mechanisms use variable frequency drives (VFD). A VFD can lower the speed of a fan or motor under partial load conditions, achieving a drastic reduction in energy expenses.

NOTE: *Under some climate conditions, it is possible to use a waterside economizer to increase the efficiency of a chiller or heat pump. When weather conditions are adequate, a waterside economizer can assume a portion of the space cooling load, reducing the electricity consumed by chillers or heat pumps.*

16.7.5.4 Refrigeration and freezing machines

Refrigerators and freezers use electricity and refrigeration technology to reduce the temperature of an enclosed space. These systems are considered appliances that provide cold storage space for food, liquids, lab samples, and other heat-sensitive items. The purpose of the refrigerator is to keep food fresh for a longer duration of time. In general, food kept in an environment around 6 degrees celsius will remain fresher for a longer duration of time. Hence, the task of a refrigerator is to maintain a low temperature.

Refrigeration and freezing machines have the following parameters:

1. Size of machine in liters as total gross capacity.
2. Size of refrigeration in liters.
3. Size of freezer in liters.
4. Degree of coldness.
   A. Freezerless refrigerator (no-freezer refrigerator).
   B. Freezer.
   C. Combination refrigerator and freezer.

Refrigeration-type appliances, like many HVAC systems, requires clearance space behind, to the sides, in front, and at the top. This clearance space ensures the relative free flow of air around the appliance.

16.7.6 Purification atmospheric processing systems

A.k.a., Purification specific atmospheric fixtures.

Atmospheric filtration systems can be integrated into architecture in two ways:

1. In-line filters integrated into HVAC systems, or
2. Portable filtration systems that are separated, individual items (i.e., portable air filters).

Household air filters are available in two basic types:

1. Media filters create a physical barrier that traps minute particles.
2. Electronic filters (electrostatic precipitators) use a high-voltage charge to attract and capture contaminants.

However, more completely, there are four types of whole house filters:

1. Flat filters (normal for central HVAC systems).
2. Extended media filters (HEPA type filters).
3. Electronic filters (electrostatic precipitators) - these systems produce some ozone (O^3) as a byproduct.
4. Ultraviolet filters.
5. Portable room filters.
6. Ozone (O^3) systems.

16.7.6.1 Ozone generators

Ozone generators introduce ozone gas into the environment to purify the air of pathogenic organisms and statically charge airborne particles so they more easily stick to surfaces. Ozone generators take in oxygen from the air (O^2) and give it a strong electrical charge. This electrical charge forces the oxygen molecules to rearrange themselves and form O^3. Ozone generators have several primary uses:

1. Killing airborne mold and mildew
2. Preventing the growth of mold and mildew.
3. Killing bacteria and viruses.
4. Removing odors.

It is important to note here that high concentrations of ozone can damage materials and harm human lungs. Other types of air purifiers generally do not release pollution into the air. While ozone generators release a gas that is considered a pollutant to clean and sanitize.

16.7.7 De-/humidifying specific atmospheric processing systems

A.k.a., De-/humidification specific atmospheric fixtures.

It is possible to control the humidity of the general indoor environment and localized indoor spaces to:

1. Provide greater comfort.
2. Protect materials.
3. Dry wet textiles.

Within the indoor environment, low and high air humidity can causes discomfort for humans, it can also lead to several health issues, and can be damaging to buildings, technologies and other indoor objects. Humidity control is important in all indoor environments.

The most common material concerns for humidification in a building include, but are not limited to:

1. Low humid air can cause dryness in wooden floors, surfaces and furniture making them more prone to deformation and cracking.
2. Low humid air can cause dryness in paint and plaster causing it to crack and fall off.
3. Especially humid air can precipitate water within an enclosed environment and lead to mold growth.

Humidification systems can also protect sensitive electronic equipment from electrostatic discharge.

16.7.7.1 Humidification systems (humidifiers)

Outdoor air tends to have the lowest humidity during winter, and it becomes even drier as it passes through heating systems. As a result, indoor air can easily reach a relative humidity value below human comfort.

The following are the most common types of humidification systems:

1. **Steam humidifiers** - increase indoor air humidity with a controlled dispersion of steam, often with the assistance of ventilation systems. Steam-based humidification is the most expensive method but also the cleanest, and for this reason it is preferred in healthcare applications.
2. **Atomizing humidifiers** - spray water at high pressure to increase indoor air humidity, and they have the lowest operating cost among humidification systems. Atomizing humidifiers are also characterized by their flexible design, and adaptability to serve a wide variety of humidification loads.
3. **Ultrasonic humidifiers** - produce a cool mist to humidify indoor spaces. They are less efficient than atomizing humidifiers, but still much more efficient than steam humidifiers. The mist produced by ultrasonic humidifiers is quickly absorbed into the air, preventing the accumulation of droplets on surfaces.

MEASUREMENT: *Humidification is measured in kilograms per hour (kg/h).*

16.7.7.2 Humidity removal systems (dehumidifiers)

A.k.a., De-humidification systems.

Outdoor air tends to have the highest humidity during summer. As a result, indoor air can easily reach a relative humidity value higher than human comfort and appropriate conditions for indoor technologies and other objects.

The three ways to remove humidity (moisture) in a building are:

1. Dehumidifier specific systems.
2. Air conditioning system. Air conditioning systems by design will pull humidity out of the air, thus reducing the likelihood of mold in the environment. However, air conditioners themselves must be regularly cleaned to prevent mold buildup within the air-conditioned itself.
3. Energy recovery ventilator (erv) systems.

All of the above need to channel the moisture outside the building, otherwise the water will simply evaporate into the building maintain undesired humidity therein.

> **MEASUREMENT:** *De-humidification is measured in kilograms per hour (kg/h).*

16.7.7.3 Drying machines

Drying machines are used to dry textile materials and remove separated fibers (Read: lint). Lint sticks to clothes that have not been dried in a drier and often enters the atmosphere when the textiles are moved. Lint is a common source of indoor and outdoor air pollution and can be harmful (particularly over time) to human respiratory health. Additionally, without a drying machine, if the clothes are dried indoors, then the humidity in the local environment will increase.

All dryers use heat, air, and motion to catalyze the process of drying textiles while using electricity. To perform the drying function, drying machines create warm/hot air within which wet textiles are tumbled within a rotating drum. There are two categories of drying machine based upon the different ways they produce heat:

1. Electric heating coils.
2. Gas burners.
   A. Natural gas (most common).
   B. Propane (least common).

Gas and electric dryers work similarly, but gas models typically cost less to operate because they dry clothes faster. Hence, gas dryers are more energy efficient than electric only dryers. Gas drying machines also dry clothes more quickly because they heat up more quickly. Most electric dryers require a 240V outlet to provide enough power to produce heat and tumble the clothes. Most new gas dryers use 120 volts of electricity.

Drying machines come in two general types depending upon whether they have a vent to the exterior environment:

1. **Ventless dryers** - dryers that do not require a vent to the outside. These dryers are used when there is no vent to the outdoor, or venting to the exterior is not possible. When using a ventless dryer there is no need to cut holes in the walls or run ducting. In Europe, ventless dryers are more common than vented dryers. The two major types of ventless dryers are:
   A. Condensation dryers.
   B. Heat pump dryers. Heat pump dryers are a newer type of ventless dryer.
2. **Vented** - dryers that have require a vent to the outside. In the United States, vented dryers are the most common.
   In general, ventless dryers are more expensive than vented options. Additionally, ventless heat pump dryers are more costly up-front than condensation ventless dryers. However, the operating costs for ventless heat pump dryers are lower - half or more the cost per load of a traditional vented dryer in gas or electric.

16.8 Installation of atmospheric systems

There are many ways to install atmospheric systems. These systems are usually embedded into or afixed onto a structure. These systems should usually be installed with space around them for optimized air flow and access. Specific atmospheric systems have specific installation requirements.

16.9 Hazards with the atmospheric system

Lack of appropriate technical unit selection, installation, and maintenance can lead to atmospheric hazards. The following are some common issues and risks with HVAC systems:

1. Noise and vibration:
   A. HVAC systems normally create noise and vibration due to the fans and compressors.
2. Electricity and gas:
   A. HVAC systems typically use electricity, and therefore are an electrical hazard. Some HVAC systems use gas, and have associated combustion are carbon monoxide hazards.
3. Leakage:
   A. Duct leakage refers to the leakage of air from the air distribution system ductwork.
      1. Ducts that leak atmosphere.
      2. Ducts that are not sufficiently insulated and pass near thermal bridges or areas where temperature is not controlled.
   B. Water leakage, which is particularly possible case with the inside unit of a split heat exchange system. Sometimes the drain gets clogged, and sometimes the machine malfunctions and

begins leaking water.

4. Blowage:
   A. Air may inappropriately blowing on people and or objects. For instance, an air conditioner may be inappropriately positioned so that it blows directly on users in a room, or may blow on curtains causing them to move, which are a distraction to users of the space and could cause a security motion sensor to trigger when no one is in the space.
5. Indoor air quality:
   A. Gas buildup:
      1. The buildup of hazardous chemicals due to insufficient ventilation.
   B. Humidity buildup:
      1. Humidification of (Read: humidity buildup in) the indoor environment leading to mold and rot.
   C. Dryness:
      1. It is possible to have too much dehumidification occurring leading to an indoor atmosphere that is too dry, which may cause respiratory irritation.

The following are potentially hazardous atmospheres:

1. Fog - tiny water droplets suspended in the air near the earth's surface.
2. Steam - water in the gas phase, due to boiling. Steam is very hot and can harm or kill someone.
3. Vapor - substance in the gas phase at a temperature lower than its critical temperature, which means that the vapor can be condensed to a liquid by increasing the pressure on it without reducing the temperature. Most vapors are dangerous to some degree. Water vapor (humidity) can cause mold and other water-damage issues in specific environments.
4. Aerosol - suspension of fine solid particles or liquid droplets in air or another gas, usually refers to an aerosol spray that delivers a consumer product from a can. Most aerosols are dangerous to human health.
5. Mist - a phenomenon caused by small droplets of water suspended in the air, an example of a dispersion, where warm, moist air meets sudden cooling, such as in exhaled air in the winder, or when throwing water onto the hot stove of a sauna. Like water vapor, mist can cause water-related damage.
6. Volatile organic chemicals (VOCs) - are a group of organic chemicals that can easily vaporize into the air due to their low boiling points. They can enter the atmosphere through various natural and human-made processes; they will create air pollution, respiratory issues, environmental damage, ozone production and reduce indoor air quality.
7. Smoke - a collection of airborne particulates and gases emitted when a material undergoes combustion. Most smoke is dangerous to humans.
8. Cloud - an aerosol consisting of a visible mass of minute liquid droplets, frozen crystals, or other particles suspended in the atmosphere of a planetary body or similar space.
9. Fire - oxidation of a material in the exothermic chemical process of combustion.
10. Flame - gaseous part of a fire.

ASSOCIATION: *For gas and fuel risks, see the associated gas and fuel section of the architectural subsystem and power subsystem.*

16.9.1 Circulation best practices

A.k.a., Ventilation best practices.

The following atmospheric circulation best practices should be followed:

1. The air circulation should not blow air on people positioned normally in a module. This is especially true where people sleep; air should not blow onto a bed (or in the specific area where a person is sleeping or working).
2. In general, air needs to be conditioned prior to entering a building, otherwise moisture will increase in the building (leading to a higher potential for mold growth).
3. Airtight homes don't breath fresh air, and without dehumidification, humidity will build up and lead to mold growth. Mold needs water to grow. If a building is sealed, then terrarium like conditions will appear where mold is a likely result. All commercial building codes require fresh air exchange per hour, but in many residential building codes, fresh air exchange generally isn't required by code. Unless a building has installed a ventilator exchange system, then the building isn't breathing and the following are likely consequences:
   A. Mold creation and buildup.
   B. VOCs and off gassing chemicals will rise in the atmosphere.
   C. CO_2 levels will rise.
4. Buildings can be left open to the outside, and hence, will spend less on heating and cooling, or they can closed and will require ventilation and/or dehumidification. Hence, either:
   A. Air is moved from the outside in, it is filtered, and it is cooled or heated, which requires electricity, or

   B. The building is entirely and continuously open (and not ever close), or
   C. The building is sealed and without ventilation/ dehumidification and mold is likely to result.
5. Do not set the thermostat of a ventilation system to the "fan on" position. In this position the fan blows air all the time whether the cooling system is running or not. When this happens a lot of the moisture the system just took out of the air will be blown back into the house before it can drain way.
6. Use exhaust fans during moisture-producing activities. Cooking, bathing, washing, and similar activities produce a lot of moisture inside the home. Exhaust that moisture directly outdoors using a fan. Similarly, avoid drying clothes indoors except with a clothes dryer that is exhausted directly outdoors.
7. Do not open windows or use ventilative cooling when it is too humid outside.
8. One of the most effective ways to economize resources, power, and human labor, is to "centralize" the production of cold and/or warm air for atmospheric thermal regulation for several blocks and/or buildings. Duct energy loss over distance ought to be accounted for when taking this decision. It must be remembered that there may be return vents for circulation of large areas. Recirculated air will need higher quality filtration and/or sterilization than proximal usage-distribution systems.
9. Fans and heat exchange systems should have space between them and other surfaces (e.g., walls) to allow for air flow and maintenance/replacement access.

16.10 Operation of atmospheric system

This system is more split in terms of operational characteristics on the supply and demand sides, and depends on installed configuration. With ducts, there is the need for supply side dynamic air pressure. On the demand side, the user will operate a thermostat and possibly airflow volume and/or direction control system in order to adjust temperature of the air, the amount of air, and the direction of air.

16.10.1 Atmospheric load demands

A.ka., Electrical loading.

HVAC loads are measured in several ways, most notably, energy consumed to produce:

1. Conditioned air flow, and
2. Surface temperature.

In order to do work, HVAC systems are split into a power usage system and an airflow and surface temperature changing service system:

1. A power usage system:
   A. Energy consumed may be by electricity or combustion of fuel.
      1. Most HVAC electrical loads are measured in watts [of electrical] power. Often, the kilowatt hour (kW.h)
      2. Heating and cooling systems can be measured in BTU [of heating or cooling] power
2. An airflow conditioning (production and distribution) system:
   A. Airflow volume is air flow rate, or quantity of air being moved, which is measured in:
      1. m3/sec (cubic meters per second) or
      2. cubic feet per minute (CFM).
   B. Airflow velocity (Read: distance travelled per unit of time) is measured by sensing the pressure that is produced through the movement of the air. Velocity is also related to air density with assumed constants of 70° F and 29.92 in Hg. Air velocity is generally measured using anemometers, which are one of the most effective instruments for measuring air flow, or the speed of the air, and are available in vane and hot-wire technologies. The vane anemometer is in essence a small fan driven by the movement of air across the fan blades. The hot wire anemometer uses a heated wire that is cooled by the movement of air across the wire. It is possible to measure the velocity at different points in a duct and find the average velocity in the duct. The most common measuring units for velocity are:
      1. Meters per second (m/s, m/sec)
      2. Feet per minute (FPM)
   C. Temperature production is measured in kelvins or Celsius (or Fahrenheit in imperial).
   D. Static pressure is measured using a manometer with pressure probes. Early manometers used a column of water to reflect system pressure. A manometer is an instrument used to measure and indicate pressure. The air pressure physically elevated the water in a measured in inches, which is why static pressure is expressed today in inches. Readings need to be taken at the supply side and return side of the system. It is an important design consideration to have these openings built into the design so that post installation construction to drill holes is not required. The most common measuring units for pressure are:
      1. kPa

2. psi
3. $H2O$
3. The conduit lines (ducting, transmission lines) and filters are another type of load.
   A. Friction causes losses in conduit lines and filters.
4. Non-usage, but presence, may still equate to system service usage.
   A. If a usage circuit has no load in the form of a power factor of zero the user would consume NO watt.hours, but the supplier may still have to send static pressure to them and incur real energy losses in conduits, fans, and filters. Power factor is the relationship (phase) of volume and velocity in HVAC production-distribution system.

16.11 Engineering calculations for atmospherics

Factually, heat will flow spontaneously from a region of higher temperature to a region of lower temperature. Heat will not flow spontaneously from lower temperature to higher, but it can be made to flow in this direction if work is performed. The work required to transfer a given amount of heat is usually much less than the amount of heat present. The amount of work required to drive an amount of heat Q from a lower-temperature reservoir (e.g., ambient air) to a higher-temperature reservoir (e.g., the interior of a building) is:

- $W = Q / COP$
- Wherein,
  - W is the work performed on the working fluid by the heat pump's compressor.
  - Q is the heat transferred from the lower-temperature reservoir to the higher-temperature reservoir.
  - COP is the instantaneous coefficient of performance for the heat pump at the temperatures prevailing in the reservoirs at one instant.

16.11.1 Calculated engineering performance of HVAC systems

The following are terms used in measuring the performance of a HVAC system:

1. **COP rating (coefficient of performance)** - indicates the ratio of heating or cooling provided by a unit relative to the amount of electrical input required to generate it. The higher the number, the more efficient a heat pump is and the less energy it consumes. COP is not a good indicator of efficiency because it only gives a snapshot of performance at very specific good conditions.
   - COP = heating/cooling output (kW) / electricity input (kW).
     - For example, if an air conditioner creates 5kW of heat from a 1kW electrical input, its COP is 5.0.
2. **SCOP rating (seasonal coefficient of efficiency)** - the manufacturer has to test the units at different outside air temperatures. Units are expected to operate for a certain number of hours per temperature, which simulates the hot season.
   A. The higher the number, the more efficient a heat pump is and the less energy it consumes.
3. **AFUE rating (annualized fuel utilization efficiency)** - is a measure of how efficiently a unit uses fuel. All combustion furnaces have an energy efficiency rating known as the AFUE. This is a percentage that shows how much of the energy consumed by the furnace becomes heat rather than escaping as energy loss. The higher the AFUE percentage, the more efficient the furnace is. This measure is for oil or gas (not electric) fired heaters and boilers. This rating compares the heater's annual heat (energy) output to its annual energy input in Btu. The calculation includes expected pilot flame losses and heater use during a typical year at an "average" location. The higher the rating, the more efficient a unit is.
   A. In the U.S.A. the minimum allowed AFUE rating for a non-condensing (typical home heater) fossil-fueled, warm-air furnace is 78 percent; the minimum rating for a fossil-fueled boiler is 80 percent; and the minimum rating for a gas-fueled steam boiler is 75 percent. However, there are some systems capable of very high AFUE's of around 97 percent.
4. **SEER rating (seasonal energy efficiency ratio)** - is the total cooling capacity of an air conditioner or heat pump in Btus during its normal annual usage, divided by the total electric input in watt-hours during the same time period. In other words, SEER is calculated by dividing the cooling output of the unit in a given season by the energy it used during that period. It measures a heat exchange efficiency in cooling mode. The higher the SEER number, the more efficiently the unit is at converting electricity into cooling
   A. High efficiency units must have a SEER of at least 14. In the U.S.A., at present, the minimum standard SEER for newly manufactured air conditioning and heat pump units (other than window units) is 13 SEER.
   B. It should be note that a unit's actual SEER rating will decline over time as coils get dirty, motors

and compressors age, and the refrigerant degrades. The SEER rating also declines as the outside temperature rises. If the unit is installed incorrectly or the ductwork is leaky and not well made, the actual overall SEER rating can be much lower as well.

5. **HSPF (heat season performance factor)** - is a measure of a heat pump's efficiency in heating mode. It measures the total heating output of the heat pump during its normal annual usage in BTUs divided by the total electric input in watt-hours during the same time period. It is used to measure a heat pump's efficiency when it is in heating mode (note: similar to how the SEER rating measures efficiency in cooling mode). It is only used with heat pumps. The higher the HSPF, the more efficient the heat pump. In other words, the higher the HSPF, the less the unit costs to heat a space during one year. A heat pump system with a high HSPF score will perform better during cold snaps.
   A. Split system heat pumps that are considered high-efficiency have at least an HSPF of 8.2 (some units currently go as high as 9.35). Ground source heat pumps ("geothermal") tend to have high HSPF's because the heat source (ground temperature) is very stable and predictable, therefore the equipment can be designed very specifically.
6. **EER ratings (energy-efficiency ratio)** - is the ratio of the cooling output in Btu's divided by the unit's power consumption in Watts at a specific temperature (usually 95 degrees Fahrenheit). This rating is only useful for hot climates. The higher the EER, the more efficient the model.
   A. For example, if an air conditioner generates 5kW of cooling from a 1kW electrical input its EER is also 5.0.
7. **BTU rating (British thermal unit)** - measures the amount of heat energy needed to raise one pound of water to one degree Fahrenheit at sea level. The higher the BTU, the faster the unit can cool a space.
8. **Ton** - is used for air conditioning and heat pumps as a measure of energy usage in british thermal units (Btu). The common rating term for air conditioning size is the "ton," which is 12,000 Btu per hour of cooling. Before refrigeration air conditioning was invented, cooling was done by saving big blocks of ice. When cooling machines started to get used, they rated their capacity by the equivalent amount of ice melted in a day, which is where the term "ton" came from sizing air conditioning. Relatedly, a Btu is the amount of heat energy required to raise the temperature of one pound of water (about a pint) one degree Fahrenheit in one hour. This is also about the amount of energy given off by completely burning a wooden kitchen match. A heating unit is used to identify air conditioners, because air conditioners are just moving heat – not producing "cold." There is no such thing as a unit of cold, just units of heat moving out of one environment and into another.
   - For instance, a 4 ton air conditioner is one that can remove 48,000 BTUs of heat per hour from the house.
   - TON = $Q_{ABSORBED}$
   - 1 TON = # of Watts
9. **Metric units use:** Watts of cooling / Watts of electricity.
10. **Imperial units use:** BTU of cooling / Watts of electricity.

16.11.1.1 Ton rating

There are 12,000 BTUs per ton, a two-ton heat pump has a capacity of 24,000 BTUs of heating or cooling, meaning that it would be rated at 24,000 BTU per hour. Compared to larger heat pumps, a two-ton unit will be less expensive and likely occupy less space. These units are more suited for heating and cooling smaller spaces or enhancing comfort in areas with moderate heating and cooling needs.

A capacity of 24,000 BTUs will heat or cool areas of up to 1,000 square feet. But it's important to confirm that a two-ton unit is suitable for your home and climate before investing in one. Picking the right unit ensures you save on energy consumption, reduce wear and tear and maximize comfort.

A ton of heat pump capacity is equivalent to 12,000 BTU per hour, and a three-ton heat pump is rated at 36,000 BTUs per hour. This rating means that it has a higher heating and cooling capacity than a two-ton unit and a lower capacity compared to a 4-ton heat pump. It will also consume more energy that a 2-ton unit to maintain indoor air at the desired temperatures. While it's not necessarily heavier than smaller-capacity pumps, it will likely cost more to buy and install. A quality three-ton heat pump can effectively heat or cool an average area of 1,500 square feet, but will be too large for smaller spaces.

16.11.1.2 Standard atmospheric efficiencies

HVAC systems run at different efficiencies. To provide 10,000 kWh of heating from a device that runs at 85% efficiency, the system needs to provide the device 11,765 kWh of heat from some source, for example, gas:

- 10,000 kWh / 0.85 = 11,765
- Inevitably, some thermal output will go to waste, which is where the 85% efficiency comes in.

If an electric heater is 100% efficient. Hence, to provide 10,000 kwH of heating, the system needs to provide

10,000 kWh of heat from electricity.

17 Architecture gas and fuel sub-system

Note that an architectural gas and fuel service system is similar to a water service system in the plumbing networks/systems are used to access and distribute the materials to endpoints.

17.1 Natural gas sub-systems

Natural gas and propane are common resources used in many different home appliances, specifically in cooking and heating systems.

17.1.1 Hazards with the natural gas system

The primary natural gas risks include, but may not be limited to:

1. Leakage.
2. Explosion.
3. Buildup of dangerous combustion by-products.

17.1.2 Natural gas piping

Gas enters the building through a gas-based plumbing/piping network. There are several best practices that ought to be followed when creating a piping network for gas (Plumbing systems, 2021):

1. Gas piping entering the building must be protected from accidental damage by vehicles, foundation settlement or vibration. Where practical, the entrance should be above grade and provided with a self tightening swing joint prior to entering the building.
2. Gas piping shall not be placed in unventilated spaces, such as trenches or unventilated shafts, where leaking gas could accumulate and explode.
3. Gas shall not be piped through confined spaces, such as trenches or unventilated shafts.
4. All spaces containing gas-fired equipment, such as boilers, chillers and generators, shall be mechanically ventilated.
5. Vertical shafts carrying gas piping shall be ventilated.
6. Gas meters shall be located in a gas meter room, thus avoiding leakage concerns and providing direct access to the local gas utility.
7. Gas detectors should be placed on the ceiling where gas is used.
8. All gas piping inside ceiling spaces shall have plenum rated fittings.
9. Diaphragms and regulators in gas piping must be vented to the outside.

Vents to the outside environment must be installed wherever natural gas is burned; because the combustion creates by-products (e.g., carbon monoxide) that are dangerous to humans and other animals.

17.1.3 Objects in the gas system: fixtures, fittings, and appliances

Natural gas fixtures and fittings are equipment that interface with the natural gas in a building:

1. **Natural gas fixture** - A device for receiving natural gas. The most common fixtures include, but may not be limited to:
   A. Gas meters.
   B. Natural gas sensors.
2. **Natural gas fitting** - a device designed to control and guide the flow of natural gas. The most common fittings include, but may not be limited to:
   A. Hoses.
   B. Connectors.
3. **Natural gas appliances** - appliance devices that use natural gas, the most common of which include:
   A. Gas ovens.
   B. Gas burners.
   C. Gas grills.
   D. Tankless water heaters.
   E. Tank-based water heaters.
   F. Fireplaces.
   G. Dryers.
   H. Furnaces.
   I. Boilers.
   J. Outdoor gas lights.

17.2 Fuel oil sub-systems

Fuel oil systems require tanks of oil to be delivered to the architecture, which are then connected to fuel oil fittings and appliances. Fuel oils are all petroleum-based (hydrocarbons), and most commonly include kerosene , diesel, and gasoline.

17.2.1 Hazards with the fuel oil system

The primary natural gas risks include, but may not be limited to:

1. Oil discharge when connecting.
2. Leakage.
3. Fire.
4. Frequent maintenance.
5. Oil deliveries.
6. Buildup of dangerous combustion by-products.

17.2.2 Fuel oil piping

Fuel oil enters the building through a gas-based plumbing/piping network. There are several best practices that ought to be followed when creating a piping network for gas (Plumbing systems, 2021):

1. Fuel oil piping system shall use at least Schedule 40 black steel or black iron piping.
2. Fittings shall be of the same grade as the pipe material. Valves shall be bronze, steel or iron and may be screwed, welded, flanged or grooved.
3. Double-wall piping with a leak detection system shall be used for buried fuel piping.
4. Duplex fuel-oil pumps with basket strainers and exterior enclosures shall be used for pumping the oil to the fuel burning equipment.
5. Underground fuel oil storage tanks shall be of double wall, non-metallic construction or contained in lined vaults to prevent environmental contamination.
6. Tanks shall be sized for sufficient capacity to provide 48 hours of system operation under emergency conditions (72 hours for remote locations such as border stations). For underground tanks and piping a leak detection system, with monitors and alarms for both, is required. The installation must comply with local, State and Federal requirements, as well as EPA 40 CFR 280 and 281.

Vents to the outside environment must be installed wherever natural gas is burned; because the combustion creates by-products (e.g., carbon monoxide) that are dangerous to humans and other animals.

17.2.3 Objects in the fuel oil system: fixtures, fittings, and appliances

Fuel oil fixtures and fittings are equipment that interface with the fuel oil in a building:

1. **Fuel oil fixture** - A device for receiving fuel oil. The most common fixtures include, but may not be limited to:
   A. Not applicable.
2. **Fuel oil fitting** - a device designed to control and guide the flow of fuel oil. The most common fittings include, but may not be limited to:
   A. Tanks.
   B. Hoses.
   C. Connectors.
3. **Fuel oil appliances** - appliance devices that use fuel oil, the most common of which include:
   A. Oil-fired burners.
   B. Oil-fired furnaces.
   C. Electrical generators.

18 Architecture electrical sub-system

A.k.a., Electrical service engineering, electrical power system.

Electrical systems either use electricity to function or are involved in the production and/or transmission of electricity.

The most common electrical sub-systems in a building are:

1. Electrical production systems; electrical supply.
2. Electrical distribution systems.
3. Lighting.
4. Heating, ventilation and air conditioning.
5. Automated control.
6. Operation of machines (e.g., motors and appliances).
7. Data processing, transmission/telecommunications.

Within architecture, there are three types of equipment:

1. **Electrical demand equipment** - equipment that uses electricity, such as motors, computers, lighting, HVAC, etc.
2. **Electrical production / supply equipment** - equipment that produces electricity, such as solar panels and generators.
3. **Electrical distribution and sub-processing equipment** - equipment that allows for the transmitted distribution of electricity and the sub-processing to ensure compatibility with end devices. Such as wires and transformers before endpoint electrical devices.

In relation to electricity in buildings, the term electrical power is usually associated with:

1. Electrical demand.
2. Electrical rating.
3. Electrical supply capacity.

In this context, electrical power is concerned with how much power a building or a circuit may require, which in turn will relate to capacity of supply, size and rating of conductors, type and rating of protective equipment as well as functional switching capacity.

Power calculation variables include, but are not limited to:

1. **The watt** - is the SI unit of electrical power that measures energy transfer at a rate of 1 joule per second. Herein, one watt is defined as the energy consumption rate of one joule per second (J/s). One watt is also defined as the current flow of one ampere with a voltage of one volt.
2. **The circuit-watt** - is the power consumed in lighting circuits by lamps, and where applicable, their associated control gear (including transformers and drivers) and power factor correction equipment.
   A. **Lamp lumens per circuit-watt** - is the total lamp lumens summed for all luminaires in the relevant areas of the building, divided by the total circuit-watts for all the luminaires.
   B. **Luminaire lumens per circuit-watt** - is the (lamp lumens x LOR) summed for all luminaires in the relevant areas of the building, divided by the total circuit-watts for all the luminaires.

18.1 Electrical standards

Significant electrical standards include, but are not limited to:

1. U.S. Occupational Safety and Health Administration (OSHA; or its equivalent) - is part of the United States Department of Labor and was created to ensure safe and healthful working conditions for working men and women by setting and enforcing standards and by providing training, outreach, education and assistance.
2. Institute of Electrical and Electronics Engineers (IEEE) - is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity. The IEEE has developed standards for over a century using technical experts from all over the world. The IEEE has over 1100 active standards.
   A. IEEE 1547 - Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces. This is the standard that describes the interconnection of PV and other distributed energy resources (DERs) to the utility grid.
3. International Electrotechnical Commission (IEC) - is an international standards organization that prepares and publishes international standards for all electrical, electronic and related technologies.
4. American National Standards Institute (ANSI) - is a private, not-for-profit organization dedicated to supporting voluntary standards. ANSI accredits many different standards developers, including those familiar to the electrical industry like NFPA, UL, and IEEE. ANSI has over 11,500 active standards.
   A. ANSI /IEEE Standard C37.2 - Standard for Electrical Power System Device Function Numbers, Acronyms, and Contact Designations.

Identifies the features and function number of a protective device such as a relay or circuit breaker.

5. National Electrical Manufacturers Association (NEMA) - develops performance standards and promotes product interoperability to increase market demand while improving safety to mitigate risks.
6. North American Electric Reliability Corporation (NERC) - is a not-for-profit international regulatory authority whose mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Significant electrical codes include, but are not limited to:

1. The International Code Council (ICC) has a chapter in its international building code (IBC) related to electricity, chapter 13 (2018). [codes.iccsafe.org]
2. U.S. National Fire Protection Association (NFPA).
3. U.S. National Electrical Code (NEC).
4. Institute of Electrical and Electronics Engineers (IEEE).
5. National Electrical Safety Code (NESC).
6. International Code Council (ICC).
7. International Building Code (IBC).
8. International Fire Code (IFC).
9. International Energy Conservation Code (IECC).
10. Energy Market Authroity (EMA) Codes of Practice.
11. Etc.

NOTE: *In some jurisdictions, there are also testing agencies, that test and then certify the building as meeting a set of criteria.*

18.1.1 Standard electrical documentation

A.k.a., Atmospheric system specification and drawings.

Electrical systems are documented via specifications and drawings.

1. **Electrical drawings (a.k.a., electrical schematics, electrical schematics):** illustrate the system that will support airflow and transfer thermal energy. Atmospheric (HVAC) drawings illustrates the atmospheric system.
2. **Electrical specifications:** include all written content, reasoning for decisions, and calculations.

18.1.1.1 Electrical load data tables

Electrical system equipment includes two primary categories:

1. **Electrical usage equipment [data] table (a.k.a., electrical usage equipment list)** - is appliances, devices and other equipment that uses electricity to meet human technical needs. All endpoint equipment that uses electricity.
2. **Electrical equipment [data] table (a.k.a., electrical equipment list)** - is equipment that relates specifically to the electrical system (e.g., solar power equipment, transformers, circuit breakers, etc.). All electrical system specific equipment.
3. **Load calculation table (a.k.a., demand calculation table)** - this table shows electrical load calculations for each family. The calculations in this table are often separated first by family, and then, totals.
4. **Load forecast table** - this table shows

18.1.1.2 Electrical production drawings and specifications

A.k.a., Electrical system diagrams, electrical system schematics.

An electrical drawing illustrates the electrical circuit system.

1. Circuit diagram (a.k.a., wiring diagram, wiring circuit diagram).
2. One-line electrical wiring diagram.

An electrical specification includes a materials list:

1. Schedule for a power panel.
2. Schedule for electrical circuit.
3. Schedule for solar system.

18.1.1.3 Electrical system plan

An electrical plan covers the following elements:

1. System concept.
2. Load calculation.
3. System zoning.
4. Electricity distribution.
5. Equipment selection.
6. Wiring size calculation.
7. Adjustment, testing and balance.

The electrical plan includes standards for safety and electricity quality for all buildings. It also covers requirements for the prevention of fires and other hazards.

18.1.1.4 Electrical efficiency plan

The analysis to determine the best system to meet the energy/power requirements for a habitat service system, and may be produced through the following steps:

1. **Step 1:** Determine the following [for the whole HSS,

individual buildings and combined buildings]:
   A. Hourly electrical load for the whole HSS
      1. Demand loads.
   B. Hourly thermal loads for the HSS.
   C. Hourly heating loads for the HSS
   D. Hourly cooling loads for the HSS.
   E. The final estimation, which can be based on measured data or simulation analysis.
2. **Step 2:** Identify the main energy resources available within or close to the site where the HSS is located. These resources typically include solar, wind, geothermal, hydroelectric, fossil fuel, and biomass.
3. **Step 3:** Collect specific analysis data including market-economic parameters such as fuel costs and electricity prices from the grid as well as the capital and operation and maintenance (O&M) costs for various power-generating technologies.
4. **Step 4:** Carry out optimal analysis for various technically feasible options for power generation technologies, including fuel-based as well as renewable energy technologies. Calculation formulas within tables, as well as simulation tools, are typically used in the analysis.
5. **Step 5:** Rank and select the most [cost-]effective system, including the optimal capacities.

18.1.2 Standard electrical requirements

What is required for a viable electrical production-distribution system is:

1. **For architecture** - Electrical production proportionate to electrical demand [via a load, motion].
2. **For economic calculation** - Data sheet about loads (electrical appliances) to produce optimization calculation.
3. **For life support demand** - electricity proportionate to human demand.
4. **For technology and exploratory demand** - electricity proportionate to human demand.
5. **For buildings** - Appropriated localized electrical production proportionate to a mains supply (Read: supply from a distance).

18.1.3 Hazards with the electrical system

The most common hazards with an electrical system are:

1. Outage.
2. Load growth.
3. Electrical shocks.
4. Fires.
5. Lightning.
6. Damage to devices. Some electrical equipment and devices are sensitive to changes in supply frequency and voltage levels. In most cases, electrical systems are designed to operate within certain ranges of tolerances of specific values of frequencies and voltages.
7. Over or under parameter electricity (e.g., over voltage, under current, etc.).
8. Short-circuiting. Occurs when electrical wires that are not intended to touch come into contact with one another.

18.1.3.1 Electrical safety

Electrical safety covers the design, installation, inspection and testing, and operation of electrical installations in order to prevent injuries from electrical shocks and burns, and to prevent injuries arising from fires due to electrical components overheating or arcing. To ensure safety, all electrical equipment should be able to handle, control and dissipate electrical power safely, to avoid the risk of fire or electric shock.

18.1.3.2 Power quality disturbance protection elements

In order to protect against power quality disturbances, the following are some preventive and corrective devices and strategies that can be considered:

1. **Pulsed rectifiers** - are utilized to improve the shape of voltage and current sinusoidal waveforms, especially when operating motors
2. **Power harmonic filters** - are commonly used to reduce the effects of harmonic distortions
3. **Dynamic voltage compensators** - installed between power sources and loads to protect electrical systems against voltage sags
4. **Capacitor banks** - are specified to provide several benefits to the electrical distribu-tion systems, including increase in the power factor, improvement of voltage regu-lation, reduction in energy losses, and prevention of harmonic resonances
5. **Special transformers** - are utilized to control harmonic currents and mitigate voltage sags
6. **Uninterruptible power supply (UPS) systems** - are commonly specified as backup power sources for critical loads that require stable voltage levels. For several buildings, UPS systems consist typically of battery-powered devices that are charged from the utility power source using inverters and rectifiers. When the source voltage level is reduced due to any disturbances, a bypass switch is activated and power is supplied from the battery. The battery continues to provide steady power to the critical loads until the main power source returns to its normal operating condition, unless

the battery is totally discharged. Generally, battery-powered UPS systems come in a variety of sizes from 100 W to 500 kW. It should be noted that these standard sizes of batteries can only maintain the necessary voltage level for short periods. For large critical building loads, such as data centers or operating rooms in hospitals, UPS systems include, standby engine generators. The generators are connected to the critical load through transfer switches and can provide power for extended periods of time.

18.1.3.3 Electrical grounding

It is important to properly ground electrical systems to minimize fire hazards, electrical shocks and injuries to occupants, and damage to equipment. Grounding systems are passive systems used to establish an electrical potential reference point in an electrical system for the proper dissipation of electrical energy in case of abnormal or transient conditions.

Design documents for grounding systems shall indicate at a minimum the following:

1. Type and location of grounding electrodes.
2. Bonding requirements.
3. Testing requirements.
4. Conductor material type, size and protection requirements.
5. Separate grounding systems, properly bonded, per code and use requirements.

The following types of grounded systems may be used in a building:

1. **Electrical system grounding:** Electrical systems that are grounded shall be connected to earth in a manner that will limit the voltage imposed by lightning, line surges, or unintentional contact with higher-voltage lines and that will stabilize the voltage to earth during normal operation.
2. **Grounding of electrical equipment:** Normally non-current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected to earth so as to limit the voltage to ground on these materials.
3. **Bonding of electrical equipment:** Normally non-current-carrying conductive materials enclosing electrical conductors or equipment, or forming part of such equipment, shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path.
4. **Bonding of electrically conductive materials and other equipment:** Normally non-current-carrying electrically conductive materials that are likely to become energized shall be connected together and to the electrical supply source in a manner that establishes an effective ground-fault current path. Figure 5.26 illustrates the application of a bonding jumper system to connect the panel enclosure to the neutral wires.
5. **Effective ground-fault current path:** Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a permanent, low-impedance circuit facilitating the operation of the protection device or ground detector for high-impedance grounded systems. It shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point in the wiring system where a ground fault may occur to the electrical supply source. The earth shall not be considered as an effective ground-fault current path.

The following grounding electrodes are possible for use in a grounding system:

1. Metal underground water pipe.
2. Metal frame of the building or structure.
3. Concrete-encased electrode.
4. Ground ring.
5. Rod and pipe electrodes.
6. Other listed electrodes.
7. Plate electrodes.
8. Other local metal underground systems or structures.

Some building standards do not allow for the following types of grounding electrodes:

1. Metal underground gas piping system.
2. Aluminum electrodes.

There are several basic rules for specifying grounding electrodes to protect building electrical systems from fault currents:

1. Each [circuit] system has to be grounded.
2. Grounding location needs to be as close to the power source of the derived. The grounding connection should be inside tripping protection device. If the tripping device trips, then the circuit would become ungrounded.
3. There should be only one grounding connection per derived system. When two or more locations are connected to the earth may result in return flow of ground-fault current back to the system.
4. In order to facilitate the flow of fault currents into the ground, low resistance path for the grounding conductor is needed. The ground electrode system

connecting a building electrical system to ground will often have an electrical resistance lower than 25 Ω. Several parameters and factors can affect the resistance of the ground electrode system (e.g., oxidation, earth movement, and moisture).

5. In order to ensure that all non-electrical conductive parts of equipment are safe to touch under normal operation, equipment grounding is required. The frames, enclosures, or structural supports of electrical equipment and distribution systems such as transformers, switchboards, panels, motor controllers, motors, generators, cabinets, lighting equipment, and outlet boxes have to be connected to earth through permanent and continuous paths that may include raceways, cable trays, armors of cables, and equipment grounding buses.

18.1.3.4 Lightning protection

Lightning protection systems are passive systems used to protect building and structures from damage caused by lightning and static discharges. Direct lightning strikes can be neutralized by a structural lightning protection system (a structural LPS). This interception establishes a circuit, allowing the structural LPS to conduct the lightning current to the earth, bypassing the building structure while equalizing the potential between the cloud and the earth. Roof lightning protection systems are essential to protect buildings, persons, and equipment from lightning. The lightning protection system intercepts lightning strikes and safely passing their extremely high currents to ground.

Electrical engineering documents for lightning protection systems shall indicate:

1. Air terminals height and spacing.
2. Arrangement of main and down conductors.
3. Grounding points and spacing.
4. Legend.
5. Testing requirements of grounds.

18.2 Conception of the electrical service system

A.k.a., Electrical supply sub-system.

In a habitat, power is produced for buildings as endpoints. Power production system are often differently configured around the world depending on their earth geo-position and the local jurisdiction (market-State). Buildings are connected to electrical supplies from either proximal or distal locations. When distal, a transmission network exists to supply multiple locations. The specific voltages distributed and served to buildings vary significantly worldwide and depend on the building types. Note that in most design cases, electrical systems are designed to operate within certain ranges of tolerances of specific values of frequencies and voltages.

Different jurisdictions in the world use different power system specifications:

1. Frequencies (Hz).
2. Number of phases.
3. Low voltages.
4. Medium voltages.

For example, as of 2017, the following jurisdictions maintain the following specifics for their power systems (Krarti, 2017):

Country	Frequency (Hz)	Number of phases	Low voltages (V)	Medium voltages (kV)
Argentina	50	1.3	230/400	6.6, 13.2, 33
Brazil	60	1.3	110/220, 125/216, 127/220, 220/380 120/240	6, 11.4, 13.8, 22, 25, 34.5
France	50	1.3	115/220, 127/220, 220/380	3.3, 5.5, 10, 15, 20, 30
Japan	50	1.3	100/200	3, 6, 6.6, 11, 20, 22, 60
United States	60	1.3	120/240, 120/208, 227/480	2.4, 4.16, 4.8, 6.9, 8.32, 12, 12.47
Venezuela	60	1.3	120/240	2.4, 4.16, 4.8, 12.47, 13.8

Some systems are more affected by current and voltage levels, and others more by frequency levels. A larger current flow can result in higher heat to be dissipated in the device. Specifically, the dissipated heat is proportional to the square of the current flow. For instance, doubling the voltage will typically double the current, resulting in the device dissipating four times the heat. Most devices cannot tolerate large increases in heat generation and may be significantly damaged. Most electrical devices cannot operate reliably with supply voltage levels that are higher than 10% of their rated voltage. Alternatively, some devices depend on magnetic fields to transfer and convert electrical energy to operate (such as motors and transformers) and are thus affected by any changes in frequency levels. For example, a pump driven by a 60 Hz electrical motor transfers less fluid when operated with 50 Hz source voltage. The electrical motor shaft speed is reduced by the ratio 5/6. Therefore, the output of direct-driven systems (such as HVAC equipment including pumps and fans) should be derated, typically by a factor of 5/6. It should be noted, however, that a 60 Hz motor can be operated to deliver the same mechanical power even when operated from a 50 Hz source, by increasing the torque has to be increased when operated at 50 Hz since the mechanical power is the product of the torque and the shaft speed (i.e., if shaft speed is 50Hz then the torque must be increased over a motor shaft speed of 60Hz. Similarly, operating a 60 Hz transformer using a 50 Hz source may cause saturation of its core resulting in overheating conditions. Other electrical systems can be sensitive to changes in frequencies from 60 to 50 Hz. For instance, circuit breakers have different tripping curves depending on the frequency level. It is important to ensure that adequate trip curves with the proper frequency value are utilized when coordinating protection devices. Moreover, reading meters may lose their accuracy when operating at different frequency systems.

High voltage levels are not safe to human life and require special safety precautions. For safe utilization, low voltages are typically used in buildings. High voltages are sometimes used in specialized manufacturing operations.

18.3 Conception of the electrical distribution sub-system

Power distribution systems are often differently configured for:

1. Dwellings,
2. Units of dwellings (apartments), and
3. Commercial buildings.

A typical electrical distribution system for a building consists of:

1. A supply line from some source.
2. If the supply line is from the market-State, then there is a meter (to measure usage for payment).
3. The line continues through the meter to a circuit breaker panel that serves a set of branch circuits with fuses.
4. The branch circuits provide electricity to various loads (lighting and receptacles) located within the building.
5. In the United States, small buildings are served using 240/120 V system (dwellings and detached homes) or 208Y/120-V system (small commercial buildings or apartment buildings). These voltages are obtained directly from a utility transformer that is served by a 13.8 kV distribution voltage.

Electrical distribution systems can include, but are not limited to the following additional elements:

1. A step-down transformer(s).
2. Power panels.
3. Protection devices.
4. Grounding systems.
5. Wiring methods.

Residential buildings generally include the following base elements (in order from endpoint to production source):

1. **Loads:** usage sub-systems.
2. **Branch circuits:** to many endpoints. Electricity feeds a panel that then feeds a branch-like connection of loads (Read: demands...for electricity).
3. **Panel-board circuitry**: connects branches with a main (or, mains) sources. This type of panel can house:
   A. A connected main and branch distribution panel (a.k.a., main distribution panel, MDP). Herein, the main panel supply is served by the main feeder from some step-down transformer.
   B. A branch to branch distribution panel.
4. **Panel-board protection device:** with breakers or fuses, or even uninterpatible connections between a mains the branches.
5. **Grounding elements:** are often connected to the panel-board and ground the whole electrical system into the earth.
6. **Electricity usage meter** : used by market entities to "profit" and "big data", or used in community to monitor and adjust production.
7. **Proximal feeder:** service entrance feeder.
8. **Transformer:** to ensure safe voltage and current enter architecture.
9. **Mains feeder and entrance of electricity:** from the (Intersystem team or market-State entity) utility production organization.

A typical electrical distribution system consists of a meter connected to one panel that serves a set of branch circuits to provide electricity to various loads (lighting and receptacles) located within the building. The production of electricity comes from one or more sources.

The electrical power distribution systems for commercial buildings is more complex than those of residential buildings, but utilizes the same basic component configuration, including: a network of step-down transformers, lighting and power panels, protection devices, grounding systems, monitoring systems, and wiring methods. In production and/or high occupancy buildings (a.k.a., commercial buildings in the market-State), the electricity is supplied at a high voltage of, for example, 13.8 kV and is distributed to the building at lower levels of 480Y/277-V and/or 208Y/120-V. Herein, the main feeder supplies electricity from the utility, which moves through a transformer served by the main feeder and transforms it into a safer and more usable for electricity using loads (Read: demands) within the building. Here, a main distribution panel (MDP), served by the main feeder from the main step-down transformer (13.8-kV–480Y/277-V), provides electricity safely to various loads through subfeeders, low-voltage step-down transformers (480Y/277-V–208Y/120-V), and panels. While the MDP is protected by power circuit breakers as well as a grounding system, the panels include several molded-case breakers that protect branch circuits serving building end-use loads such as plug-loads (receptacles) and lighting fixtures, or motors.

The complexity of power distribution in a larger building, versus individual residences, includes the following base elements (in order from endpoint to production source):

1. Loads connected to end-point distribution branch circuits. The building will be divided into electrical areas, each connecting loads directly with the endpoint branch circuit.
2. Endpoint branch panels house the branch circuitry, and connect loads to transformers.
3. These transformers step-down current from the interior sub-feeder. In other words, the interior sub-feeder feeds many transformers that subsequently feed safer electricity into as many branch panels as there are branch areas (and branch circuitry).
4. The main distribution panel (MDP) connects the buildings electrical sub-feeder to the main electrical supply coming from outside the building (generally).
5. The main feeder from outside the building connects to the main distribution panel (MDP).
6. The main feeder is in turn connected to another transformer for stepping down electricity from the utility to the interior of the building.
7. A meter may exist between the building (from the point of the transformer forward) to measure electricity usage by the building and its interior occupation. In the market-State, this meter is used to tax (State behavior) and profit (market behavior).

18.4 Conception of the electrical wiring sub-system

The laying of electrical wire can be optimized by the following best practices:

1. Use a conduit (or, raceway) with pre-placed "pull wire" to pull a new wire and/or replace an old.
2. Use a metal conduit to reduce attenuation of the wire's electromagnetic field, as well as reduce shocks and the potential for damage by insects and/or rodents.
3. Never permanently staple wires (any type of wire, including power and data).

Electrical wire conductors transport electricity. These wire conductors include:

1. Different materials.
2. Different configuration of wiring (e.g., flat, twisted, etc.).
3. Different number of wires (most homes have three-wire service - two hot wires and one neutral).
4. Different sizes.
5. Different coverings (Read: insulation).

NOTE: *There are also different wiring methods.*

18.4.3.1 Primary electrical circuits

There are two primary electrical circuits in a building, which are generally rated differently:

1. **Main circuit** - is a conductor that attaches to the primary outside source of electricity (often coming from a municipal electric utility fed from an electrical grid). The main circuit is generally rated on the amapcity of the conductors.
   A. The question is, how much amperage can the main circuit [into the building] handle?
2. **Branch circuit(s)** - is a conductor or a set of conductors that extends typically from a panel (such as a circuit power panel or a lighting panel) to the utilization equipment (e.g., a electrical outlet, receptacle, a motor, or a lighting fixture). A building can have many branch circuits. Branch circuits are generally not rated based on the ampacity of the conductors, but by the size of the overcurrent protection devices connected to them with ratings of 15, 20, 30, 40, and 50 A.
   A. The main safety question is, how much overcurrent protection does the branch have?
   B. The main design question is, what is the demand load associated with the panel to determine the best circuit breaker size (Read: amperage rating) of each circuit breaker in the panel.

18.4.1 Electrical loading specification

In order to specify the components for electrical distribution systems for a building, it is necessary to determine:

1. **All the end-use loads** that need to be served by electricity as well as their:
   A. Rated voltages.
   B. Rated frequencies.

The procedure is generally as follows:

1. The loads are estimated
2. The branch circuits are selected
3. The panels as well as the feeders and subfeeders are specified.
4. If required, transformers are added as needed to supply voltages throughout the building.

Design objectives include, but are not limited to:

1. Safety should be the most important objective for specifying various components of the power distribution systems for buildings.
2. When any problem occurs, such as a fire due to short-circuiting, arcing, or melting within a power unit, any person located near has access to a fire extinguisher device and can have a safe pathway to the exit.
3. Electrical production and distribution systems should be designed to ensure that they operate reliably without interruption under normal loading conditions.
4. The design specifications of any electrical production and distribution system should allow for some flexibility. In particular, the system should be able to handle additional electrical loads due to future expansion and/or change of end-use equipment or loads (i.e., lighting, appliances, or motor loads).
5. The components of the power production and distribution systems should be designed to be easily accessible in order to facilitate their maintenance, repair, and replacement.
6. Selecting a rating of 20Amp for a circuit breaker provides more reliability (and safety) than using a 15Amp circuit breaker.

18.5 Objects in the electrical system: fixtures, fittings, and appliances

Electrical fixtures and fittings are equipment that interface with the electricity in a building:

1. **Electrical fixtures** - a device for producing and/or processing electricity. The most common fixtures include, but may not be limited to:
   A. Circuit breaker.
   B. Solar panels.
   C. Backup batteries.
   D. Transformers.
   E. Generators.
   F. Grounding elements and electrodes.
   G. Lightning protection elements.
   H. Feeders.
2. **Electrical fittings** - a device designed to control and guide the flow of electricity. The most common fittings include, but may not be limited to:
   A. Switches.
   B. Sockets.
   C. Light fittings.
   D. Fans (etc.)
   E. Electrical wiring (note that this could also be considered a fixture. Additionally, some buildings make is so wiring cannot be replaced without demolishing walls -- in this case, builders sometimes staple the wiring to the studs).
3. **Electrical appliances** - most appliances require electricity.
   A. Motors.
   B. Robots.

IMPORTANT: *All fixtures, fittings, and appliances must be specified with the right capacity for their placement.*

18.5.1 Outlets

Outlet receptacles in an electrical system can be of many types , including but not limited to:

1. Duplex receptacle.
2. Ground fault current interrupter.
3. Weatherproof duplex receptacle.
4. Duplex receptacle served by an emergency branch circuit.

18.5.2 Switches

Switches in an electrical system can be of many types, including but not limited to:

1. Simple switch.
2. Three way switch.
3. Switch with built-in dimmer.

18.5.3 Electrical processing equipment

Electrical processing equipment in an electrical system can be of many types, including but not limited to:

1. Power panels.
2. Junction boxes.
3. Transformers - are electrical components designed to do one of three things:
   A. Decouple one circuit from another,
   B. Increase voltage from one value to a higher potential, or
   C. Decrease voltage to a lower potential.
4. Electrical meters (instrument transformers).

18.5.3.1 Electrical transformers

Common types of transformers used in building include, but may not be limited to:

1. **Power transformers** - change power parameters, of which there are two usages:
   A. Used for electricity transmission and distribution. Electrical power is transmitted long distances at very high voltages. This power must be stepped down for most buildings. A transformer may be installed to step-down transmission voltages to voltages expected for individual buildings.
   B. Used within buildings In particular, power transformers are cost-effective devices to make available voltages needed for lighting and other specialized applications.
2. **Electrical instrument meters (instrument transformers)** - are often instrument transformers that monitor (and "meter") electricity use. These instrument transformers allow the measurement of high voltage and current with low-scale voltmeters and ammeters. There are two basic types of instrument transformers: voltage transformers (a.k.a., potential transformers, PT) and current transformers (CT).
3. **Autotransformers** - are small and relatively inexpensive transformers used to that step down voltages to low voltage.

There are basically two types of connections for electrical transformers used for building systems:

1. Single-phase transformers.
2. Three-phase transformers.

There are basically two types of transformers for building applications:

1. Liquid-filled transformers - wherein the liquid acts as a coolant and an insulation dielectric. Oil-filled transformers can create a severe fire and explosion hazard and therefore have to be mounted outdoors unless fireproof and explosion-proof vaults are used for indoor installations.
2. Dry-type transformers - are constructed so that the core and coils are open to allow cooling by the free movement of air. In some cases, fans may be installed to increase the cooling effect. The dry-type transformers are widely used because of their lighter weight and simpler installation method compared to the liquid-filled transformers. Dry-type transformers are more expensive, typically by more than 200%, than the oil-filled transformers.

There are several potential hazards that need to be considered in the case of transformers:

1. Noise problems: To reduce noise problems, it is recommended to specify transformers with minimum sound level (50 dB or lower). Moreover, it is desirable to place the transformer in the least valuable space of the building away from any quiet areas. In some cases, the electrical room where the transformer is located may need to be soundproofed using adequate acoustical materials.
2. Vibration problems: To reduce the vibration associated with the operation of transformers, isolators should be placed beneath the transformer mounting pads. Moreover, flexible conduits should be installed to house the secondary and primary feeders of the transformer. Without these measures, vibration may be transferred to other building parts and cause structural damages.
3. Heat problems: Heat is dissipates by transformers as part of the copper conduit losses. This heat can represent 0.5%–2% of the total transformer power rating depending on the transformer efficiency. To avoid overheating of the transformer and the room housing the transformer, ventilation should be provided or adjustable louver should be installed in the wall or the door adjacent to the transformer.
4. Electromagnetic field problems: Transformers should not be placed near normal human occupied locations because of their strong electromagnetic fields (e.g., a transformer should not be on the other side of the wall of a couch, bed, or any potentially normally occupied location).

18.5.4 Electrical protection equipment

Types of electrical panel protection devices include, but are not limited to, all of which are designed to interrupt the power to a circuit when the current flow exceeds safe levels:

1. **Fuses ("fuse box")** - are an over-current protective device with a circuit opening fusible part that is heated and severed by the passage of current through it. A fuse box is a place where one or more fuses may be installed into a system. A fuse should not be used in situations that require a GFCI.
2. **Circuit breakers ("breaker box")** - are a device designed to open and close a circuit by non-automatic means (i.e., manually) and to open the circuit automatically on a predetermined matter without damage to itself when properly applied within its rating. A circuit breaker is a trip mechanism for shutting of the electricity in cases of potential danger. The circuit trip mechanism

itself can wear out over time and may/will need to be replaced. A typical circuit breaker consists of a main breaker handle and multiple branch circuit breakers. The main breaker handle mechanism is the most often replaced part due to failure. The branch breakers and the main breaker are, basically the same thing. They function in the same way, but the branch breakers are smaller. The main breaker is designed to interrupt a larger amperage load. Circuit breakers are available for various voltages and continuous current ratings as well as interrupting current ratings, response characteristics, and methods of operation. A branch circuit is a conductor (or a set of conductors) that extend from a panel to the utilization equipment (e.g., receptacles, motors, and lighting fixtures). Branch circuits are generally not rated based on the ampacity of the conductors but by the size of the overcurrent protection devices connected to them with ratings of 15, 20, 30, 40, and 50 A. The mechanism of opening the contacts may involve solid-state, thermal, magnetic, or thermal-magnetic trip units. In general, circuit breakers have two different ways of working: the first is through the use of an electromagnet and the other is through the use of a bi-metal strip. In both instances, when turned on, the breaker allows electrical current to pass from a bottom to an upper terminal across the strip. Once the current reaches any unsafe levels, the magnetic force of the solenoid or strip becomes strong enough to throw a metal lever in the switch mechanism, breaking the current. The other option that can happen is that the metal strip can bend, throwing the switch and breaking the connection. In order to reset the flow of electricity, the switch can just be turned back on (generally, manually). This movement of the switch reconnects the circuit. Circuit breakers have other applications, such as using for ground-fault circuit interrupter, or GFCI. The function of GFCI is to prevent electric shock, rather than just overheating. It breaks the circuit in an outlet if the current gets unbalanced. To reduce and even eliminate the potential damages associated with ground faults, addi-tional protection systems are needed. In particular, the use of ground-fault current inter-rupters (GFCIs) is required for several locations within buildings. GFCIs allow the detection of small ground faults (as low as 6 mA) and to quickly open the circuit to avoid any harm to humans and damages to electrical equipment. The GFCI can generally be reset by the touch of a button. GFCI technology is widely found in kitchens or bathrooms, where electrocution is a risk from the use of electrical appliances near water sources such as sinks or faucets. GFCI circuit breakers are commonly installed in panels and provide ground-fault protection to all the loads served by the branch circuits connecting the breakers. There are also portable in-line GFCI units that go in between an outlet and the power cable to an electrical device. Circuit breakers can be installed either in single pole or multipole. Multipole breakers are generally gang operated so that all the poles are closed and opened simultaneously by one common operating mechanism (such as a handle). Therefore, circuit breakers cannot cause single phasing in three-phase systems as can be the case when using fuses as protection devices. Circuit breakers do not contain fuses, instead electrical circuitry are used. Circuit breakers have several advantages compared to fuse only systems:

A. Can serve as means of both protecting and switching an electrical circuit.
B. Does not cause single phasing.
C. Can be remotely operated.
D. Can easily incorporate ground-fault protection.

Non-panel fault protection types include, but may not be limited to:

- Grounding (earthing).

18.5.5 Feeders

Electrical feeders are the power lines through which electricity is transmitted in power systems. These electrically conductive lines (Read: feeders) transmit power from a generating station or substation to the distribution points. In power engineering, a feeder line is part of an electric distribution network, usually a radial circuit of intermediate voltage. For sizing the feeders and subfeeders, demand loads rather than the actual connected loads should be considered to account for the fact that not all the loads would be utilized simultaneously.

In small buildings there is just one main feeder supplying a branch circuit breaker panel. In larger buildings there are two feeders, one that supplies the mains circuit breaker panel and a sub-feeder that feeds

18.5.6 Motors

Motors convert electrical energy to mechanical energy and are typically used to drive machines. The driven machines can serve a myriad of purposes in buildings, including moving air (supply and exhaust fans), moving liquids (pumps), moving physical objects (gates), and compressing gases (refrigerators). To select the type of motor to be used for a particular application, several factors have to be considered, which include the following (Krarti, 2017):

1. The form of the electrical energy that can be delivered to the motor:
   A. Direct current (DC), or
   B. Alternating current (AC), single phase or three phases.
2. The requirements of the driven machine, such as motor speed and load cycles.
3. The environment in which the motor is to operate:
   A. Normal (where a motor with an open-type ventilated enclosure can be used).
   B. Hostile (where a totally enclosed motor must be used to prevent outdoor air from infiltrating inside the motor).
   C. Hazardous (where a motor with an explosion-proof enclosure must be used to prevent fires and explosions).
4. Depending on materials and configurations, motors can be more or less efficient. In the market, more efficient motors cost more.

The difference in electrical efficiency between two motors can be calculated by (Krarti, 2017):

- $\Delta P_R = P_M \left((1/\eta_S) - (1/\eta_E) \right)$
  - Wherein,
  - PM is the mechanical power output of the motor. η_S is the design (i.e., full-load) efficiency of the standard motor. η_E is the design (i.e., full-load) efficiency of the energy-efficient motor.

Hence, the electric energy savings incurred from the motor replacement is thus:

- $\Delta kWh = \Delta PN_R * N_h \times LF_M$
  - Wherein,
    - ΔP_R is the reduction in motor real power demand estimated using the equation for the difference in electrical efficiency between two motors *(see above)*.
    - N_h is the number of hours per year during which the motor is operating.
    - LFM is the load factor of the motor's operation during 1 year.

18.6 Installation of electrical system

A.k.a., Wiring installation.

There are many ways to install electrics. These systems are usually embedded into structure.

18.7 Operation of electrical system

A.k.a., Wiring operation.

Most significant operational activities are located on the supply side because of the requirement for static pressure given dynamic demand. Some demand-side specialized electrical systems, such as solar panels, may have significant operational activities.

18.7.1 Electrical load demands

A.ka., Electrical loading.

In order to do work, electrical systems are split into an electrical power production, distribution, and usage service system. Herein, electrical loads are measured in several ways, most notably, energy consumed:

1. Most electrical loads are measured in watts [of electrical] power. Watts is a unit of power.
   A. Kilowatt hour (kW.h or kWh) is a unit of energy equal to one kilowatt of power sustained for one hour or 3600 kilojoules (3.6 megajoules).
      1. How many kWh does a load use? A 60-watt load uses 60 watts of energy/power; if energy usage is accounted in hours of usage, then power usage for loads may be expressed in some scaled unit of the watt hour (e.g., kilowatt hours). One kilowatt hour is equal to 1,000 watts continuously for 1 hour. Therefore, a 60-watt bulb uses 60 watts hours or . 06 kilowatt hours of energy for each hour it's on.
2. Volt-ampere hour (V.A.h, VAh, or VA) which are the same as W.h or Wh when power factor =1.
   A. As power factor drops (current & voltage increasingly are out of phase) the user gets increasingly-less Watts for the same VA.
3. The transmission lines and transforms are another type of load.
   A. Current causes losses in transmission lines and transformers.
4. Non-usage, but presence, will still equate to system service usage.
   A. If a usage circuit has no load in the form of a power factor of zero the user would consume NO watt.hours, but the supplier would still have to send current to them and incur real energy losses in lines and transformers. Power factor is the relationship (phase) of current and voltage in AC electrical distribution systems.

NOTE: *It is important to note that when calculating usage of electricity by a device, measuring amperes don't provide sufficient information about energy transfer from a source to a load. If a load took 100 amperes at 1 volt, the power consumption (joules of energy per second) is 100 watts. If a different load took 100 amperes at 100 volts, the energy transfer per second is 10,000 watts.*

Electrical load evaluation includes the following calculable variables:

CLARIFICATION: *Load = demand.*

1. **Connected load** - is the total electric power-consuming rating of all devices connected to an electrical distribution system, the total demand.
2. **Demand load** - is calculated in a certain time interval by measuring the greatest load demand during this time interval.

Demand loads can be calculated using demand factors as summarized for lighting loads *(generalized examples shown)*:

Occupancy type	Connected loads range (VA)	Demand factors (%)
Dwelling units	0-3,000	100
	3,001-120,000	35
	Over 120,000	25
Hospitals	0-50,000	40
Warehouses for storage	0-12,500	100
	Over 12,500	50

Demand factors for non-dwelling receptacle loads *(generalized examples shown)*:

Connected loads range (VA)	Demand factors (%)
0-10,000	100
Over 10,000	50

3. **Maximum demand** - the integrated demand for a specified time interval (i.e., 5 minutes, 15 minutes, 30 minutes, or other appropriate time intervals, rather than the instantaneous demand or peak demand).
   A. **Maximum load demand** - is defined as the sum of ratings of all electrical equipments that are connected at the supply point regardless of their status of operation It is calculated depending on the installed equipment without measuring or testing their actual demand The connected load, which is independent of time, is greater than the maximum load demand.
4. **Instantaneous demand (a.k.a., instantaneous load)** - the power that something is using (or generating) at any one moment in time.
5. **Peak demand (a.k.a., peak load)** - the power that everything is using at some peak time(s).
6. **Demand factor (a.k.a., power factor) -** is the ratio of the sum of the maximum demand of a system (or part of a system) to the total connected load on the system (or part of the system). Demand factor is always less than one. The ratio of the maximum coincident demand of a system, or part of a system, to the total connected load of the system. Demand factor is express as a percentage (%) or in a ratio (less than 1). Demand factor is always < =1. The lower the demand factor, the less system capacity required to serve the connected load. The term demand factor is used to refer to the fractional amount of some quantity being used relative to the maximum amount that could be used by the same system. The word "demand" itself says the meaning of Demand Factor. The ratio of the maximum coincident demand of a system, or part of a system, to the total connected load of the system. The demand factor is always less than or equal to one. As the amount of demand is a time dependent quantity so is the demand factor. Demand factor is the ratio of the maximum (peak) demand to the full load of a device in a specific period of time.

The demand factor is the ratio of the maximum demand on a system to the total connected load of the system or

EQUATION: Demand factor = Maximum demand load / Total load connected

Demand Factor = Maximum demand / Total connected load

A. To calculate demand for a part of a system:

- $f_{Demand}(t)$ = demand / maximum demand
  - Wherein,
  - f_{Demand} = demand for load in a given time period / maximum possible demand for load

B. To calculate demand for a whole system:

DF = Maximum demand of a system (M.D) / Total connected load (TL) on the system

- DF = M.D / TL
- Wherein (i.e., this formula uses 2 variables):

1. Maximum demand - Maximum coincident demand is the maximum of all the demands that have occurred during a given period.
   - Measured in Watt.
2. Total connected load - Total Connected Load is the load connected across the system.
   - Measured in Kilowatt.

EXAMPLE: *If a residence having 6000W equipment connected has a maximum demand of 300W, then demand factor = 6000W / 3300W = 55%. Or, for example, an over sized motor 20 Kw drives a constant 15 Kw load whenever it is ON. The motor demand factor is then 15/20 =*

0.75= 75 %.

7. **Coincidence factor** - is the ratio of the maximum demand of a system, or part under consideration, to the sum of the individual maximum demands of the subdivisions.

   EQUATION: Coincidence factor = Maximum system demand / Sum of individual maximum demands

8. **The load factor (f_{load})**- Is defined as the average load divided by the peak load in a specified time period. It is a measure of the utilization rate, or efficiency of electrical energy usage; a high load factor indicates that load is using the electric system more efficiently, whereas consumers or generators that underutilize the electric distribution will have a low load factor. The load factor is the ratio of the average load over a designated period of time, usually 1 year, to the maximum load occurring in that period.

   EQUATION: Load factor = Average load / Maximum load

   f_{load} = *average load (or, demand) / maximum load (or demand) in a given time period*

9. **Diversity factor** - is the ratio of the sum of the individual maximum demands of the various subdivisions of a system (or part of a system) to the maximum demand of the whole system (or part of the system) under consideration. The diversity factor is the reciprocal of the coincidence factor. Diversity is usually more than one. Consider two buildings with the same maximum demand, but that demand occurs at different intervals of time. When supplied by the same feeder, the demand on such a system is less the sum of the two demands. In electrical design, this condition is known as diversity. Diversity factors have been developed for main feeders supplying a number of feeders, and typically, they are 1.10 to 1.50 for lighting loads and 1.50 to 2.00 for power and lighting loads. Feeder conductors should have sufficient Ampere Capacity to carry the load. For example, consider that a feeder supplies five users with the following load conditions: On Monday, user one reaches a maximum demand of 100 amps; on Tuesday, two reaches 95 amps; on Wednesday, three reaches 85 amps; on Thursday, four reaches 75 amps; on Friday, five reaches 65 amps. The feeder's maximum demand is 250 amps.

   EQUATION: Diversity factor = Sum of individual maximum demands / Maximum system demand

   Hence, in this example, the diversity factor can be determined as follows:

   Diversity factor = Sum of total demands ÷ Maximum demand on feeder = 420 ÷ 250 = 1.68 × 100 = 168%

   Diversity Factor = (Sum of individual maximum demand) / (Maximum demand of power station)

   Diversity Factor = Installed load / running load.

The demand load for a panel:

	Connected Load			Demand Load	
Load type	P_R (kW)	P_X (kVAR)	DF	P_R (kW)	P_X (kVAR)
Lighting	14	1	1.00	15	4.2
Appliances	4.1	2.1	0.5	4.1	2.1
Heatpump	14.8	4.9	1.1	15	8.8
Total				34.1	15.1

To determine true load and compare between loads, the following factors are required:

1. Idling/standby losses.
2. Raw electrical transformation efficiency.
3. Raw power output supply potential.

18.8 Engineering calculations electricity

To determine electrical power usage ("consumption") for a building, a control system may have an instrument transformer (utility "meter") installed in the high-voltage side of the service transformer. In particular, potential transformers (PTs) and current transformers (CTs) are installed to form wattmeters. One method that is commonly used to measure energy use in buildings (kWh) consists of using three wattmeters (one per phase). A wattmeter is made of a PT and a CT with a common turns ratio of 100. Estimate the actual current supply to a building supplied by 208Y/120 voltage system if a phase.

Optimization of an electrical system can occur on both the production and demand side of the system. Effective power systems need planning and demand forecasting to ensure that power supply meets power demand.

Here, it is essential to calculate the power factor of every system. The power factor is defined as the ratio of actual power used by the consumer (expressed in kW) to the total power supplied by the utility (expressed in kVA).

18.8.1.1 Power generation cost

A.k.a., Power generation cost, energy cost.

It is possible to determine the cost effectiveness of local power production systems and transported power (Read: utility grid power) systems, which can then be compared and combined. In general, the cost of energy is calculated as the cost of generating one kWh by the power production system/technology; while, accounting for its capital costs, financing costs, fuel costs, and fixed and variable operating and maintenance (O&M) costs over an assumed lifetime. Typically, the term levelized cost of energy (LCOE) is utilized when the present worth of all costs are considered. The specific calculations for LCOE depend on the power generating technology, but a general method is provided:

$$\text{LCOE} = \left(\sum\nolimits^{N}_{K=0} Ck * \text{SPPW}(d,k) \right) / \sum\nolimits^{N}_{K=0} E_k$$

- Wherein,
  - C_k are the total costs incurrent in year k and include investment expenditures, operations and maintenance (O&M) expenditures, and fuel costs.
  - E_k is the total electrical energy produced at year k.

NOTE: *In the market, for a power generating technology to be economically competitive, LCOE should be lower than the baseline (typically from the grid) prices.*

18.8.1.1 Life cycle financial cost

The life cycle analysis method is the most commonly accepted method to assess the financial costs of energy efficiency or distributed generation technology applications over their lifetime. For instance, it is possible to decide between two alternatives for the same project: install an energy-efficient transformer or consider premium efficiency motors), or both.

The basic procedure of the method is relatively simple, since it seeks to determine the total cost incurred by various alternatives over the lifetime of the system. The total costs are estimated over the system lifetime including installation, operation, replacement, and maintenance costs. The cost is commonly determined using:

1. The current cost [to legally acquire and legally install the capital/technology]. There word "legal" is used here because there are often legal and/or State taxes related to the acquisition of assets.
2. The annualized cost [to continue to legally own, operate, replace, and maintain the capital/ technology].

In the market-State, the system alternative with the lowest total cost is typically selected.

18.8.1.2 Electricity production resources and costs

There are resources and costs (market only) associated with electricity production, including but not limited to:

1. Generation plant: The cost of acquisition and operation of the power plant to generate electricity represents typically the highest cost category. The power generation plants have to meet several regulatory and safety requirements.
2. Transmission/distribution systems: To deliver the electricity from the generation plant, where it is produced, to areas where it is utilized, transmissions lines, sub-stations, and distribution networks have to be used. The cost of the transmission/distribution systems depends on the distances to be covered as well as transformers, capacitors, and meters to be used. Moreover, the delivery energy losses can be a significant part of the transmission/distribution costs.
3. Fuel systems: The electricity is generated using a primary fuel source depending on the power plant. The fuel cost can be small as in the case of hydroelectric plants or significant as in conventional fuel oil or coal power plants. The cost of fuel may fluctuate depending on the world markets.
4. Administrative costs: In the market, these are the salaries of management, technical, and office staff as well as insurance.
5. Maintenance costs: In the market there are maintenance costs for the power plant equipment.

19 Architecture illumination sub-system

A.k.a., Lighting, illumination engineering, lighting engineering.

Lighting systems convert electrical energy or fuel into light. Herein, light and illumination are one thing. Principle and attribute. Principle refers to what something is (e.g., light), and attribute is what something does (e.g., illumination).The illumination of buildings is a design process aimed at generating light for the user's well-being. The layering and patterning of light is considered successful when complex physiological and psychological requirements are satisfied. Such requirements arise from vision: the medium through which information and perceptions about a given space are received by photosensitive organs and processed by the brain. The illumination of an architectural space is simply the result of transmitted or reflected light emanating from proximal and distal surrounding surfaces. Only with a proper understanding of physiological and psychological factors, and a familiarity with available technologies, can lighting decisions be made for proper effect.

When available and well controlled, daylight is by far the preferred source of illumination. Today, the common design approach combines the contribution of both electric and natural lights.

Architectural illumination has several significant design elements:

1. Illumination within the building.
   A. Natural sunlight.
   B. Artificial (by means of electrical power).
2. Illumination surrounding the building.
   A. Natural sunlight.
   B. Artificial (by means of electrical power).
   C. Ventilation (can occur through light fixtures hooked for both illumination and ventilation).

The most significant characteristics of an illumination system are:

1. Volume of area consumed by technology.
2. Connector type.
3. Power type.
4. Lumen output (measured in lumens or luminous flux).
5. Color rendering index.
6. Color temperature.
7. Thermal output (note that some lighting adds relevant heat to a building).
8. Electrical load.
9. Total wattage.
10. Nominal wattage.
11. Lifetime.

19.1 Illumination standards

Just like other subsystem services (e.g., plumbing, electrical), there are illuminance standards, produced with different objectives.

19.1.1 Standard illumination documentation

Illumination systems are documented via specifications and drawings.

1. Illumination drawings (a.k.a., illumination schematics, light drawings) illustrate the system that will support illumination.
2. Illumination specifications include all written content, reasoning for decisions, and calculations.

An illumination drawing (illumination system schematic) illustrates the illumination system, including its wiring and electrical subsystem, and its lighted surface values. Note that an electrical diagram may/will include a circuit diagram for lighting.

There are two primary lighting diagrams:

1. An electrical lighting circuit diagram - shows the wiring of a lighting circuit(s) and the endpoints. In some cases, the main electric lighting circuits are separate from the power ring main circuit.
2. An illuminance diagram - shows the illuminance values of all surfaces, including time-of-day and illumination programming.

19.1.1.1 Illumination system plan

NOTE: *An illumination plan may be a sub-section of the electrical plan.*

An illumination (lighting and shading) plan necessarily involves:

1. Illuminance design diagram includes location and orientation of illumination:
   A. Light transportation surfaces (e.g., windows and mirrors).
   B. Illumination points.
      1. Natural.
      2. Artificial.
   C. Shading from view.
      1. Privacy.
   D. Shading from local illumination:
      1. Functional and desired.
      2. Function and not desired (i.e., light pollution).
   E. Shading from sun.
2. Electrical [lighting] design diagram for the circuitry that provides electricity and control to the illumination (and sensor) points.

19.1.2 Standard illumination requirements

What is required for a viable illumination system is:

1. **For architecture** - Illumination production proportionate to user demand.
2. **For economic calculation** - Data sheeting about demand (lighting) to produce optimization calculation.
3. **For life support demand** - illumination proportionate to human demand.
4. **For technology and exploratory demand** - illumination proportionate to human demand.
5. **For transport** - Lighting proportionate to motion and safety.
6. **For walking** - Lighting proportionate to motion and human biorhythms.
7. **For dwellings** - Appropriate space lighting with a human circadian light proportionate setting.
8. **For working areas** - Appropriate space lighting for safety, motion, and/or human biorhythms.

19.1.2.1 Bio-compatibility requirements

When designing an illumination system, circadian compliant environmental lighting is preferred. Designs have a requirement to account for light [artificial production] in relationship to natural restoration cycles, both in existence, illuminance power, and frequency duration. In particular, a general rule for outdoor human compliance outdoor lighting is designed to protect eyes from higher frequency blue light and to increase contrast. The best choice is for specific tints of:

1. Red.
2. Orange.
3. Red-orange = 100% protection (no visible blue).
4. Yellow.
5. Amber.
6. Gold.
7. Brown = moderate protection (some visible blue).

It is noted that some areas may be specifically light with tints of higher frequency blue for a specific localized reason (e.g., event or recreational landscape, possibly including buildings). It is also important to remember here that the farther into full red the color filter (in the form of glasses, or emitted in the form of a red bulb/ led) the more other colors will be distorted and blend together. This can have consequences in situations where high visual precision in a complex environment requires contrast awareness between objects.

The most biocompatible light bulbs are those that are capable of emitting a full-spectrum of light during the day (capable of matching sky blue also) while dimming and emitting more red-type wavelengths when electrically dimmed.

To protect the eyes from the wrong frequencies of light at night, and to increase contrast over pure red, it is relevant to select specific tints:

1. 100% protection (no visible blue)
   A. Orange.
   B. Red-orange .
2. Moderate protection (some visible view, but more contrast.
   A. Yellow.
   B. Amber.
   C. Gold.
   D. Brown.

> **NOTE:** I*t is important to be aware, for safety, that 100% blue blocking (Read: only red light) will distort other colors. And, the closer to all red, the more colors will lose contrast between one another. For this reason, some tasks that require high physical precision should likely not be performed with them on. Of additional note, after someone removes blue-blocking glasses, for example, their color perception will be temporarily altered so that specific colors appear to be other colors.*

19.1.2.2 Efficiency possibilities

In general, the most energy efficient lights are LEDs (light emitting diodes).

19.1.3 Hazards with the illumination system

There are several hazards associated with an illumination system, including but no necessarily limited to:

1. **Light pollution** - refers to outdoor or indoor artificial light that is considered excessive or obtrusive - artificial light which shines where it is neither wanted, nor needed. Light pollution has the potential to disrupt breeding patterns of nocturnal animals, insects and the migration of birds. It can also have an adverse impact on the health and wellbeing of people, disrupting natural body cycles regulated by darkness and light. Light after dusk, when people are attempting to sleep, can trigger daytime physiology, telling the brain to become more alert, increasing the heart rate and body temperature, and suppressing the production of melatonin. It is thought that sleep disorders, increased stress and certain types of cancer can be developed if sleep is disturbed by artificial lighting. Light pollution can also be a significant waste of energy. The main categories of light pollution are (Light pollution, 2021):
   A. **Glare** - is a discomforting or disabling brightness that causes a loss in visibility as stray light scatters within the eyes.

B. **Sky glow** - occurs from both natural and artificial sources of lighting that increase night sky brightness. Light can be emitted directly or reflected into the atmosphere to produce a luminous background. Here, the ability of ground observers to view the stars at night is hindered.
C. **Light trespass** - occurs when light enters into areas in which it is unwanted (or, unneeded). An example of this would be the light from an exterior street light entering a bedroom window and illuminating the interior.
D. **Over-illumination** - simply refers to the excessive use of lights.
E. **Light clutter** - occurs when an area where there are large group of lights that may cause distraction or confusion. Clutter can be found in particular in parts of cities or on busy roads.

2. **Shadow** - refers to places blocked by light (either at night by artificial lights, or during the day with sunlight). Shaded areas with a lot of decomposing organic matter, and/or high humidity, are likely to develop mold and bacterial growth.
3. **Fires.**
4. **Electrical shocks**.

19.2 Conception of the illumination system

NOTE: *Sometimes the illumination system is considered a sub-system of the electrical system.*

Illumination is the attribute (quality) of 'light'. Light is a physical process measured by means of electromagnetism, and illumination is measured by the quality of the light in meeting fulfillment and the quantity of the light in lux (illuminance) and kelvin (color temperature). Fundamentally, a light source is a controlled loss of energy emitter.

19.2.1 Natural illumination

A.k.a., Natural lighting.

Natural light, as opposed to artificial light, refers to light produced by sunlight. This type of light is only provided during times of sunlight. Natural illumination can be allowed to enter an interior architectural environment through:

1. Unobstructed openings in the structure.
   A. No material present.
2. Obstructed openings in the structure (lowest to highest opacity).
   A. Transparent materials.
   B. Translucent materials.

Natural illumination most easily enters a building through:

1. Openings without barriers (gap in wall).
2. Openings with barrier (e.g., glass).
3. Openings with barrier and additional light screening filtration (Read: filter film on window pane).
4. Piping daylight systems - only provides light during times of sunlight. A single highly pipe refracts the light and channels it to one or more endpoints. The inside of the ducts are made of a highly reflective material. A transparent semi-sphere on the roof collects sunlight from all angles. A filter in the duct can be used to filter out UV.

Light may be transmitted to facilitate illumination through the use of:

1. Light color tints of paint (nearing glossy white).
2. Mirrors (high metallic).

19.2.2 Artificial illumination

A.k.a., Artificial lighting.

Artificial light, as opposed to natural light, refers to any light source that is produced by electrical means.

The most common forms of artificial illumination are:

1. **Incandescent** - uses a wire or filament being heated to incandescence (emitting light) by a flow of current through it. It can be run directly on line current and therefore does not require a ballast. It can also be dimmed using relatively simple equipment. Produces light in a well accepted warm tone.
2. **Fluorescent** - produces light by activating selected phosphors on the inner surface of the bulb with ultraviolet energy, which is generated by a mercury arc. Because of the characteristics of a gaseous arc, a ballast is needed to start and operate fluorescent lamps. Produces bluer light and has a flicker rate that can be draining to human energy levels.
   A. **Induction** - Induction lamps are electrodeless fluorescent lamps driven by high-frequency current, typically between 250kHz and 2.65mHz, usually via an external generator. They are available in limited wattages and are known for exceptionally long service life: up to 100,000 hours. Lamp efficacies typically range from 64 to 88 lumens per watt. Color rendition with induction lamps is very good.
3. **High intensity discharge (HID)** - Light is produced in HID and low pressure sodium (LPS) sources through a gaseous arc discharge using a variety of elements. Each HID lamp consists of an arc tube

which contains certain elements or mixtures of elements which, when an arc is created between the electrodes at each end, gasify and generate visible radiation.
   A. Metal halide (MH).
   B. Mercury vapor (MV).
   C. High pressure sodium (HPS).
   D. Low pressure sodium (LPS) - similar to high pressure sodium.
4. **Light-emitting diode (LED**) - a semiconductor light source that emits light when current flows through it. LEDs have a flicker rate. LEDs require a separate power supply. LEDs come in to types:
   A. LED bulbs.
   B. LED strips.

Artificial lighting in an illumination system can be of many types, including but not limited to:

1. Lighting panel.
2. Recessed light.
3. Recessed light served by an emergency branch circuit.
4. Recessed linear light.
5. Recessed linear light served by an emergency branch circuit.
6. Track light.
7. Recessed can light.
8. Wall-mounted light.
9. Recessed wall wash light.
10. Battery-powered emergency light.
11. Ceiling-mounted exit sign - arrow for direction.
12. Wall-mounted exit sign - arrow for direction.

19.2.3 Shadows (deprivation of illumination)

The shadow of each building needs to be accounted for. Large buildings have been blamed for casting a shadow over public areas. In other cases, the design of highly reflective buildings can creating a "death ray" type beam of sunlight capable of melting cars on the street.

In most common areas, unless intended for specialized reasons, dark spaces should be avoided.

19.2.4 Redirecting light (reflecting illumination)

Objects redirect light to varying degrees. Some objects can be designed to absorb near all light.

Light can be redirected in several ways.

1. Redirected sunlight using an inside mirror.
2. Redirecting light using non-mirrored surfaces.
3. Redirecting light using buildings. Architects can now designed buildings which don’t block out the light by diffusing light from one building onto a wide area (possibly, including other buildings). Such building designs and configurations work together to disperse and refract sunlight. They are designed so that when one building creates shade, the other can act as a huge curved mirror, allowing the light to be reflected downwards into its shadow.

19.2.5 Effects of illumination

Illumination has effects on its environment, both for the object(s) reflecting the illumination and the organisms inhabiting that environment. The most notable effect of illumination on objects is that of heat and appearance to organisms. Blue light is an indicator of sunlight and daytime, under normal conditions. Additionally, under natural conditions the near infrared is always present, and the human body has evolved and adapted to its presence.

19.2.5.1 Illumination and heat

Two components to the heat of the light are:

1. The way the light is generated.
2. The power consumed.

19.2.5.2 Illumination and human biorhythms

A.k.a., Light and biological cycles.

INSIGHT: *Humans (and some other organisms) are designed to live under light, to take in light, and to use it for bio-cellular processes.*

Both sunlight and artificial light are likely to have an affect upon human biorhythms. Both daytime light and night time light ought to be compatible with human biorhythms. Technology can facilitate human connection or disconnection from oneself and the natural environment. Humans and other animals react to light cycles. Humans are designed to live under light, to take in light, and to use it for bio-cellular processes.

Humans evolved under the presence of natural high blue light during the day and the absence of that type of light at night. Through evolution humans have had a very predictable day and night, light and dark pattern. With the advent of modern technology, humans can now simulate day-time during the night-time, which leads to the disregulation of natural circadian and cortisol rhythms. Daylight during night-time is often is a detrimental influence, because it stops (or at least hinders) the human body's ability to regenerate itself during sleep mode. It is possible that If you the use of the wrong kind of light at night can reduce the effectiveness of the regeneration phase, opening the door for degenerative diseases. Potentially, it is in human DNA to have reduced brightness and color temperature after sunset. Fundamentally, light influences biological timings.

It is important to note here that the brightness and frequency of light at night can affect other organisms, including plants and other mammals (e.g., owls).

> *“We need to realize that it’s in our DNA to have darkness after sunset, before we go to sleep. That gives us access to our intuition, our creativity. I would put it right up there with survival.”*
> *- Pam Morriss, Lighting Expert, San Francisco Magazine October 2009*

19.2.5.3 Illumination flicker and humans

Flicker refers to the on and off pulsing of a light source. LEDs and other sources of light have some degree of flicker (a stroboscopic effect). The lower the flicker rate, the more perceptible it is to human physiology, and the higher the likelihood of causing stress (or even, distress) to human physiology. In order to not negatively affect human biophysiology, an LED pulse width modulation of 10000hz or higher is considered optimal for human safety. This means the light turns on and off 10000 times per second, and the flicker will not be visible to human sight.

When flicker is present, the brain has to eliminate these pulses, and this is what makes people exceedingly tired after being its presence for relative durations of time. When significant flicker is present the body has to significantly adapt to it.

19.2.5.4 Illumination and performance

Some technology can make it more difficult to perform and function. For example, working under florescent light tinted toward the blue spectrum, with high contrast, and with relative flicker is likely to stress the human brain and reduce performance on work with a focused task. Light can reduce or improve performance in relation to both:

1. **Visual sight accuracy.** This element is associated with a color rendering index and contrast index. Herein, visual contrast sensitivity (VCS), is the ability to distinguish between an object and its background or detect differences between objects. Note that color depends on frequency presence in conjunction with how something absorbs and reflects light.
2. **Visual physiological performance.** This is a subjective element and relative to the individual, the context, and the illumination configuration. There are a variety of known causes of in concern to light, including:
   A. Brightness at the wrong time.
   B. Color at the wrong time.
   C. Frequency (flicker) at the wrong time.
   D. Electrical-magnetic fields that power electrical lights.

19.2.5.5 Biocompatible light bulb technology

Commercial products in this category include, but may not be limited to:

1. TrueLight Luna Red™ Sunset Light - is an adjustable wavelength emitting lightbulb by TrueDark [truedark.com]. These are a 4-way adjustable light bulb emitting wavelengths from 1000K to 3000K with the ability to dim or brighten to customize the illumination of the environment.
   A. The characteristics of the bulb include:
      1. Standard A19 size with E26 base
      2. AC 85V–265V / 50Hz – 60Hz
      3. Flicker-Free LED Bulb
      4. Lumens: 121lm – 447lm (1000K = 121lm / 2000K = 264lm / 3000K = 447lm)
      5. CRI: 1000K Ra=51.4 / 2000K Ra=92.1 / 3000K Ra=81.8
   B. The costs of the bulb include:
      1. Monetary acquisition cost: 22.5 USD per unit (or, 4 bulbs = 90 USD).
      2. Power requirement cost per bulb: 7 watts (per hour).
      3. Replacement life span: 30,000 hours / 27.4 years (based on 3 hrs/day).

19.3 Conception of the electrical illumination circuit sub-system

Electrical illumination circuits come in both types of electricity:

1. AC electrical illumination circuits.
2. DC electrical illumination circuits.

19.4 Conception of the illumination control sub-system

A lighting control system is the system of controls that change lighting parameters over time. Such a system incorporates communication between various system inputs and outputs related to lighting. Lighting control may be more automated ("intelligent") or more manual. Lighting control systems are used on both indoor and outdoor lighting. Lighting control systems serve to provide the right amount of light where and when it is needed.

An illumination control system may have any of the following functions:

1. **On/Off switch** that turns the illumination on and off.
2. **Dimmer switch** that makes the illumination brighter or dimmer.
3. **Color spectrum control**:
   A. By means of control built into the bulb (such that when the power changes, the color

temperature changes).
B. By means of a light panel that allows for controlling the color temperature of LEDs.

Lights can be regulated through the following methods:

1. Lights can be put on timers.
2. Shades can be put on timers.
3. Lights can be connected to motion sensors.
4. Lights can be connected to electromagnetic sensors (i.e., sensors that detect sunlight).
5. Lights can be connected to alarms.
6. Lights can be dimmed (so as to reduce power input, for example, at night).

Automated control of an illumination system can account for the following factors:

1. Chronological time - schedules incorporate specific times of the day, week, month or year.
2. Solar time - schedules incorporate sunrise and sunset times, often used to switch outdoor lighting. Solar time scheduling requires that the location of the building be set. This is accomplished using the building's geographic location via either latitude and longitude or by picking the nearest city in a given database giving the approximate location and corresponding solar times.
3. Occupancy - is primarily determined with occupancy sensors.
4. Alarm conditions - typically include inputs from other building systems such as the fire alarm or HVAC system, which may trigger an emergency 'all lights on' or ' all lights flashing' command for example.
5. Program logic - specialized logic set by a user(s).

19.4.1 Shading control

Shading is the term used when illumination from non-controllable sources are to be reduced or blocked (i.e., to be controlled).

Shading control involves:

1. Shading requirements:
   A. Shading of light during day.
      1. Shading from sun.
      2. Shading from sources of light exterior to architecture.
   B. Shading of light during night.
      1. Shading from moon.
      2. Shading from sources of light exterior to architecture.
2. Architectural shading with exterior blinds.
   A. Attachments at top and bottom of exterior (veranda) at edge and surrounding walkway.
      1. Allows for customization of shades in appearance and materials.
3. Architectural shading with interior blinds, curtains, or other.
   A. Attachments at top and possibly bottom of interior edge near the exterior surface (wall or window).

19.4.2 Safety control

Within a habitat, lights may be used as signals in the case of emergency. Also, at night and when there is presence they come on to illuminate the surroundings, but importantly, at night the color temperature of their illumination remains low so as not to disrupt our bodies production of melatonin and its other restoration cycles.

19.5 Objects in the illumination system: fixtures, fittings, and appliances

Illumination fixtures and fittings are equipment that interface with the electrical-illumination in a building:

1. **Illumination fixtures** - a device for producing light. The most common fixtures include, but may not be limited to:
   A. Light fixtures - hold light bulbs.
   B. Shade fixtures (e.g., blinds, screens) - allows for control of illumination.
   C. Curtains - allows for control of illumination.
   D. Windows (*also classified as* 'structural' and 'surface') - window surfaces are a light permittance surfaces, and can be part of construction and/or installation. These surfaces can let different amounts of frequencies of light through.
   E. Light controllers - provide electrical control of some light sources.
   F. Lighting electrical ballasts - provide appropriate electrical power for some light sources.
   G. Electrical transformers - provide appropriate electrical power for some light sources.
   H. Mirror - light redirecting surface fixture (*also classified as* 'surface').
2. **Illumination fittings** - a device designed to control and guide the flow of electricity and illumination. The most common fittings include, but may not be limited to:
   A. Switches - control points for lights and shades.
   B. Light bulbs - come in many different types and can be categorized according to their energy usage and emission wavelength and brightness
3. **Illumination appliances** - appliance devices that change the atmosphere, the most common of which include:

A. Portable lamps with light bulbs.

IMPORTANT: *All fixtures, fittings, and appliances must be specified with the right capacity for their placement.*

19.5.3 Light switches

A.k.a., Illumination switches.

A light switch is an electrically wired switch most commonly used to operate electric lights, permanently connected equipment, or electrical outlets. External to the architectural wiring of a building, portable lamps such as table lamps may have a light switch mounted on the socket, base, or in-line with the cord.

NOTE: *In many architectural constructions, buildings are a mess of light switches. Light switch placement can be confusing to users and use materials unnecessarily given available wireless technologies. Light switch wiring diagrams are some of the most complex diagrams for an architectural construction.*

There are several types of light switch:

1. Manually operated on/off switches.
2. Dimmer switches that allow control of the brightness of lights as well as turning them on or off.
3. Time-controlled switches (some of which are integrated into the wiring and others are separate external items that fit into an electrical socket and into which the cord of a lamp is placed). This may be a type of smart home system.
4. Occupancy-sensing switches (motion sensors). This is a type of smart home system.
5. Daylight-sensing switches. This is a type of smart home system.
6. Remote controlled physical switches and dimmers (a.k.a., physical smart switches, physical wifi switches). This is a type of smart home system.
7. Remote controlled software-only switches and dimmers (no-touch switches). This is a type of smart home system.

NOTE: *Light switches are also found in flashlights, vehicles, and other devices.*

There are two general types of illumination control for a building; illumination control:

1. **With light switches** - the use of physical light switches placed [generally on walls] within the building.
2. **Without light switches** - the use of digital controllers, and possibly, physical [motion] sensors. Of course, a hidden "switch" or circuit breaker must still exist, but there's no need to have a visible switch on the wall surface. This method uses software-only switches and dimmers (no-touch switches).

19.5.4 Panellized light switches

A.k.a., Panellized illumination switches.

In the case of a panellized lighting solutions, switches are replaced with keypads and motion sensors that trigger scene lighting. All lights are run to a panel and the panel circuits are smart.

19.6 Installation of illumination system

A.k.a., Illumination circuit installation.

There are many ways to install illumination circuitry. These systems are usually embedded into structure.

19.6.1 Illumination point placement

Lights can be placed on all allowable surfaces. The placement of lights depends on context.

19.6.1.1 Interior lighting

There are four general types of interior lighting:

1. **Accent** - lighting aimed at areas of interest.
2. **Ambient** - appropriate lighting that fills an area with an appropriate brightness and color temperature.
3. **Decorative** - lighting that provides for a type of festivity (e.g., christmas lighting) or fixture-based beauty (e.g., chandelier lighting).
4. **Task** - lighting for an activity that facilitates performance and reduces unwanted stress.

19.6.2 LED strip placement

There are a series of best practices that should be followed when placing LED strips:

1. LED strips should never be directly exposed (i.e., visible to users). They should be mounted out of sight and projected toward another surface.
2. With long led strips, the voltage will decrease along the strip. Hence, there will be very bright lights at the beginning of the strip where the voltage is high, and dim lights at the end where the voltage is less. If many light strips are combined in series, then the voltage and brightness decrease over distance.
3. LED strips should be placed inside of a channel with a diffuser where appropriate. This isn't of high importance when the LED strip is hidden from view. In instances where there is nothing for the

light to be projected onto, LED strips should be installed inside of a channel with a diffuser. These channels hide the led strips, but they are also much easier to mount and keep straight than the bare LED strip. Typically, these channels are made out of aluminum or silica gel. Aluminum channels come in two options: a corner mount option or a flat surface option. There are also silica gel covered channels. Silica gel channels are bendable, while the aluminum ones are not (note: bends are up and down, and not left and right). Some of these channels are waterproof while others are not. Note here that surface attachable mounting clips can be used in place of channels to attach LED strips to surfaces. If there is adhesive on the back of the strip, these mounting clips will reinforce that adhesive.

4. Installations should keep a uniform distance and angle to the surface they are projecting onto. Not doing so can cause Hotspot in the illumination. These Hotspot can also be cause by turns in the led strip themselves (creating more illumination in one area versus others). Loops at corners will create a hotspot because the number of LEDs in that area will increase. A better option is to use solderless corner connectors. Here, the number of copper connects on the strip are matched to a corner connecter with the same amount of pins.
5. LED strips do not need to be RGB. There are at least three types of LED strips in relation to color:
   A. RGB strips - each channel can be turned on or off.
   B. RGB + W (white) strips - each channel can be turned on or off.
   C. White strips (or, another single color).
6. Choose the right power for the application, including voltage and watts. Note that watts will add up when LED strips are connected. The voltage needs to match exactly, but it is OK to go over in concern to watts.
7. Choose the right number of LEDs per meter (density). The greater the LED density, the more expensive the strip will be, but it will also provide greater color accuracy and brightness. Note here that a higher density equates to higher power consumption and higher heat. Additionally, heat will lower the lifespan on the strip.
8. Select the right waterproofing type. Note here that as waterproofing increases, heat dissipation decreases. There are three types of waterproofing for LED strips:
   A. IP 20/30 - no water protection.
   B. IP 65 (silicone coating) - the top of the strip is coated in a waterproof silicone layer. This is sufficient for LEDs that will occasionally be splashed or exposed to high humidity.
   C. IP 67 (silicone sleeve) - the strips are sealed in a silicone sleeve that provides a completely water-tight seal.
9. Individually addressable LEDs include microchips connected to each LED that takes instructions, allowing for each LED to take different actions. Note here that in some cases, a single dead addressable LED can cause the rest of the strip to start working.

19.7 Operation of illumination system

In concern to electrics, most significant operational activities are located on the supply side because of the requirement for static pressure given dynamic demand. In concern to illuminance, most significant operational activities are located on the demand side because of needed changes (e.g., occupancy and time of day) in the illuminance of areas.

19.7.1 Illumination load demands

A.k.a., Illumination loading.

Illumination loads are measured in several ways, most notably, energy consumed to produce:

1. Energy consumed,
2. Illumination produced, and
3. Thermal temperature.

In order to do work, illumination systems are split into a power usage system and an illuminance changing service system:

1. A power usage system:
   A. Energy consumed may be by electricity or combustion of fuel.
      1. Most electrical illumination loads are measured in watts [of electrical] power. Often, the kilowatt hour (kW.h)
      2. Illumination systems can be measured in BTU [of heating or cooling] power.
2. An illumination-flow conditioning (production and distribution) system:
   A. Light flow illuminance is light flow rate, or quantity of light being moved, which is measured in:
      1. Light intensity emitted [from a source]: Lumen (lm) is the unit for luminous flux. It measures the total amount of light emitted by a light source in all directions. Luminous flux takes into account the sensitivity of the eye to the visible part of the electromagnetic radiation. Lumen is therefore the unit to measure the

brightness of a light source independently of the direction of the light beam. Luminous flux is a measure of the total amount of light in a light beam. Light intensity is a measure of the light density.

2. Light intensity received [to a surface]: Lux (lx) is a unit of illumination: 1 lux is the illuminance produced by 1 candela on a surface perpendicular to the light rays at a distance of 1 meter from the source. Lux corresponds to the illuminance that is obtained by an observer when each square meter of the considered surface receives a luminous flux of one lumen. Lux can be measured from different distances. With a light meter it is possible to measure the lux value of any surface or space.
3. Light intensity observed [by someone]: Candela (cd) is the unit for brightness. The word candela means candle in Latin. One candela corresponds approximately to the light intensity of a normal candle. The candela is related to the lumen and lux units. The unit lumen is used for the total luminous flux in a light beam. A light beam with a strength of 1 candela and a space angle of 1 steradian (for a cone-shaped beam corresponds to an opening angle of 65.5 °) has a total luminous flux of 1 lumen. 1 candela is thus equal to 1 lumen per steradian. When a beam with a strength of 1 lumen illuminates a surface of 1 square meter, this gives an illuminance of 1 lux. 1 lux is therefore equal to 1 lumen per square meter.

B. Light temperature is frequency of the light (tint).It is possible to measure the color of light at different points on a surface and find the average frequency of the light. The most common measuring unit for temperature:
   1. Kelvin

C. Thermal temperature production is measured in kelvins or Celsius (or Fahrenheit in imperial).

3. The conduits and circuitry connected to electrical illumination loads are another type of load.
   - Current causes losses in transmission lines, transformers, and circuitry.
4. Non-usage, but presence, will still equate to system service usage.
   - If a usage circuit has no load in the form of a power factor of zero the user would consume NO illumination (i.e., no usage), but the supplier would still have to send static illumination to them and incur real energy losses in electrical lines, circuitry, and filters. Power factor is the relationship (phase) of light and timing in an illumination production-distribution system.

19.8 Engineering calculations for illumination

Illuminance area calculations for different configurations of lighting and different types of day, with different configurable shading configurations.

To provide appropriate light and/or other desirable elements (e.g., heat), an illumination system must be designed to account for:

1. Electrical service illumination object name.
2. Electrical service illumination object identifier.
3. Table of technical electrical specifics of illumination object.
4. Table of electrical usage specifics of illumination object.
5. Table of applicable access categories (person to common to InterSystem).
6. Time of day (t) of usage(s).
7. For each task and activity of usage [of illumination object], calculate:
   A. E_m (Lx)
   B. U_0
   C. UGR_L
   D. R_a

Illuminance is the level of light on a surface; measured in lux (lx, illumination value). It can be used as a reference measurement of the performance of a lighting system as related to the activity.

Lux is a measure of the amount of light on a surface.

1. One lux is equal to one lumen per square metre (lm/m^2).
   A. Wherein, a lumen (lm) is the SI unit of luminous flux, describing the quantity of light emitted by a lamp or received at a surface.

Average illuminance is the illuminance averaged over a specific area. This may be derived from either:

1. An average of the illuminances at a representative number of points on the surface.
2. From the total luminous flux falling on the surface divided by the total area of the surface.

Characteristics of illuminance include, but may not be limited to:

1. **Correlated colour temperature (CCT; a.k.a., color temperature and color appearance)** - refers to the visual sensation correlated with the 'warmth' or 'coolness' of light. The metric used to characterise

the colour appearance of the light emitted by a light source is the, expressed in Kelvin (K).
   A. Warm white light is produced by light having a colour temperature below 3,000 K (reddish hues), whereas 4,000 K and above (bluish) is cool and cold white light.
2. **Colour rendering index (CRI)** - refers to the ability of a light source to show surface colours as they should be, usually in comparison with a tungsten or daylight source. Measured on the colour rendering index (CRI) scale.
   A. A value of 0 means it is impossible to discern colours at all, and a score of 100 means no colour distortion. For most indoor lighting applications a value of at least 80 is recommended.

Items to be included in lighting design and analysis engineering are:

1. Average illuminance.
2. Equivalent spherical illuminance.
3. Uniformity ratios.
4. Visual comfort probability.
5. Visual bio-compatibility probability.
6. Special purpose lighting characteristics.

Electrical engineering documents for lighting systems shall, at a minimum, indicate the following:

1. Lighting fixture performance specifications and arrangements
2. Emergency Lighting
3. Exit Lighting
4. Lighting Control and circuiting

19.8.1 Standard illumination efficiencies

A.k.a., Illumination control and automation, smart lighting, intelligent lighting control.

Often, the greatest three efficiencies achievable in an illumination system are:

1. Identifying and eliminating (or significantly reducing) light pollution.
2. On when needed only, and off when needed only. (i.e., not leaving lights on when not needed, which can be achieved easily through automation).
3. Using natural sunlight. Daylight availability can be used to reduce artificial illumination. Reducing the amount of artificial lighting used when daylight is available is known as, daylight harvesting.

Given current technology, it is possible to construct buildings without the need or presence for physical light switches. Switches are gradually being replaced by touch panels or directly operated via apps on smartphones/ tablets.

NOTE: *It is reasonable to consider how it may always be important to have a manual backup of the system.*

Instead of physical switches, illumination control works by means of:

1. **Presence sensors (not necessarily required)** - these sensors are installed strategically to detect human movement that in turn, triggers the systems to be activated or deactivated and at different intensities as per the specific programming of different zones in the building. The following sensors detect motion and presence:
   A. **Passive infrared sensor (PIR) sensors** - detect changes in the levels of energy around the area. PIR sensors don't actually emit the infrared; objects give the sensor infrared rays.
   B. **Active infrared sensors (AIR, sometimes just IR)** - will detect motion and presence by emitting infrared rays and then recording and measuring the result over time to detect changes that indicate the presence of motion and presence.
2. **Control software** - computer programs running on a computing system with a display and can effect digital and mechanical control devices.
   A. Tablet - a device for interfacing with the software program.
   B. OpenHAB to control the illumination.

INSIGHT: *In an optimized scenario, users simply walk from room to room and the lights adjust accordingly.*

In the following cases, having no light switches may be preferable:

1. Turning on the light should be as easy or easier than flipping a wall switch.
2. Guests, children, and occupants who currently can’t find their phone must be able to control those aspects of the system that do require human interaction. In these cases, a dedicated mounted tablet or a remote control may be suitable.

Alternatively, in certain building cases it is not feasible to have no light switches (i.e., complete automation of illumination):

1. The building may not be to meet jurisdictional code.
2. The building may be difficult to resell.
3. The lights won’t work if your central controller goes down.