Mobile Homes

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  Considering Weight Distribution on Mobile Home Roofs Analyzing Space Limitations for Duct Installation Minimizing Vibrations through Effective Mounting Checking for Clearances near Windows and Doors Verifying Electrical Capacity for New Units Inspecting Crawl Spaces before Major Installations Protecting Exterior Components from Windy Conditions Resolving Access Issues in Narrow Hallways Planning Around Existing Plumbing or Gas Lines Prioritizing Safety in Confined Work Areas Ensuring Adequate Ventilation for Heat Pumps Mitigating Moisture Risks in Humid Climates
- **Comparing Basic and Extended Coverage Options**
  Comparing Basic and Extended Coverage Options Reviewing Part Replacement Clauses in Detail Understanding Labor Inclusions in Contracts Assessing Multi year Agreements for Homeowners Outlining Limitations of Warranty Claims Inspecting Renewal Terms for Ongoing Coverage Checking Deductible Requirements for Repairs Estimating Future Costs through Contract Analysis Tracking Service Visits Outlined in Agreements Selecting Clauses that Cover Seasonal Tuneups Transferring Warranty Benefits to New Owners Planning Budget Strategies for Contract Renewals
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Mobile homes, often celebrated for their affordability and flexibility, require specialized care when it comes to heating, ventilation, and air conditioning (HVAC) systems. These systems are integral to maintaining a comfortable living environment regardless of the season. Understanding how these HVAC systems work and what labor inclusions exist in related contracts is crucial for homeowners looking to optimize comfort while ensuring financial prudence.

To begin with, mobile home HVAC systems are typically smaller and more compact than those found in traditional residential homes. This is due to the size constraints inherent in mobile home construction. The most common types include packaged units that combine heating and cooling functions into one unit, as well as split systems where components are divided between indoor and outdoor units. These systems must be carefully selected to suit the specific needs of a mobile home's limited space while providing efficient climate control.

High SEER-rated units are recommended for mobile home energy savings **mobile home hvac replacement cost** crawl space.

When considering installation or maintenance contracts for these HVAC systems, understanding labor inclusions is essential. Labor costs can make up a significant portion of any service contract or installation agreement. Therefore, knowing what tasks are covered can help homeowners avoid unexpected expenses and ensure that they receive comprehensive care for their system.

Typically, labor inclusions in HVAC contracts will cover the installation of new units, which involves setting up the equipment according to manufacturer specifications and connecting necessary electrical or fuel lines. It also usually includes system testing to confirm proper operation post-installation. For maintenance agreements, labor coverage might include routine inspections such as checking refrigerant levels, cleaning coils or filters, calibrating thermostats, and examining ductwork for leaks.

However, not all labor-related tasks may be included in standard contracts. Homeowners should be aware that additional services like extensive duct cleaning or emergency repairs outside regular business hours could incur extra charges unless explicitly stated otherwise in the contract terms.

In conclusion, having a clear understanding of mobile home HVAC systems alongside knowledge about labor inclusions within service contracts empowers homeowners to make informed decisions regarding their climate control needs. This comprehension not only aids in selecting suitable equipment but also ensures that financial resources are allocated efficiently without unforeseen costs overshadowing the overall benefits provided by a well-maintained HVAC system. As with any contractual agreement, clarity on coverage specifics remains key to achieving long-term satisfaction with one's investment in home comfort solutions.

In the realm of construction and mechanical services, particularly within the Heating, Ventilation, and Air Conditioning (HVAC) sector, the clarity of contractual agreements can significantly impact project outcomes. One critical aspect of these agreements is specifying labor inclusions. Understanding and detailing labor inclusions in HVAC installation contracts is not merely a matter of procedural formality; it plays a pivotal role in safeguarding both parties' interests and ensuring the seamless execution of projects.

To begin with, specifying labor inclusions provides transparency. An HVAC installation involves various tasks ranging from system design and site preparation to equipment installation and testing. By clearly outlining which tasks are included under the labor scope in a contract, all parties involved-contractors, subcontractors, and clients-can have a unified understanding of what is expected. This transparency reduces ambiguities that often lead to disputes or misunderstandings during project execution.

Furthermore, detailed labor inclusions help in accurate cost estimation. Costs associated with HVAC installations can be substantial; hence, having a precise breakdown of labor activities allows for better budgeting. Contractors can allocate resources effectively while clients gain insight into where their investment is being directed. This clarity aids in preventing unexpected expenses that might arise from assuming certain tasks were included when they were not.

Another dimension to consider is risk management. By explicitly stating what labor is covered within an HVAC contract, contractors can mitigate risks associated with scope creep-where additional tasks are added without clear agreement or compensation. It ensures that any work beyond the specified scope must be renegotiated and adequately compensated for, protecting contractors from unanticipated workload increases without corresponding financial adjustment.

From an operational perspective, specifying labor inclusions fosters efficient project management. With defined responsibilities laid out from the onset, teams can plan their workflow more effectively. It enhances coordination among different stakeholders as everyone knows their role within the larger framework of the installation process. Such organization minimizes delays caused by task overlaps or omissions.

Moreover, well-documented labor inclusions set standards for quality assurance. When expectations are defined clearly in terms of who does what and how it should be done, maintaining quality becomes easier to manage and evaluate against predetermined criteria.

Lastly, establishing thorough labor specifications cultivates trust between contracting parties. When clients see that every detail has been considered and documented professionally, it builds confidence in the contractor's commitment to deliver on promises made-a cornerstone for fostering long-term business relationships.

In conclusion, specifying labor inclusions within HVAC installation contracts transcends being just a contractual obligation; it establishes a foundation for successful project delivery through enhanced clarity, cost control, risk mitigation, efficient management practices, quality assurance standards adherence-and ultimately building trust amongst engaged entities. As such complexity defines modern-day construction ventures increasingly so does necessity dictate precision-in this case via detailed articulation about who does what when where why-and importantly at what cost!

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Considerations for maintaining structural integrity during HVAC installation

When it comes to the world of mobile home HVAC (heating, ventilation, and air conditioning) systems, understanding the intricacies of labor components in contracts is crucial for homeowners. These contracts form the backbone of any installation or maintenance project, ensuring that all parties are well aware of their responsibilities and expectations. Yet, deciphering what exactly is included under "labor components" can often be a daunting task for those unfamiliar with industry jargon.

At its core, the term "common labor components" in mobile home HVAC contracts refers to the essential tasks and services that technicians perform as part of installing or maintaining an HVAC system. These components typically encompass a wide range of activities designed to ensure that the system operates efficiently and safely within a mobile home setting.

One primary labor component involves the initial assessment and planning phase. This step includes evaluating the mobile home's specific requirements, such as size, layout, and insulation levels, to determine the most suitable HVAC system. Technicians must also consider any existing infrastructure and potential obstacles that might affect installation. This thorough evaluation ensures that both contractor and homeowner are aligned on what needs to be done.

Following this assessment is the installation process itself. Common labor tasks during this phase include setting up ductwork, mounting units-whether they be air conditioners or heaters-and connecting necessary electrical wiring. In mobile homes especially, where space can be limited and configurations unique, precision in these tasks is paramount. Technicians need to carefully navigate these constraints while ensuring compliance with local building codes.

Maintenance services also fall under common labor components in HVAC contracts. Regular check-ups are vital for extending the life of an HVAC system and maintaining its efficiency over time. Tasks may involve cleaning filters, inspecting ducts for leaks or blockages, checking refrigerant levels in air conditioning units, and testing thermostats for accuracy. By including these routine checks in a contract's labor components section, homeowners can rest assured knowing their investment is protected against premature wear and tear.

It's equally important for homeowners to understand what might not be covered under standard labor inclusions. For instance, any major structural changes needed to accommodate new systems or extensive repairs due to pre-existing damage might incur additional costs beyond standard labor fees outlined in a contract.

Ultimately, clear communication about common labor components helps avoid misunderstandings between homeowners and contractors. It's advisable for homeowners to thoroughly review contract terms before agreeing to them-and don't hesitate to ask questions if any aspect regarding labor seems unclear.

In summary, comprehending common labor components in mobile home HVAC contracts is vital for anyone looking into installing or maintaining such systems within their property. By understanding what tasks are typically included-and which ones might require extra negotiation-homeowners can enter agreements confidently knowing they're adequately informed about their investment's scope of work.

Strategies for evenly distributing weight across the roof when adding or upgrading HVAC systems

In the complex world of contract law, clear and precise language is paramount. This is particularly true when it comes to labor terms within contracts, as ambiguity in these terms can lead to a host of potential issues that can affect both employers and employees alike. Understanding labor inclusions in contracts requires careful consideration of the terminology used to define roles, responsibilities, and expectations.

One major issue with ambiguous labor terms is the risk of misinterpretation. When a contract includes vague or unclear language regarding job duties or employment conditions, both parties may have differing interpretations of what those terms actually mean. For instance, if a contract simply states that an employee will perform "various tasks as needed," without specifying what those tasks might entail, it leaves room for disagreement over what constitutes reasonable work expectations.

This lack of clarity can also lead to disputes over compensation and benefits. Ambiguous language concerning payment structures, overtime eligibility, or bonus criteria can result in disagreements that may require legal intervention to resolve. Employees might believe they are entitled to certain compensations based on their understanding of the contract's terms, while employers might have an entirely different interpretation.

Moreover, ambiguous labor terms pose significant challenges during performance evaluations and disciplinary actions. Without clearly defined job descriptions and performance metrics, assessing an employee's work becomes subjective and potentially unfair. This could lead to dissatisfaction among employees who feel they are being evaluated against shifting standards or arbitrary criteria.

The potential for litigation is another critical issue arising from ambiguous labor terms. Disagreements stemming from unclear contract provisions often escalate into legal disputes that consume time and resources for all parties involved. Employers may face lawsuits alleging breach of contract or unfair labor practices if employees believe their rights under the contract have been violated due to ambiguities.

To mitigate these potential issues, it is crucial for contracts to be drafted with precision and care. Employers should strive to use clear language when defining roles and responsibilities, specifying work hours, outlining compensation structures, and detailing any other employment conditions. Additionally, involving legal experts in the drafting process can help ensure that contracts meet legal standards while minimizing ambiguities.

In conclusion, ambiguity in labor terms within contracts poses significant risks that can lead to misunderstandings, disputes over compensation and benefits, challenges in evaluating performance fairly, and even litigation. By prioritizing clarity in contractual language and seeking professional guidance during the drafting process, employers can foster more harmonious working relationships with their employees while safeguarding against potential conflicts down the line. Ultimately, understanding labor inclusions in contracts is not just about legal compliance; it's about building trust through transparency and mutual understanding between both parties involved.

Potential risks of improper weight distribution on mobile home roofs and HVAC efficiency

When it comes to crafting HVAC contracts, one of the most critical components is the clear delineation of labor inclusions. Understanding and articulating labor inclusions effectively can prevent disputes, foster transparency, and ensure a smooth working relationship between contractors and clients. Best practices in this area are essential for both parties to be fully aware of their responsibilities and expectations, ultimately leading to successful project completion.

First and foremost, clarity is key. An HVAC contract should clearly specify what labor services are included in the agreement. This typically involves listing out tasks such as installation, maintenance, repair work, or any other service that falls under the contractor's purview. By being explicit about these details, contractors eliminate ambiguity, which can often lead to misunderstandings or disputes down the line.

Additionally, it is important for contracts to outline not only what is included but also what is excluded from the labor provisions. Specifying exclusions helps manage client expectations by clarifying what additional charges might arise if further services are needed beyond those initially agreed upon. For instance, emergency repairs or after-hours services could be listed as exclusions unless otherwise negotiated.

Another best practice involves defining the scope of work with precision. This includes detailing timelines for each phase of the project and specifying the number of workers assigned to different tasks if applicable. Having a well-defined scope ensures that both parties have a mutual understanding of how long tasks should take and who will be responsible for them.

Moreover, including a breakdown of costs associated with labor inclusions can further enhance transparency. Providing an itemized list that separates labor costs from material costs allows clients to see exactly where their money is going. This practice not only builds trust but also aids in budget management on both sides.

Communication plays a pivotal role in reinforcing these best practices. Before finalizing any contract, it's advisable for contractors to discuss all terms related to labor inclusions with their clients thoroughly. Such discussions provide an opportunity for questions to be answered and adjustments to be made before legal commitments are established.

Lastly, regular updates during the course of the project should not be overlooked. As projects progress, unforeseen circumstances may necessitate changes in scope or timelines; keeping open lines of communication ensures that any modifications are mutually agreed upon and documented appropriately within contract amendments if needed.

In conclusion, implementing best practices for clear labor inclusions in HVAC contracts involves more than just drafting precise language; it requires ongoing communication and collaboration between parties involved. By focusing on clarity, specificity regarding inclusions and exclusions, transparent cost breakdowns, thorough pre-contract discussions, and consistent updates throughout project execution-contractors can pave the way for successful engagements characterized by minimal disputes and maximum satisfaction on all fronts.

Guidelines for professional assessment and installation to ensure balanced weight

distribution

In the intricate landscape of business transactions, contractual agreements serve as the backbone that holds parties accountable and ensures mutual understanding. One pivotal aspect of such agreements is the inclusion of labor considerations, which not only defines the working relationship but also safeguards both parties' interests. Navigating legal considerations and compliance in this realm requires meticulous attention to detail and a deep understanding of applicable laws and regulations.

At its core, a labor inclusion clause in a contract delineates the expectations and obligations related to employment or services provided. These clauses can encompass a variety of elements, including but not limited to wages, working hours, benefits, dispute resolution mechanisms, termination conditions, and nondisclosure agreements. The precise language used in these clauses is crucial because it establishes the framework for how labor-related issues will be managed throughout the contract's duration.

Legal considerations are paramount when drafting labor inclusions. Laws governing employment contracts can vary significantly from one jurisdiction to another, influenced by national legislation as well as regional or state-specific mandates. Key regulations often include minimum wage laws, overtime requirements, health and safety standards, anti-discrimination statutes, and workers' compensation provisions. Failure to comply with these legal requisites can lead to severe penalties, including fines or legal action against offending parties.

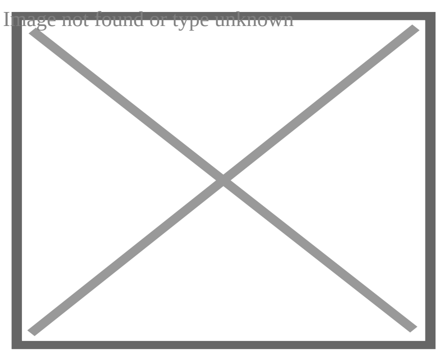
Moreover, compliance with established labor laws not only avoids legal repercussions but also fosters a more ethical work environment. By adhering to these standards, organizations demonstrate their commitment to fair treatment and respect for workers' rights. This commitment can enhance an organization's reputation and contribute positively to employee morale and productivity.

Another critical consideration is ensuring that contracts are equitable for all parties involved. Unbalanced agreements that disproportionately favor one party over another may lead to disputes or even contract voidance if deemed unconscionable by a court of law. Therefore, transparency during negotiations is vital; both parties should clearly understand their rights and responsibilities before signing any agreement.

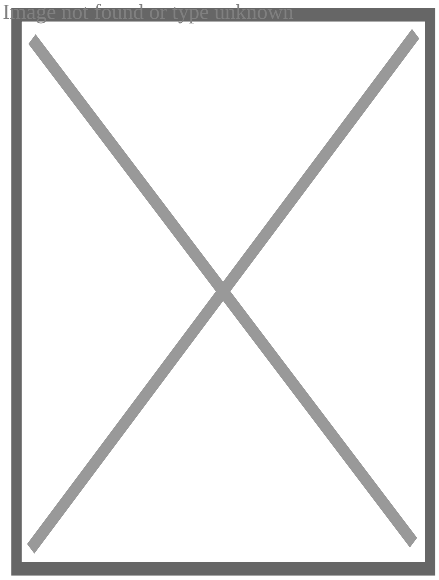
Furthermore, globalization has introduced additional layers of complexity into labor inclusions within contracts. When dealing with international partners or employees across borders, it's essential to consider cross-jurisdictional differences in labor laws. This might necessitate consultation with legal experts who specialize in international employment law to ensure full compliance with all relevant rules.

In conclusion, understanding labor inclusions in contractual agreements involves more than simply drafting terms on paper; it encompasses rigorous adherence to legal standards alongside ethical practices that honor worker rights. Businesses must remain vigilant about evolving legislation while aiming for transparency and fairness in all their dealings. In doing so, they not only protect themselves from potential litigation but also promote a culture of trust-an invaluable asset in today's interconnected world economy.

About Heat exchanger



Tubular heat exchanger



Partial view into inlet plenum of shell and tube heat exchanger of a refrigerant based chiller for providing air-conditioning to a building

A **heat exchanger** is a system used to transfer heat between a source and a working fluid. Heat exchangers are used in both cooling and heating processes.[1] The fluids may be separated by a solid wall to prevent mixing or they may be in direct contact.[2] They are widely used in space heating, refrigeration, air conditioning, power stations, chemical plants, petrochemical plants, petroleum refineries, natural-gas processing, and sewage treatment. The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air. Another example is the heat sink, which is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant.[3]

Flow arrangement

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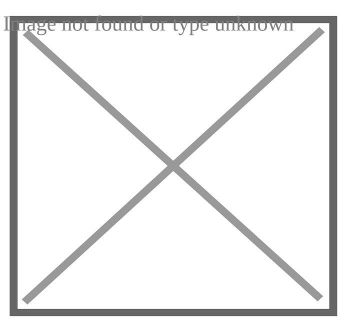

Countercurrent (A) and parallel (B) flows

There are three primary classifications of heat exchangers according to their flow arrangement. In *parallel-flow* heat exchangers, the two fluids enter the exchanger at the same end, and travel in parallel to one another to the other side. In *counter-flow* heat exchangers the fluids enter the exchanger from opposite ends. The counter current design is the most efficient, in that it can transfer the most heat from the heat (transfer) medium per unit mass due to the fact that the average temperature difference along any unit length is *higher*. See countercurrent exchange. In a *cross-flow* heat exchanger, the fluids travel roughly perpendicular to one another through the exchanger.

For efficiency, heat exchangers are designed to maximize the surface area of the wall between the two fluids, while minimizing resistance to fluid flow through the exchanger. The exchanger's performance can also be affected by the addition of fins or corrugations in one or both directions, which increase surface area and may channel fluid flow or induce turbulence.

Fig. 1: Shell and tube heat ex

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Fig. 1: Shell and tube heat exchanger, single pass (1–1 parallel flow)

The driving temperature across the heat transfer surface varies with position, but an appropriate mean temperature can be defined. In most simple systems this is the "log mean temperature difference" (LMTD). Sometimes direct knowledge of the LMTD is not available and the NTU method is used.

Fig. 2: Shell and tube heat ex

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Fig. 2: Shell and tube heat exchanger, 2-pass tube side (1–2 crossflow)

Types

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Double pipe heat exchangers are the simplest exchangers used in industries. On one hand, these heat exchangers are cheap for both design and maintenance, making them a good choice for small industries. On the other hand, their low efficiency coupled with the high space occupied in large scales, has led modern industries to use more efficient heat exchangers like shell and tube or plate. However, since double pipe heat exchangers are simple, they are used to teach heat exchanger design basics to students as the fundamental rules for all heat exchangers are the same.

Fig. 3: Shell and tube heat ex

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Fig. 3: Shell and tube heat exchanger, 2-pass shell side, 2-pass tube side (2-2 countercurrent)

1. Double-pipe heat exchanger

When one fluid flows through the smaller pipe, the other flows through the annular gap between the two pipes. These flows may be parallel or counter-flows in a double pipe heat exchanger.

(a) Parallel flow, where both hot and cold liquids enter the heat exchanger from the same side, flow in the same direction and exit at the same end. This configuration is preferable when the two fluids are intended to reach exactly the same temperature, as it reduces thermal stress and produces a more uniform rate of heat transfer.

(b) Counter-flow, where hot and cold fluids enter opposite sides of the heat exchanger, flow in opposite directions, and exit at opposite ends. This configuration is preferable when the objective is to maximize heat transfer between the fluids, as it creates a larger temperature differential when used under otherwise similar conditions.[*citation needed*]

The figure above illustrates the parallel and counter-flow flow directions of the fluid exchanger.

2. Shell-and-tube heat exchanger

In a shell-and-tube heat exchanger, two fluids at different temperatures flow through the heat exchanger. One of the fluids flows through the tube side and the other fluid flows outside the tubes, but inside the shell (shell side).

Baffles are used to support the tubes, direct the fluid flow to the tubes in an approximately natural manner, and maximize the turbulence of the shell fluid. There are many various kinds of baffles, and the choice of baffle form, spacing, and geometry depends on the allowable flow rate of the drop in shell-side force, the need for tube support, and the flow-induced vibrations. There are several variations of shell-and-tube exchangers available; the differences lie in the arrangement of flow configurations and details of construction.

In application to cool air with shell-and-tube technology (such as intercooler / charge air cooler for combustion engines), fins can be added on the tubes to increase heat transfer area on air side and create a tubes & fins configuration.

3. Plate Heat Exchanger

A plate heat exchanger contains an amount of thin shaped heat transfer plates bundled together. The gasket arrangement of each pair of plates provides two separate channel system. Each pair of plates form a channel where the fluid can flow through. The pairs are attached by welding and bolting methods. The following shows the components in the heat exchanger.

In single channels the configuration of the gaskets enables flow through. Thus, this allows the main and secondary media in counter-current flow. A gasket plate heat exchanger has a heat region from corrugated plates. The gasket function as seal between plates and they are located between frame and pressure plates. Fluid flows in a counter current direction throughout the heat exchanger. An efficient thermal performance is produced. Plates are produced in different depths, sizes and corrugated shapes. There are different types of plates available including plate and frame, plate and shell and spiral plate heat exchangers. The distribution area guarantees the flow of fluid to the whole heat transfer surface. This helps to prevent stagnant area that can cause accumulation of unwanted material on solid surfaces. High flow turbulence between plates results in a greater transfer of heat and a decrease in pressure.

4. Condensers and Boilers Heat exchangers using a two-phase heat transfer system are condensers, boilers and evaporators. Condensers are instruments that take and cool hot gas or vapor to the point of condensation and transform the gas into a liquid form. The point at which liquid transforms to gas is called vaporization and vice versa is called condensation. Surface condenser is the most common type of condenser where it includes a water supply device. Figure 5 below displays a two-pass surface condenser.

The pressure of steam at the turbine outlet is low where the steam density is very low where the flow rate is very high. To prevent a decrease in pressure in the movement of steam from the turbine to condenser, the condenser unit is placed underneath and connected to the turbine. Inside the tubes the cooling water runs in a parallel way, while steam moves in a vertical downward position from the wide opening at the top and travel through the tube. Furthermore, boilers are categorized as initial application of heat exchangers. The word steam generator was regularly used to describe a boiler unit where a hot liquid stream is the source of heat rather than the combustion products. Depending on the dimensions and configurations the boilers are manufactured. Several boilers are only able to produce hot fluid while on the other hand the others are manufactured for steam production.

Shell and tube

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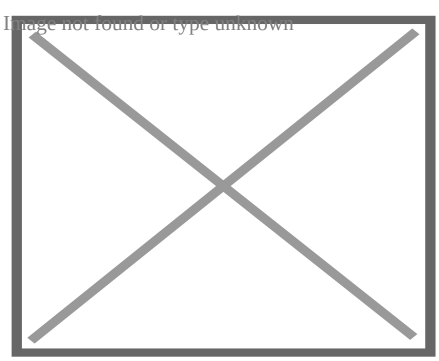
Main article: Shell and tube heat exchanger



A shell and tube heat exchanger

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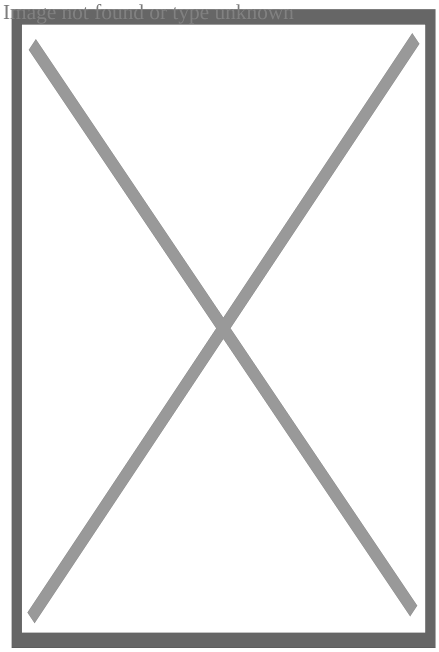

Shell and tube heat exchanger

Shell and tube heat exchangers consist of a series of tubes which contain fluid that must be either heated or cooled. A second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned, etc. Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C).[4] This is because the shell and tube heat exchangers are robust due to their shape.
Several thermal design features must be considered when designing the tubes in the shell and tube heat exchangers: There can be many variations on the shell and tube design. Typically, the ends of each tube are connected to plenums (sometimes called water boxes) through holes in tubesheets. The tubes may be straight or bent in the shape of a U, called U-tubes.

- Tube diameter: Using a small tube diameter makes the heat exchanger both economical and compact. However, it is more likely for the heat exchanger to foul up faster and the small size makes mechanical cleaning of the fouling difficult. To prevail over the fouling and cleaning problems, larger tube diameters can be used. Thus to determine the tube diameter, the available space, cost and fouling nature of the fluids must be considered.
- Tube thickness: The thickness of the wall of the tubes is usually determined to ensure:
  - There is enough room for corrosion
  - That flow-induced vibration has resistance
  - Axial strength
  - Availability of spare parts
  - Hoop strength (to withstand internal tube pressure)
  - Buckling strength (to withstand overpressure in the shell)

- Tube length: heat exchangers are usually cheaper when they have a smaller shell diameter and a long tube length. Thus, typically there is an aim to make the heat exchanger as long as physically possible whilst not exceeding production capabilities. However, there are many limitations for this, including space available at the installation site and the need to ensure tubes are available in lengths that are twice the required length (so they can be withdrawn and replaced). Also, long, thin tubes are difficult to take out and replace.
- Tube pitch: when designing the tubes, it is practical to ensure that the tube pitch (i.e., the centre-centre distance of adjoining tubes) is not less than 1.25 times the tubes' outside diameter. A larger tube pitch leads to a larger overall shell diameter, which leads to a more expensive heat exchanger.
- Tube corrugation: this type of tubes, mainly used for the inner tubes, increases the turbulence of the fluids and the effect is very important in the heat transfer giving a better performance.
- Tube Layout: refers to how tubes are positioned within the shell. There are four main types of tube layout, which are, triangular (30°), rotated triangular (60°), square (90°) and rotated square (45°). The triangular patterns are employed to give greater heat transfer as they force the fluid to flow in a more turbulent fashion around the piping. Square patterns are employed where high fouling is experienced and cleaning is more regular.
- Baffle Design: baffles are used in shell and tube heat exchangers to direct fluid across the tube bundle. They run perpendicularly to the shell and hold the bundle, preventing the tubes from sagging over a long length. They can also prevent the tubes from vibrating. The most common type of baffle is the segmental baffle. The semicircular segmental baffles are oriented at 180 degrees to the adjacent baffles forcing the fluid to flow upward and downwards between the tube bundle. Baffle spacing is of large thermodynamic concern when designing shell and tube heat exchangers. Baffles must be spaced with consideration for the conversion of pressure drop and heat transfer. For thermo economic optimization it is suggested that the baffles be spaced no closer than 20% of the shell's inner diameter. Having baffles spaced too closely causes a greater pressure drop because of flow redirection. Consequently, having the baffles spaced too far apart means that there may be cooler spots in the corners between baffles. It is also important to ensure the baffles are spaced close enough that the tubes do not sag. The other main type of baffle is the disc and doughnut baffle, which consists of two concentric baffles. An outer, wider baffle looks like a doughnut, whilst the inner baffle is shaped like a disk. This type of baffle forces the fluid to pass around each side of the disk then through the doughnut baffle generating a different type of fluid flow.
- Tubes & fins Design: in application to cool air with shell-and-tube technology (such as intercooler / charge air cooler for combustion engines), the difference in heat transfer between air and cold fluid can be such that there is a need to increase heat transfer area on air side. For this function fins can be added on the tubes to increase heat transfer area on air side and create a tubes & fins configuration.

Fixed tube liquid-cooled heat exchangers especially suitable for marine and harsh applications can be assembled with brass shells, copper tubes, brass baffles, and forged brass integral end hubs.[*citation needed*] *(See: Copper in heat exchangers).*

Plate

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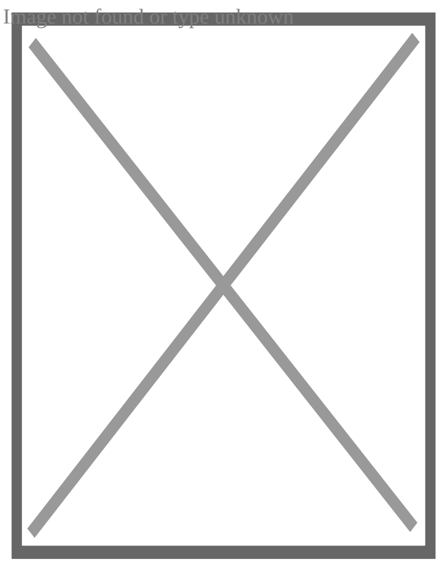
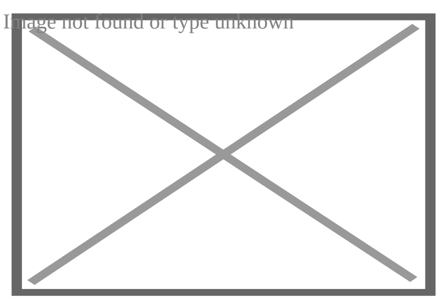
Main article: Plate heat exchanger



Conceptual diagram of a plate and frame heat exchanger



A single plate heat exchanger

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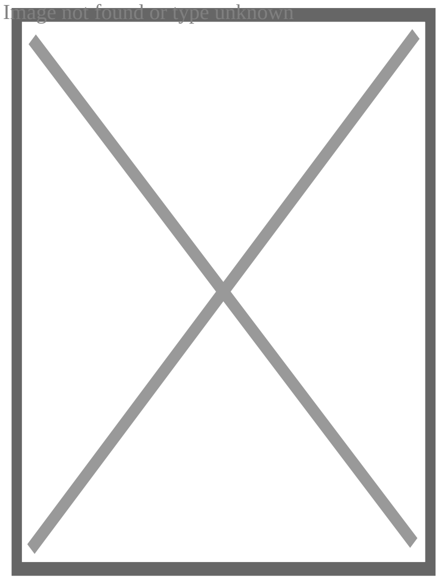

An interchangeable plate heat exchanger directly applied to the system of a swimming pool

Another type of heat exchanger is the plate heat exchanger. These exchangers are composed of many thin, slightly separated plates that have very large surface areas and small fluid flow passages for heat transfer. Advances in gasket and brazing technology have made the plate-type heat exchanger increasingly practical. In HVAC applications, large heat exchangers of this type are called *plate-and-frame*; when used in open loops, these heat exchangers are normally of the gasket type to allow periodic disassembly, cleaning, and inspection. There are many types of permanently bonded plate heat exchangers, such as dip-brazed, vacuum-brazed, and welded plate varieties, and they are often specified for closed-loop applications such as refrigeration. Plate heat exchangers also differ in the types of plates that are used, and in the configurations of those plates. Some plates may be stamped with "chevron", dimpled, or other patterns, where others may have machined fins and/or grooves.

When compared to shell and tube exchangers, the stacked-plate arrangement typically has lower volume and cost. Another difference between the two is that plate exchangers typically serve low to medium pressure fluids, compared to medium and high pressures of shell and tube. A third and important difference is that plate exchangers employ more countercurrent flow rather than cross current flow, which allows lower approach temperature differences, high temperature changes, and increased efficiencies.

Plate and shell

[edit]

A third type of heat exchanger is a plate and shell heat exchanger, which combines plate heat exchanger with shell and tube heat exchanger technologies. The heart of the heat exchanger contains a fully welded circular plate pack made by pressing and cutting round plates and welding them together. Nozzles carry flow in and out of the platepack (the 'Plate side' flowpath). The fully welded platepack is assembled into an outer shell that creates a second flowpath (the 'Shell side'). Plate and shell technology offers high heat transfer, high pressure, high operating temperature, compact size, low fouling and close approach temperature. In particular, it does completely without gaskets, which provides security against leakage at high pressures and temperatures.

Adiabatic wheel

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A fourth type of heat exchanger uses an intermediate fluid or solid store to hold heat, which is then moved to the other side of the heat exchanger to be released. Two examples of this are adiabatic wheels, which consist of a large wheel with fine threads rotating through the hot and cold fluids, and fluid heat exchangers.

Plate fin

[edit]
Main article: Plate fin heat exchanger

This type of heat exchanger uses "sandwiched" passages containing fins to increase the effectiveness of the unit. The designs include crossflow and counterflow coupled with various fin configurations such as straight fins, offset fins and wavy fins.

Plate and fin heat exchangers are usually made of aluminum alloys, which provide high heat transfer efficiency. The material enables the system to operate at a lower temperature difference and reduce the weight of the equipment. Plate and fin heat exchangers are mostly used for low temperature services such as natural gas, helium and oxygen liquefaction plants, air separation plants and transport industries such as motor and aircraft engines.

Advantages of plate and fin heat exchangers:

- High heat transfer efficiency especially in gas treatment
- Larger heat transfer area
- Approximately 5 times lighter in weight than that of shell and tube heat exchanger. [*citation ne*
- Able to withstand high pressure

Disadvantages of plate and fin heat exchangers:

- Might cause clogging as the pathways are very narrow
- Difficult to clean the pathways
- Aluminium alloys are susceptible to Mercury Liquid Embrittlement Failure

Finned tube

[edit]

The usage of fins in a tube-based heat exchanger is common when one of the working fluids is a low-pressure gas, and is typical for heat exchangers that operate using ambient air, such as automotive radiators and HVAC air condensers. Fins dramatically increase the surface area with which heat can be exchanged, which improves the efficiency of conducting heat to a fluid with very low thermal conductivity, such as air. The fins are typically made from aluminium or copper since they must conduct heat from the tube along the length of the fins, which are usually very thin.

The main construction types of finned tube exchangers are:

- A stack of evenly-spaced metal plates act as the fins and the tubes are pressed through pre-cut holes in the fins, good thermal contact usually being achieved by deformation of the fins around the tube. This is typical construction for HVAC air coils and large refrigeration condensers.
- Fins are spiral-wound onto individual tubes as a continuous strip, the tubes can then be assembled in banks, bent in a serpentine pattern, or wound into large spirals.
- Zig-zag metal strips are sandwiched between flat rectangular tubes, often being soldered or brazed together for good thermal and mechanical strength. This is common in low-pressure heat exchangers such as water-cooling radiators. Regular flat tubes will expand and deform if exposed to high pressures but flat microchannel tubes allow this construction to be used for high pressures.[5]

Stacked-fin or spiral-wound construction can be used for the tubes inside shell-and-tube heat exchangers when high efficiency thermal transfer to a gas is required.

In electronics cooling, heat sinks, particularly those using heat pipes, can have a stacked-fin construction.

Pillow plate

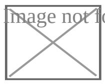
[edit]

A pillow plate heat exchanger is commonly used in the dairy industry for cooling milk in large direct-expansion stainless steel bulk tanks. Nearly the entire surface area of a tank can be integrated with this heat exchanger, without gaps that would occur between pipes welded to the exterior of the tank. Pillow plates can also be constructed as flat plates that are stacked inside a tank. The relatively flat surface of the plates allows easy cleaning, especially in sterile applications.

The pillow plate can be constructed using either a thin sheet of metal welded to the thicker surface of a tank or vessel, or two thin sheets welded together. The surface of the plate is welded with a regular pattern of dots or a serpentine pattern of weld lines. After welding the enclosed space is pressurised with sufficient force to cause the thin metal to bulge out around the welds, providing a space for heat exchanger liquids to flow, and creating a characteristic appearance of a swelled pillow formed out of metal.

Waste heat recovery units

[edit]



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A waste heat recovery unit (WHRU) is a heat exchanger that recovers heat from a hot gas stream while transferring it to a working medium, typically water or oils. The hot gas stream can be the exhaust gas from a gas turbine or a diesel engine or a waste gas from industry or refinery.

Large systems with high volume and temperature gas streams, typical in industry, can benefit from steam Rankine cycle (SRC) in a waste heat recovery unit, but these cycles are too expensive for small systems. The recovery of heat from low temperature systems requires different working fluids than steam.

An organic Rankine cycle (ORC) waste heat recovery unit can be more efficient at low temperature range using refrigerants that boil at lower temperatures than water. Typical organic refrigerants are ammonia, pentafluoropropane (R-245fa and R-245ca), and toluene.

The refrigerant is boiled by the heat source in the evaporator to produce super-heated vapor. This fluid is expanded in the turbine to convert thermal energy to kinetic energy, that is converted to electricity in the electrical generator. This energy transfer process decreases the temperature of the refrigerant that, in turn, condenses. The cycle is closed and completed using a pump to send the fluid back to the evaporator.

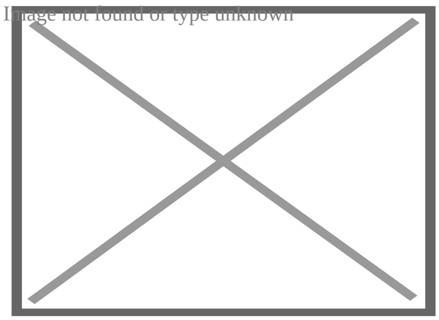
Dynamic scraped surface

[edit]

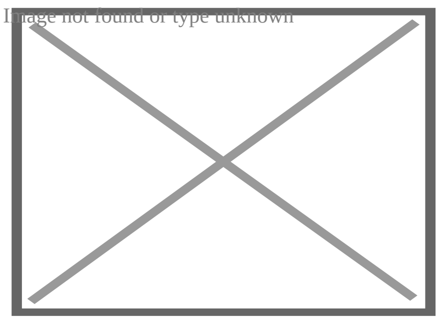
Another type of heat exchanger is called "(dynamic) scraped surface heat exchanger". This is mainly used for heating or cooling with high-viscosity products, crystallization processes, evaporation and high-fouling applications. Long running times are achieved due to the continuous scraping of the surface, thus avoiding fouling and achieving a sustainable heat transfer rate during the process.

Phase-change

[edit]



Typical kettle reboiler used for industrial distillation towers



Typical water-cooled surface condenser

In addition to heating up or cooling down fluids in just a single phase, heat exchangers can be used either to heat a liquid to evaporate (or boil) it or used as condensers to cool a vapor and condense it to a liquid. In chemical plants and refineries, reboilers used to heat incoming feed for distillation towers are often heat exchangers.[6][7]

Distillation set-ups typically use condensers to condense distillate vapors back into liquid.

Power plants that use steam-driven turbines commonly use heat exchangers to boil water into steam. Heat exchangers or similar units for producing steam from water are often called boilers or steam generators.

In the nuclear power plants called pressurized water reactors, special large heat exchangers pass heat from the primary (reactor plant) system to the secondary (steam plant) system, producing steam from water in the process. These are called steam generators. All fossil-fueled and nuclear power plants using steam-driven turbines have surface condensers to convert the exhaust steam from the turbines into condensate (water) for re-use.[8][9]

To conserve energy and cooling capacity in chemical and other plants, regenerative heat exchangers can transfer heat from a stream that must be cooled to another stream that must be heated, such as distillate cooling and reboiler feed pre-heating.

This term can also refer to heat exchangers that contain a material within their structure that has a change of phase. This is usually a solid to liquid phase due to the small volume difference between these states. This change of phase effectively acts as a buffer because it occurs at a constant temperature but still allows for the heat exchanger to accept additional heat. One example where this has been investigated is for use in high power aircraft electronics.

Heat exchangers functioning in multiphase flow regimes may be subject to the Ledinegg instability.

Direct contact

[edit]

Direct contact heat exchangers involve heat transfer between hot and cold streams of two phases in the absence of a separating wall.[10] Thus such heat exchangers can be classified as:

- Gas – liquid
- Immiscible liquid – liquid
- Solid-liquid or solid – gas

Most direct contact heat exchangers fall under the Gas – Liquid category, where heat is transferred between a gas and liquid in the form of drops, films or sprays.[4]

Such types of heat exchangers are used predominantly in air conditioning, humidification, industrial hot water heating, water cooling and condensing plants.[11]

Phases[12]	Continuous phase	Driving force	Change of phase	Examples
Gas – Liquid	Gas	Gravity	No	Spray columns, packed columns
			Yes	Cooling towers, falling droplet evaporators
		Forced	No	Spray coolers/quenchers
		Liquid flow	Yes	Spray condensers/evaporation, jet condensers
	Liquid	Gravity	No	Bubble columns, perforated tray columns
			Yes	Bubble column condensers
		Forced	No	Gas spargers
		Gas flow	Yes	Direct contact evaporators, submerged combustion

Microchannel

[edit]

Microchannel heat exchangers are multi-pass parallel flow heat exchangers consisting of three main elements: manifolds (inlet and outlet), multi-port tubes with the hydraulic diameters smaller than 1mm, and fins. All the elements usually brazed together using controllable atmosphere brazing process. Microchannel heat exchangers are characterized by high heat transfer ratio, low refrigerant charges, compact size, and lower airside pressure drops compared to finned tube heat exchangers.[*citation needed*] Microchannel heat exchangers are widely used in automotive industry as the car radiators, and as condenser, evaporator, and cooling/heating coils in HVAC industry.

Main article: Micro heat exchanger

Micro heat exchangers, **Micro-scale heat exchangers**, or **microstructured heat exchangers** are heat exchangers in which (at least one) fluid flows in lateral confinements with typical dimensions below 1 mm. The most typical such confinement are microchannels, which are channels with a hydraulic diameter below 1 mm. Microchannel heat exchangers can be made from metal or ceramics.[13] Microchannel heat exchangers can be used for many applications including:

- high-performance aircraft gas turbine engines[14]
- heat pumps[15]
- Microprocessor and microchip cooling[16]
- air conditioning[17]

HVAC and refrigeration air coils

[edit]

One of the widest uses of heat exchangers is for refrigeration and air conditioning. This class of heat exchangers is commonly called *air coils*, or just *coils* due to their often-serpentine internal tubing, or condensers in the case of refrigeration, and are typically of the finned tube type. Liquid-to-air, or air-to-liquid HVAC coils are typically of modified crossflow arrangement. In vehicles, heat coils are often called heater cores.

On the liquid side of these heat exchangers, the common fluids are water, a water-glycol solution, steam, or a refrigerant. For *heating coils*, hot water and steam are the most common, and this heated fluid is supplied by boilers, for example. For *cooling coils*, chilled water and refrigerant are most common. Chilled water is supplied from a chiller that is potentially located very far away, but refrigerant must come from a nearby condensing unit. When a refrigerant is used, the cooling coil is the evaporator, and the heating coil is the condenser in the vapor-compression refrigeration cycle. HVAC coils that use this direct-expansion of refrigerants are commonly called *DX coils*. Some *DX coils* are "microchannel" type.[5]

On the air side of HVAC coils a significant difference exists between those used for heating, and those for cooling. Due to psychrometrics, air that is cooled often has moisture condensing out of it, except with extremely dry air flows. Heating some air increases that airflow's capacity to hold water. So heating coils need not consider moisture condensation on their air-side, but cooling coils *must* be adequately designed and selected to handle their particular *latent* (moisture) as well as the *sensible* (cooling) loads. The water that is removed is called *condensate*.

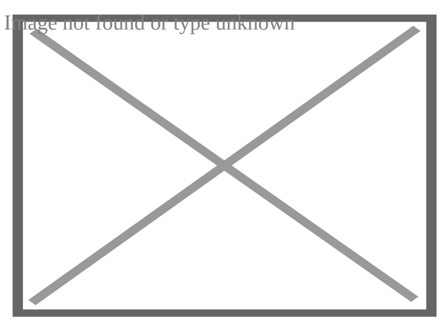
For many climates, water or steam HVAC coils can be exposed to freezing conditions. Because water expands upon freezing, these somewhat expensive and difficult to replace thin-walled heat exchangers can easily be damaged or destroyed by just one freeze. As such, freeze protection of coils is a major concern of HVAC designers, installers, and operators.

The introduction of indentations placed within the heat exchange fins controlled condensation, allowing water molecules to remain in the cooled air.[18]

The heat exchangers in direct-combustion furnaces, typical in many residences, are not 'coils'. They are, instead, gas-to-air heat exchangers that are typically made of stamped steel sheet metal. The combustion products pass on one side of these heat exchangers, and air to heat on the other. A *cracked heat exchanger* is therefore a dangerous situation that requires immediate attention because combustion products may enter living space.

Helical-coil

[edit]



Helical-Coil Heat Exchanger sketch, which consists of a shell, core, and tubes (Scott S. Haraburda design)

Although double-pipe heat exchangers are the simplest to design, the better choice in the following cases would be the helical-coil heat exchanger (HCHE):

- The main advantage of the HCHE, like that for the Spiral heat exchanger (SHE), is its highly efficient use of space, especially when it's limited and not enough straight pipe can be laid.[19]
- Under conditions of low flowrates (or laminar flow), such that the typical shell-and-tube exchangers have low heat-transfer coefficients and becoming uneconomical.[19]
- When there is low pressure in one of the fluids, usually from accumulated pressure drops in other process equipment.[19]

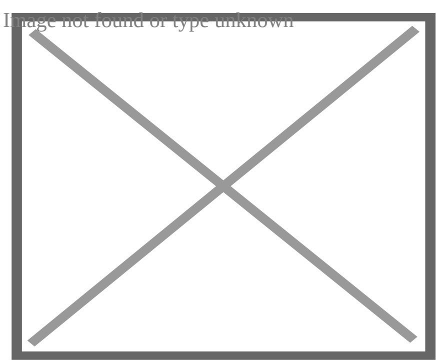
- When one of the fluids has components in multiple phases (solids, liquids, and gases), which tends to create mechanical problems during operations, such as plugging of small-diameter tubes.[20] Cleaning of helical coils for these multiple-phase fluids can prove to be more difficult than its shell and tube counterpart; however the helical coil unit would require cleaning less often.

These have been used in the nuclear industry as a method for exchanging heat in a sodium system for large liquid metal fast breeder reactors since the early 1970s, using an HCHE device invented by Charles E. Boardman and John H. Germer.[21] There are several simple methods for designing HCHE for all types of manufacturing industries, such as using the Ramachandra K. Patil (et al.) method from India and the Scott S. Haraburda method from the United States.[19][20]

However, these are based upon assumptions of estimating inside heat transfer coefficient, predicting flow around the outside of the coil, and upon constant heat flux.[22]

Spiral

[edit]



Schematic drawing of a spiral heat exchanger

A modification to the perpendicular flow of the typical HCHE involves the replacement of shell with another coiled tube, allowing the two fluids to flow parallel to one another, and which requires the use of different design calculations.[23] These are the Spiral Heat Exchangers (SHE), which may refer to a helical (coiled) tube configuration, more generally, the term refers to a pair of flat surfaces that are coiled to form the two channels in a counter-flow arrangement. Each of the two channels has one long curved path. A pair of fluid ports are connected tangentially to the outer arms of the spiral, and axial ports are common, but optional.[24]

The main advantage of the SHE is its highly efficient use of space. This attribute is often leveraged and partially reallocated to gain other improvements in performance, according to well known tradeoffs in heat exchanger design. (A notable tradeoff is capital cost vs operating cost.) A compact SHE may be used to have a smaller footprint and thus lower all-around capital costs, or an oversized SHE may be used to have less pressure drop, less pumping energy, higher thermal efficiency, and lower energy costs.

Construction

[edit]

The distance between the sheets in the spiral channels is maintained by using spacer studs that were welded prior to rolling. Once the main spiral pack has been rolled, alternate top and bottom edges are welded and each end closed by a gasketed flat or conical cover bolted to the body. This ensures no mixing of the two fluids occurs. Any leakage is from the periphery cover to the atmosphere, or to a passage that contains the same fluid.[25]

Self cleaning

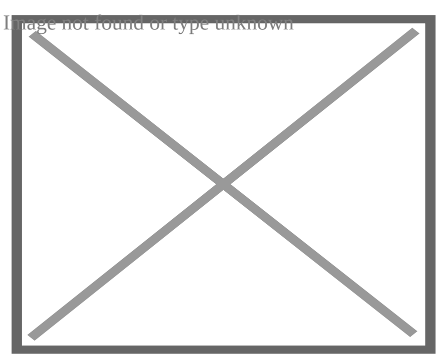
[edit]

Spiral heat exchangers are often used in the heating of fluids that contain solids and thus tend to foul the inside of the heat exchanger. The low pressure drop lets the SHE handle fouling more easily. The SHE uses a “self cleaning” mechanism, whereby fouled surfaces cause a localized increase in fluid velocity, thus increasing the drag (or fluid friction) on the fouled surface, thus helping to dislodge the blockage and keep the heat exchanger clean. "The internal walls that make up the heat transfer surface are often rather thick, which makes the SHE very robust, and able to last a long time in demanding environments."[*citation need* They are also easily cleaned, opening out like an oven where any buildup of foulant can be removed by pressure washing.

Self-cleaning water filters are used to keep the system clean and running without the need to shut down or replace cartridges and bags.

Flow arrangements

[edit]



A comparison between the operations and effects of a **cocurrent and a countercurrent flow exchange system** is depicted by the upper and lower diagrams respectively. In both it is assumed (and indicated) that red has a higher value (e.g. of temperature) than blue and that the property being transported in the channels therefore flows from red to blue. Channels are contiguous if effective exchange is to occur (i.e. there can be no gap between the channels).

There are three main types of flows in a spiral heat exchanger:

- **Counter-current Flow**: Fluids flow in opposite directions. These are used for liquid-liquid, condensing and gas cooling applications. Units are usually mounted vertically when condensing vapour and mounted horizontally when handling high concentrations of solids.
- **Spiral Flow/Cross Flow:** One fluid is in spiral flow and the other in a cross flow. Spiral flow passages are welded at each side for this type of spiral heat exchanger. This type of flow is suitable for handling low density gas, which passes through the cross flow, avoiding pressure loss. It can be used for liquid-liquid applications if one liquid has a considerably greater flow rate than the other.
- **Distributed Vapour/Spiral flow:** This design is that of a condenser, and is usually mounted vertically. It is designed to cater for the sub-cooling of both condensate and non-condensables. The coolant moves in a spiral and leaves via the top. Hot gases that enter leave as condensate via the bottom outlet.

Applications

[edit]

The Spiral heat exchanger is good for applications such as pasteurization, digester heating, heat recovery, pre-heating (see: recuperator), and effluent cooling. For sludge treatment, SHEs are generally smaller than other types of heat exchangers.[*citation needed*] These are used to transfer the heat.

Selection

[edit]

Due to the many variables involved, selecting optimal heat exchangers is challenging. Hand calculations are possible, but many iterations are typically needed. As such, heat exchangers are most often selected via computer programs, either by system designers, who are typically engineers, or by equipment vendors.

To select an appropriate heat exchanger, the system designers (or equipment vendors) would firstly consider the design limitations for each heat exchanger type. Though cost is often the primary criterion, several other selection criteria are important:

- High/low pressure limits
- Thermal performance
- Temperature ranges
- Product mix (liquid/liquid, particulates or high-solids liquid)

- Pressure drops across the exchanger
- Fluid flow capacity
- Cleanability, maintenance and repair
- Materials required for construction
- Ability and ease of future expansion
- Material selection, such as copper, aluminium, carbon steel, stainless steel, nickel alloys, ceramic, polymer, and titanium.[26][27]

Small-diameter coil technologies are becoming more popular in modern air conditioning and refrigeration systems because they have better rates of heat transfer than conventional sized condenser and evaporator coils with round copper tubes and aluminum or copper fin that have been the standard in the HVAC industry. Small diameter coils can withstand the higher pressures required by the new generation of environmentally friendlier refrigerants. Two small diameter coil technologies are currently available for air conditioning and refrigeration products: copper microgroove[28] and brazed aluminum microchannel.[*citation needed*

Choosing the right heat exchanger (HX) requires some knowledge of the different heat exchanger types, as well as the environment where the unit must operate. Typically in the manufacturing industry, several differing types of heat exchangers are used for just one process or system to derive the final product. For example, a kettle HX for pre-heating, a double pipe HX for the 'carrier' fluid and a plate and frame HX for final cooling. With sufficient knowledge of heat exchanger types and operating requirements, an appropriate selection can be made to optimise the process.[29]

Monitoring and maintenance

[edit]

Online monitoring of commercial heat exchangers is done by tracking the overall heat transfer coefficient. The overall heat transfer coefficient tends to decline over time due to fouling.

By periodically calculating the overall heat transfer coefficient from exchanger flow rates and temperatures, the owner of the heat exchanger can estimate when cleaning the heat exchanger is economically attractive.

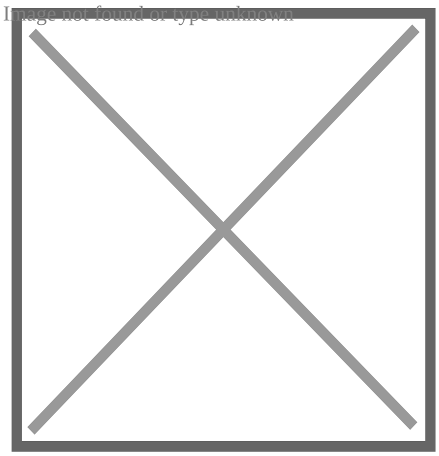
Integrity inspection of plate and tubular heat exchanger can be tested in situ by the conductivity or helium gas methods. These methods confirm the integrity of the plates or tubes to prevent any cross contamination and the condition of the gaskets.

Mechanical integrity monitoring of heat exchanger tubes may be conducted through Nondestructive methods such as eddy current testing.

Fouling

[edit]

Main article: Fouling



A heat exchanger in a steam power station contaminated with macrofouling

Fouling occurs when impurities deposit on the heat exchange surface. Deposition of these impurities can decrease heat transfer effectiveness significantly over time and are caused by:

- Low wall shear stress
- Low fluid velocities
- High fluid velocities
- Reaction product solid precipitation
- Precipitation of dissolved impurities due to elevated wall temperatures

The rate of heat exchanger fouling is determined by the rate of particle deposition less re-entrainment/suppression. This model was originally proposed in 1959 by Kern and Seaton.

Crude Oil Exchanger Fouling. In commercial crude oil refining, crude oil is heated from 21 °C (70 °F) to 343 °C (649 °F) prior to entering the distillation column. A series of shell and tube heat exchangers typically exchange heat between crude oil and other oil streams to heat the crude to 260 °C (500 °F) prior to heating in a furnace. Fouling occurs on the crude side of these exchangers due to asphaltene insolubility. The nature of asphaltene solubility in crude oil was successfully modeled by Wiehe and Kennedy.[30] The precipitation of insoluble asphaltenes in crude preheat trains has been successfully modeled as a first order reaction by Ebert and Panchal[31] who expanded on the work of Kern and Seaton.

Cooling Water Fouling. Cooling water systems are susceptible to fouling. Cooling water typically has a high total dissolved solids content and suspended colloidal solids. Localized precipitation of dissolved solids occurs at the heat exchange surface due to wall temperatures higher than bulk fluid temperature. Low fluid velocities (less than 3 ft/s) allow suspended solids to settle on the heat exchange surface. Cooling water is typically on the tube side of a shell and tube exchanger because it's easy to clean. To prevent fouling, designers typically ensure that cooling water velocity is greater than 0.9 m/s and bulk fluid temperature is maintained less than 60 °C (140 °F). Other approaches to control fouling control combine the "blind" application of biocides and anti-scale chemicals with periodic lab testing.

Maintenance

[edit]

Plate and frame heat exchangers can be disassembled and cleaned periodically. Tubular heat exchangers can be cleaned by such methods as acid cleaning, sandblasting, high-pressure water jet, bullet cleaning, or drill rods.

In large-scale cooling water systems for heat exchangers, water treatment such as purification, addition of chemicals, and testing, is used to minimize fouling of the heat exchange equipment. Other water treatment is also used in steam systems for power plants, etc. to minimize fouling and corrosion of the heat exchange and other equipment.

A variety of companies have started using water borne oscillations technology to prevent biofouling. Without the use of chemicals, this type of technology has helped in providing a low-pressure drop in heat exchangers.

Design and manufacturing regulations

[edit]

The design and manufacturing of heat exchangers has numerous regulations, which vary according to the region in which they will be used.

Design and manufacturing codes include: ASME Boiler and Pressure Vessel Code (US); PD 5500 (UK); BS 1566 (UK);[32] EN 13445 (EU); CODAP (French); Pressure Equipment Safety Regulations 2016 (PER) (UK); Pressure Equipment Directive (EU); NORSOK (Norwegian); TEMA;[33] API 12; and API 560.[*citation needed*]

In nature

[edit]

Humans

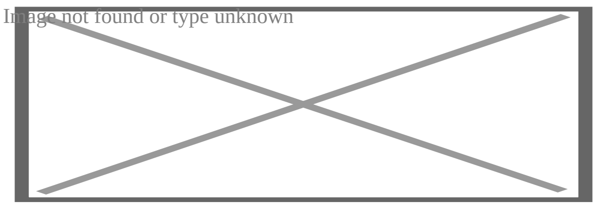
[edit]

The human nasal passages serve as a heat exchanger, with cool air being inhaled and warm air being exhaled. Its effectiveness can be demonstrated by putting the hand in front of the face and exhaling, first through the nose and then through the mouth. Air exhaled through the nose is substantially cooler.[34][35] This effect can be enhanced with clothing, by, for example, wearing a scarf over the face while breathing in cold weather.

In species that have external testes (such as human), the artery to the testis is surrounded by a mesh of veins called the pampiniform plexus. This cools the blood heading to the testes, while reheating the returning blood.

Birds, fish, marine mammals

[edit]



Counter-current exchange conservation circuit

Further information: Counter-current exchange in biological systems

"Countercurrent" heat exchangers occur naturally in the circulatory systems of fish, whales and other marine mammals. Arteries to the skin carrying warm blood are intertwined with veins from the skin carrying cold blood, causing the warm arterial blood to exchange heat with the cold venous blood. This reduces the overall heat loss in cold water. Heat exchangers are also present in the tongues of baleen whales as large volumes of water flow through their mouths.[36][37] Wading birds use a similar system to limit heat losses from their body through their legs into the water.

Carotid rete

[edit]

Carotid rete is a counter-current heat exchanging organ in some ungulates. The blood ascending the carotid arteries on its way to the brain, flows via a network of vessels where heat is discharged to the veins of cooler blood descending from the nasal passages. The carotid rete allows Thomson's gazelle to maintain its brain almost 3 °C (5.4 °F) cooler than the rest of the body, and therefore aids in tolerating bursts in metabolic heat production such as associated with outrunning cheetahs (during which the body temperature exceeds the maximum temperature at which the brain could function).[38] Humans with other primates lack a carotid rete.[39]

In industry

[edit]

Heat exchangers are widely used in industry both for cooling and heating large scale industrial processes. The type and size of heat exchanger used can be tailored to suit a process depending on the type of fluid, its phase, temperature, density, viscosity, pressures, chemical composition and various other thermodynamic properties.

In many industrial processes there is waste of energy or a heat stream that is being exhausted, heat exchangers can be used to recover this heat and put it to use by heating a different stream in the process. This practice saves a lot of money in industry, as the heat supplied to other streams from the heat exchangers would otherwise come from an external source that is more expensive and more harmful to the environment.

Heat exchangers are used in many industries, including:

- Waste water treatment
- Refrigeration
- Wine and beer making
- Petroleum refining
- Nuclear power

In waste water treatment, heat exchangers play a vital role in maintaining optimal temperatures within anaerobic digesters to promote the growth of microbes that remove pollutants. Common types of heat exchangers used in this application are the double pipe heat exchanger as well as the plate and frame heat exchanger.

In aircraft

[edit]

In commercial aircraft heat exchangers are used to take heat from the engine's oil system to heat cold fuel.[40] This improves fuel efficiency, as well as reduces the possibility of water entrapped in the fuel freezing in components.[41]

Current market and forecast

[edit]

Estimated at US$17.5 billion in 2021, the global demand of heat exchangers is expected to experience robust growth of about 5% annually over the next years. The market value is expected to reach US$27 billion by 2030. With an expanding desire for environmentally friendly options and increased development of offices, retail sectors, and public buildings, market expansion is due to grow.[42]

A model of a simple heat exchanger

[edit]

A simple heat exchange [43][44] might be thought of as two straight pipes with fluid flow, which are thermally connected. Let the pipes be of equal length *L*, carrying fluids with heat capacity C_i (energy per unit mass per unit change in temperature) and let the mass flow rate of the fluids through the pipes, both in the same direction, be j_i (mass per unit time), where the subscript *i* applies to pipe 1 or pipe 2.

Temperature profiles for the pipes are $T_1(x)$ and $T_2(x)$ where *x* is the distance along the pipe. Assume a steady state, so that the temperature profiles are not functions of time. Assume also that the only transfer of heat from a small volume of fluid in one pipe is to the fluid element in the other pipe at the same position, i.e., there is no transfer of heat along a pipe due to temperature differences in that pipe. By Newton's law of cooling the rate of change in energy of a small volume of fluid is proportional to the difference in temperatures between it and the corresponding element in the other pipe:

$$\frac{du_1}{dt}=\gamma (T_2-T_1)$$

$$\frac{du_2}{dt}=\gamma (T_1-T_2)$$

(this is for parallel flow in the same direction and opposite temperature gradients, but for counter-flow heat exchange countercurrent exchange the sign is opposite in the second equation in front of $\gamma (T_1-T_2)$), where $u_i(x)$ is the thermal energy per unit length and ? is the thermal connection constant per unit length between the two pipes. This change in internal energy results in a change in the temperature of the fluid element. The time rate of change for the fluid element being carried along by the flow is:

$$\frac{du_1}{dt}=J_1\frac{dT_1}{dx}$$

$$\frac{du_2}{dt}=J_2\frac{dT_2}{dx}$$

where $J_i=C_i j_i$ is the "thermal mass flow rate". The differential equations governing the heat exchanger may now be written as:

$$J_1\frac{\partial T_1}{\partial x}=\gamma (T_2-T_1)$$

$$J_2\frac{\partial T_2}{\partial x}=\gamma (T_1-T_2).$$

Since the system is in a steady state, there are no partial derivatives of temperature with respect to time, and since there is no heat transfer along the pipe, there are no second derivatives in *x* as is found in the heat equation. These two coupled first-order differential equations may be solved to yield:

$$T_1=A-\frac{B}{k_1}k\,e^{-kx}$$

$$T_2=A+\frac{B}{k_2}k\,e^{-kx}$$

where $k_1=\gamma /J_1$, $k_2=\gamma /J_2$

$$k=k_1+k_2$$

(this is for parallel-flow, but for counter-flow the sign in front of k_2 is negative, so that if $k_2=k_1$ for the same "thermal mass flow rate" in both opposite directions, the gradient of temperature is constant and the temperatures linear in position *x* with a constant difference (T_2-T_1) along the exchanger, explaining why the counter current design countercurrent exchange is the most efficient)

and *A* and *B* are two as yet undetermined constants of integration. Let T_{10} and T_{20} be the temperatures at x=0 and let T_{1L} and T_{2L} be the temperatures at the end of the pipe at x=L. Define the average temperatures in each pipe as:

$$\overline{T}_1=\frac{1}{L}\int_0^L T_1(x)dx$$

$$\overline{T}_2=\frac{1}{L}\int_0^L T_2(x)dx.$$

Using the solutions above, these temperatures are:

$$T_{10}=A-\frac{B}{k_1}k \qquad T_{20}=A+\frac{B}{k_2}k$$

$$T_{1L}=A-\frac{B}{k_1}ke^{-kL} \qquad T_{2L}=A+\frac{B}{k_2}ke^{-kL}$$

$$\overline{T}_1=A-\frac{B}{k_1 k^2 L}(1-e^{-kL}) \qquad \overline{T}_2=A+\frac{B}{k_2 k^2 L}(1-e^{-kL}$$

Choosing any two of the temperatures above eliminates the constants of integration, letting us find the other four temperatures. We find the total energy transferred by integrating the expressions for the time rate of change of internal energy per unit length:

$$\frac{dU_1}{dt}=\int_0^L\frac{du_1}{dt}\,dx=J_1(T_{1L}-T_{10})=\gamma L(\overline{T}_2$$

$$\frac{dU_2}{dt}=\int_0^L\frac{du_2}{dt}\,dx=J_2(T_{2L}-T_{20})=\gamma L(\overline{T}_1$$

By the conservation of energy, the sum of the two energies is zero. The quantity \displaystyle \overl Image not found or type unkn is known as the *Log mean temperature difference*, and is a measure of the effectiveness of the heat exchanger in transferring heat energy.

See also

[edit]

- Architectural engineering
- Chemical engineering
- Cooling tower
- Copper in heat exchangers
- Heat pipe
- Heat pump
- Heat recovery ventilation
- Jacketed vessel
- Log mean temperature difference (LMTD)
- Marine heat exchangers
- Mechanical engineering
- Micro heat exchanger
- Moving bed heat exchanger
- Packed bed and in particular Packed columns
- Pumpable ice technology
- Reboiler
- Recuperator, or cross plate heat exchanger
- Regenerator
- Run around coil
- Steam generator (nuclear power)
- Surface condenser
- Toroidal expansion joint
- Thermosiphon
- Thermal wheel, or rotary heat exchanger (including enthalpy wheel and desiccant wheel)
- Tube tool
- Waste heat

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- EU Pressure Equipment Guideline
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Heating, ventilation, and air conditioning

Fundamental concepts

- Air changes per hour
- Bake-out
- Building envelope
- Convection
- Dilution
- Domestic energy consumption
- Enthalpy
- Fluid dynamics
- Gas compressor
- Heat pump and refrigeration cycle
- Heat transfer
- Humidity
- Infiltration
- Latent heat
- Noise control
- Outgassing
- Particulates
- Psychrometrics
- Sensible heat
- Stack effect
- Thermal comfort
- Thermal destratification
- Thermal mass
- Thermodynamics
- Vapour pressure of water

Technology	◦ Absorption-compression heat pump ◦ Absorption refrigerator ◦ Air barrier ◦ Air conditioning ◦ Antifreeze ◦ Automobile air conditioning ◦ Autonomous building ◦ Building insulation materials ◦ Central heating ◦ Central solar heating ◦ Chilled beam ◦ Chilled water ◦ Constant air volume (CAV) ◦ Coolant ◦ Cross ventilation ◦ Dedicated outdoor air system (DOAS) ◦ Deep water source cooling ◦ Demand controlled ventilation (DCV) ◦ Displacement ventilation ◦ District cooling ◦ District heating ◦ Electric heating ◦ Energy recovery ventilation (ERV) ◦ Firestop ◦ Forced-air ◦ Forced-air gas ◦ Free cooling ◦ Heat recovery ventilation (HRV) ◦ Hybrid heat ◦ Hydronics ◦ Ice storage air conditioning ◦ Kitchen ventilation ◦ Mixed-mode ventilation ◦ Microgeneration ◦ Passive cooling ◦ Passive daytime radiative cooling ◦ Passive house ◦ Passive ventilation ◦ Radiant heating and cooling ◦ Radiant cooling ◦ Radiant heating ◦ Radon mitigation ◦ Refrigeration ◦ Renewable heat ◦ Room air distribution ◦ Solar air heat ◦ Solar combisystem ◦ Solar cooling ◦ Solar heating ◦ Thermal insulation

- Air conditioner inverter
- Air door
- Air filter
- Air handler
- Air ionizer
- Air-mixing plenum
- Air purifier
- Air source heat pump
- Attic fan
- Automatic balancing valve
- Back boiler
- Barrier pipe
- Blast damper
- Boiler
- Centrifugal fan
- Ceramic heater
- Chiller
- Condensate pump
- Condenser
- Condensing boiler
- Convection heater
- Compressor
- Cooling tower
- Damper
- Dehumidifier
- Duct
- Economizer
- Electrostatic precipitator
- Evaporative cooler
- Evaporator
- Exhaust hood
- Expansion tank
- Fan
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- Fan filter unit
- Fan heater
- Fire damper
- Fireplace
- Fireplace insert
- Freeze stat
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- Fume hood
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- Gas compressor
- Gas heater
- Gasoline heater
- Grease duct
- Grille
- Ground-coupled heat exchanger

Components

Measurement and control	○ Air flow meter ○ Aquastat ○ BACnet ○ Blower door ○ Building automation ○ Carbon dioxide sensor ○ Clean air delivery rate (CADR) ○ Control valve ○ Gas detector ○ Home energy monitor ○ Humidistat ○ HVAC control system ○ Infrared thermometer ○ Intelligent buildings ○ LonWorks ○ Minimum efficiency reporting value (MERV) ○ Normal temperature and pressure (NTP) ○ OpenTherm ○ Programmable communicating thermostat ○ Programmable thermostat ○ Psychrometrics ○ Room temperature ○ Smart thermostat ○ Standard temperature and pressure (STP) ○ Thermographic camera ○ Thermostat ○ Thermostatic radiator valve
Professions, trades, and services	○ Architectural acoustics ○ Architectural engineering ○ Architectural technologist ○ Building services engineering ○ Building information modeling (BIM) ○ Deep energy retrofit ○ Duct cleaning ○ Duct leakage testing ○ Environmental engineering ○ Hydronic balancing ○ Kitchen exhaust cleaning ○ Mechanical engineering ○ Mechanical, electrical, and plumbing ○ Mold growth, assessment, and remediation ○ Refrigerant reclamation ○ Testing, adjusting, balancing

Industry organizations	◦ AHRI ◦ AMCA ◦ ASHRAE ◦ ASTM International ◦ BRE ◦ BSRIA ◦ CIBSE ◦ Institute of Refrigeration ◦ IIR ◦ LEED ◦ SMACNA ◦ UMC
Health and safety	◦ Indoor air quality (IAQ) ◦ Passive smoking ◦ Sick building syndrome (SBS) ◦ Volatile organic compound (VOC)
See also	◦ ASHRAE Handbook ◦ Building science ◦ Fireproofing ◦ Glossary of HVAC terms ◦ Warm Spaces ◦ World Refrigeration Day ◦ Template:Home automation ◦ Template:Solar energy

About Air pollution

"Bad air quality" and "Air quality" redirect here. For the obsolete medical theory, see Miasma theory. For the measurement of air pollution, see Air quality index. For the qualities of air, see Atmosphere of Earth.

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Air pollution from a coking oven

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2016 Environmental Performance Index – darker colors indicate lower concentrations of fine particulate matter and nitrogen dioxide, as well as better indoor air quality.

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Deaths from air pollution per 100,000 inhabitants (IHME, 2019)

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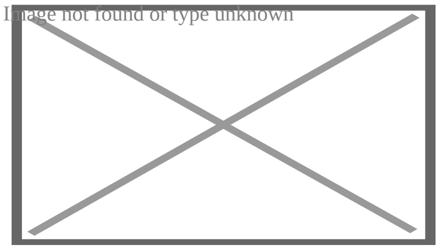
Part of a series on



Air pollution from a factory

Air

- Acid rain
- Air quality index
- Atmospheric dispersion modeling
- Chlorofluorocarbon
- Combustion
- Exhaust gas
- Haze
- Global dimming
- Global distillation
- Indoor air quality
- Non-exhaust emissions
- Ozone depletion
- Particulates
- Persistent organic pollutant
- Smog
- Soot
- Volatile organic compound

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- Image not found or type unknown icon Ecology portal

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Part of a series on

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Tropical seasons

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  - Landspout
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- Fire whirl
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- Polar low
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- Subtropical cyclone
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- Dust storm
  - Simoom
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- Tropical cyclone terms

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Air pollution is the contamination of air due to the presence of substances called pollutants in the atmosphere that are harmful to the health of humans and other living beings, or cause damage to the climate or to materials.[1] It is also the contamination of the indoor or outdoor environment either by chemical, physical, or biological agents that alters the natural features of the atmosphere.[1] There are many different types of air pollutants, such as gases (including ammonia, carbon monoxide, sulfur dioxide, nitrous oxides, methane and chlorofluorocarbons), particulates (both organic and inorganic) and biological molecules. Air pollution can cause diseases, allergies, and even death to humans; it can also cause harm to other living organisms such as animals and crops, and may damage the natural environment (for example, climate change, ozone depletion or habitat degradation) or built environment (for example, acid rain).[2] Air pollution can be caused by both human activities[3] and natural phenomena.[4]

Air quality is closely related to the Earth's climate and ecosystems globally. Many of the contributors of air pollution are also sources of greenhouse emission i.e., burning of fossil fuel.[1]

Air pollution is a significant risk factor for a number of pollution-related diseases, including respiratory infections, heart disease, chronic obstructive pulmonary disease (COPD), stroke, and lung cancer.[5] Growing evidence suggests that air pollution exposure may be associated with reduced IQ scores, impaired cognition,[6] increased risk for psychiatric disorders such as depression[7] and detrimental perinatal health.[8] The human health effects of poor air quality are far reaching, but principally affect the body's respiratory system and the cardiovascular system.[9][10] Individual reactions to air pollutants depend on the type of pollutant a person is exposed to,[11][12] the degree of exposure, and the individual's health status and genetics.[13]

Air pollution is the largest environmental risk factor for disease and premature death[5][14] and the fourth largest risk factor overall for human health.[15] Air pollution causes the premature deaths of around 7 million people worldwide each year,[5] or a global mean loss of life expectancy (LLE) of 2.9 years,[16] and there has been no significant change in the number of deaths caused by all forms of pollution since at least 2015.[14][17][18] Outdoor air pollution attributable to fossil fuel use alone causes ~3.61 million deaths annually,[19] making it one of the top contributors to human death.[5] Anthropogenic ozone causes around 470,000 premature deaths a year and fine particulate ($PM_{2.5}$) pollution around another 2.1 million.[20] The scope of the air pollution crisis is large: In 2018, WHO estimated that "9 out of 10 people breathe air containing high levels of pollutants."[21]

Although the health consequences are extensive, the way the problem is handled is considered largely haphazard[22][21][23] or neglected.[14]

The World Bank has estimated that welfare losses (premature deaths) and productivity losses (lost labour) caused by air pollution cost the world economy $5 trillion per year.[24][25][26] The costs of air pollution are generally an externality to the contemporary economic system and most human activity, although they are sometimes recovered through monitoring, legislation, and regulation.[27][28]

Many different technologies and strategies are available for reducing air pollution.[29] Although a majority of countries have air pollution laws, according to UNEP, 43 percent of countries lack a legal definition of air pollution, 31 percent lack outdoor air quality standards, 49 percent restrict their definition to outdoor pollution only, and just 31 percent have laws for tackling pollution originating from outside their borders.[30] National air quality laws have often been highly effective, notably the 1956 Clean Air Act in Britain and the US Clean Air Act, introduced in 1963.[31][32] Some of these efforts have been successful at the international level, such as the Montreal Protocol,[33] which reduced the release of harmful ozone depleting chemicals, and the 1985 Helsinki Protocol,[34] which reduced sulfur emissions,[35] while others, such as international action on climate change,[36][37][38] have been less successful.

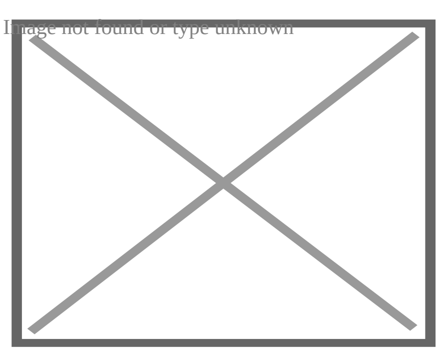
Sources of air pollution

[edit]

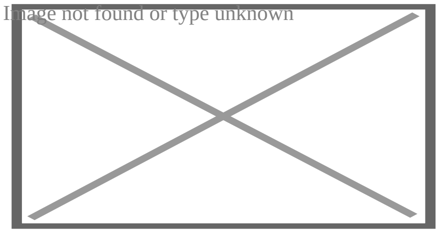
There are many different sources of air pollution. Some air pollutants (such as nitrogen oxides) originate mainly from human activities,[39] while some (notably radon gas) come mostly from natural sources.[40] However, many air pollutants (including dust and sulfur dioxide) come from a mixture of natural and human sources.[41]

Anthropogenic (human-made) sources

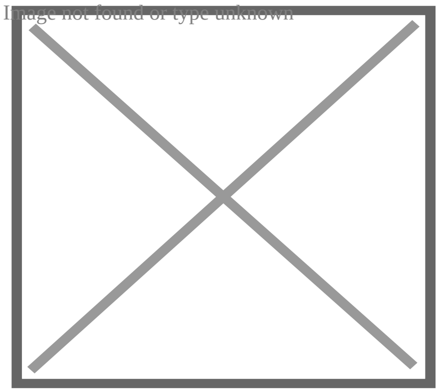
[edit]



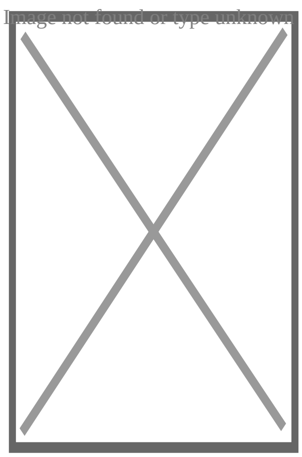
Demolition of the cooling towers of a power station, Athlone, Cape Town, South Africa, 2010



Controlled burning of a field outside of Statesboro, Georgia, US, in preparation for spring planting



Smoking of fish over an open fire in Ghana, 2018



Burning of joss paper in a Chinese temple in Hong Kong

- Stationary sources include:
  - fossil-fuel power plants and biomass power plants both have smoke stacks (see for example environmental impact of the coal industry)[42]
    - Oil and gas sites that have methane leaks[43][44][45][46]
  - burning of traditional biomass such as wood, crop waste and dung. (In developing and poor countries,[47] traditional biomass burning is the major source of air pollutants.[48][49] It is also the main source of particulate pollution in many developed areas including the UK & New South Wales.[50][51] Its pollutants include PAHs.[52])
  - manufacturing facilities (factories)[53]

    - a 2014 study found that in China equipment-, machinery-, and devices-manufacturing and construction sectors contributed more than 50% of air pollutant emissions.[54][*better source needed*] This high emission is due to high emission intensity and high emission factors in its industrial structure.[55]
  - construction[56][57]
  - renovation[58]
  - waste incineration (incinerators as well as open and uncontrolled fires of mismanaged waste, making up about a fourth of municipal solid terrestrial waste)[59][60]
  - furnaces and other types of fuel-burning heating devices[61]
- Mobile sources include motor vehicles, trains (particularly diesel locomotives and DMUs), marine vessels and aircraft[62] as well as rockets and re-entry of components and debris.[63] The air pollution externality of cars enters the air from the exhaust gas and car tires (including microplastics[64]). Road vehicles make a significant amount of all air pollution (typically, for example, around a third to a half of all nitrogen dioxide emissions)[65][66][67] and are a major driver of climate change.[68][69]
- Agriculture and forest management strategies using controlled burns. Practices like slash-and-burn in forests like the Amazon cause large air pollution with the deforestation.[70] Controlled or prescribed burning is a practice used in forest management, agriculture, prairie restoration, and greenhouse gas reduction.[71] Foresters can use controlled fire as a tool because fire is a natural feature of both forest and grassland ecology.[72][73] Controlled burning encourages the sprouting of some desirable forest trees, resulting in a forest renewal.[74]

There are also sources from processes other than combustion:

- Fumes from paint, hair spray, varnish, aerosol sprays and other solvents. These can be substantial; emissions from these sources was estimated to account for almost half of pollution from volatile organic compounds in the Los Angeles basin in the 2010s.[75]
- Waste deposition in landfills produces methane[76] and open burning of waste releases harmful substances.[77]
- Nuclear weapons, toxic gases, germ warfare, and rocketry are examples of military resources.[78]
- Agricultural emissions and emissions from meat production or livestock contribute substantially to air pollution[79][80]
  - Fertilized farmland may be a major source of nitrogen oxides.[81]

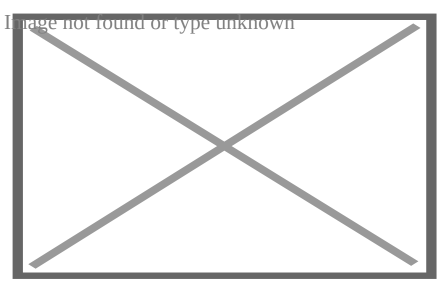
Mean acidifying emissions (air pollution) of different foods per 100g of protein[82]

Food Types	Acidifying Emissions (g SO_2eq per 100g protein)
Beef	343.6
Cheese	165.5

Pork	142.7
Lamb and mutton	139.0
Farmed crustaceans	133.1
Poultry	102.4
Farmed fish	65.9
Eggs	53.7
Groundnuts	22.6
Peas	8.5
Tofu	6.7

Natural sources

[edit]



Dust storm approaching Stratford, Texas, in 1935

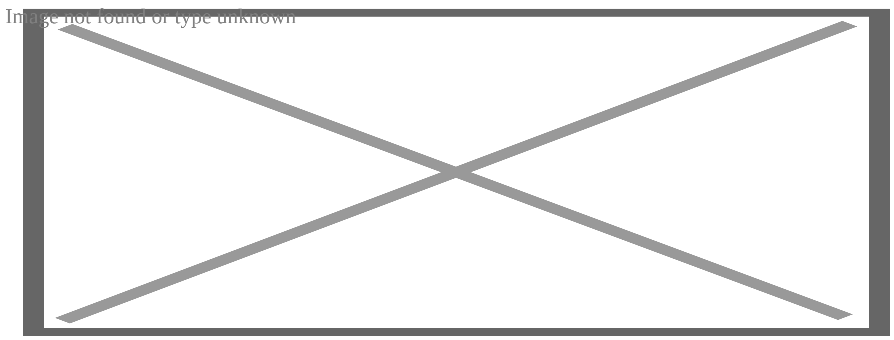
- Dust from natural sources, usually large areas of land with little or no vegetation.
- Methane, emitted by the digestion of food by animals, for example cattle.
- Radon gas from radioactive decay within the Earth's crust. Radon is a colorless, odorless, naturally occurring, radioactive noble gas that is formed from the decay of radium. It is considered to be a health hazard. Radon gas from natural sources can accumulate in buildings, especially in confined areas such as the basement and it is the second most frequent cause of lung cancer, after cigarette smoking.
- Smoke and carbon monoxide from wildfires. During periods of active wildfires, smoke from uncontrolled biomass combustion can make up almost 75% of all air pollution by concentration.[83]
- Vegetation, in some regions, emits environmentally significant amounts of volatile organic compounds (VOCs) on warmer days. These VOCs react with primary anthropogenic pollutants – specifically, NO_x, SO_2, and anthropogenic organic carbon

compounds – to produce a seasonal haze of secondary pollutants.[84] Black gum, poplar, oak and willow are some examples of vegetation that can produce abundant VOCs. The VOC production from these species result in ozone levels up to eight times higher than the low-impact tree species.[85]

- Volcanic activity, which produces sulfur, chlorine, and ash particulates.[86]

Emission factors

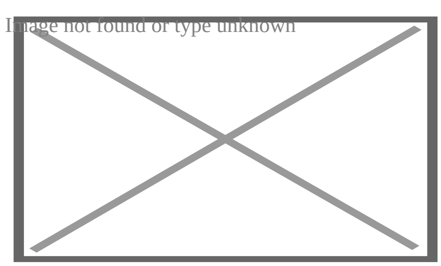
[edit]
Main article: AP 42 Compilation of Air Pollutant Emission Factors



Beijing air in 2005 after rain (left) and a smoggy day (right)

Air pollutant emission factors are reported representative values that aim to link the quantity of a pollutant released into the ambient air to an activity connected with that pollutant's release.[2][87][88][89] The weight of the pollutant divided by a unit weight, volume, distance, or time of the activity generating the pollutant is how these factors are commonly stated (e.g., kilograms of particulate emitted per tonne of coal burned). These criteria make estimating emissions from diverse sources of pollution easier. Most of the time, these components are just averages of all available data of acceptable quality, and they are thought to be typical of long-term averages.

The Stockholm Convention on Persistent Organic Pollutants identified pesticides and other persistent organic pollutants of concern. These include dioxins and furans which are unintentionally created by combustion of organics, like open burning of plastics, and are endocrine disruptors and mutagens.

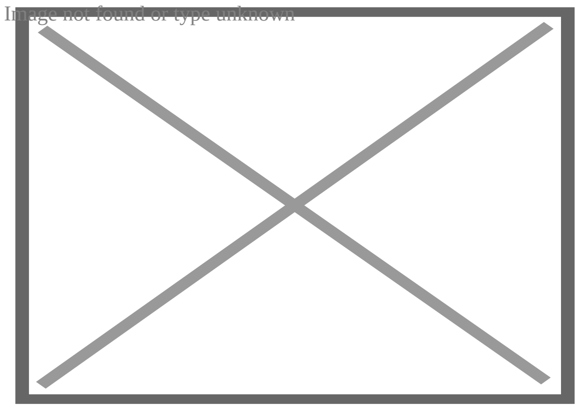


E-waste processing in Agbogbloshie, Ghana, using open-burning of electronics to access valuable metals like copper. Open burning of plastics is common in many parts of the world without the capacity for processing. Especially without proper protections, heavy metals and other contaminates can seep into the soil, and create water pollution and air pollution.

The United States Environmental Protection Agency has published a compilation of air pollutant emission factors for a wide range of industrial sources.[90] The United Kingdom, Australia, Canada, and many other countries have published similar compilations, as well as the European Environment Agency.[91][92][93][94]

Pollutants

[edit]
Main articles: Pollutant and Greenhouse gas emissions



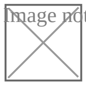
Schematic drawing, causes and effects of air pollution: (1) greenhouse effect, (2) particulate contamination, (3) increased UV radiation, (4) acid rain, (5) increased ground-level ozone concentration, (6) increased levels of nitrogen oxides

An air pollutant is a material in the air that can have many effects on humans and the ecosystem.[95] The substance can be solid particles, liquid droplets, or gases, and often takes the form of an aerosol (solid particles or liquid droplets dispersed and carried by a gas).[96] A pollutant can be of natural origin or man-made. Pollutants are classified as primary or secondary. Primary pollutants are usually produced by processes such as ash from a volcanic eruption.

Other examples include carbon monoxide gas from motor vehicle exhausts or sulfur dioxide released from factories. Secondary pollutants are not emitted directly. Rather, they form in the air when primary pollutants react or interact. Ground level ozone is a prominent example of a secondary pollutant. Some pollutants may be both primary and secondary: they are both emitted directly and formed from other primary pollutants.

Primary pollutants

[edit]



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Pollutants emitted into the atmosphere by human activity include:

- Ammonia: Emitted mainly by agricultural waste. Ammonia is a compound with the formula NH_3. It is normally encountered as a gas with a characteristic pungent odor. Ammonia contributes significantly to the nutritional needs of terrestrial organisms by serving as a precursor to foodstuffs and fertilizers. Ammonia, either directly or indirectly, is also a building block for the synthesis of many pharmaceuticals. Although in wide use, ammonia is both caustic and hazardous.[97] In the atmosphere, ammonia reacts with oxides of nitrogen and sulfur to form secondary particles.[98]
- Carbon dioxide (CO_2): Carbon dioxide is a natural component of the atmosphere, essential for plant life and given off by the human respiratory system.[99] It is potentially lethal at very high concentrations (typically 100 times "normal" atmospheric levels).[100][101] Although the World Health Organization recognizes CO_2 as a climate pollutant, it does not include the gas in its *Air Quality Guidelines* or set recommended targets for it.[102] Because of its role as a greenhouse gas, CO_2 has been described as "the worst climate pollutant".[103] Statements such as this refer to its long-term atmospheric effects rather than shorter-term effects on such things as human health, food crops, and buildings. This question of terminology has practical consequences, for example, in determining whether the U.S. Clean Air Act (which is designed to improve air quality) is deemed to regulate CO_2 emissions.[104] That issue was resolved in the United States by the Inflation Reduction Act of 2022, which specifically amended the Clean Air Act "to define the carbon dioxide produced by the burning of fossil fuels as an 'air pollutant.'"[105] CO_2 currently forms about 410 parts per million (ppm) of Earth's atmosphere, compared to about 280 ppm in pre-industrial times,[106] and billions of metric tons of CO_2 are emitted annually by burning of fossil fuels.[107] CO_2 increase in Earth's atmosphere has been accelerating.[108] CO_2 is an asphyxiant gas and not classified as toxic or harmful in general.[109] Workplace exposure limits exist in places like UK (5,000 ppm for long-term exposure and 15,000 ppm for short-term exposure).[101] Natural disasters like the limnic eruption at Lake Nyos can result in a sudden release of huge amount of CO_2 as well.[110]
- Carbon monoxide (CO): CO is a colorless, odorless, toxic gas.[111] It is a product of combustion of fuel such as natural gas, coal or wood. Vehicular exhaust contributes to the majority of carbon monoxide let into the atmosphere. It creates a smog type formation in the air that has been linked to many lung diseases and disruptions to the natural environment and animals.
- Chlorofluorocarbons (CFCs): Emitted from goods that are now prohibited from use; harmful to the ozone layer. These are gases emitted by air conditioners, freezers, aerosol sprays, and other similar devices. CFCs reach the stratosphere after being released into the atmosphere.[112] They interact with other gases here, causing harm to the ozone layer. UV rays are able to reach the Earth's surface as a result of this. This can result in skin cancer, eye problems, and even plant damage.[113]
- Nitrogen oxides (NO_x): Nitrogen oxides, particularly nitrogen dioxide, are expelled from high temperature combustion, and are also produced during thunderstorms by electric discharge. They can be seen as a brown haze dome above or a plume downwind of cities. Nitrogen dioxide is a chemical compound with the formula NO_2. It is one of several nitrogen oxides. One of the most prominent air pollutants, this

reddish-brown toxic gas has a characteristic sharp, biting odor.

- Odors: Such as from garbage, sewage, and industrial processes.
- Particulate matter/particles (PM), also known as particulates, atmospheric particulate matter (APM), or fine particles, are microscopic solid or liquid particles suspended in a gas.[114] Aerosol is a mixture of particles and gas. Volcanoes, dust storms, forest and grassland fires, living plants, and sea spray are all sources of particles. Aerosols are produced by human activities such as the combustion of fossil fuels in automobiles, power plants, and numerous industrial processes.[115] Averaged worldwide, anthropogenic aerosols – those made by human activities – currently account for approximately 10% of the atmosphere. Increased levels of fine particles in the air are linked to health hazards such as heart disease,[116] altered lung function and lung cancer. Particulates are related to respiratory infections and can be particularly harmful to those with conditions like asthma.[117]
- Persistent organic pollutants, which can attach to particulates. Persistent organic pollutants are organic compounds that are resistant to environmental degradation due to chemical, biological, or photolytic processes (POPs). As a result, they've been discovered to survive in the environment, be capable of long-range transmission, bioaccumulate in human and animal tissue, biomagnify in food chains, and pose a major threat to human health and the ecosystem.[118]
- Persistent free radicals connected to airborne fine particles are linked to cardiopulmonary disease.[119][120]
- Polycyclic Aromatic Hydrocarbons (PAHs): a group of aromatic compounds formed from the incomplete combustion of organic compounds including coal and oil and tobacco.[121]
- Radioactive pollutants: Produced by nuclear explosions, nuclear events, war explosives, and natural processes such as the radioactive decay of radon.
- Sulfur oxides (SO_x): particularly sulfur dioxide, a chemical compound with the formula SO_2. SO_2 is produced by volcanoes and in various industrial processes. Coal and petroleum often contain sulfur compounds, and their combustion generates sulfur dioxide. Further oxidation of SO_2, usually in the presence of a catalyst such as NO_2, forms H_2SO_4, and thus acid rain is formed. This is one of the causes for concern over the environmental impact of the use of these fuels as power sources.
- Toxic metals, such as lead and mercury, especially their compounds.
- Volatile organic compounds (VOC): VOCs are both indoor and outdoor air pollutants.[122] They are categorized as either methane (CH_4) or non-methane (NMVOCs). Methane is an extremely efficient greenhouse gas which contributes to enhanced global warming. Other hydrocarbon VOCs are also significant greenhouse gases because of their role in creating ozone and prolonging the life of methane in the atmosphere. This effect varies depending on local air quality. The aromatic NMVOCs benzene, toluene and xylene are suspected carcinogens and may lead to leukemia with prolonged exposure. 1,3-butadiene is another dangerous compound often associated with industrial use.

Secondary pollutants

[edit]

Secondary pollutants include:

- Ground level ozone (O_3): Ozone is created when NOx and VOCs mix. It is a significant part of the troposphere.[123] It's also an important part of the ozone layer, which can be found in different sections of the stratosphere. Photochemical and chemical reactions involving it fuel many of the chemical activities that occur in the atmosphere during the day and night. It is a pollutant and a component of smog that is produced in large quantities as a result of human activities (mostly the combustion of fossil fuels).[124] O_3 is largely produced by chemical reactions involving NO_x gases (nitrogen oxides, especially from combustion) and volatile organic compounds in the presence of sunlight. Due to the influence of temperature and sunlight on this reaction, high ozone levels are most common on hot summer afternoons.[125]
- Peroxyacetyl nitrate ($C_2H_3NO_5$): similarly formed from NO_x and VOCs.
- Photochemical smog: particles are formed from gaseous primary contaminants and chemicals.[126] Smog is a type of pollution that occurs in the atmosphere. Smog is caused by a huge volume of coal being burned in a certain region, resulting in a mixture of smoke and sulfur dioxide.[127] Modern smog is usually caused by automotive and industrial emissions, which are acted on in the atmosphere by UV light from the sun to produce secondary pollutants, which then combine with the primary emissions to generate photochemical smog.

Other pollutants

[edit]

There are many other chemicals classed as hazardous air pollutants. Some of these are regulated in the USA under the Clean Air Act and in Europe under numerous directives (including the Air "Framework" Directive, 96/62/EC, on ambient air quality assessment and management, Directive 98/24/EC, on risks related to chemical agents at work, and Directive 2004/107/EC covering heavy metals and polycyclic aromatic hydrocarbons in ambient air).[128][129]

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Hazardous air pollutants (4 C, 68 P)

Before flue-gas desulfurization was installed, the emissions from this power plant in New Mex

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Before flue-gas desulfurization was installed, the emissions from this power plant in New Mexico contained excessive amounts of sulfur dioxide.
Thermal oxidisers are air pollution abatement options for hazardous air pollutants (HAPs), vola

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  Thermal oxidisers are air pollution abatement options for hazardous air pollutants (HAPs), volatile organic compounds (VOCs), and odorous emissions.

- This video provides an overview of a NASA study on the human fingerprint on global air quality.

Exposure

[edit]

The risk of air pollution is determined by the pollutant's hazard and the amount of exposure to that pollutant. Air pollution exposure can be measured for a person, a group, such as a neighborhood or a country's children, or an entire population. For example, one would want to determine a geographic area's exposure to a dangerous air pollution, taking into account the various microenvironments and age groups. This can be calculated[130] as an inhalation exposure. This would account for daily exposure in various settings, e.g. different indoor micro-environments and outdoor locations. The exposure needs to include different ages and other demographic groups, especially infants, children, pregnant women, and other sensitive subpopulations.[130]

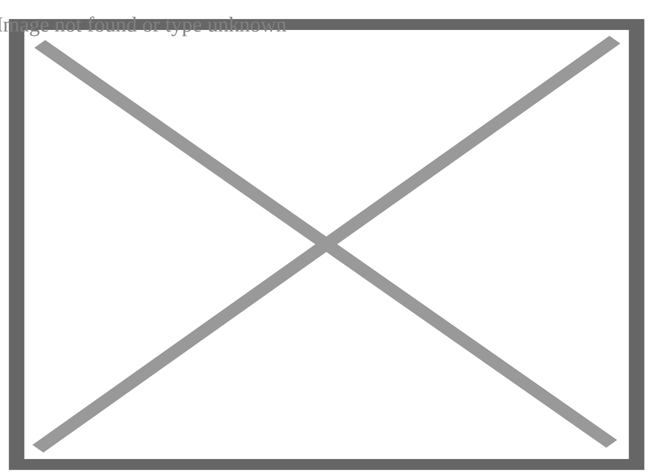
For each specific time that the subgroup is in the setting and engaged in particular activities, the exposure to an air pollutant must integrate the concentrations of the air pollutant with regard to the time spent in each setting and the respective inhalation rates for each subgroup, playing, cooking, reading, working, spending time in traffic, etc. A little child's inhaling rate, for example, will be lower than that of an adult. A young person engaging in strenuous exercise will have a faster rate of breathing than a child engaged in sedentary activity. The daily exposure must therefore include the amount of time spent in each micro-environmental setting as well as the kind of activities performed there. The air pollutant concentration in each microactivity/microenvironmental setting is summed to indicate the exposure.[130]

For some pollutants such as black carbon, traffic related exposures may dominate total exposure despite short exposure times since high concentrations coincide with proximity to major roads or participation in (motorized) traffic.[131] A large portion of total daily exposure occurs as short peaks of high concentrations, but it remains unclear how to define peaks and determine their frequency and health impact.[132]

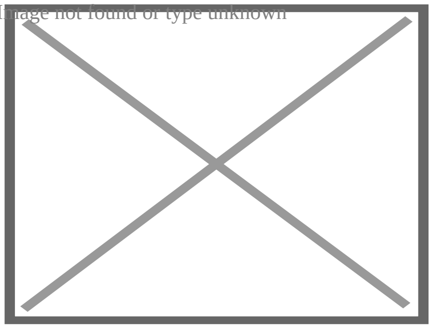
In 2021, the WHO halved its recommended guideline limit for tiny particles from burning fossil fuels. The new limit for nitrogen dioxide (NO_2) is 75% lower.[133] Growing evidence that air pollution—even when experienced at very low levels—hurts human health, led the WHO to revise its guideline (from 10 ?g/m^3 to 5 ?g/m^3) for what it considers a safe level of exposure of particulate pollution, bringing most of the world—97.3 percent of the global population—into the unsafe zone.[134]

Indoor air quality

[edit]
Main articles: Indoor air quality and Indoor air pollution in developing countries



The share of total deaths from indoor air pollution, 2017



Air quality monitoring, New Delhi, India

A lack of ventilation indoors concentrates air pollution where people often spend the majority of their time. Indoor air pollution can pose a significant health risk. According to EPA reports, the concentrations of many air pollutants can be two to five times higher in indoor air than in outdoor air. Indoor air pollutants can be up to 100 times higher in some cases than they are inside. People can spend up to 90% of their time indoors, according to the American Lung Association; the US Consumer Product Safety Commission (CPSC) 2012; and the US Environmental Protection Agency 2012a.[135]

Indoor contaminants that can cause pollution include asbestos, biologic agents, building materials, radon, tobacco smoke, and wood stoves, gas ranges, or other heating systems.[135]

Radon (Rn) gas, a carcinogen, is exuded from the Earth in certain locations and trapped inside houses. Building materials including carpeting and plywood emit formaldehyde (H-CHO) gas. Paint and solvents give off volatile organic compounds (VOCs) as they dry. Lead paint can degenerate into dust and be inhaled.[136][137]

Intentional air pollution is introduced with the use of air fresheners, incense, and other scented items. Controlled wood fires in cook stoves and fireplaces can add significant amounts of harmful smoke particulates into the air, inside and out.[136][137] Indoor pollution fatalities may be caused by using pesticides and other chemical sprays indoors without proper ventilation. Also the kitchen in a modern produce harmful particles and gases, with equipment like toasters being one of the worst sources.[138]

Carbon monoxide poisoning and fatalities are often caused by faulty vents and chimneys, or by the burning of charcoal indoors or in a confined space, such as a tent.[139] Chronic carbon monoxide poisoning can result even from poorly-adjusted pilot lights. Traps are built into all domestic plumbing to keep sewer gas and hydrogen sulfide, out of interiors. Clothing emits tetrachloroethylene, or other dry cleaning fluids, for days after dry cleaning.

Though its use has now been banned in many countries, the extensive use of asbestos in industrial and domestic environments in the past has left a potentially very dangerous material in many localities. Asbestosis is a chronic inflammatory medical condition affecting the tissue of the lungs. It occurs after long-term, heavy exposure to asbestos from asbestos-containing materials in structures. Those with asbestosis have severe dyspnea (shortness of breath) and are at an increased risk regarding several different types of lung cancer. As clear explanations are not always stressed in non-technical literature, care should be taken to distinguish between several forms of relevant diseases. According to the World Health Organization,[140] these may be defined as asbestosis, lung cancer, and peritoneal mesothelioma (generally a very rare form of cancer, when more widespread it is almost always associated with prolonged exposure to asbestos).

Biological sources of air pollution are also found indoors, as gases and airborne particulates. Pets produce dander, people produce dust from minute skin flakes and decomposed hair, dust mites in bedding, carpeting and furniture produce enzymes and micrometre-sized fecal droppings, inhabitants emit methane, mold forms on walls and generates mycotoxins and spores, air conditioning systems can incubate Legionnaires' disease and mold, and houseplants, soil and surrounding gardens can produce pollen, dust, and mold. Indoors, the lack of air circulation allows these airborne pollutants to accumulate more than they would otherwise occur in nature.

Health effects

[edit]

Air pollution has both acute and chronic effects on human health, affecting a number of different systems and organs but principally affect the body's respiratory system and the cardiovascular system. Afflictions include minor to chronic upper respiratory irritation such as difficulty in breathing, wheezing, coughing, asthma[141] and heart disease, lung cancer, stroke, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks.

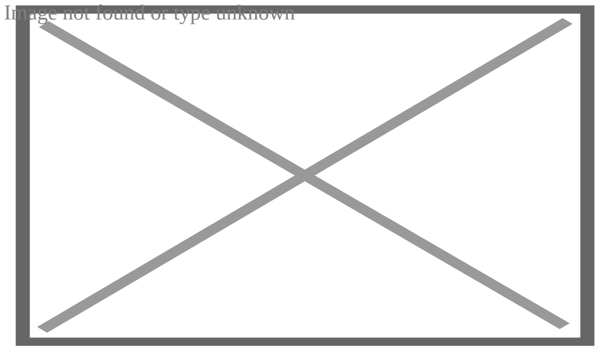
Short and long term exposures have been linked with premature mortality and reduced life expectancy[142] and can result in increased medication use, increased doctor or emergency department visits, more hospital admissions and premature death.[130][*better source ne*
Diseases that develop from persistent exposure to air pollution are environmental health diseases, which develop when a health environment is not maintained.[143]

Even at levels lower than those considered safe by United States regulators, exposure to three components of air pollution, fine particulate matter, nitrogen dioxide and ozone, correlates with cardiac and respiratory illness.[144] Individual reactions to air pollutants depend on the type of pollutant a person is exposed to, the degree of exposure, and the individual's health status and genetics.[130] The most common sources of air pollution include particulates and ozone (often from burning fossil fuels),[145] nitrogen dioxide, and sulfur dioxide. Children aged less than five years who live in developing countries are the most vulnerable population to death attributable to indoor and outdoor air pollution.[146]

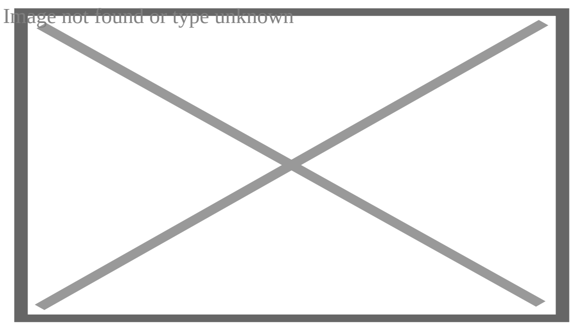
Under the Clean Air Act, U.S. EPA sets limits on certain air pollutants, including setting limits on how much can be in the air anywhere in the United States.[147] Mixed exposure to both carbon black and ozone could result in significantly greater health affects.[148]

Mortality

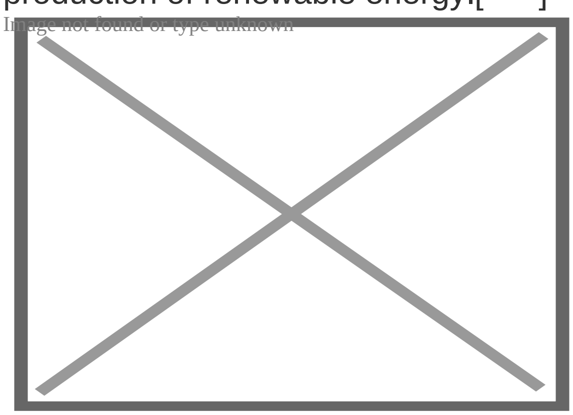
[edit]



Estimates of the death toll from air pollution vary across publications.



Deaths caused by accidents and air pollution from fossil fuel use in power plants exceed those caused by production of renewable energy.[149]



Estimated annual number of deaths attributed to air pollution in 2019. This includes three categories of air pollution: indoor household, outdoor particulate matter and ozone.

Estimates of deaths toll due to air pollution vary.[150] In 2014 the World Health Organization estimated that every year air pollution causes the premature death of 7 million people worldwide,[5] 1 in 8 deaths worldwide.[151] A study published in 2019 indicated that in 2015 the number may be closer to 8.8 million, with 5.5 million of these premature deaths due to air pollution from anthropogenic sources.[152][153] A 2022 review concluded that in 2019 air pollution was responsible for approximately 9 million premature deaths. It concluded that since 2015 little real progress against pollution has been made.[14][154] Causes of deaths include strokes, heart disease, COPD, lung cancer, and lung infections.[5] Children are particularly at risk.[155]

In 2021, the WHO reported that outdoor air pollution was estimated to cause 4.2 million premature deaths worldwide in 2019.[156]

The global mean loss of life expectancy (LLE; similar to YPLL) from air pollution in 2015 was 2.9 years, substantially more than, for example, 0.3 years from all forms of direct violence.[16] Communities with persons that live beyond 85 years have low ambient air pollution, suggesting a link between air pollution levels and longevity.[157]

Primary mechanisms

[edit]

The WHO estimates that in 2016, ~58% of outdoor air pollution-related premature deaths were due to ischaemic heart disease and stroke.[156] The mechanisms linking air pollution to increased cardiovascular mortality are uncertain, but probably include pulmonary and systemic inflammation.[158]

By region

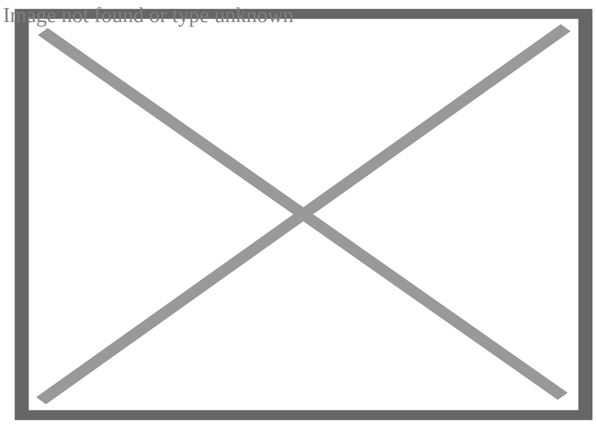
[edit]

India and China have the highest death rate due to air pollution.[159][160] India also has more deaths from asthma than any other nation according to the World Health Organization. In 2019, 1.6 million deaths in India were caused by air pollution.[161] In 2013, air pollution was estimated to kill 500,000 people in China each year.[162] In 2012, 2.48% of China's total air pollution emissions were caused by exports due to US demand, causing an additional 27,963 deaths across 30 provinces.[163]

Annual premature European deaths caused by air pollution are estimated at 430,000[164] to 800,000.[153] An important cause of these deaths is nitrogen dioxide and other nitrogen oxides (NOx) emitted by road vehicles.[164] Across the European Union, air pollution is estimated to reduce life expectancy by almost nine months.[165] In a 2015 consultation document the UK government disclosed that nitrogen dioxide is responsible for 23,500 premature UK deaths per annum.[166] There is a positive correlation between pneumonia-related deaths and air pollution from motor vehicle emissions in England.[167]

Eliminating energy-related fossil fuel emissions in the United States would prevent 46,900–59,400 premature deaths each year and provide $537–$678 billion in benefits from avoided $PM_{2.5}$-related illness and death.[168]

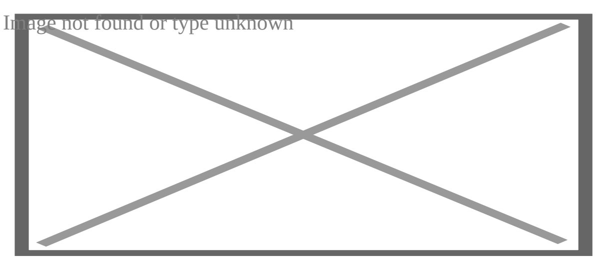
A study published in 2023 in *Science* focused on sulfur dioxide emissions by coal power plants (coal $PM_{2.5}$) and concluded that "exposure to coal $PM_{2.5}$ was associated with 2.1 times greater mortality risk than exposure to $PM_{2.5}$ from all sources."[169] From 1999 to 2020, a total of 460,000 deaths in the US were attributed to coal $PM_{2.5}$.[169]



Air pollution deaths by nation due to fossil fuels

Major causes

[edit]
Further information: § Sources



A comparison of footprint-based and transboundary pollution-based relationships among G20 nations for the number of $PM_{2.5}$-related premature deaths[170]

The largest cause of air pollution is fossil fuel combustion[171] – mostly the production and use of cars, electricity production, and heating.[172] There are estimated 4.5 million annual premature deaths worldwide due to pollutants released by high-emission power stations and vehicle exhausts.[173]

Diesel exhaust (DE) is a major contributor to combustion-derived particulate matter air pollution. In several human experimental studies, using a well-validated exposure chamber setup, DE has been linked to acute vascular dysfunction and increased thrombus formation.[174][175]

A study concluded that $PM_{2.5}$ air pollution induced by the contemporary free trade and consumption by the 19 G20 nations causes two million premature deaths annually, suggesting that the average lifetime consumption of about ~28 people in these countries causes at least one premature death (average age ~67) while developing countries "cannot be expected" to implement or be able to implement countermeasures without external support or internationally coordinated efforts.[176][170]

Guidelines

[edit]
Main article: Air quality guideline

The US EPA has estimated that limiting ground-level ozone concentration to 65 parts per billion (ppb), would avert 1,700 to 5,100 premature deaths nationwide in 2020 compared with the 75 ppb standard. The agency projected the more protective standard would also prevent an additional 26,000 cases of aggravated asthma, and more than a million cases of missed work or school.[177][178] Following this assessment, the EPA acted to protect public health by lowering the National Ambient Air Quality Standards (NAAQS) for ground-level ozone to 70 ppb.[179]

A 2008 economic study of the health impacts and associated costs of air pollution in the Los Angeles Basin and San Joaquin Valley of Southern California shows that more than 3,800 people die prematurely (approximately 14 years earlier than normal) each year because air pollution levels violate federal standards. The number of annual premature deaths is considerably higher than the fatalities related to auto collisions in the same area, which average fewer than 2,000 per year.[180][181][182] A 2021 study found that outdoor air pollution is associated with substantially increased mortality "even at low pollution levels below the current European and North American standards and WHO guideline values" shortly before the WHO adjusted its guidelines.[183][184]

Cardiovascular disease

[edit]

According to the Global Burden of Disease Study, air pollution is responsible for 19% of all cardiovascular deaths.[185][186] There is strong evidence linking both short- and long-term exposure to air pollution with cardiovascular disease mortality and morbidity, stroke, blood pressure, and ischemic heart diseases (IHD).[186]

Air pollution is a leading risk factor for stroke, particularly in developing countries where pollutant levels are highest.[187] A systematic analysis of 17 different risk factors in 188 countries found air pollution is associated with nearly one in three strokes (29%) worldwide

(33.7% of strokes in developing countries versus 10.2% in developed countries).[187][188] In women, air pollution is not associated with hemorrhagic but with ischemic stroke.[189] Air pollution was found to be associated with increased incidence and mortality from coronary stroke.[190] Associations are believed to be causal and effects may be mediated by vasoconstriction, low-grade inflammation and atherosclerosis.[191] Other mechanisms such as autonomic nervous system imbalance have also been suggested.[192][193]

Lung disease

[edit]

Research has demonstrated increased risk of developing asthma[194] and chronic obstructive pulmonary disease (COPD)[195] from increased exposure to traffic-related air pollution. Air pollution has been associated with increased hospitalization and mortality from asthma and COPD.[196][197]

COPD comprises a spectrum of clinical disorders that include emphysema, bronchiectasis, and chronic bronchitis.[198] COPD risk factors are both genetic and environmental. Elevated particle pollution contributes to the exacerbation of this disease and likely its pathogenesis.[199]

The risk of lung disease from air pollution is greatest for infants and young children, whose normal breathing is faster than that of older children and adults; the elderly; those who work outside or spend a lot of time outside; and those who have heart or lung disease comorbidities.[200]

A study conducted in 1960–1961 in the wake of the Great Smog of 1952 compared 293 London residents with 477 residents of Gloucester, Peterborough, and Norwich, three towns with low reported death rates from chronic bronchitis. All subjects were male postal truck drivers aged 40 to 59. Compared to the subjects from the outlying towns, the London subjects exhibited more severe respiratory symptoms (including cough, phlegm, and dyspnea), reduced lung function (FEV_1 and peak flow rate), and increased sputum production and purulence. The differences were more pronounced for subjects aged 50 to 59. The study controlled for age and smoking habits, so concluded that air pollution was the most likely cause of the observed differences.[201] More studies have shown that air pollution exposure from traffic reduces lung function development in children[202] and lung function may be compromised by air pollution even at low concentrations.[203]

It is believed that, much like cystic fibrosis, serious health hazards become more apparent when living in a more urban environment. Studies have shown that in urban areas people experience mucus hypersecretion, lower levels of lung function, and more self-diagnosis of chronic bronchitis and emphysema.[204]

Cancer

[edit]

Dark factory clouds obscure the Clark Avenue Bridge in Cleveland, Ohio, July 1973.

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Dark factory-emitted clouds obscuring the Clark Avenue Bridge in Cleveland, Ohio in July 1973

Around 300,000 lung cancer deaths were attributed globally in 2019 to exposure to fine particulate matter, $PM_{2.5}$, suspended in the air.[205] $PM_{2.5}$ exposure, such as from car exhausts, activates dormant mutations in lung cells, causing them to become cancerous.[206][205] Unprotected exposure to $PM_{2.5}$ air pollution can be equivalent to smoking multiple cigarettes per day,[207][*dead link*] potentially increasing the risk of cancer, which is mainly the result of environmental factors.[208]

Long-term exposure to $PM_{2.5}$ (fine particulates) increases the overall risk of non-accidental mortality by 6% per 10 ?g/m^3 increase. Exposure to $PM_{2.5}$ is also associated with an increased risk of mortality from lung cancer (range: 15–21% per 10 ?g/m^3 increase) and total cardiovascular mortality (range: 12–14% per 10 ?g/m^3 increase).[209]

The review further noted that living close to busy traffic appears to be associated with elevated risks of these three outcomes – increase in lung cancer deaths, cardiovascular deaths, and overall non-accidental deaths. The reviewers also found suggestive evidence that exposure to $PM_{2.5}$ is positively associated with mortality from coronary heart diseases and exposure to SO_2 increases mortality from lung cancer, but the data was insufficient to provide solid conclusions.[209] Another investigation showed that higher activity level increases deposition fraction of aerosol particles in human lung and recommended avoiding heavy activities like running in outdoor space at polluted areas.[210]

In 2011, a large Danish epidemiological study found an increased risk of lung cancer for people who lived in areas with high nitrogen oxide concentrations.[211] Another Danish study, likewise noted evidence of possible associations between air pollution and other forms of cancer, including cervical cancer and brain cancer.[212]

Kidney disease

[edit]

A study of 163,197 Taiwanese residents over the period of 2001–2016 estimated that every 5 ?g/m^3 decrease (from an approximate peak of 30?g/m^3) in the ambient concentration of PM$_{2.5}$ was associated with a 25% reduced risk of chronic kidney disease development.[213] According to a cohort study involving 10,997 atherosclerosis patients, higher PM 2.5 exposure is associated with increased albuminuria.[214]

Fertility

[edit]

Nitrogen dioxide (NO_2)

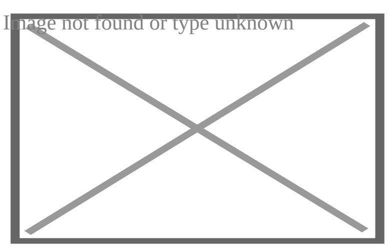
[edit]

An increase in NO_2 is significantly associated with a lower live birth rate in women undergoing IVF treatment.[215] In the general population, there is a significant increase in miscarriage rate in women exposed to NO_2 compared to those not exposed.[215]

Carbon monoxide (CO)

[edit]

CO exposure is significantly associated with stillbirth in the second and third trimester.[215]



Standard line-angle structure of benzo-a-pyrene (BaP)

Polycyclic aromatic hydrocarbons

[edit]

Polycyclic aromatic hydrocarbons (PAHs) have been associated with reduced fertility. Benzo(a)pyrene (BaP) is a well-known PAH and carcinogen which is often found in exhaust fumes and cigarette smoke.[216] PAHs have been reported to administer their toxic effects through oxidative stress by increasing the production of Reactive Oxygen Species (ROS) which can result in inflammation and cell death. More long-term exposure to PAHs can result in DNA damage and reduced repair.[217]

Exposure to BaP has been reported to reduce sperm motility and increasing the exposure worsens this effect. Research has demonstrated that more BaPs were found in men with reported fertility issues compared to men without.[218]

Studies have shown that BaPs can affect folliculogenesis and ovarian development by reducing the number of ovarian germ cells via triggering cell death pathways and inducing inflammation which can lead to ovarian damage.[219]

Particulate matter

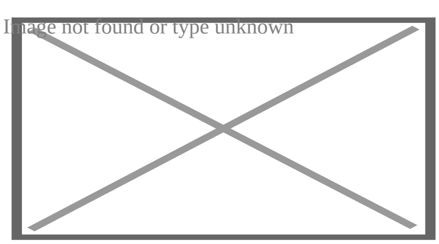
[edit]

Particulate matter (PM) refers to the collection of solids and liquids suspended in the air. These can be harmful to humans, and more research has shown that these effects may be more extensive than first thought; particularly on male fertility. PM can be different sizes, such as $PM_{2.5}$ which are tiny particles of 2.5 microns in width or smaller, compared with PM_{10} which are classified as 10 microns in diameter or less.

A study in California found that increased exposure to $PM_{2.5}$ led to decreased sperm motility and increased abnormal morphology. Similarly, in Poland exposure to $PM_{2.5}$ and PM_{10} led to an increase in the percentage of cells with immature chromatin (DNA that has not fully developed or has developed abnormally).[220]

In Turkey, a study examined the fertility of men who work as toll collectors and are therefore exposed to high levels of traffic pollutants daily. Traffic pollution often has high levels of PM_{10} alongside carbon monoxide and nitrogen oxides.[220] There were significant differences in sperm count and motility in this study group compared to a control group with limited air pollution exposure.

In women, while overall effects on fertility do not appear significant there is an association between increased exposure to PM_{10} and early miscarriage. Exposure to smaller particulate matter, $PM_{2.5}$, appears to have an effect on conception rates in women undergoing IVF but does not affect live birth rates.[215]



Ozone structure showing three oxygen atoms

Ground-level ozone pollution

[edit]

Ground-level ozone (O_3), when in high concentrations, is regarded as an air pollutant and is often found in smog in industrial areas.

There is limited research about the effect that ozone pollution has on fertility.[215] At present, there is no evidence to suggest that ozone exposure poses a deleterious effect on spontaneous fertility in either females or males. However, there have been studies which suggest that high levels of ozone pollution, often a problem in the summer months, exert an effect on in vitro fertilisation (IVF) outcomes. Within an IVF population, NO_x and ozone pollutants were linked with reduced rates of live birth.[215]

While most research on this topic is focused on the direct human exposure of air pollution, other studies have analysed the impact of air pollution on gametes and embryos within IVF laboratories. Multiple studies have reported a marked improvement in embryo quality, implantation and pregnancy rates after IVF laboratories have implemented air filters in a concerted effort to reduce levels of air pollution.[221] Therefore, ozone pollution is considered to have a negative impact on the success of assisted reproductive technologies (ART) when occurring at high levels.

Ozone is thought to act in a biphasic manner where a positive effect on live birth is observed when ozone exposure is limited to before IVF embryo implantation. Conversely, a negative effect is demonstrated upon exposure to ozone after embryo implantation. However, after adjusting for NO2, the association between O3 and IVF live birth rate was no longer significant.[222][223]

In terms of male fertility, ozone is reported to cause a significant decrease in the concentration and count of sperm in semen after exposure.[224] Similarly, sperm vitality, the proportion of live spermatozoa in a sample, was demonstrated to be diminished as a result of exposure to air pollution.[223] However, findings on the effect of ozone exposure on male fertility are somewhat discordant, highlighting the need for further research.[223]

Children

[edit]

Children and infants are among the most vulnerable to air pollution. Polluted air leads to the poisoning of millions of children under the age of 15, resulting in the death of some 600,000 children annually (543,000 under 5 years of age and 52,000 aged 5-15 years).[225] Children in low or middle income countries are exposed to higher levels of fine particulate matter than those in high income countries.[225]

Health effects of air pollution on children include asthma, pneumonia and lower respiratory tract infections and low birth weight.[226] A study in Europe found that exposure to ultrafine particles can increase blood pressure in children.[227]

Prenatal exposure

[edit]

Prenatal exposure to polluted air has been linked to a variety of neurodevelopmental disorders in children. For example, exposure to polycyclic aromatic hydrocarbons (PAH) was associated with reduced IQ scores and symptoms of anxiety and depression.[228] They can also lead to detrimental perinatal health outcomes that are often fatal in developing countries.[8] A 2014 study found that PAHs might play a role in the development of childhood attention deficit hyperactivity disorder (ADHD).[229]

Researchers have found a correlation between air pollution and risk of autism spectrum disorder (ASD) diagnosis, although definitive causality has not yet been established. In Los Angeles, children living in areas with high levels of traffic-related air pollution were more likely to be diagnosed with autism between three–five years of age.[230] A cohort study in Southern California linked in-utero exposure to near-roadway air pollution to an increased risk of ASD diagnosis[231] and a study in Sweden concluded that exposure to $PM_{2.5}$ during pregnancy was associated with ASD.[232] A Danish study linked exposure to air pollution during infancy, but not during pregnancy, to an increased risk of ASD diagnosis.[233]

The connection between air pollution and neurodevelopmental disorders in children is thought to be related to epigenetic dysregulation of the primordial germ cells, embryo, and fetus during a critical period. Some PAHs are considered endocrine disruptors and are lipid soluble. When they build up in adipose tissue they can be transferred across the placenta can exert a genotoxic effect, cauding DNA damange and mutations.[234] Air pollution has been associated with the prevalence of preterm births.[235]

Infants

[edit]

Ambient levels of air pollution have been associated with preterm birth and low birth weight. A 2014 WHO worldwide survey on maternal and perinatal health found a statistically significant association between low birth weights (LBW) and increased levels of exposure to $PM_{2.5}$. Women in regions with greater than average $PM_{2.5}$ levels had statistically significant higher odds of pregnancy resulting in a low-birth weight infant even when adjusted for country-related variables.[236] The effect is thought to be from stimulating inflammation and increasing oxidative stress.

A study found that in 2010 exposure to $PM_{2.5}$ was strongly associated with 18% of preterm births globally, which was approximately 2.7 million premature births. The countries with the highest air pollution associated preterm births were in South and East Asia, the Middle East, North Africa, and West sub-Saharan Africa.[237] In 2019, ambient particulate matter pollution in Africa resulted in at least 383,000 early deaths, according to new estimates of the cost of air pollution in the continent. This increased from 3.6% in 1990 to around 7.4% of all premature deaths in the area.[238][239][240]

The source of $PM_{2.5}$ differs greatly by region. In South and East Asia, pregnant women are frequently exposed to indoor air pollution because of wood and other biomass fuels being used for cooking, which are responsible for more than 80% of regional pollution. In the Middle East, North Africa and West sub-Saharan Africa, fine PM comes from natural sources, such as dust storms.[237] The United States had an estimated 50,000 preterm births associated with exposure to $PM_{2.5}$ in 2010.[237]

A study between 1988 and 1991 found a correlation between sulfur dioxide (SO_2) and total suspended particulates (TSP) and preterm births and low birth weights in Beijing. A group of 74,671 pregnant women, in four separate regions of Beijing, were monitored from early pregnancy to delivery along with daily air pollution levels of SO_2 and TSP (along with other particulates). The estimated reduction in birth weight was 7.3 g for every 100 ?g/m^3 increase in SO_2 and 6.9 g for each 100 ?g/m^3 increase in TSP. These associations were statistically significant in both summer and winter, although summer was greater. The proportion of low birth weight attributable to air pollution, was 13%. This is the largest attributable risk ever reported for the known risk factors of low birth weight.[241] Coal stoves, which are in 97% of homes, are a major source of air pollution in this area.

Brauer et al. studied the relationship between air pollution and proximity to a highway with pregnancy outcomes in a Vancouver cohort of pregnant women using addresses to estimate exposure during pregnancy. Exposure to NO, NO_2, CO, PM_{10} and $PM_{2.5}$ were associated with infants born small for gestational age (SGA). Women living less than 50 meters away from an expressway or highway were 26% more likely to give birth to a SGA infant.[242]

Central nervous system

[edit]
See also: Brain health and pollution and neuroplastic effects of pollution

Data is accumulating that air pollution exposure also affects the central nervous system.[243]

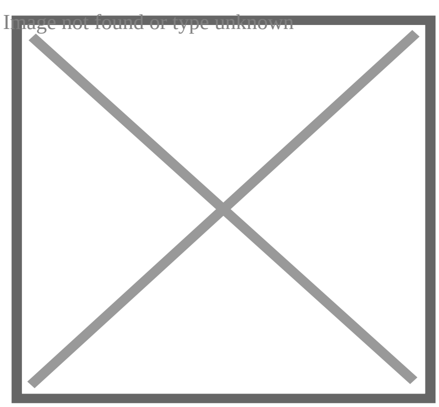
Air pollution increases the risk of dementia in people over 50 years old.[244] Indoor air pollution exposure during childhood may negatively affect cognitive function and neurodevelopment.[245][246] Prenatal exposure may also affect neurodevelopment.[247][248] Studies show that air pollution is associated with a variety of developmental disabilities, oxidative stress, and neuro-inflammation and that it may contribute to Alzheimer's disease and Parkinson's disease.[246]

Researchers found that early exposure to air pollution causes the same changes in the brain as autism and schizophrenia in mice. It also showed that air pollution also affected short-term memory, learning ability, and impulsivity. In this study, air pollution had a larger negative impact on male mice than on females.[249][250] Lead researcher on the study, Deborah Cory-Slechta, said that:[251]

> When we looked closely at the ventricles, we could see that the white matter that normally surrounds them hadn't fully developed. It appears that inflammation had damaged those brain cells and prevented that region of the brain from developing, and the ventricles simply expanded to fill the space. Our findings add to the growing body of evidence that air pollution may play a role in autism, as well as in other neurodevelopmental disorders.

Exposure to fine particulate matter can increase levels of cytokines - neurotransmitters produced in response to infection and inflammation that are also associated with depression and suicide. Pollution has been associated with inflammation of the brain, which may disrupt mood regulation. Heightened $PM_{2.5}$ levels are linked to more self-reported depressive symptoms, and increases in daily suicide rates.[252][253]

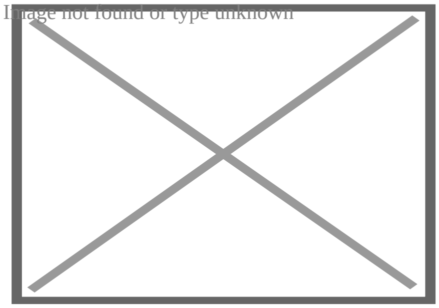
In 2015, experimental studies reported the detection of significant episodic (situational) cognitive impairment from impurities in indoor air breathed by test subjects who were not informed about changes in the air quality. Significant deficits were observed in the performance scores achieved in increasing concentrations of either volatile organic compounds (VOCs) or carbon dioxide, while keeping other factors constant. The highest impurity levels reached are not uncommon in some classroom or office environments.[254][255] Higher $PM_{2.5}$ and CO_2 concentrations were shown to be associated with slower response times and reduced accuracy in tests.[256]



PM2.5 Levels Across the World's 5 Most Populated Nations in 2019

"Clean" areas

[edit]



Share of the population exposed to air pollution levels above WHO guidelines, 2017

Even in areas with relatively low levels of air pollution, public health effects can be significant and costly, since a large number of people breathe in such pollutants. A study found that even in areas of the U.S. where ozone and $PM_{2.5}$ meet federal standards, Medicare recipients who are exposed to more air pollution have higher mortality rates.[257]

Rural populations in India, like those in urban areas, are also exposed to high levels of air pollution.[258] In 2020, scientists found that the boundary layer air over the Southern Ocean around Antarctica is 'unpolluted' by humans.[259]

Agricultural effects

[edit]

Various studies have estimated the impacts of air pollution on agriculture, especially ozone. A 2020 study showed that ozone pollution in California may reduce yields of certain perennial crops such as table grapes by as much as 22% per year, translating into economic damages of more than $1 billion per year.[260] After air pollutants enter the agricultural environment, they not only directly affect agricultural production and quality, but also enter agricultural waters and soil.[261] The COVID-19 induced lockdown served as a natural experiment to expose the close links between air quality and surface greenness. In India, the lockdown induced improvement in air quality, enhanced surface greenness and photosynthetic activity, with the positive response of vegetation to reduce air pollution was dominant in croplands.[262] On the other hand, agriculture in its traditional form is one of the primary contributors to the emission of trace gases like atmospheric ammonia.[263]

Economic effects

[edit]

Air pollution costs the world economy $5 trillion per year as a result of productivity losses and degraded quality of life.[24][25][26] These productivity losses are caused by deaths due to diseases caused by air pollution. One out of ten deaths in 2013 was caused by diseases associated with air pollution and the problem is getting worse.

A small improvement in air quality (1% reduction of ambient $PM_{2.5}$ and ozone concentrations) would produce $29 million in annual savings in the lower Fraser Valley region in 2010.[264] This finding is based on health valuation of lethal (death) and sub-lethal (illness) affects.

The problem is even more acute in the developing world. "Children under age 5 in lower-income countries are more than 60 times as likely to die from exposure to air pollution as children in high-income countries."[24][25] The report states that additional economic losses caused by air pollution, including health costs[265] and the adverse effect on agricultural and other productivity were not calculated in the report, and thus the actual costs to the world economy are far higher than $5 trillion.

A study published in 2022 found "a strong and significant connection between air pollution and construction site accidents" and that "a 10-ppb increase in NO_2 levels increases the likelihood of an accident by as much as 25%".[266]

Other effects

[edit]

Artificial air pollution may be detectable on Earth from distant vantage points such as other planetary systems via atmospheric SETI – including NO_2 pollution levels and with telescopic technology close to today. It may also be possible to detect extraterrestrial civilizations this way.[267][268][269]

Historical disasters

[edit]

The world's worst short-term civilian pollution crisis was the 1984 Bhopal Disaster in India.[270] Leaked industrial vapours from the Union Carbide factory, belonging to Union Carbide, Inc., U.S.A. (later bought by Dow Chemical Company), killed at least 3787 people and injured from 150,000 to 600,000. The United Kingdom suffered its worst air pollution event when the 4 December Great Smog of 1952 formed over London. In six days more than 4,000 died and more recent estimates put the figure at nearer 12,000.[271]

An accidental leak of anthrax spores from a biological warfare laboratory in the former USSR in 1979 near Yekaterinburg (formerly Sverdlovsk) is believed to have caused at least 64 deaths.[272] The worst single incident of air pollution to occur in the US occurred in Donora, Pennsylvania, in late October 1948, when 20 people died and over 7,000 were injured.[273]

Reduction and regulation

[edit]

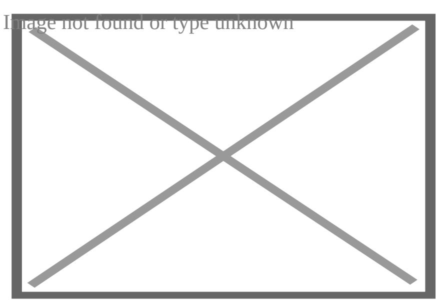
Global depletion of the surrounding air pollution will require valiant leadership, a surplus of combined resources from the international community, and extensive societal changes.[274] Pollution prevention seeks to prevent pollution such as air pollution and could include adjustments to industrial and business activities such as designing sustainable manufacturing processes (and the products' designs)[275] and related legal regulations as well as efforts towards renewable energy transitions.[276][277]

Efforts to reduce particulate matter in the air may result in better health.[278]

The 9-Euro-Ticket scheme in Germany which allowed people to buy a monthly pass allowing use on all local and regional transport (trains, trams and busses) for 9 euro (€) for one month of unlimited travel saved 1.8 million tons of CO_2 emissions during its three-month implementation from June to August 2022.[279]

Pollution control

[edit]



Burning of items polluting Jamestown environment in Accra, Ghana

Various pollution control technologies and strategies are available to reduce air pollution.[280][281] At its most basic level, land-use planning is likely to involve zoning and transport infrastructure planning. In most developed countries, land-use planning is an important part of social policy, ensuring that land is used efficiently for the benefit of the wider economy and population, as well as to protect the environment.[282] Stringent environmental regulations, effective control technologies and shift towards the renewable source of energy also helping countries like China and India to reduce their sulfur dioxide pollution.[283]

Titanium dioxide has been researched for its ability to reduce air pollution. Ultraviolet light will release free electrons from material, thereby creating free radicals, which break up VOCs and

NO*x* gases. One form is superhydrophilic.[284]

Pollution-eating nanoparticles placed near a busy road were shown to absorb toxic emission from around 20 cars each day.[285]

Energy transition

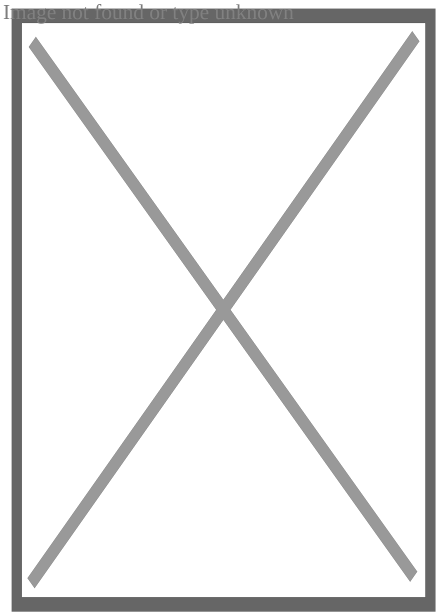
[edit]

Since a large share of air pollution is caused by combustion of fossil fuels such as coal and oil, the reduction of these fuels can reduce air pollution drastically. Most effective is the switch to clean power sources such as wind power, solar power, hydro power which do not cause air pollution.[286] Efforts to reduce pollution from mobile sources includes expanding regulation to new sources (such as cruise and transport ships, farm equipment, and small gas-powered equipment such as string trimmers, chainsaws, and snowmobiles), increased fuel efficiency (such as through the use of hybrid vehicles), conversion to cleaner fuels, and conversion to electric vehicles. For example, buses in New Delhi, India, have run on compressed natural gas since 2000, to help eliminate the city's "pea-soup" smog.[226][287]

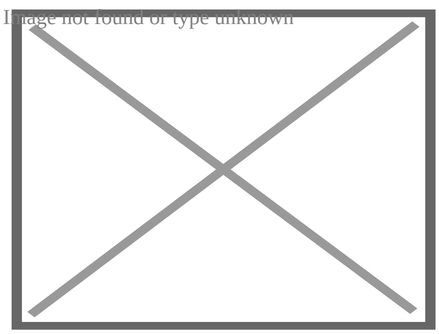
A very effective means to reduce air pollution is the transition to renewable energy. According to a study published in Energy and Environmental Science in 2015 the switch to 100% renewable energy in the United States would eliminate about 62,000 premature mortalities per year and about 42,000 in 2050, if no biomass were used. This would save about $600 billion in health costs a year due to reduced air pollution in 2050, or about 3.6% of the 2014 U.S. gross domestic product.[286] Air quality improvement is a near-term benefit among the many societal benefits from climate change mitigation.

Alternatives to pollution

[edit]



Support for a ban on high-emission vehicles in city centres in Europe, China and the US from respondents to the European Investment Bank Climate Survey



Support, use and infrastructure-expansion of forms of public transport that do not cause air pollution may be a critical key alternative to pollution.

There are now practical alternatives to the principal causes of air pollution:

- Strategic substitution of air pollution sources in transport with lower-emission or, during the lifecycle, emission-free forms of public transport[288][289] and bicycle use and infrastructure (as well as with remote work, reductions of work, relocations, and localizations)
  - Phase-out of fossil fuel vehicles is a critical component of a shift to sustainable transport; however, similar infrastructure and design decisions like electric vehicles may be associated with similar pollution for production as well as mining and resource exploitation for large numbers of needed batteries as well as the energy for their recharging[290][291]
- Areas downwind (over 20 miles) of major airports have more than double *total particulate emissions in air* than other areas, even when factoring in areas with frequent ship calls, and heavy freeway and city traffic like Los Angeles.[292] Aviation biofuel mixed in with jetfuel at a 50/50 ratio can reduce jet derived cruise altitude particulate emissions by 50–70%, according to a NASA led 2017 study (however, this

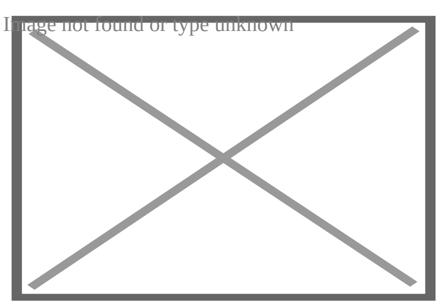
should imply ground level benefits to urban air pollution as well).[293]

- Ship propulsion and idling can be switched to much cleaner fuels like natural gas. (Ideally a renewable source but not practical yet)
- Combustion of fossil fuels for space heating can be replaced by using ground source heat pumps and seasonal thermal energy storage.[294]
- Electricity generated from the combustion of fossil fuels can be replaced by nuclear and renewable energy. Heating and home stoves, which contribute significantly to regional air pollution, can be replaced with a much cleaner fossil fuel, such as natural gas, or, preferably, renewables, in poor countries.[295][296]
- Motor vehicles driven by fossil fuels, a key factor in urban air pollution, can be replaced by electric vehicles. Though lithium supply and cost is a limitation, there are alternatives. Herding more people into clean public transit such as electric trains can also help. Nevertheless, even in emission-free electric vehicles, rubber tires produce significant amounts of air pollution themselves, ranking as 13th worst pollutant in Los Angeles.[297]
- Reducing travel in vehicles can curb pollution. After Stockholm reduced vehicle traffic in the central city with a congestion tax, nitrogen dioxide and PM_{10} pollution declined, as did acute pediatric asthma attacks.[298]
- Biodigesters can be utilized in poor nations where slash and burn is prevalent, turning a useless commodity into a source of income. The plants can be gathered and sold to a central authority that will break them down in a large modern biodigester, producing much needed energy to use.[299]
- Induced humidity and ventilation both can greatly dampen air pollution in enclosed spaces, which was found to be relatively high inside subway lines due to braking and friction and relatively less ironically inside transit buses than lower sitting passenger automobiles or subways.[300]

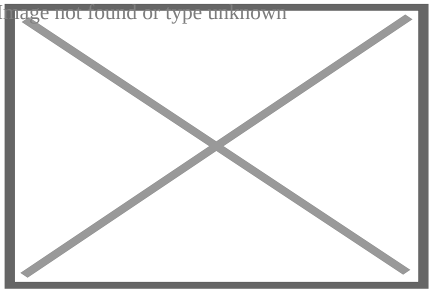
Further information: § Sources

Control devices

[edit]



Tarps and netting are often used to reduce the amount of dust released from construction sites.



Air pollution from a car

The following items are commonly used as pollution control devices in industry and transportation. They can either destroy contaminants or remove them from an exhaust stream before it is emitted into the atmosphere.

- **Particulate control**
  - Mechanical collectors (dust cyclones, multicyclones)
  - Electrostatic precipitators: An electrostatic precipitator (ESP), or electrostatic air cleaner, is a particulate collection device that removes particles from a flowing gas (such as air), using the force of an induced electrostatic charge. Electrostatic precipitators are highly efficient filtration devices that minimally impede the flow of gases through the device, and can easily remove fine particulates such as dust and smoke from the air stream.
  - Baghouses: Designed to handle heavy dust loads, a dust collector consists of a blower, dust filter, a filter-cleaning system, and a dust receptacle or dust removal system (distinguished from air cleaners which utilize disposable filters to remove the dust).
  - Particulate scrubbers: A wet scrubber is a form of pollution control technology. The term describes a variety of devices that use pollutants from a furnace flue gas or from other gas streams. In a wet scrubber, the polluted gas stream is brought into contact with the scrubbing liquid, by spraying it with the liquid, by forcing it through a pool of liquid, or by some other contact method, so as to remove the pollutants.
- **Scrubbers**
  - Baffle spray scrubber
  - Cyclonic spray scrubber
  - Ejector venturi scrubber
  - Mechanically aided scrubber
  - Spray tower
  - Wet scrubber
- **NO*x* control**
  - LO-NOx burners
  - Selective catalytic reduction (SCR)
  - Selective non-catalytic reduction (SNCR)
  - NOx scrubbers
  - Exhaust gas recirculation
  - Catalytic converter (also for VOC control)
- **VOC abatement**

        - Adsorption systems, using activated carbon, such as Fluidized Bed Concentrator
        - Flares
        - Thermal oxidizers
        - Catalytic converters
        - Biofilters
        - Absorption (scrubbing)
        - Cryogenic condensers
        - Vapor recovery systems
    - **Acid gas/SO_2 control**
        - Wet scrubbers
        - Dry scrubbers
        - Flue-gas desulfurization
    - **Mercury control**
        - Sorbent injection technology
        - Electro-catalytic oxidation (ECO)
        - K-Fuel
    - **Dioxin and furan control**
    - **Miscellaneous associated equipment**
        - Source capturing systems
        - Continuous emissions monitoring systems (CEMS)

Monitoring

[edit]
See also: Smart city
Further information: Air pollution measurement and Environmental monitoring

Spatiotemporal monitoring of air quality may be necessary for improving air quality, and thereby the health and safety of the public, and assessing impacts of interventions.[301] Such monitoring is done to different extents with different regulatory requirements with discrepant regional coverage by a variety of organizations and governance entities such as using a variety of technologies for use of the data and sensing such mobile IoT sensors,[302][303] satellites,[304][305][306] and monitoring stations.[307][308] Some websites attempt to map air pollution levels using available data.[309][310][311]

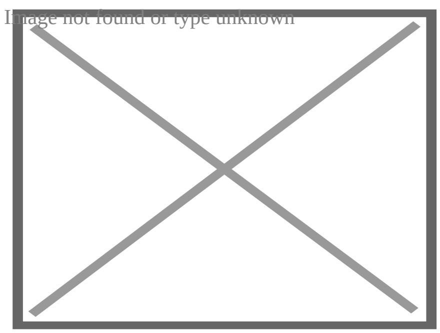
Air quality modeling

[edit]
Main article: Air quality modeling

Numerical models either on a global scale using tools such as GCMs (general circulation models coupled with a pollution module) or CTMs (Chemical transport model) can be used to simulate the levels of different pollutants in the atmosphere. These tools can have several types (Atmospheric model) and different uses. These models can be used in forecast mode which can help policy makers to decide on appropriate actions when an air pollution episode is detected. They can also be used for climate modeling including evolution of air quality in the future, for example the IPCC (Intergovernmental Panel on Climate Change) provides climate simulations including air quality assessments in their reports (latest report accessible through their site).

Regulations

[edit]
Main article: Air quality law



Smog in Cairo

In general, there are two types of air quality standards. The first class of standards (such as the U.S. National Ambient Air Quality Standards and E.U. Air Quality Directive[312]) set maximum atmospheric concentrations for specific pollutants. Environmental agencies enact regulations which are intended to result in attainment of these target levels. The second class (such as the North American air quality index) take the form of a scale with various thresholds, which is used to communicate to the public the relative risk of outdoor activity. The scale may or may not distinguish between different pollutants.

Canada

[edit]

In Canada, air pollution and associated health risks are measured with the Air Quality Health Index (AQHI).[313] It is a health protection tool used to make decisions to reduce short-term exposure to air pollution by adjusting activity levels during increased levels of air pollution.

The AQHI is a federal program jointly coordinated by Health Canada and Environment Canada. However, the AQHI program would not be possible without the commitment and support of the provinces, municipalities and NGOs. From air quality monitoring to health risk communication and community engagement, local partners are responsible for the vast majority of work related to AQHI implementation. The AQHI provides a number from 1 to 10+ to indicate the level of health risk associated with local air quality. Occasionally, when the amount of air pollution is abnormally high, the number may exceed 10. The AQHI provides a local air quality current value as well as a local air quality maximums forecast for today, tonight and tomorrow and provides associated health advice.

1	2	3	4	5	6	7	8	9	10	+

Risk: Low **(1–3)** Moderate **(4–6)** High **(7–10)** Very high **(above 10)**

As it is now known that even low levels of air pollution can trigger discomfort for the sensitive population, the index has been developed as a continuum: The higher the number, the greater the health risk and need to take precautions. The index describes the level of health risk associated with this number as 'low', 'moderate', 'high' or 'very high', and suggests steps that can be taken to reduce exposure.[314]

Health risk	Air Quality Health Index	Health messages[315]	
		At risk population	**General population**
Low	**1–3**	**Enjoy** your usual outdoor activities.	**Ideal** air quality for outdoor activities
Moderate	**4–6**	**Consider reducing** or rescheduling strenuous activities outdoors if you are experiencing symptoms.	**No need to modify** your usual outdoor activities unless you experience symptoms such as coughing and throat irritation.
High	**7–10**	**Reduce** or reschedule strenuous activities outdoors. Children and the elderly should also take it easy.	**Consider reducing** or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation.
Very high	**Above 10**	**Avoid** strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion and should stay indoors.	**Reduce** or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation.

The measurement is based on the observed relationship of nitrogen dioxide (NO_2), ground-level ozone (O_3) and particulates ($PM_{2.5}$) with mortality, from an analysis of several Canadian cities. Significantly, all three of these pollutants can pose health risks, even at low levels of exposure, especially among those with pre-existing health problems.

When developing the AQHI, Health Canada's original analysis of health effects included five major air pollutants: particulates, ozone, and nitrogen dioxide (NO_2), as well as sulfur dioxide (SO_2), and carbon monoxide (CO). The latter two pollutants provided little information in predicting health effects and were removed from the AQHI formulation.

The AQHI does not measure the effects of odour, pollen, dust, heat or humidity.

Germany

[edit]

TA Luft is the German air quality regulation.[316]

Governing urban air pollution

[edit]
Further information: Phase-out of fossil fuel vehicles § Cities and territories

In Europe, Council Directive 96/62/EC on ambient air quality assessment and management provides a common strategy against which member states can "set objectives for ambient air quality in order to avoid, prevent or reduce harmful effects on human health and the environment ... and improve air quality where it is unsatisfactory".[317]

In July 2008, in the case *Dieter Janecek v. Freistaat Bayern*, the European Court of Justice ruled that under this directive[317] citizens have the right to require national authorities to implement a short term action plan that aims to maintain or achieve compliance to air quality limit values.[318][319]

This important case law appears to confirm the role of the EC as centralised regulator to European nation-states as regards air pollution control. It places a supranational legal obligation on the UK to protect its citizens from dangerous levels of air pollution, furthermore superseding national interests with those of the citizen.

In 2010, the European Commission (EC) threatened the UK with legal action against the successive breaching of PM_{10} limit values.[320] The UK government has identified that if fines are imposed, they could cost the nation upwards of £300 million per year.[321]

In March 2011, the Greater London Built-up Area remained the only UK region in breach of the EC's limit values, and was given three months to implement an emergency action plan aimed at meeting the EU Air Quality Directive.[322] The City of London has dangerous levels of PM_{10} concentrations, estimated to cause 3000 deaths per year within the city.[323] As well as the threat of EU fines, in 2010 it was threatened with legal action for scrapping the western congestion charge zone, which is claimed to have led to an increase in air pollution levels.[324]

In response to these charges, mayor of London Boris Johnson has criticised the current need for European cities to communicate with Europe through their nation state's central government, arguing that in future "A great city like London" should be permitted to bypass its government and deal directly with the European Commission regarding its air quality action plan.[322]

This can be interpreted as recognition that cities can transcend the traditional national government organisational hierarchy and develop solutions to air pollution using global governance networks, for example through transnational relations. Transnational relations include but are not exclusive to national governments and intergovernmental organisations, [325] allowing sub-national actors including cities and regions to partake in air pollution control as independent actors.

Global city partnerships can be built into networks, for example the C40 Cities Climate Leadership Group, of which London is a member. The C40 is a public 'non-state' network of the world's leading cities that aims to curb their greenhouse emissions.[326] The C40 has been identified as 'governance from the middle' and is an alternative to intergovernmental policy.[327] It has the potential to improve urban air quality as participating cities "exchange information, learn from best practices and consequently mitigate carbon dioxide emissions independently from national government decisions".[326] A criticism of the C40 network is that its exclusive nature limits influence to participating cities and risks drawing resources away from less powerful city and regional actors.

Indigenous people

[edit]

Because Indigenous people[328] frequently experience a disproportionate share of the effects of environmental degradation and climate change, even while they have made very little contribution to the processes causing these changes, environmental justice is especially important to them. Indigenous peoples have been marginalized and their lands and resources have been exploited as a result of historical and continuing colonization, institutional injustices, and inequality.

Indigenous groups frequently lack the political and financial clout to influence policy decisions that impact their lands and means of subsistence or to lessen the effects of climate change. This makes the already-existing inequalities in these communities' social, economic, and health conditions worse. Furthermore, traditional ecological knowledge and Indigenous knowledge systems provide insightful information about sustainable resource management and climate change adaptation techniques. To promote persistence and environmental justice, Indigenous viewpoints must be acknowledged and integrated into efforts to mitigate the effects of climate change and adapt to them.

Combating climate change necessitates an all-encompassing strategy that recognizes the interdependence of social, economic, and environmental elements. This entails defending treaty rights, advancing Indigenous sovereignty and self-determination, and aiding Indigenous-led projects for sustainable development and environmental preservation.

Hotspots

[edit]
Main article: Toxic hotspot

See also: Cancer alley and Superfund

Air pollution hotspots are areas where air pollution emissions expose individuals to increased negative health effects.[329] They are particularly common in highly populated, urban areas, where there may be a combination of stationary sources (e.g. industrial facilities) and mobile sources (e.g. cars and trucks) of pollution. Emissions from these sources can cause respiratory disease, childhood asthma,[141] cancer, and other health problems. Fine particulate matter such as diesel soot, which contributes to more than 3.2 million premature deaths around the world each year, is a significant problem. It is very small and can lodge itself within the lungs and enter the bloodstream. Diesel soot is concentrated in densely populated areas, and one in six people in the U.S. live near a diesel pollution hot spot.[330]

External videos

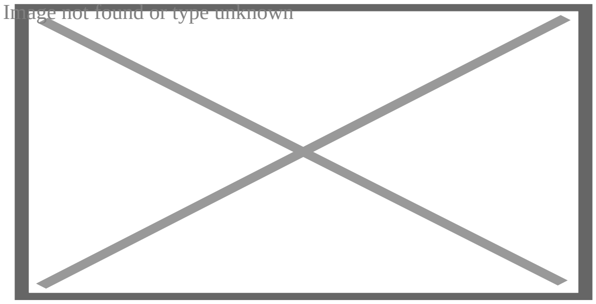
Image not found or type unknown
video icon *Air Visual Earth* – realtime map of global wind and air pollution[331]

While air pollution hotspots affect a variety of populations, some groups are more likely to be located in hotspots. Previous studies have shown disparities in exposure to pollution by race and/or income. Hazardous land uses (toxic storage and disposal facilities, manufacturing facilities, major roadways) tend to be located where property values and income levels are low. Low socioeconomic status can be a proxy for other kinds of social vulnerability, including race, a lack of ability to influence regulation and a lack of ability to move to neighborhoods with less environmental pollution. These communities bear a disproportionate burden of environmental pollution and are more likely to face health risks such as cancer or asthma.[332]

Studies show that patterns in race and income disparities not only indicate a higher exposure to pollution but also higher risk of adverse health outcomes.[333] Communities characterized by low socioeconomic status and racial minorities can be more vulnerable to cumulative adverse health impacts resulting from elevated exposure to pollutants than more privileged communities.[333] Blacks and Latinos generally face more pollution than Whites and Asians, and low-income communities bear a higher burden of risk than affluent ones.[332] Racial discrepancies are particularly distinct in suburban areas of the Southern United States and metropolitan areas of the Midwestern and Western United States.[334] Residents in public housing, who are generally low-income and cannot move to healthier neighborhoods, are highly affected by nearby refineries and chemical plants.[335]

Cities

[edit]
See also: List of most polluted cities in the world by particulate matter concentration
Further information: List of least polluted cities by particulate matter concentration



Nitrogen dioxide concentrations as measured from satellite 2002–2004

Air pollution is usually concentrated in densely populated metropolitan areas, especially in developing countries where cities are experiencing rapid growth and environmental regulations are relatively lax or nonexistent. Urbanization leads to a rapid rise in premature mortality due to anthropogenic air pollution in fast-growing tropical cities.[336] However, even populated areas in developed countries attain unhealthy levels of pollution, with Los Angeles and Rome being two examples.[337] Between 2002 and 2011 the incidence of lung cancer in Beijing near doubled. While smoking remains the leading cause of lung cancer in China, the number of smokers is falling while lung cancer rates are rising .[338]

[339]

World's Most Polluted Cities 2020	2020 Average	2019 Average
Hotan, China	110.2	110.1
Ghaziabad, India	106.6	110.2
Bulandshahr, India	98.4	89.4
Bisrakh Jalalpur, India	96.0	-
Bhiwadi, India	95.5	83.4

Tehran was declared the most polluted city in the world on May 24, 2022.[340]

Projections

[edit]

In a 2019 projection, by 2030 half of the world's pollution emissions could be generated by Africa.[341] Potential contributors to such an outcome include increased burning activities (such as the burning of open waste), traffic, agri-food and chemical industries, sand dust from the Sahara, and overall population growth.

In a 2012 study, by 2050 outdoor air pollution (particulate matter and ground-level ozone) is projected to become the top cause of environmentally related deaths worldwide.[342]

See also

[edit]

- icon Image not found or type unknown Global warming portal

- icon
  Image not found or type unknown Plants portal
- icon
  Image not found or type unknown Trees portal

Source

- Beehive burner
- Bottom ash
- Concrete#Concrete – health and safety
- Diwali-related air pollution
- Flue-gas emissions from fossil-fuel combustion
- Health impacts of sawdust
- Joss paper
- Metal working
- Mining
- Non-exhaust emissions
- Power tool
- Rubber pollution
- Slag
- Smelting
- Tire fire
- Welding
- Wood ash

Measurement

- Air pollutant concentrations
- Air pollution measurement
- Organic molecular tracers
- Intake fraction
- Particulate matter sampler

Others

- Air stagnation
- ASEAN Agreement on Transboundary Haze Pollution
- Asian brown cloud
- Atmospheric chemistry
- BenMAP
- Best Available Control Technology
- Critical load
- Emission standard
- Emissions & Generation Resource Integrated Database
- Environmental agreement
- Environmental racism
- Exposome
- Global Atmosphere Watch

- Global dimming
- Great Smog of London
- Haze
- Health Effects Institute (HEI)
- Indicator value
- International Agency for Research on Cancer
- International Day of Clean Air for Blue Skies
- Kyoto Protocol
- Light water reactor sustainability
- List of smogs by death toll
- Lowest Achievable Emissions Rate
- NASA Clean Air Study
- NIEHS
- Phytoremediation
- Polluter pays principle
- Regulation of greenhouse gases under the Clean Air Act
- Silicosis#Prevention

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Further reading

[edit]
Library resources about
Air pollution

- Resources in your library
- Resources in other libraries
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External links

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Wikivoyage has travel information for ***Air pollution***.

- WHO fact sheet on outdoor air pollution
- Air Pollution: Everything You Need to Know Guide by the Natural Resources Defense Council (NRDC)
- Global real-time air quality index map
- Air Quality Index (AQI) Basics
- AQI Calculator AQI to Concentration and Concentration to AQI for five pollutants
- UNEP Urban environmental planning
- European Commission > Environment > Air > Air Quality
- Database: outdoor air pollution in cities from the World Health Organization
- The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom, UK Committee on the Medical Effects of Air Pollution, 2010.
- Hazardous air pollutants | What are hazardous pollutants at EPA.gov

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Pollution

History

Air

- Acid rain
- Air quality index
- Atmospheric dispersion modeling
- Chlorofluorocarbon
- Combustion
  - Biofuel
  - Biomass
  - Joss paper
  - Open burning of waste
- Construction
  - Renovation
- Demolition
- Exhaust gas
  - Diesel exhaust
- Haze
  - Smoke
- Indoor air quality
- Internal combustion engine
- Global dimming
- Global distillation
- Mining
- Ozone depletion
- Particulates
  - Asbestos
  - Metal working
  - Oil refining
  - Wood dust
  - Welding
- Persistent organic pollutant
- Smelting
- Smog
- Soot
  - Black carbon
- Volatile organic compound
- Waste

Biological

- Biological hazard
- Genetic pollution
- Introduced species
  - Invasive species

Digital

- Information pollution

Electromagnetic

- Light
  - Ecological light pollution
  - Overillumination
- Radio spectrum pollution

Natural

- Ozone
- Radium and radon in the environment
- Volcanic ash
- Wildfire

Noise

- Transportation
    - Land
    - Water
    - Air
    - Rail
    - Sustainable transport
- Urban
- Sonar
    - Marine mammals and sonar
- Industrial
- Military
- Abstract
- Noise control

Radiation

- Actinides
- Bioremediation
- Nuclear fission
- Nuclear fallout
- Plutonium
- Poisoning
- Radioactivity
- Uranium
- Electromagnetic radiation and health
- Radioactive waste

Soil

- Agricultural pollution
    - Herbicides
    - Manure waste
    - Pesticides
- Land degradation
- Bioremediation
- Open defecation
- Electrical resistance heating
- Soil guideline values
- Phytoremediation

Solid waste	○ Advertising mail
	○ Biodegradable waste
	○ Brown waste
	○ Electronic waste
	    ○ Battery recycling
	○ Foam food container
	○ Food waste
	○ Green waste
	○ Hazardous waste
	    ○ Biomedical waste
	    ○ Chemical waste
	    ○ Construction waste
	    ○ Lead poisoning
	    ○ Mercury poisoning
	    ○ Toxic waste
	○ Industrial waste
	    ○ Lead smelting
	○ Litter
	○ Mining
	    ○ Coal mining
	    ○ Gold mining
	    ○ Surface mining
	    ○ Deep sea mining
	    ○ Mining waste
	    ○ Uranium mining
	○ Municipal solid waste
	    ○ Garbage
	○ Nanomaterials
	○ Plastic pollution
	    ○ Microplastics
	○ Packaging waste
	○ Post-consumer waste
	○ Waste management
	    ○ Landfill
	    ○ Thermal treatment

Space	○ Satellite
Visual	○ Air travel ○ Clutter (advertising) ○ Traffic signs ○ Overhead power lines ○ Vandalism

War	○ Chemical warfare ○ Herbicidal warfare (Agent Orange) ○ Nuclear holocaust (Nuclear fallout - nuclear famine - nuclear winter) ○ Scorched earth ○ Unexploded ordnance ○ War and environmental law

Water	○ Agricultural wastewater
	○ Biological pollution
	○ Diseases
	○ Eutrophication
	○ Firewater
	○ Freshwater
	○ Groundwater
	○ Hypoxia
	○ Industrial wastewater
	○ Marine
	    ○ debris
	○ Monitoring
	○ Nonpoint source pollution
	○ Nutrient pollution
	○ Ocean acidification
	○ Oil exploitation
	○ Oil exploration
	○ Oil spill
	○ Pharmaceuticals
	○ Sewage
	    ○ Septic tanks
	    ○ Pit latrine
	○ Shipping
	○ Stagnation
	○ Sulfur water
	○ Surface runoff
	○ Thermal
	○ Turbidity
	○ Urban runoff
	○ Water quality

Topics	○ Pollutants
	    ○ Heavy metals
	    ○ Paint
	○ Brain health and pollution

Misc	○ Area source ○ Debris ○ Dust ○ Garbology ○ Legacy pollution ○ Midden ○ Point source ○ Waste
Responses	○ Cleaner production ○ Industrial ecology ○ Pollution haven hypothesis ○ Pollutant release and transfer register ○ Polluter pays principle ○ Pollution control ○ Waste minimisation ○ Zero waste
Lists	○ Diseases ○ Law by country ○ Most polluted cities ○ Least polluted cities by $PM_{2.5}$ ○ Most polluted countries ○ Most polluted rivers ○ Treaties

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Asia pollution topics

Air pollution

- **Notable incidents**
  - **Dust storm**
    - 2010 China dust storms
  - **Forest fires and haze**
    - 1997 SEA haze
    - 1997 Indonesian forest fires
    - 2005 Malaysian haze
    - 2006 SEA haze
    - 2009 SEA haze
    - 2010 SEA haze
    - 2013 SEA haze
    - 2015 SEA haze
    - 2016 Malaysian haze
    - 2016 SEA haze
    - 2017 SEA haze
    - 2019 SEA haze
    - 2019 Vietnam forest fires
    - 2024 Indo-Pakistani smog
  - **Air radioactive contamination**
    - 1982 Bukit Merah radioactive pollution
- **By countries**
  - China
  - Hong Kong
  - India
  - Macau
  - Malaysia
  - Taiwan
- **Recurrent issues**
  - Asian brown cloud
  - Asian Dust
  - Shamal
  - Southeast Asian haze
- **Counter-measures**
  - ASEAN Agreement on Transboundary Haze Pollution
    - Operation Haze
    - Pollutant Standards Index
  - Great Green Wall (China)

- **Water pollution**
  - **Notable incidents**
    - **Water radioactive contamination**
      - 2011 Fukushima Daiichi nuclear disaster
    - **Marine pollution**
      - 2016 Vietnam marine life disaster
      - 2019 Kim Kim River toxic pollution
      - Pollution of the Pasig River
  - **By countries**
    - China
      - Water crisis
    - India
    - Japan
    - Philippines
    - Vietnam

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Environmental science

- **Main fields**
  - Atmospheric science
  - Biogeochemistry
  - Ecology
  - Environmental chemistry
  - Geosciences
  - Hydrology
  - Limnology
  - Oceanography
  - Soil science

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Related fields

- Biology
- Chemistry
  - green
- Ecological economics
- Environmental design
- Environmental economics
- Environmental engineering
- Environmental health
  - epidemiology
- Environmental studies
- Environmental humanities
- Environmental statistics
- Environmental toxicology
- Geodesy
- Physics
- Radioecology
- Sustainability science
- Systems ecology
- Urban ecology

Applications

- Energy conservation
- Environmental technology
- Natural resource management
- Pollution control
- Public transport encouragement
- Recycling
- Remediation
- Renewable energy
- Road ecology
- Sewage treatment
- Urban metabolism
- Water purification
- Waste management

Lists

- Degrees
- Journals
- Research institutes
- Glossary

See also

- Environment by year
- Human impact on the environment
- Sustainability
- Technogaianism

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  - scientists
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Public health

General

- Auxology
- Biological hazard
- Chief Medical Officer
- Cultural competence
- Deviance
- Environmental health
- Eugenics
  - History of
  - Liberal
- Euthenics
- Genomics
- Globalization and disease
- Harm reduction
- Health economics
- Health literacy
- Health policy
  - Health system
  - Health care reform
- Housing First
- Human right to water and sanitation
- Management of depression
  - Public health law
  - National public health institute
- Health politics
- Labor rights
- Maternal health
- Medical anthropology
- Medical sociology
- Mental health (Ministers)
- Occupational safety and health
- Pharmaceutical policy
- Pollution
  - Air
  - Water
  - Soil
  - Radiation
  - Light
- Prisoners' rights
- Public health intervention
- Public health laboratory
- Right to food
- Right to health
- Right to housing
- Right to rest and leisure
- Right to sit
- Security of person
- Sexual and reproductive health
- Social psychology
- Sociology of health and illness
- Unisex changing rooms

Preventive healthcare	◦ Behavior change
	    ◦ Theories
	◦ Family planning
	◦ Health promotion
	◦ Human nutrition
	    ◦ Healthy diet
	    ◦ Preventive nutrition
	◦ Hygiene
	    ◦ Food safety
	    ◦ Hand washing
	    ◦ Infection control
	    ◦ Oral hygiene
	◦ Occupational safety and health
	    ◦ Human factors and ergonomics
	    ◦ Hygiene
	    ◦ Controlled Drugs
	    ◦ Injury prevention
	    ◦ Medicine
	    ◦ Nursing
	◦ Patient safety
	    ◦ Organization
	◦ Pharmacovigilance
	◦ Safe sex
	◦ Sanitation
	    ◦ Emergency
	    ◦ Fecal–oral transmission
	    ◦ Open defecation
	    ◦ Sanitary sewer
	    ◦ Waterborne diseases
	    ◦ Worker
	◦ School hygiene
	◦ Smoking cessation
	◦ Vaccination
	◦ Vector control

Population health	◦ Biostatistics
	◦ Child mortality
	◦ Community health
	◦ Epidemiology
	◦ Global health
	◦ Health impact assessment
	◦ Health system
	◦ Infant mortality
	◦ Open-source healthcare software
	◦ Multimorbidity
	◦ Public health informatics
	◦ Social determinants of health
	    ◦ Commercial determinants of health
	    ◦ Health equity
	    ◦ Race and health
	◦ Social medicine

Biological and epidemiological statistics	◦ Case–control study
	◦ Randomized controlled trial
	◦ Relative risk
	◦ Statistical hypothesis testing
	    ◦ Analysis of variance (ANOVA)
	    ◦ Regression analysis
	    ◦ ROC curve
	    ◦ Student's *t*-test
	    ◦ *Z*-test
	◦ Statistical software

Infectious and epidemic disease prevention	◦ Asymptomatic carrier
	◦ Epidemics
	    ◦ List
	◦ Notifiable diseases
	    ◦ List
	◦ Public health surveillance
	    ◦ Disease surveillance
	◦ Quarantine
	◦ Sexually transmitted infection
	◦ Social distancing
	◦ Tropical disease
	◦ Vaccine trial
	◦ WASH

Food hygiene and safety management

- Food
  - Additive
  - Chemistry
  - Engineering
  - Microbiology
  - Processing
  - Safety
  - Safety scandals
- Good agricultural practice
- Good manufacturing practice
  - HACCP
  - ISO 22000

Health behavioral sciences

- Diffusion of innovations
- Health belief model
- Health communication
- Health psychology
- Positive deviance
- PRECEDE–PROCEED model
- Social cognitive theory
- Social norms approach
- Theory of planned behavior
- Transtheoretical model

Organizations, education and history

Organizations

- Caribbean
  - Caribbean Public Health Agency
- China
  - Center for Disease Control and Prevention
- Europe
  - Centre for Disease Prevention and Control
  - Committee on the Environment, Public Health and Food Safety
- India
  - Ministry of Health and Family Welfare
- Canada
  - Health Canada
  - Public Health Agency
- U.S.
  - Centers for Disease Control and Prevention
  - Health departments in the United States
  - Council on Education for Public Health
  - Public Health Service
- World Health Organization
- World Toilet Organization
- (Full list)

Education

- Health education
- Higher education
  - Bachelor of Science in Public Health
  - Doctor of Public Health
  - Professional degrees of public health
  - Schools of public health

History

- Sara Josephine Baker
- Samuel Jay Crumbine
- Carl Rogers Darnall
- Joseph Lister
- Margaret Sanger
- John Snow
- Typhoid Mary
- Radium Girls
- Germ theory of disease
- Social hygiene movement

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Natural resources

Air	Pollution / quality	- Ambient standards (US) - Index - Indoor - Law - Clean Air Act (US) - Ozone depletion
	Emissions	- Airshed - Trading - Deforestation (REDD)

Energy	- Bio
	- Law
	- Resources
	- Fossil fuels (gas, peak coal, peak gas, peak oil)
	- Geothermal
	- Hydro
	- Nuclear
	- Solar
	    - sunlight
	    - shade
	- Wind	

Land

- Agricultural
  - arable
    - peak farmland
- Degradation
- Field
- Landscape
  - cityscape
  - seascape
  - soundscape
  - viewshed
- Law
  - property
- Management
  - habitat conservation
- Minerals
  - gemstone
  - industrial
  - ore
    - metal
  - mining
    - law
    - sand
  - peak
    - copper
    - phosphorus
  - rights
- Soil
  - conservation
  - fertility
  - health
  - resilience
- Use
  - planning
  - reserve

Life

- Biodiversity
- Bioprospecting
  - biopiracy
- Biosphere
- Bushfood
- Bushmeat
- Fisheries
  - climate change
  - law
  - management
- Forests
  - genetic resources
  - law
  - management
  - non-timber products
- Game
  - law
- Marine conservation
- Meadow
- Pasture
- Plants
  - FAO Plant Treaty
  - food
  - genetic resources
  - gene banks
  - herbal medicines
  - UPOV Convention
  - wood
- Rangeland
- Seed bank
- Wildlife
  - conservation
  - management

Water

Types / location

- Aquifer
  - storage and recovery
- Drinking
- Fresh
- Groundwater
  - pollution
  - recharge
  - remediation
- Hydrosphere
- Ice
  - bergs
  - glacial
  - polar
- Irrigation
  - *huerta*
- Marine
- Rain
  - harvesting
- Stormwater
- Surface water
- Sewage
  - reclaimed water
- Watershed

Aspects

- Desalination
- Floods
- Law
- Leaching
- Sanitation
  - improved
- Scarcity
- Security
- Supply
- Efficiency
- Conflict
- Conservation
- Peak water
- Pollution
- Privatization
- Quality
- Right
- Resources
  - improved
  - policy

Related

- Commons
  - enclosure
  - global
  - land
  - tragedy of
- Economics
  - ecological
  - land
- Ecosystem services
- Exploitation
  - overexploitation
  - Earth Overshoot Day
- Management
  - adaptive
- Natural capital
  - accounting
  - good
- Natural heritage
- Nature reserve
  - remnant natural area
- Systems ecology
- Urban ecology
- Wilderness

Resource

- Common-pool
- Conflict (perpetuation)
- Curse
- Depletion
- Extraction
- Nationalism
- Renewable / Non-renewable

Politics

- Oil war
- Petrostate
- Resource war

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National

- Germany
- United States
- France
- BnF data
- Japan
- Czech Republic
  - 2
- Spain
- Israel

Other

- NARA

About Royal Supply South

Things To Do in Arapahoe County

Photo

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Cherry Creek State Park

4.6 (9044)

Photo

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Molly Brown House Museum

4.7 (2528)

Photo

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Cherry Creek Valley Ecological Park

4.7 (484)

Photo

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Meow Wolf Denver | Convergence Station

4.5 (14709)

Photo

Morrison Nature Center

4.7 (128)

Photo

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The Aurora Highlands North Sculpture

4.9 (11)

Driving Directions in Arapahoe County

Driving Directions From Mullen High School to Royal Supply South

Driving Directions From Wells Fargo ATM to Royal Supply South

Driving Directions From Denver to Royal Supply South

Driving Directions From VRCC Veterinary Specialty and Emergency Hospital to Royal Supply South

Driving Directions From Walgreens to Royal Supply South

Driving Directions From U.S. Bank ATM to Royal Supply South

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105.0233105!2d39.6435918!3e2

Driving Directions From Aurora Reservoir to Royal Supply South

Driving Directions From Molly Brown House Museum to Royal Supply South

Driving Directions From Big Blue Bear to Royal Supply South

Driving Directions From Morrison Nature Center to Royal Supply South

Driving Directions From Aurora Reservoir to Royal Supply South

Driving Directions From Cherry Creek Valley Ecological Park to Royal Supply South

**https://www.google.com/maps/dir/The+Aurora+Highlands+North+Sculpture/Royal+Sup
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Reviews for Royal Supply South

Understanding Labor Inclusions in Contracts**View GBP**

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- **Protecting Exterior Components from Windy Conditions**
- **Comparing Basic and Extended Coverage Options**
- **Assessing Multi year Agreements for Homeowners**
- **Considering Weight Distribution on Mobile Home Roofs**

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Google Business Profile

Company Website : **https://royal-durhamsupply.com/locations/wichita-kansas/**

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