

Building Biology



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First Edition, 2012

ISBN 978-81-323-2838-4

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Published by:

Orange Apple

4735/22 Prakashdeep Bldg,

Ansari Road, Darya Ganj,

Delhi - 110002

Email: info@wtbooks.com

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Introduction

Building biology (or **Baubiologie** as it was coined in Germany) is a field of building science that investigates the indoor living environment for a variety of irritants. Practitioners consider the built environment as something with which the occupants interact, and believe its functioning can produce a restful or stressful environment. The major areas focused on by building biologists are building materials/processes, indoor air quality (IAQ) and electromagnetic fields (EMFs) and radiation (EMR). Building Biology is a holistic approach to the built environment. It is concerned with the interaction between the built environment and the health of the occupants. This can be in residential, public, or commercial buildings. There are 25 Principles of Building Biology, which govern the decision making of Building Biologists.

Effects of poor building

After World War II, new houses were quickly built in Germany to accommodate the growing population. Studies of these new houses found a pattern of illnesses not characteristic of the population, but characteristic to the commonalities of the living environments. The new housing, being quickly built, and unable to properly air out ("outgas", or "offgas") provided for an environment where the occupants were the recipients of every volatile organic compound (VOC) emitted from the construction materials. Along with this, other irritations became manifest because of the electrical systems. These two major irritants set to work simultaneously, and enhanced effects arose.

From these discoveries a study began in earnest among a few individuals to catalog and characterize the offending components. What emerged was a *Standard of Baubiologie Method of Testing*, with recommended threshold guidelines for sleeping areas (the space where and when one is most susceptible to biological irritation and damage). A small cadre of individuals was formed among whom Dr. Anton Schneider, Wolfgang Maes, and the Institut für Baubiologie und Ökologie Neubeuern (IBN) started a training system to educate those that were willing.

One of the architects, Helmut Ziehe, took the program and its possibilities to the USA. In 1987, he founded the International Institute of Building Biologie and Ecology (IBE) which presently offers seminars across the USA. Two certification streams are available, the Building Biology and Environmental Consultant (BBEC), and the Building Biology Practitioner (BBP).

The three groups of most sensitive individuals that reap the greatest benefits are: infants, the elderly, and the immuno-compromised. Some people become environmentally hypersensitive, and although conventional medicine suggests that the problem(s) may be psychological, there is growing acceptance that there is an environmental cause. One aspect of this problem is known as Multiple Chemical Sensitivity (MCS).

Criticism in USA

Some practices of building biology are contrary to the International Building Code, which is enforced by various government agencies in the USA and elsewhere.

Responses to Criticism in the USA

Some practitioners of building biology cite the inertia of the insurance industry as a force that has kept unhealthy building practices in legal building codes in the USA.

Strong lobbying efforts on the part of some building material and chemical manufacturers whose products are currently permissible in standard building code may also play a role in communities keeping those codes that prevent Bau Biologie recommended building practices - practices that are traditional and time tested throughout the world and are regionally appropriate.

Chapter- 1

Zero-Energy Building



BedZED zero energy housing in the UK

A **zernet energy building (ZNE)** is a popular term to describe a buildings use with zero net energy consumption and zero carbon emissions annually. ZeroNet Energy buildings can be used autonomously from the energy grid supply – energy can be harvested on-site usually in combination with energy producing technologies like Solar and Wind while reducing the overall use of energy with extremely efficient HVAC and Lighting technologies. The ZeroNet design principle is becoming more practical in adopting due to the increasing costs of traditional fossil fuels and their negative impact on the planet's climate and ecological balance.

The ZNE consumption principle is gaining considerable interest as renewable energy harvesting as a means to cut greenhouse gas emissions. Traditional building use consumes 40% of the total fossil energy in the US and European Union. In developing countries many people have to live in zero-energy buildings out of necessity. Many

people live in huts, yurts, tents and caves exposed to temperature extremes and without access to electricity. These conditions and the limited size of living quarters would be considered uncomfortable in the developed countries.

Modern Evolution

The development of modern ZeroNet Energy (ZNE) buildings became possible not only through the progress made in new construction technologies and techniques, but it has also been significantly improved by academic research on traditional and experimental buildings, which collected precise energy performance data. Today's advanced computer models can show the efficacy of engineering design decisions.

Energy use can be measured in different ways (relating to cost, energy, or carbon emissions) and, irrespective of the definition used, different views are taken on the relative importance of energy harvest and energy conservation to achieve a net energy balance. Although zero energy buildings remain uncommon in developed countries, they are gaining importance and popularity. The ZeroNet Energy approach has potential to reduce carbon emissions, and reduce dependence on fossil fuels.

A building approaching ZeroNet Energy use may be called a *near-zero energy building* or *ultra-low energy house*. Buildings that produce a surplus of energy during a portion of the year may be known as *energy-plus buildings*.

If the building is located in an area that requires heating or cooling throughout parts of the year, it is easier to achieve ZeroNet Energy consumption when the available living space is kept small.

Definitions

Despite sharing the name **zeronet energy**, there are several definitions of what ZNE means in practice, with a particular difference in usage between North America and Europe.

ZeroNet site energy use

In this type of ZNE, the amount of energy provided by on-site renewable energy sources is equal to the amount of energy used by the building. In the United States, “zeronet energy building” generally refers to this type of building.

ZeroNet source energy use

This ZNE generates the same amount of energy as is used, including the energy used to transport the energy to the building. This type accounts for losses during electricity transmission. These ZNEs must generate more electricity than ZeroNet site energy buildings.

Net zero energy emissions

Outside the United States and Canada, a ZEB is generally defined as one with zero net energy emissions, also known as a *zero carbon building* or *zero emissions building*. Under this definition the carbon emissions generated from on-

site or off-site fossil fuel use are balanced by the amount of on-site renewable energy production. Other definitions include not only the carbon emissions generated by the building in use, but also those generated in the construction of the building and the embodied energy of the structure. Others debate whether the carbon emissions of commuting to and from the building should also be included in the calculation.

Net zero cost

In this type of building, the cost of purchasing energy is balanced by income from sales of electricity to the grid of electricity generated on-site. Such a status depends on how a utility credits net electricity generation and the utility rate structure the building uses.

Net off-site zero energy use

A building may be considered a ZEB if 100% of the energy it purchases comes from renewable energy sources, even if the energy is generated off the site.

Off-the-grid

Off-the-grid buildings are stand-alone ZEBs that are not connected to an off-site energy utility facility. They require distributed renewable energy generation and energy storage capability (for when the sun is not shining, wind is not blowing, etc.). An energy autarkic house is a building concept where the balance of the own energy consumption and production can be made on an hourly or even smaller basis. Energy autarkic houses can be taken off-the-grid.

Design and Construction

The most cost-effective steps toward a reduction in a building's energy consumption usually occurs during the design process. To achieve efficient energy use, zero energy design departs significantly from conventional construction practice. Successful zero energy building designers typically combine time tested passive solar, or natural conditioning, principles that work with the on site assets. Sunlight and solar heat, prevailing breezes, and the cool of the earth below a building, can provide daylighting and stable indoor temperatures with minimum mechanical means. ZEBs are normally optimized to use passive solar heat gain and shading, combined with thermal mass to stabilize diurnal temperature variations throughout the day, and in most climates are superinsulated. All the technologies needed to create zero energy buildings are available off-the-shelf today. Sophisticated 3D computer simulation tools are available to model how a building will perform with a range of design variables such as building orientation (relative to the daily and seasonal position of the sun), window and door type and placement, overhang depth, insulation type and values of the building elements, air tightness (weatherization), the efficiency of heating, cooling, lighting and other equipment, as well as local climate. These simulations help the designers predict how the building will perform before it is built, and enable them to model the economic and financial implications on building cost benefit analysis, or even more appropriate - life cycle assessment.

Zero-Energy Buildings are built with significant energy-saving features. The heating and cooling loads are lowered by using high-efficiency equipment, added insulation, high-

efficiency windows, natural ventilation, and other techniques. These features vary depending on climate zones in which the construction occurs. Water heating loads can be lowered by using water conservation fixtures, heat recovery units on waste water, and by using solar water heating, and high-efficiency water heating equipment. In addition, daylighting with skylites or solartubes can provide 100% of daytime illumination within the home. Nighttime illumination is typically done with fluorescent and LED lighting that use 1/3 or less power than incandescent lights, without adding unwanted heat. And miscellaneous electric loads can be lessened by choosing efficient appliances and minimizing phantom loads or standby power. Other techniques to reach net zero (dependent on climate) are Earth sheltered building principles, superinsulation walls using straw-bale construction, Vitruvianbuilt pre-fabricated building panels and roof elements plus exterior landscaping for seasonal shading.

Zero-energy buildings are often designed to make dual use of energy including white goods; for example, using refrigerator exhaust to heat domestic water, ventilation air and shower drain heat exchangers, office machines and computer servers, and body heat to heat the building. These buildings make use of heat energy that conventional buildings may exhaust outside. They may use heat recovery ventilation, hot water heat recycling, combined heat and power, and absorption chiller units.

Energy harvest

ZEBs harvest available energy to meet their electricity and heating or cooling needs. In the case of individual houses, various microgeneration technologies may be used to provide heat and electricity to the building, using solar cells or wind turbines for electricity, and biofuels or solar collectors linked to seasonal thermal stores for space heating. To cope with fluctuations in demand, zero energy buildings are frequently connected to the electricity grid, export electricity to the grid when there is a surplus, and drawing electricity when not enough electricity is being produced. Other buildings may be fully autonomous.

Energy harvesting is most often more effective (in cost and resource utilization) when done on a local but combined scale, for example, a group of houses, co-housing, local district, village, etc. rather than an individual basis. An energy benefit of such localized energy harvesting is the virtual elimination of electrical transmission and electricity distribution losses. These losses amount to about 7.2%-7.4% of the energy transferred. Energy harvesting in commercial and industrial applications should benefit from the topography of each location. The production of goods under net zero fossil energy consumption requires locations of geothermal, microhydro, solar, and wind resources to sustain the concept.

Zero-energy neighborhoods, such as the BedZED development in the United Kingdom, and those that are spreading rapidly in California and China, may use distributed generation schemes. This may in some cases include district heating, community chilled water, shared wind turbines, etc. There are current plans to use ZEB technologies to build entire off-the-grid or net zero energy use cities.

The "energy harvest" versus "energy conservation" debate

One of the key areas of debate in zero energy building design is over the balance between energy conservation and the distributed point-of-use harvesting of renewable energy (solar energy and wind energy). Most zero energy homes use a combination of the two strategies.

As a result of significant government subsidies for photovoltaic solar electric systems, wind turbines, etc., there are those who suggest that a ZEB is a conventional house with distributed renewable energy harvesting technologies. Entire additions of such homes have appeared in locations where photovoltaic (PV) subsidies are significant, but many so called "Zero Energy Homes" still have utility bills. This type of energy harvesting without added energy conservation may not be cost effective with the current price of electricity generated with photovoltaic equipment (depending on the local price of power company electricity), and may also require greater embodied energy and greater resources so be thus the less ecological approach.

Since the 1980s passive solar building design and passive house have demonstrated heating energy consumption reductions of 70% to 90% in many locations, without active energy harvesting. For new builds, and with expert design, this can be accomplished with little additional construction cost for materials over a conventional building. Very few industry experts have the skills or experience to fully capture benefits of the passive design. Such passive solar designs are much more cost effective than adding expensive photovoltaic panels on the roof of a conventional inefficient building. A few kilowatt-hours of photovoltaic panels (costing 2 to 3 dollars per annual kW-hr production, U.S. dollar equivalent) may only reduce external energy requirements by 15% to 30%. A 100,000 BTU (110 MJ) high seasonal energy efficiency ratio 14 conventional air conditioner requires over 7 kW of photovoltaic electricity while it is operating, and that does not include enough for off-the-grid night-time operation. Passive cooling, and superior system engineering techniques, can reduce the air conditioning requirement by 70% to 90%. Photovoltaic generated electricity becomes more cost-effective when the overall demand for electricity is lower.

Occupant behavior

The energy used in a building can vary greatly depending on the behavior of its occupants. The acceptance of what is considered comfortable varies widely. Studies of identical homes in the United States have shown dramatic differences in energy use, with some homes using more than twice the energy of others. Occupant behavior can vary from differences in setting and programming thermostats, varying levels of illumination and hot water, and the amount of miscellaneous electric devices used.

Development efforts

Wide acceptance of zero energy building technology may require more government incentives or building code regulations, the development of recognized standards, or significant increases in the cost of conventional energy.

The Google photovoltaic campus, and the Microsoft 480-kilowatt photovoltaic campus relied on U.S. Federal, and especially California, **subsidies** and financial incentives. California is now providing \$3.2 billion USD in subsidies for residential-and-commercial near-zero-energy buildings, due to California's serious electricity shortage, frequent power outages, and air pollution problems. The details of other American states' renewable energy subsidies (up to \$5.00 USD per watt) can be found in the Database of State Incentives for Renewables and Efficiency. The Florida Solar Energy Center has a slide presentation on recent progress in this area.

The **World Business Council for Sustainable Development** has launched a major initiative to support the development of ZEB. Led by the CEO of United Technologies and the Chairman of Lafarge, the organization has both the support of large global companies and the expertise to mobilize the corporate world and governmental support to make ZEB a reality. Their first report, a survey of key players in real estate and construction, indicates that the costs of building green are overestimated by 300 percent. Survey respondents estimated that greenhouse gas emissions by buildings are 19 percent of the worldwide total, in contrast to the actual value of roughly 40 percent.

Influential zero- and low-energy buildings

Those who commissioned construction of Passive Houses and Zero Energy Homes (over the last three decades) were essential to iterative, incremental, cutting-edge, technology innovations. Much has been learned from many significant successes, and a few expensive failures.

The zero energy building concept has been a progressive evolution from other low-energy building designs. Among these, the Canadian R-2000 and the German *passive house* standards have been internationally influential. Collaborative government demonstration projects, such as the superinsulated Saskatchewan House, and the International Energy Agency's *Task 13*, have also played their part.

Advantages and disadvantages

Advantages

- isolation for building owners from future energy price increases
- increased comfort due to more-uniform interior temperatures (this can be demonstrated with comparative isotherm maps)
- reduced requirement for energy austerity
- reduced total cost of ownership due to improved energy efficiency

- reduced total net monthly cost of living
- improved reliability - photovoltaic systems have 25-year warranties - seldom fail during weather problems - the 1982 photovoltaic systems on the Walt Disney World EPCOT Energy Pavilion are still working fine today, after going through 3 recent hurricanes
- extra cost is minimized for new construction compared to an afterthought retrofit
- higher resale value as potential owners demand more ZEBs than available supply
- the value of a ZEB building relative to similar conventional building should increase every time energy costs increase
- future legislative restrictions, and carbon emission taxes/penalties may force expensive retrofits to inefficient buildings

Disadvantages

- initial costs can be higher - effort required to understand, apply, and qualify for ZEB subsidies
- very few designers or builders have the necessary skills or experience to build ZEBs
- possible declines in future utility company renewable energy costs may lessen the value of capital invested in energy efficiency
- new photovoltaic solar cells equipment technology price has been falling at roughly 17% per year - It will lessen the value of capital invested in a solar electric generating system - Current subsidies will be phased out as photovoltaic mass production lowers future price
- challenge to recover higher initial costs on resale of building - appraisers are uninformed - their models do not consider energy
- climate-specific design may limit future ability to respond to rising-or-falling ambient temperatures (global warming)
- while the individual house may use an average of net zero energy over a year, it may demand energy at the time when peak demand for the grid occurs. In such a case, the capacity of the grid must still provide electricity to all loads. Therefore, a ZEB may not reduce the required power plant capacity.
- without an optimised thermal envelope the embodied energy, heating and cooling energy and resource usage is higher than needed. ZEB by definition do not mandate a minimum heating and cooling performance level thus allowing oversized renewable energy systems to fill the energy gap.
- solar energy capture using the house envelope only works in locations unobstructed from the South. The solar energy capture cannot be optimized in South facing shade or wooded surroundings.

Zero energy building versus green building

The goal of green building and sustainable architecture is to use resources more efficiently and reduce a building's negative impact on the environment. Zero energy buildings achieve one key green-building goal of completely or very significantly reducing energy use and greenhouse gas emissions for the life of the building. Zero

energy buildings may or may not be considered "green" in all areas, such as reducing waste, using recycled building materials, etc. However, zero energy, or net-zero buildings do tend to have a much lower ecological impact over the life of the building compared with other 'green' buildings that require imported energy and/or fossil fuel to be habitable and meet the needs of occupants.

Because of the design challenges and sensitivity to a site that are required to efficiently meet the energy needs of a building and occupants with renewable energy (solar, wind, geothermal, etc.), designers must apply holistic design principles, and take advantage of the free naturally occurring assets available, such as passive solar orientation, natural ventilation, daylighting, thermal mass, and night time cooling.

Certification

Many Green building certification programs do not require a building to have net zero energy use, only to reduce energy use a few percentage points below the minimum required by law. The Leadership in Energy and Environmental Design (LEED) certification developed by the U.S. Green Building Council, and Green Globes, involve check lists that are measurement tools, not design tools. Inexperienced designers or architects may cherry-pick points to meet a target certification level, even though those points may not be the best design choices for a specific building or climate.

Worldwide

Canada

- In Canada the Net-Zero Energy Home Coalition is an industry association promoting net-zero energy home construction and the adoption of a near net-zero energy home (nNZEH), NZEH Ready and NZEH standard.
- The Canada Mortgage and Housing Corporation is sponsoring the EQUilibrium Sustainable Housing Competition that will see the completion of fifteen zero-energy and near-zero-energy demonstration projects across the country starting in 2008.
- The EcoTerra House in Eastman, Quebec, is Canada's first nearly net zero-energy housing built through the CMHC EQUilibrium Sustainable Housing Competition. The house was designed by Dr. Masa Noguchi of the Mackintosh School of Architecture for Alouette Homes and engineered by Prof. Dr. Andreas K. Athienitis of Concordia University.
- EcoPlusHome in Bathurst, New Brunswick. The Eco Plus Home is a prefabricated test house built by Maple Leaf Homes and with technology from Bosch Thermotechnology.

China

- One example of the new generation of zero energy office buildings is the 71-story Pearl River Tower, which opened in 2009, as the Guangdong Company

headquarters. It uses both modest energy efficiency, and a big distributed renewable energy generation from both solar and wind. Designed by Skidmore Owings Merrill LLP in Guangzhou, China, the tower is receiving economic support from government subsidies that are now funding many significant conventional fossil-fuel (and nuclear energy) energy reduction efforts.

- Dongtan Eco-City near Shanghai

Germany

- Technische Universität Darmstadt won first place in the international zero energy design 2007 Solar Decathlon competition, with a passivhaus design (Passive house) + renewables, scoring highest in the Architecture, Lighting, and Engineering contests
- *Self-Sufficient Solar House* Fraunhofer Institute for Solar Energy Systems(ISE), Freiburg im Breisgau

Ireland

In 2005 *Scandinavian Homes* launched the worlds first standardised passive house in Ireland, this concept makes the design and construction of passive house a standardised process. Conventional low energy construction techniques have been refined and modelled on the PHPP (Passive House Design Package) to create the standardised passive house. Building offsite allows high precision techniques to be utilised and reduces the possibility of errors in construction.

In 2009 the same company started a project to use 23,000 liters of water in a *seasonal storage tank*, heated up by evacuated solar tubes throughout the year, with the aim to provide the house with enough heat throughout the winter months thus eliminating the need for any electrical heat to keep the house comfortably warm. The system is monitored and documented by a research team from The University of Ulster and the results will be included in part of a PhD thesis.

Malaysia

In October 2007, the Malaysia Energy Centre (PTM) successfully completed the development and construction of the PTM Zero Energy Office (ZEO) Building. The building has been designed to be a super-energy-efficient building using only 286 kW·h/day. The renewable energy - photovoltaic combination is expected to result in a net zero energy requirement from the grid. The building is currently undergoing a fine tuning process by the local energy management team. Findings are expected to be published in a year.

Norway

In February 2009, the Research Council of Norway assigned The Faculty of Architecture and Fine Art at the Norwegian University of Science and Technology to host the Research Centre on Zero Emission Buildings (ZEB), which is one of eight new national

Centres for Environment-friendly Energy Research (FME). The main objective of the FME-centres is to contribute to the development of good technologies for environmentally friendly energy and to raise the level of Norwegian expertise in this area. In addition, they should help to generate new industrial activity and new jobs. Over the next eight years, the FME-Centre ZEB will develop competitive products and solutions for existing and new buildings that will lead to market penetration of zero emission buildings related to their production, operation and demolition.

Singapore

Singapore's First Zero Energy Building Launched at the Inaugural Singapore Green Building Week

United Arab Emirates

- Masdar City in Abu Dhabi

United Kingdom

In December 2006 the government announced that by 2016 all new homes in England will be zero energy buildings. To encourage this, an exemption from Stamp Duty Land Tax is planned. In Wales the plan is for the standard to be met earlier in 2011, although it is looking more likely that the actual implementation date will be 2012.

- BedZED development

United States



Net Zero Court zero emissions office building prototype in St. Louis, Missouri

In the US, ZEB research is currently being supported by the US Department of Energy (DOE) Building America Program, including industry-based consortia and researcher organizations at the National Renewable Energy Laboratory (NREL), the Florida Solar Energy Center (FSEC), Lawrence Berkeley National Laboratory (LBNL), and Oak Ridge National Laboratory (ORNL). From fiscal year 2008 to 2012, DOE plans to award \$40 million to four Building America teams, the Building Science Corporation; IBACOS; the Consortium of Advanced Residential Buildings; and the Building Industry Research Alliance, as well as a consortium of academic and building industry leaders. The funds will be used to develop net-zero-energy homes that consume at 50% to 70% less energy than conventional homes.

DOE is also awarding \$4.1 million to two regional building technology application centers that will accelerate the adoption of new and developing energy-efficient technologies. The two centers, located at the University of Central Florida and Washington State University, will serve 17 states, providing information and training on commercially available energy-efficient technologies.

The U.S. Energy Independence and Security Act of 2007 created 2008 through 2012 funding for a new solar air conditioning research and development program, which should soon demonstrate multiple new technology innovations and mass production economies of scale.

Florida

- The 1999 side-by-side Florida Solar Energy Center Lakeland Florida demonstration project was called the "Zero Energy Home." It was a first-generation university effort that significantly influenced the creation of the U.S. Department of Energy, Energy Efficiency and Renewable Energy, Zero Energy Home program. George Bush's Solar America Initiative is funding research and development into widespread near-future development of cost-effective Zero Energy Homes in the amount of \$148 million in 2008.

New Jersey

- The 31 Tannery Project, located in Branchburg, New Jersey, serves as the corporate headquarters for Ferreira Construction, the Ferreira Group, and Noveda Technologies. The 42,000-square-foot (3,900 m²) office and shop building was constructed in 2006 and is the 1st building in the state of New Jersey to meet New Jersey's Executive Order 54. The building is also the first Net Zero Electric Commercial Building in the United States.

Oklahoma

- The first 5,000-square-foot (460 m²) Zero Energy Design® home was built in 1979 with support from President Carter's new United States Department of Energy. It relied heavily on passive solar building design for space heat, water heat and space cooling. It heated and cooled itself effectively in a climate where the summer peak temperature was 110 degrees Fahrenheit, and the winter low temperature was -10 F. It did not use active solar systems. It is a double envelope house that uses a gravity-fed natural convection air flow design to circulate passive solar heat from 1,000 square feet (93 m²) of south-facing glass on its greenhouse through a thermal buffer zone in the winter. A swimming pool in the greenhouse provided thermal mass for winter heat storage. In the summer, air from two 24-inch 100-foot (30 m)-long underground earth tubes is used to cool the thermal buffer zone and exhaust heat through 7200 cfm of outer-envelope roof vents.

Chapter- 2

BioHome and HEPA

BioHome

BioHome Data	
Project Name	BioHome
Construction Dates	1989 (Completion)
Thermal Insulation Value	R-40

BioHome was a small facility created by NASA that could support one person in a fully-functional habitat. One of the influences of the project being the results from data obtained on the 1973 Skylab 3 (SL-3), where a total of 107 VOCs were offgassed by synthetic materials that composed the SL-3. However, the study of indoor air quality was not the only focus of the project, as it was a part of research into closed ecological life support systems.

The facility is still in use as of this writing and has paved inroads into creating self-supporting life support systems.

Construction

Construction of the BioHome concluded in 1989 and construction materials included synthetics which gave off the aforementioned VOCs. The BioHome itself resembles a mobile home in size where it contained a living area and treatment facilities for human waste and air.

While not completely air-tight, such as the Biosphere 2 structure, the structure was engineered for maximum air and energy confinement. This was unsurprising, given that the interior walls were composed of molded plastic panels with 30 cm of fiberglass insulation.

The BioHome had living facilities that could support one person and foliage plants were placed throughout the structure, aiding in air purification. In addition to the plants, a prototype fan-assisted plant filter was installed; the filter had the removal capacity of 15 standard potted plants.

The BioHome was equipped with monitoring ports for the detection of VOCs, which were measured using mass spectrometer / gas chromatograph equipment.

In experiments regarding wastewater treatment, the facility was outfitted with PVC piping and ultraviolet equipment.

Usage

The BioHome was used for a variety of experiments into, and including:

Wastewater treatment

In its nascence, the BioHome focused on alternative, non-chemical sewage treatment methods utilizing non-edible plants of aquatic disposition. The aquatic and semi-aquatic plants were chosen based on their previously known abilities for waste treatment. Another usage for the plants used in the wastewater treatment included its implementation as compost, which was feasible as the plants grew as more sewage was introduced.

Means

All waste material, such as feces and urine, were routed through PVC pipes, punctured so that the root systems of aquatic / semi-aquatic plants could be inserted. At different points of the flow, the water was studied (although those specific results are unavailable at this writing).

Ensuring total eradication of microorganisms, the processed water was subjected to ultraviolet radiation.

The processed water is subsequently used as toilet and plant water, though not for consumption.

Plants used

Plants, or more accurately, the root systems of aquatic plants found to have a filtering effect include bulrush, reed, soft rush and water iris. As explained by Wolverton:

"When sewage is slowly filtered through an aquatic plant root filter system, complex biological processes take place during wastewater treatment and purification. The symbiotic relationship that is normally established between the plant roots and microorganisms living on and around these roots is very complex

and important in the wastewater treatment process... This process not only removes organic chemicals, but is also thought to contribute to the reduction of other polluting substances including pathogenic bacteria and viruses. It has been shown that roots of aquatic plants such as bulrush, reed, soft rush and water iris excrete substances that can either partially or completely kill pathogenic bacteria while not harming beneficial bacterial. The aerobic zone around the aquatic root system can also support, in addition to bacteria, the growth of large numbers of protozoa which feed on bacteria, viruses and particular organic matter."

Harvesting drinking water

Water suitable for human use was extracted from the condensate from three sources: dehumidifier units, air conditioning, and plant leaves. In fact, plant leaves proved to be a major, consistently reliable source of water vapors.

The condensate was run through ultraviolet equipment to ensure its safety.

Crop growth

Crops were grown in the hydroponic sections of the BioHome, comprising edible plants (squash, corn, sorghum, tomatoes and other organics) and non-edible plants, which were an essential part of the air purification process. Compost made from wastewater treatment plants was used effectively as a growth medium.

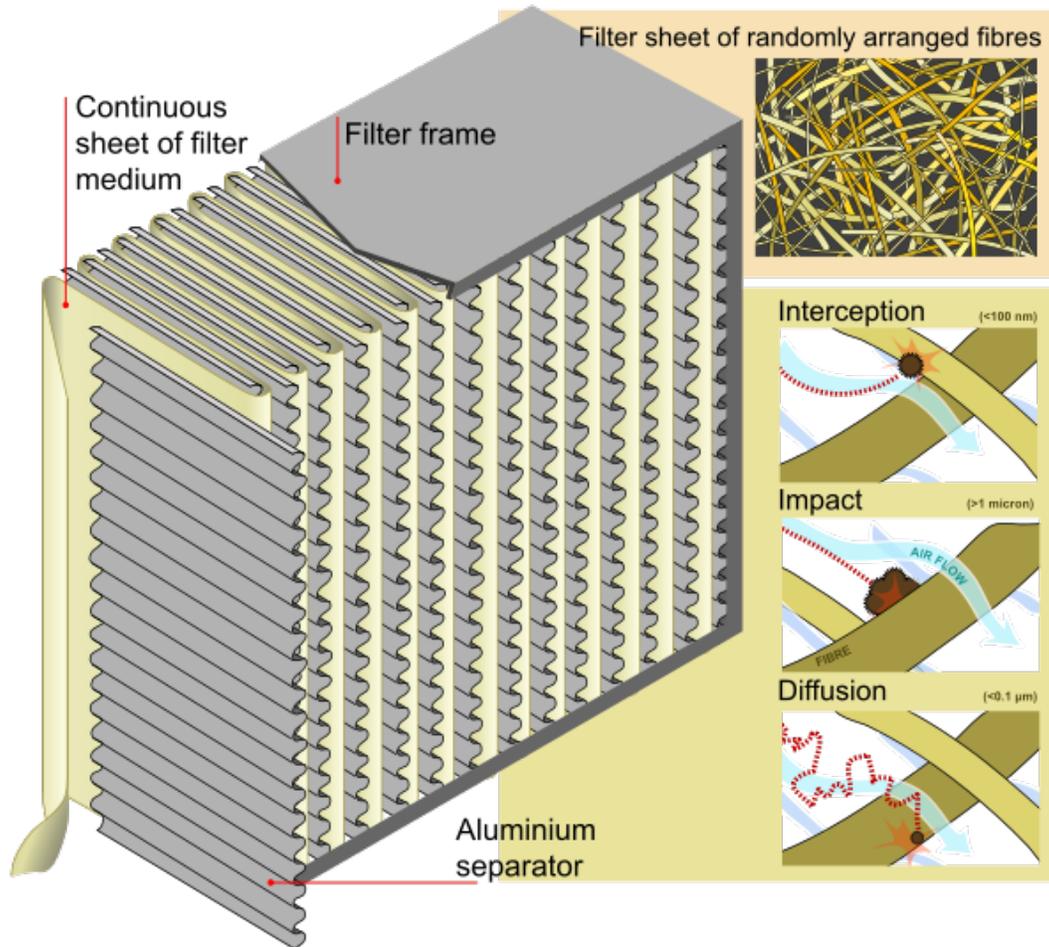
Air purification

The living areas of the BioHome were teeming with plant foliage, the purpose of which was to purify the air of carbon dioxide. As a result of the experiment, it was also found that the plants purified the air of synthetic offgases, such as those emitted from formaldehyde, benzene, toluene and organics. In essence, the plants established and maintained indoor air quality.

Other studies

As a result of the air purification studies, an unspecified student lived in the BioHome for an unspecified period of time. The student made use of the facilities and offered no complaint about the indoor air quality.

HEPA



HEPA-Filter with functional description

A **high efficiency particulate air**, or **HEPA**, filter is a type of air filter that satisfies certain standards of efficiency such as those set by the United States Department of Energy (DOE).

Function

HEPA filters are composed of a mat of randomly arranged fibres. The fibres are typically composed of fiberglass and possess diameters between 0.5 and 2.0 micrometer. Key factors affecting function are fibre diameter, filter thickness, and face velocity. The air space between HEPA filter fibres is much greater than 0.3 μm . The common assumption that a HEPA filter acts like a sieve where particles smaller than the largest opening can pass through is incorrect. Unlike membrane filters, where particles as wide as the largest opening or distance between fibres cannot pass in between them at all, HEPA filters are

designed to target much smaller pollutants and particles. These particles are trapped (they stick to a fibre) through a combination of the following three mechanisms:

1. *Interception*, where particles following a line of flow in the air stream come within one radius of a fibre and adhere to it.
2. *Impaction*, where larger particles are unable to avoid fibres by following the curving contours of the air stream and are forced to embed in one of them directly; this effect increases with diminishing fibre separation and higher air flow velocity.
3. *Diffusion*, an enhancing mechanism is a result of the collision with gas molecules by the smallest particles, especially those below 0.1 μm in diameter, which are thereby impeded and delayed in their path through the filter; this behaviour is similar to Brownian motion and raises the probability that a particle will be stopped by either of the two mechanisms above; it becomes dominant at lower air flow velocities.

Diffusion predominates below the 0.1 μm diameter particle size. Impaction and interception predominate above 0.4 μm . In between, near the Most Penetrating Particle Size (MPPS) 0.3 μm , both diffusion and interception are comparatively inefficient. Therefore, the HEPA specifications use the retention of these particles to define the filter.

Specifications

HEPA filters, as defined by the DOE standard adopted by most American industries, remove at least 99.97% of airborne particles 0.3 micrometers (μm) in diameter. The filters maximum resistance to airflow, or pressure drop, is usually specified around 300 Pa at its nominal flow rate.

The specification usually used in the European Union is the European Norm EN 1822:2009. It defines several classes of HEPA filters by their retention at MPPS:

HEPA class retention (total) retention (local)

E10	> 85 %	---
E11	> 95 %	---
E12	> 99.5 %	---
H13	> 99.95 %	> 99.75 %
H14	> 99.995 %	> 99.975 %
U15	> 99.9995 %	> 99.9975 %
U16	> 99.99995 %	> 99.99975 %
U17	> 99.999995 %	> 99.9999 %

The original HEPA filter was designed in the 1940s and was used in the Manhattan Project to prevent the spread of airborne radioactive contaminants. It was commercialized in the 1950s, and the original term became a registered trademark and a generic term for

highly efficient filters. Over the decades filters have evolved to satisfy the higher and higher demands for air quality in various high technology industries, such as aerospace, pharmaceutical processing, hospitals, health care, nuclear fuels, nuclear power, and electronic microcircuitry (computer chips).

Today, a HEPA filter rating is applicable to any highly efficient air filter that can attain the same filter efficiency performance standards as a minimum and is equivalent to the more recent NIOSH N100 rating for respirator filters. The United States Department of Energy (DOE) has specific requirements for HEPA filters in DOE regulated applications. Products that claim to be "HEPA-type", "HEPA-like", or "99% HEPA" do not satisfy these requirements and may not have been tested in independent laboratories.

Biomedical applications



Hospital staff modelling a HEPA filter, which can be used if a patient has active tuberculosis.

HEPA filters are critical in the prevention of the spread of airborne bacterial and viral organisms and, therefore, infection. Typically, medical-use HEPA filtration systems also incorporate high-energy ultra-violet light units to kill off the live bacteria and viruses trapped by the filter media. Some of the best-rated HEPA units have an efficiency rating of 99.995%, which assures a very high level of protection against airborne disease transmission.

Vacuum cleaners

Many vacuum cleaners also use HEPA filters as part of their filtration systems. This is beneficial for asthma and allergy sufferers, because the HEPA filter traps the fine particles (such as pollen and dust mite feces) which trigger allergy and asthma symptoms. For a HEPA filter in a vacuum cleaner to be effective, the vacuum cleaner must be designed so that all the air drawn into the machine is expelled through the filter, with none of the air leaking past it. This is often referred to as "Sealed HEPA" or sometimes the more vague "True HEPA." Vacuum cleaners simply labeled HEPA have a HEPA filter, but not all air necessarily passes through it. Finally, vacuum cleaner filters marketed as "HEPA-like" will typically use a filter of a similar construction to HEPA, but without the filtering efficiency. Because of the extra density of a HEPA filter, HEPA vacuum cleaners require more powerful motors to provide adequate cleaning power.

Newer models claim to be better than the first models because of being "washable". Generally washable filters are expensive. Some manufacturers claim filter standards such as "HEPA 4", without explaining the meaning behind them. It refers to their Minimum Efficiency Reporting Value (MERV) rating. These ratings are used to rate the ability of an air cleaner filter to remove dust from the air as it passes through the filter. MERV is a standard used to measure the overall efficiency of a filter. The MERV scale ranges from 1 to 20, and measures a filter's ability to remove particles from 10 to 0.3 micrometre in size. Filters with higher ratings not only remove more particles from the air, they also remove smaller particles.

Vehicle use

Cars

Some new model cars have a HEPA filter for the driver and passengers.

Airlines

Modern airliners use HEPA filters to reduce the spread of airborne pathogens in recirculated air. Test results from a Department of Transportation (DOT) study conducted on 92 randomly selected flights showed that bacteria and fungi levels measured in the airplane cabin are similar to or lower than those found in the common home. These very low microbial contaminant levels are due to the complete exchange of inside cabin air 10 to 15 times per hour and the high filtration capability of the recirculation system. The filters used on current airliners are similar to HEPA filters used in industrial "clean

rooms” and in critical wards of hospitals, such as organ transplant and burn units. By comparison, the filtration systems in typical buildings are not capable of removing microbial contaminants including bacteria and viruses.

Chapter- 3

Indoor Air Pollution in Developing Nations

Indoor air pollution in developing nations is a significant form of indoor air pollution (IAP) that is little known to those in the developed world.

Three billion people in developing nations across the globe rely on biomass, in the form of wood, charcoal, dung, and crop residue, as their domestic cooking fuel. Because much of the cooking is carried out indoors in environments that lack proper ventilation, millions of people, primarily poor women and children face serious health risks. Conservative estimates indicate that between 1.5 and 2 million deaths were attributed to exposure to IAP in developing countries in 2000. Estimates further suggest that approximately 80% of total global exposure to airborne particulate matter occurs indoors in developing nations.

Even though the rate of dependence on biomass fuel is declining, this dwindling resource will not keep up with population growth which could ultimately put environments at even greater risk. In Kenya, efforts are currently being made to address the overall health risks to rural women and children.

Health implications

Rural Kenya has been the site of various applied research projects to determine the intensity of emissions that commonly occur from use of biomass fuels, particularly wood, dung, and crop residue. Smoke is the result of the incomplete combustion of solid fuel which women and children are exposed to up to seven hours each day in closed environments. These emissions vary from day to day, season to season and with changes in the amount of airflow within the residence. Exposure in poor homes far exceeds accepted safety levels by as much as one hundred times over. Because many Kenyan women utilize a three-stone fire, the worst offender, one kilogram of burning wood produces tiny particles of soot which can clog and irritate the bronchial pathways. The smoke also contains various poisonous gases such as aldehydes, benzene, and carbon monoxide. Exposure to IAP from combustion of solid fuels has been implicated, with varying degrees of evidence, as a causal agent of several diseases. Acute lower respiratory infections (ALRI) and chronic obstructive pulmonary disease (COPD) are the

leading causes of disease and death from exposure to smoke. Cataracts and blindness, lung cancer, tuberculosis, premature births and low birth weight are also suspected of being caused by IAP.

Women and primarily girls spend excess time each day in collecting fuel-wood in Kenya which exposes them to even further hazards including vulnerability to rape and also fractures from the weight of carrying heavy loads. This time could be spent in more productive ways such as attending school or income production. The use of biomass coupled with inefficient cooking apparatus leads to a web of social and environmental concerns which directly links to the United Nations Millennium Development Goals.

Interventions

Early interventions

Unfortunately, finding an affordable solution to address the many effects of IAP – improving combustion, reducing smoke exposure, improving safety and reducing labor, reducing fuel costs, and addressing sustainability – is complex and in need of continual improvement. Efforts to improve cook stoves in the past, beginning in the 1950s, were primarily aimed at minimizing deforestation with no concern for IAP, though the effectiveness of these efforts to save firewood is debatable. Various attempts had various outcomes. For example, some improved stove designs in Kenya significantly reduced particulate emissions but produced higher CO₂ and SO₂ emissions. Flues to remove smoke were difficult to design and were fragile.

Improved Success

Current improved interventions however, include smoke hoods which operate in much the same manner as flues, to extract smoke, but are found to reduce levels of IAP more effectively than homes that relied solely on windows for ventilation. Some features of newly improved stoves include a chimney, enclosing the fire to retain heat, designing a pot holder to maximize heat transfer, dampers to control air flow, a ceramic insert to reduce heat loss, and multi-pot systems to allow for cooking multiple dishes.

Stoves are now known to be one of the least-cost means to achieve the combined objective of reducing the health burden of IAP and in some areas reducing environmental stress from biomass harvesting. Some success in installation of interventions, including improved cook stoves, has been achieved primarily due to an interdisciplinary approach which includes multiple stakeholders. These projects have discovered that key socio-economic issues must be addressed to ensure the success of intervention programs. A multitude of complex issues indicate improved stoves are not merely a tool to save fuel.

Successful Interventions

The following information represents one successful intervention known as the Kenya Smoke and Health Project (1998–2001) which involved fifty rural households in two

separate regions, Kajiado and West Kenya. These areas were chosen due to different climate, geographic, and cultural implications. Community participation was the primary focus for this project and as a result, those involved indicated the results far exceeded their expectations. Local women's groups and, in the case of the project in West Kenya, men were actively involved. By involving the end-users the project resulted in more widespread acceptance and created the further benefit of providing local income.

Three key interventions were discussed and disseminated; ventilation by enlarging windows or opening eaves spaces, adding smoke hoods over the cooking area, or the option of installing an improved cook stove such as the Upesi stove. Smoke hoods are free-standing units that act like flues or chimneys in their effort to draw smoke out of the dwelling. They can be used over traditional open fires and this study showed they contribute to considerably lower levels of IAP. The smoke hood models were made with hard manila paper and then transferred to heavy-gauge galvanized sheet metal and manufactured locally. This resulted in further employment opportunities for the artisans who were trained by the project. The Upesi stove, made of clay and kiln-fired, was developed by Practical Action and East African partners to utilize wood and agricultural wastes. Because this stove was designed and adapted for local needs it produced several winning features. Not only does it cut the use of fuel-wood by approximately half, and reduce exposure to household smoke, it also empowers local women by creating employment as they are the ones who make and market the stoves. These women's groups gain access to technical training in production and marketing and enjoy higher wage earnings and improved social status as a result of the introduction of this improved stove.

Various benefits were realized including improved health; the most important aspect to each of the villagers involved. The people reported less internal heat allowing for better sleep, fewer headaches and less fatigue, less eye irritation and coughs and dizziness. Safety increased due to the smoke hoods preventing goats and children from falling into the fire and less soot contamination was observed, along with snakes and rodents not entering the home. Windows allowed for the ability to view cattle from indoors, and also reduced kerosene needs due to improved interior lighting. Overall, the indoor environment improved greatly from various simple things that are taken for granted in modern western homes. Greater indoor light also allows for more income generation for women as they can do beadwork by the window when weather doesn't allow for this work outdoors. Children also benefit from increased lighting for homework.

Interpersonal relationships developed among the women due to the project, and men better supported their wives initiative when the end result benefited them as well. While initial efforts to improve stoves were limited in success, current efforts are more successful due to the recognition that sustainable domestic energy resources are "central to reducing poverty and hunger, improving health...and improving the lives of women and children" The optimal short-term goal in minimizing rural poverty is to provide inexpensive and acceptable solutions to the local people. Not only can stoves contribute to this intervention, but the use of cleaner fuels will also provide further benefits.

Similar improved-stove projects have proven successful in other regions of the world. Improved stoves installed as part of the Randomized Exposure Study of Pollution Indoors and Respiratory Effects (RESPIRE) study in Guatemala were found to be acceptable to the population and produce significant health benefits for both mothers and children. Mothers in the intervention group had lower blood pressure and reductions in eye discomfort and back pain. Intervention households were also found to have lower levels of small particles and carbon monoxide. Children in these households also had lower rates of asthma. This initial pilot program has evolved into CRECER (Chronic Respiratory Effects of Early Childhood Exposure to Respirable Particulate Matter), which will attempt to follow children in intervention households for a longer period of time to determine whether the improved stoves also contribute to greater health over the lifespan.

The National Program on Improved Chulhas in India has also had some success in encouraging the use of improved stoves among at-risk populations. Begun in the mid-1980s, this program provides subsidies to encourage families to purchase the longer-lasting chulhas and have a chimney installed. A 2005 study showed that stoves with chimneys are associated with a lower incidence of cataracts in women. Much of the available information from India is more of a characterization of the issue and there is less data available from intervention trials.

China has been particularly successful at encouraging the use of improved stoves, with hundreds of millions of stoves installed since the beginning of the project in the early 1980s. The government very intentionally targeted poorer, rural households, and by the late 1990s nearly 75% of such households contained “improved kitchens.” A 2007 review of 3500 households showed an improvement in indoor air quality in intervention households characterized by lower concentrations of small particles and carbon monoxide in household air. The program in China involved intervention on a large scale, but the cost of stoves was heavily subsidized so it is not known if its success could be replicated.

Environmental Impacts

Mortality and burden of disease are not the only detrimental effects from utilizing inefficient energy technology such as the combustion of biomass. Kenya’s pre-dominant energy source is biomass, providing more than 90 per cent of rural household energy needs, about one-third in the form of charcoal and the rest from firewood. Biomass energy sourced primarily from savannah woodlands includes firewood for inhabitants and charcoal for urban use. A small percentage is sourced by neighboring communities from closed and protected forests which are generally found in high population density areas. While biomass harvesting in sensitive areas is problematic, it is now determined that the great majority of biomass clearing is due to agricultural expansion and land conversion. Approximately 38% of households 'in high agro-ecological zones' utilize agricultural waste due to frequent shortages of conventional fuel-wood. Use of crop residue and animal waste for domestic energy has detrimental results on soil quality and agricultural and livestock productivity. These materials are ultimately not available as soil

conditioners, organic fertilizer, and livestock fodder, not to mention the “cumulative effects on national food security”.

Most farmers are aware however, that when agricultural waste and dung are not used for energy, they are important elements to maintaining soil fertility. One of the most efficient ways to utilize crop waste and dung for domestic energy is to produce briquettes. The process of compacting the material into a donut shape creates more efficient combustion which contributes to reduced emission levels. A simple device allows for this process and it can be done locally.

Sustainable options

Large-scale combustion of biomass is only feasible if carried out in a sustainable manner. Concern is paramount for regeneration of renewable and sustainable fuel-wood sources if it is to continue to be available long-term. Attempts at sustainable solutions in Kenya could include developing energy crops (trees and shrubs) which would also provide additional income for farmers. This solution would benefit cropland or rangeland prone to erosion and flooding as the root systems and leaf litter would enhance soil stability. Careful selection of regenerating varieties would be most sustainable because soil stability is not disrupted due to tilling and planting. Some people view this solution as a way to further exploit forests, but with proper management of forest resources this could be a viable solution.

Solar cooking is a sustainable option for reducing the use of biomass as fuel and thereby contribute to the reduction of IAP. For an example of a solar cooker that can bake, boil, fry or roast, see the Phaeton solar array. Kyoto Twist, an international aid organization has published an excellent case study where two Cookit solar cookers saved families of 6 people 2000 pounds of wood in a year.

Challenges

Widespread education and government funding will also be necessary to shift cultural practices to more sustainable energy use. For example, in an area in South Africa, even though access to electricity was available, many residents continued to use biomass fuels for cooking and heating due to cost of electrical appliances and cultural practices. Liquid petroleum gas (LPG), which has nearly 100% combustion and negligible emissions unfortunately is currently not cost effective. The use of solar power, such as solar cookers, has drawbacks in practical use because they must be used outdoors, and they are slow and do not work in the evening or on cloudy days.

Education interventions

Educational intervention can contribute to reducing exposure to smoke by developing a social marketing effort in alerting people to the dangers and encouraging a willingness to alter living and cultural practices which could have a significant impact on mitigating exposure to IAP. These interventions “must be based on felt needs...” with emphasis and

sensitivity to gender issues. Evidence of one successful government intervention was revealed by China who, between 1980 and 1995, disseminated 172 million improved cookstoves. This effort proved more successful due to the inclusion of local users, particularly women, who were involved in the design and fieldwork process.

Kenya and modern energy

As of 2004, Kenya has shown a willingness to undertake biomass energy issues with the understanding that consumption is associated with indoor air pollution and environmental degradation. Suggestions from the United Nations Development Programme include establishing an institution that will deal exclusively with biomass energy by developing policy guidelines on sustainable firewood, charcoal, and modern biomass such as cleaner fuels and wind, solar, and small scale hydropower. Short-term solutions rest in more efficient domestic energy use by way of improved cook stoves which provide more affordable options in the near future than a complete shift to nonsolid fuels. Long-term solutions rest on transition to modern cleaner fuels and alternative energy sources within a broad international and national policy and economic agenda. Government support for long-term solutions is feasible as witnessed by current efforts in Zambia to develop policy to promote biofuels.

Kenya is the world leader in the number of solar power systems installed per capita (but not the number of watts added). More than 30,000 small solar panels, each producing 12 to 30 watts, are sold in Kenya annually. For an investment of as little as \$100 for the panel and wiring, the PV system can be used to charge a car battery, which can then provide power to run a fluorescent lamp or a small television for a few hours a day. More Kenyans adopt solar power every year than make connections to the country's electric grid.

Further action

National and international effort must be stepped up to advance short and long term solutions for the millions of women and children who suffer from poverty and disease as a result of indoor air pollution. Scientists predict the African continent will be the first to experience the effects of global warming where widespread poverty will put millions at further risk due to their limited capabilities to adapt. The potential is great for a more sustainable Africa with commitment from within and outside the region. Pneumonia is the number one killer of children in the world and indoor air pollution is a strongly significant risk factor for severe pneumonia. The global health community designated November 2 to be World Pneumonia Day in order to raise awareness about the disease and its causes.

Chapter- 4

Health Effects of Radon

Radon is a radioactive, colorless, odorless, tasteless noble gas, occurring naturally as the decay product of radium. It is one of the densest substances that remains a gas under normal conditions and is considered to be a health hazard due to its radioactivity. Its most stable isotope, ^{222}Rn , has a half-life of 3.8 days. Due to its high radioactivity, it has been less well-studied by chemists, but a few compounds are known.

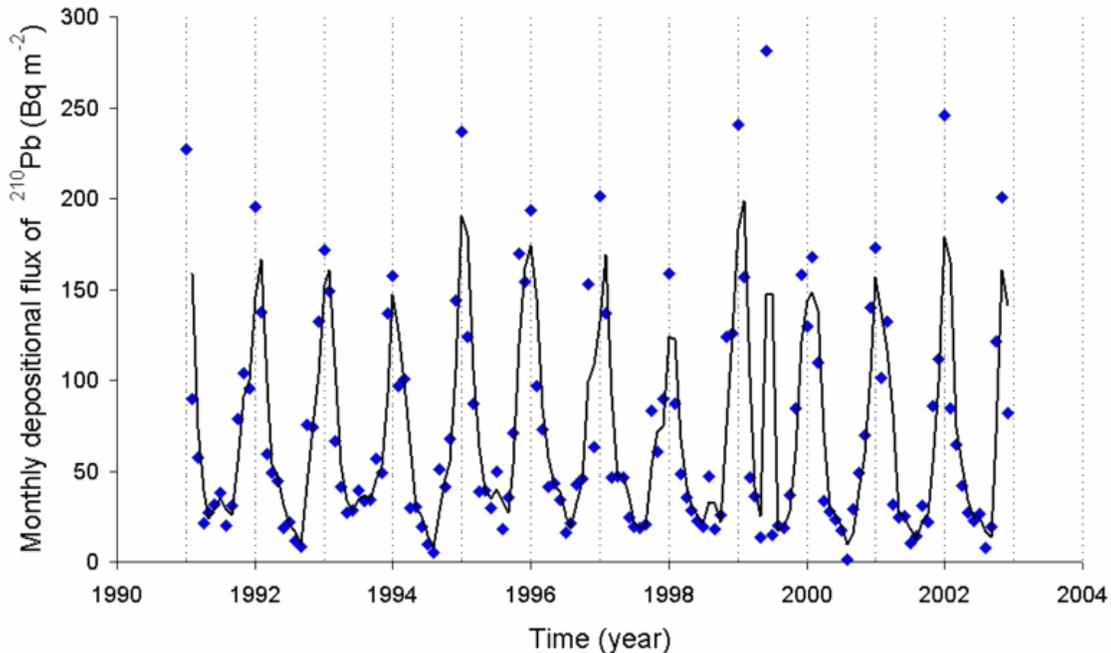
Radon is formed as part of the normal radioactive decay chain of uranium. Uranium has been around since the earth was formed and its most common isotope has a very long half-life (4.5 billion years), which is the amount of time required for one-half of uranium to break down. Uranium, radium, and thus radon, will continue to occur for millions of years at about the same concentrations as they do now.

Radon is responsible for the majority of the mean public exposure to ionizing radiation. It is often the single largest contributor to an individual's background radiation dose, and is the most variable from location to location. Radon gas from natural sources can accumulate in buildings, especially in confined areas such as attics, and basements. It can also be found in some spring waters and hot springs.

Epidemiological evidence shows a clear link between lung cancer and high concentrations of radon, with 21,000 radon-induced U.S. lung cancer deaths per year—second only to cigarette smoking—according to the United States Environmental Protection Agency. Thus in geographic areas where radon is present in heightened concentrations, radon is considered a significant indoor air contaminant.

Occurrence

Concentration units



^{210}Pb is formed from the decay of ^{222}Rn . Here is a typical deposition rate of ^{210}Pb as observed in Japan as a function of time, due to variations in radon concentration.

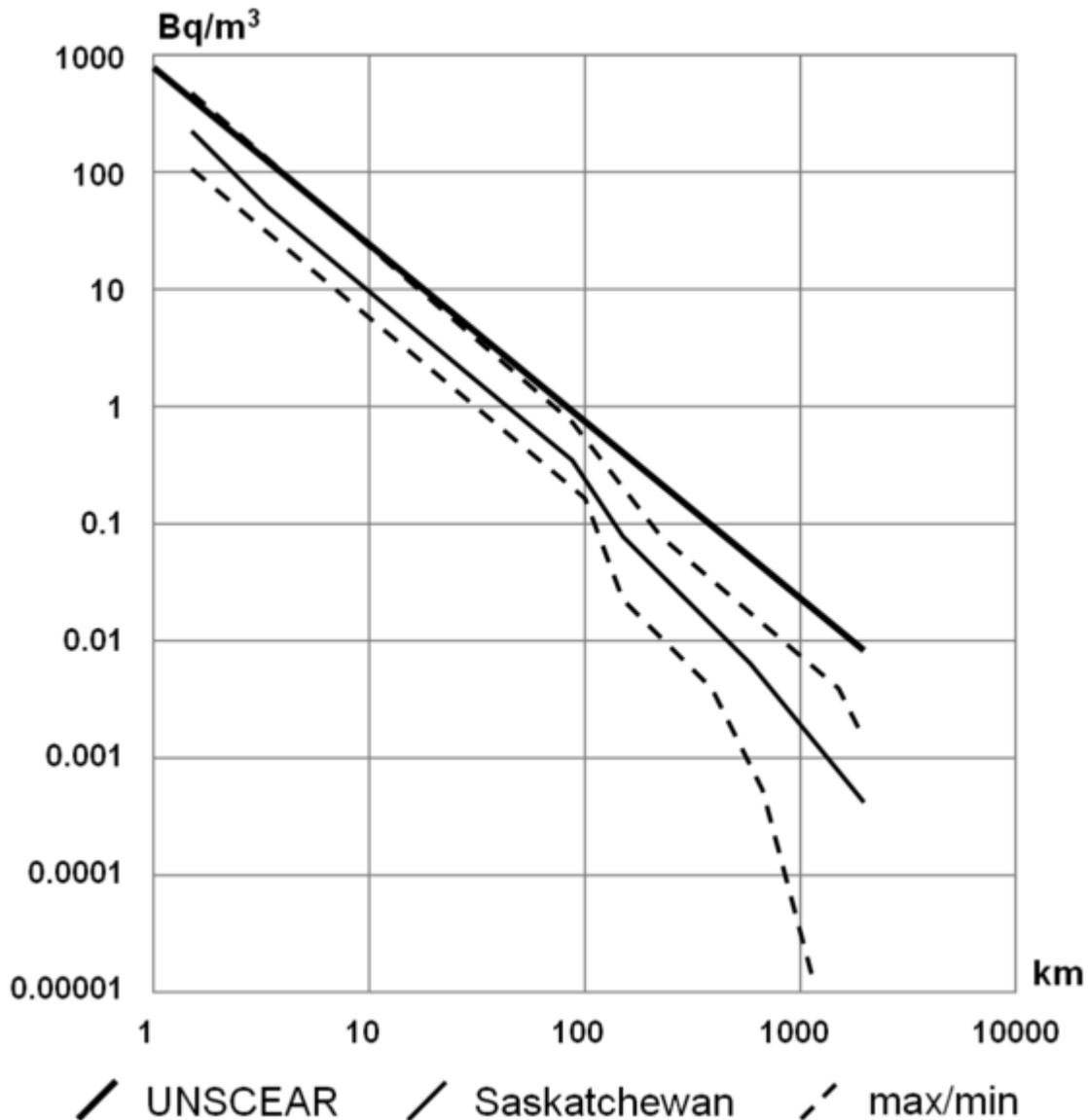
Radon concentration is usually measured in the atmosphere in becquerels per cubic meter (Bq/m^3), which is an SI derived unit. As a frame of reference, typical domestic exposures are about $100 \text{ Bq}/\text{m}^3$ indoors and $10\text{-}20 \text{ Bq}/\text{m}^3$ outdoors. In the US, radon concentrations are often measured in picocuries per liter (pCi/L), with $1 \text{ pCi}/\text{L} = 37 \text{ Bq}/\text{m}^3$.

The mining industry traditionally measures exposure using the *working level (WL)* index, and the cumulative exposure in *working level months (WLM)*: 1 WL equals any combination of short-lived ^{222}Rn progeny (^{218}Po , ^{214}Pb , ^{214}Bi , and ^{214}Po) in 1 liter of air that releases $1.3 \times 10^5 \text{ MeV}$ of potential alpha energy; one WL is equivalent to $2.08 \times 10^5 \text{ joules per cubic meter of air (J}/\text{m}^3)$. The SI unit of cumulative exposure is expressed in joule-hours per cubic meter ($\text{J}\cdot\text{h}/\text{m}^3$). One WLM is equivalent to $3.6 \times 10^{-3} \text{ J}\cdot\text{h}/\text{m}^3$. An exposure to 1 WL for 1 working month (170 hours) equals 1 WLM cumulative exposure.

A cumulative exposure of 1 WLM is roughly equivalent to living one year in an atmosphere with a radon concentration of $230 \text{ Bq}/\text{m}^3$.

The radon (^{222}Rn) released into the air decays to ^{210}Pb and other radioisotopes. The levels of ^{210}Pb can be measured. The rate of deposition of this radioisotope is dependent on the weather.

Natural



Radon concentration next to a uranium mine

Radon concentrations found in natural environments are much too low to be detected by chemical means, for example, a 1000 Bq/m³ (relatively high) concentration corresponds

to 0.17 pico-gram per cubic meter. The average concentration of radon in the atmosphere is about 6×10^{-20} atoms of radon for each molecule in the air, or about 150 atoms in each ml of air. The entire radon activity of the Earth's atmosphere at a time is due to some tens of grams of radon, consistently replaced by decay of larger amounts of radium and uranium. In reality, concentrations can vary greatly from place to place. In the open air, it ranges from 1 to 100 Bq/m³, even less (0.1 Bq/m³) above the ocean. In caves, aerated mines, or in poorly-ventilated dwellings, its concentration can climb to 20-2,000 Bq/m³.

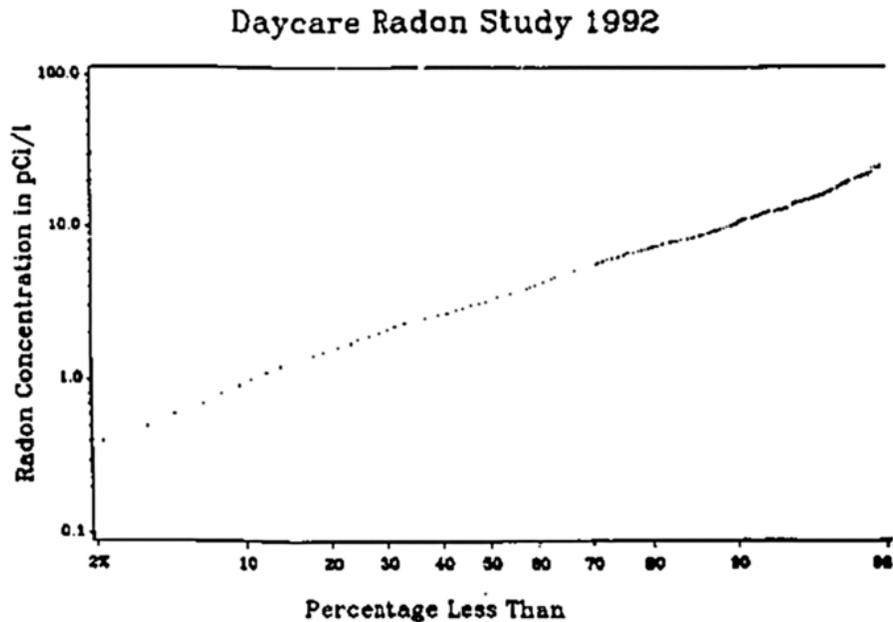
In mining contexts, radon concentrations can be much higher. However, ventilation regulations try to maintain concentrations in uranium mines under the "working level", and under 3 WL (546 pCi ^{222}Rn per liter of air; 20.2 kBq/m³ measured from 1976 to 1985) 95 percent of the time. The concentration in the air at the (unventilated) Gastein Healing Gallery averages 43 kBq/m³ (about 1.2 nCi/L) with maximal value of 160 kBq/m³ (about 4.3 nCi/L).

Radon emanates naturally from the ground and from some building materials all over the world, wherever traces of uranium or thorium can be found, and particularly in regions with soils containing granite or shale, which have a higher concentration of uranium. In fact, every square mile of surface soil, to a depth of 6 inches (2.6 km² to a depth of 15 cm), contains approximately 1 gram of radium, which releases radon in small amounts to the atmosphere. On a global scale, it is estimated that 2,400 million curies (91 TBq) of radon are released from soil annually. However, not all granitic regions are prone to high emissions of radon. Being a rare gas, it usually migrates freely through faults and fragmented soils, and may accumulate in caves or water. Due to its very small half-life (four days for ^{222}Rn), its concentration decreases very quickly when the distance from the production area increases. Its atmospheric concentration varies greatly depending on the season and conditions. For instance, it has been shown to accumulate in the air if there is a meteorological inversion and little wind.

Because atmospheric radon concentrations are very low, radon-rich water exposed to air continually loses radon by volatilization. Hence, ground water has generally higher concentrations of ^{222}Rn than surface water, because the radon is continuously produced by radioactive decay of ^{226}Ra present in rocks. Likewise, the saturated zone of a soil frequently has a higher radon content than the unsaturated zone because of diffusional losses to the atmosphere. As a below-ground source of water, some springs—including hot springs—contain significant amounts of radon. The towns of Boulder, Montana; Misasa; Bad Kreuznach, Germany; and the country of Japan have radium-rich springs which emit radon. To be classified as a radon mineral water, radon concentration must be above a minimum of 2 nCi/L (74 Bq/L). The activity of radon mineral water reaches 2,000 Bq/L in Merano and 4,000 Bq/L in Lurisia (Italy).

Radon is also found in some petroleum. Because radon has a similar pressure and temperature curve as propane, and oil refineries separate petrochemicals based on their boiling points, the piping carrying freshly separated propane in oil refineries can become partially radioactive due to radon decay particles. Residues from the oil and gas industry often contain radium and its daughters. The sulfate scale from an oil well can be radium rich, while the water, oil, and gas from a well often contains radon. The radon decays to form solid radioisotopes which form coatings on the inside of pipework. In an oil processing plant, the area of the plant where propane is processed is often one of the more contaminated areas, because radon has a similar boiling point as propane.

Accumulation in dwellings



Typical Lognormal radon distribution in dwellings.

Typical domestic exposures are of $\approx 100 \text{ Bq/m}^3$ indoors, but specifics of construction and ventilation strongly affect levels of accumulation; a further complication for risk assessment is that concentrations in a single location may differ by a factor of two over an hour, and concentrations can vary greatly even between two adjoining rooms in the same structure.

The distribution of radon concentrations tends to be asymmetrical around the average, the larger concentrations have a disproportionately greater weight. Indoor radon concentration is usually assumed to follow a lognormal distribution on a given territory. Thus, the geometric mean is generally used for estimating the "average" radon concentration in an area. The mean concentration ranges from less than 10 Bq/m^3 to over 100 Bq/m^3 in some European countries. Typical geometric standard deviations found in studies range between 2 and 3, meaning (given the 68-95-99.7 rule) that the radon concentration is expected to be more than a hundred times the mean concentration for 2 to 3% of the cases.

That radon levels in particular dwellings can occasionally be orders of magnitude higher than typical was dramatized by the 1984 "Watras Incident," in which an employee at a U.S. nuclear plant triggered radiation monitors while leaving work over several days—despite the fact that the plant had yet to be fueled, and despite the employee being decontaminated and sent home "clean" each evening. This implied a source of contamination outside the plant, which turned out to be radon levels of $100,000 \text{ Bq/m}^3$ (2.7 nCi/L) in the worker's basement. The lung cancer risk associated with living in that house was compared to the extrapolated risk from smoking 135 packs of cigarettes daily.

Radon soon became a standard homeowner concern, though typical domestic exposures are two to three order of magnitude lower (100 Bq/m³, or 2.5 pCi/L), making individual testing essential to assessment of radon risk in any particular dwelling.

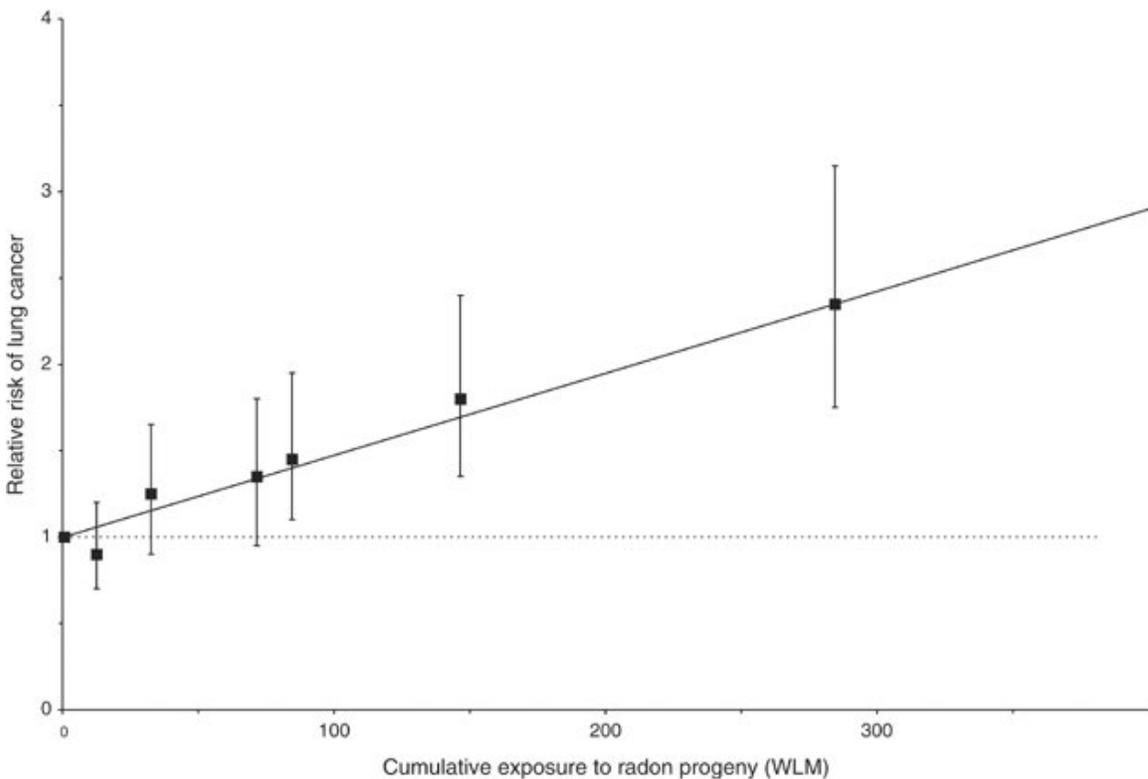
The highest average radon concentrations in the United States are found in Iowa and in the Appalachian Mountain areas in southeastern Pennsylvania. Some of the highest readings have been recorded in Mallow, County Cork, Ireland. Iowa has the highest average radon concentrations in the United States due to significant glaciation that ground the granitic rocks from the Canadian Shield and deposited it as soils making up the rich Iowa farmland. Many cities within the state, such as Iowa City, have passed requirements for radon-resistant construction in new homes. In a few locations, uranium tailings have been used for landfills and were subsequently built on, resulting in possible increased exposure to radon.

Jewelry contamination

In the early 20th century, ²¹⁰Pb-contaminated gold, from gold seeds which had held ²²²Rn, was melted down and made into a small number of jewelry pieces, such as rings, in the U.S. Wearing such a contaminated ring could lead to a skin exposure of 10 to 100 millirad/day (0.4 to 4 mSv/h)

Health effects

Cancer in miners



Relative risk of lung cancer mortality by cumulative exposure to radon decay products (in WLM) from the combined data from 11 cohorts of underground hard rock miners. Though high exposures (>50 WLM) cause statistically significant excess cancers, the evidence on small exposures (10 WLM) is inconclusive and appears slightly beneficial in this study.

The health effects of high exposure to radon in mines, where exposures reaching 1,000,000 Bq/m³ can be found, can be recognized in Paracelsus' 1530 description of a wasting disease of miners, the *mala metallorum*. Though at the time radon itself was not understood to be the cause—indeed, neither it nor radiation had even been discovered—minerologist Georg Agricola recommended ventilation of mines to avoid this mountain sickness (*Bergsucht*). In 1879, the "wasting" was identified as lung cancer by Herting and Hesse in their investigation of miners from Schneeberg, Germany.

Beyond mining in general, radon is a particular problem in the mining of uranium; significant excess lung cancer deaths have been identified in epidemiological studies of uranium miners and other hard-rock miners employed in the 1940s and 1950s.

The first major studies with radon and health occurred in the context of uranium mining, first in the Joachimsthal region of Bohemia and then in the Southwestern United States during the early Cold War. Because radon is a product of the radioactive decay of uranium, underground uranium mines may have high concentrations of radon. Many uranium miners in the Four Corners region contracted lung cancer and other pathologies as a result of high levels of exposure to radon in the mid-1950s. The increased incidence of lung cancer was particularly pronounced among Native American and Mormon miners, because those groups normally have low rates of lung cancer. Safety standards requiring expensive ventilation were not widely implemented or policed during this period.

In studies of uranium miners, workers exposed to radon levels of 50 to 150 picocuries of radon per liter of air (2000–6000 Bq/m³) for about 10 years have shown an increased frequency of lung cancer. Statistically significant excesses in lung cancer deaths were present after cumulative exposures of less than 50 WLM. There is, however, unexplained heterogeneity in these results (whose confidence interval do not always overlap). The size of the radon-related increase in lung cancer risk varied by more than an order of magnitude between the different studies.

Heterogeneities are possibly due to systematic errors in exposure ascertainment, unaccounted for differences in the study populations (genetic, lifestyle, etc.), or confounding mine exposures. There are a number of confounding factors to consider, including exposure to other agents, ethnicity, smoking history, and work experience. The cases reported in these miners cannot be attributed solely to radon or radon daughters but may be due to exposure to silica, to other mine pollutants, to smoking, or to other causes. The majority of miners in the studies are smokers and all inhale dust and other pollutants in mines. Because radon and cigarette smoke both cause lung-cancer, and since the effect

of smoking is far above that of radon, it is complicated to disentangle the effects of the two kinds of exposure; misinterpreting the smoking habit by a few percent can blur out the radon effect.

Since that time, ventilation and other measures have been used to reduce radon levels in most affected mines that continue to operate. In recent years, the average annual exposure of uranium miners has fallen to levels similar to the concentrations inhaled in some homes. This has reduced the risk of occupationally induced cancer from radon, although it still remains an issue both for those who are currently employed in affected mines and for those who have been employed in the past. The power to detect any excess risks in miners nowadays is likely to be small, exposures being much smaller than in the early years of mining.

Health risks

Radon-222 has been classified by International Agency for Research on Cancer as being carcinogenic to humans. In September 2009, the World Health Organization released a comprehensive global initiative on radon that recommended a reference level of 100 Bq/m³ for radon, urging establishment or strengthening of radon measurement and mitigation programs as well as development building codes requiring radon prevention measures in homes under construction. Elevated lung cancer rates have been reported from a number of cohort and case-control studies of underground miners exposed to radon and its decay products. There is sufficient evidence for the carcinogenicity of radon and its decay products in humans for such exposures.

The primary route of exposure to radon and its progeny is inhalation. Radiation exposure from radon is indirect. The health hazard from radon does not come primarily from radon itself, but rather from the radioactive products formed in the decay of radon. The general effects of radon to the human body are caused by its radioactivity and consequent risk of radiation-induced cancer. Lung cancer is the only observed consequence of high concentration radon exposures; both human and animal studies indicate that the lung and respiratory system are the primary targets of radon daughter-induced toxicity.

Radon has a short half-life (4 days) and decays into other solid particulate radium-series radioactive nuclides. Two of these decay products, polonium-218 and 214, present a significant radiologic hazard. If the gas is inhaled, the radon atoms decay in the airways or the lungs, resulting in radioactive polonium and ultimately lead atoms attaching to the nearest tissue. If dust or aerosol is inhaled that already carries radon decay products, the deposition pattern of the decay products in the respiratory tract depends on the behaviour of the particles in the lungs. Smaller diameter particles diffuse further into the respiratory system, whereas the larger - tens to hundreds of micron-sized - particles often deposit higher in the airways and are cleared by the body's mucociliary staircase. Deposited radioactive atoms or dust or aerosol particles continue to decay, causing continued exposure by emitting energetic alpha radiation with some associated gamma radiation too, that can damage vital molecules in lung cells, by either creating free radicals or causing DNA breaks or damage, perhaps causing mutations that sometimes turn

cancerous. In addition, through ingestion and blood transport, following crossing of the lung membrane by radon, radioactive progeny may also be transported to other parts of the body.

The risk of lung cancer caused by smoking is much higher than the risk of lung cancer caused by indoor radon. Radiation from radon has been attributed to increase of lung cancer among smokers too. It is generally believed that exposure to radon and cigarette smoking are synergistic; that is, that the combined effect exceeds the sum of their independent effects. This is because the daughters of radon often become attached to smoke and dust particles, and are then able to lodge in the lungs.

It is unknown whether radon causes other types of cancer, but recent studies suggest a need for further studies to assess the relationship between radon and leukemia.

The effects of radon, if found in food or drinking water, are unknown. Following ingestion of radon dissolved in water, the biological half-life for removal of radon from the body ranges from 30 to 70 minutes. More than 90% of the absorbed radon is eliminated by exhalation within 100 minutes, By 600 minutes, only 1% of the absorbed amount remains in the body.

Effective dose and cancer risks estimations

UNSCEAR recommends a reference value of $9 \text{ nSv (Bq}\cdot\text{h/m}^3)^{-1}$. This means that people living permanently (8760 h/year) in a high concentration of 1000 Bq/m^3 receive a dose of 80 mSv/year.

Studies of miners exposed to radon and its decay products provide a direct basis for assessing their lung cancer risk. The BEIR VI report, entitled *Health Effects of Exposure to Radon*, reported an excess relative risk from exposure to radon that was equivalent to 1.8 % per megabecquerel hours per cubic meter ($\text{MBq}\cdot\text{h/m}^3$) (95% confidence interval: 0.3, 35) for miners with cumulative exposures below $30 \text{ MBq}\cdot\text{h/m}^3$. Estimates of risk per unit exposure are 5.38×10^{-4} per WLM; 9.68×10^{-4} /WLM for ever smokers; and 1.67×10^{-4} per WLM for never smokers.

According to the UNSCEAR modeling, based on these miner's studies, the excess relative risk from long-term residential exposure to radon at 100 Bq/m^3 is considered to be about 0.16 (after correction for uncertainties in exposure assessment), with about a threefold factor of uncertainty higher or lower than that value. In other words, the absence of ill effects (or even positive hormesis effects) at 100 Bq/m^3 are compatible with the known data.

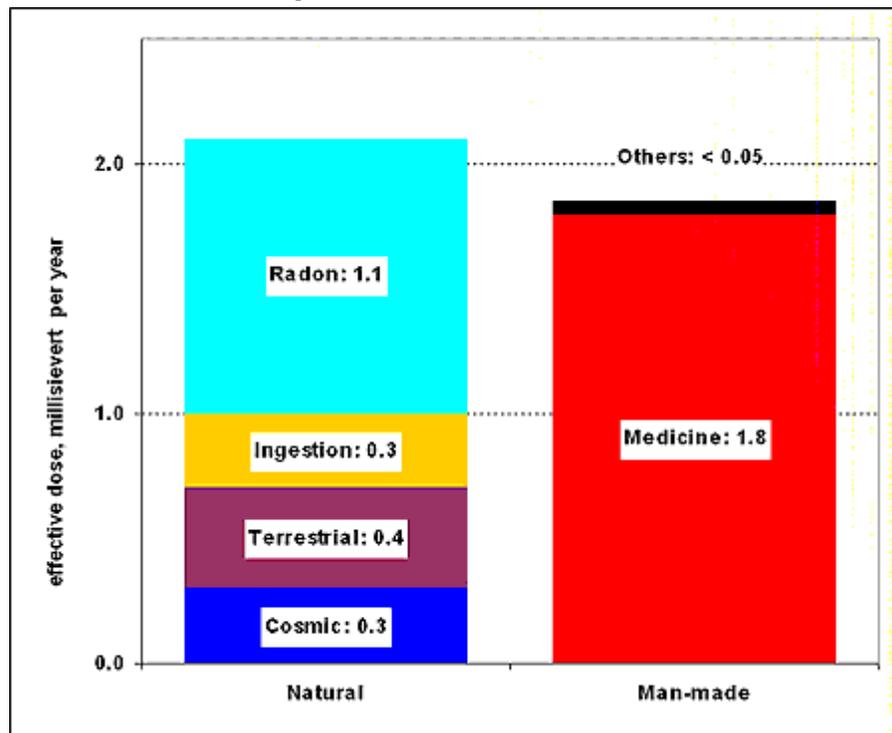
The ICPR 65 model follows the same approach, and estimates the relative life long risk probability of radon-induced cancer death to 1.23×10^{-6} per $\text{Bq}/(\text{m}^3\cdot\text{year})$. This relative risk is a global indicator; the risk estimation is independent of sex, age, or smoking habit. Thus, if a smoker's chances of dying of lung cancer are 10 times that of a nonsmoker's, the relative risks for a given radon exposure will be the same according to that model,

meaning that the absolute risk of a radon-generated cancer for a smoker is (implicitly) tenfold that of a nonsmoker. The risk estimates correspond to a unit risk of approximately $3-6 \times 10^{-5}$ per Bq/m^3 , assuming a lifetime risk of lung cancer of 3%. This means that a person living in an average European dwelling with $50 \text{ Bq}/\text{m}^3$ has a lifetime excess lung cancer risk of $1.5-3 \times 10^{-3}$. Similarly, a person living in a dwelling with a high radon concentration of $1000 \text{ Bq}/\text{m}^3$ has a lifetime excess lung cancer risk of 3–6%, implying a doubling of background lung cancer risk.

The BEIR VI model proposed by the National Academy of Sciences of the USA is more complex. It is a multiplicative model that estimates an excess risk per exposure unit. It takes into account age, elapsed time since exposure, and duration and length of exposure, and its parameters allow for taking smoking habits into account. In the absence of other causes of death, the absolute risks of lung cancer by age 75 at usual radon concentrations of 0, 100, and $400 \text{ Bq}/\text{m}^3$ would be about 0.4%, 0.5%, and 0.7%, respectively, for lifelong nonsmokers, and about 25 times greater (10%, 12%, and 16%) for cigarette smokers.

There is great uncertainty in applying risk estimates derived from studies in miners to the effects of residential radon, and direct estimates of the risks of residential radon are needed.

Studies on domestic exposure



Average radiation doses received in Germany. Radon accounts for half of the background dose; and medical doses reach the same levels as background dose.

The largest natural contributor to public radiation dose is radon, a naturally occurring, radioactive gas found in soil and rock, which comprises approximately 55% of the annual background dose. Radon gas levels vary by locality and the composition of the underlying soil and rocks.

Radon (at concentrations encountered in mines) was recognized as carcinogenic in the 1980s, in view of the lung cancer statistics for miners' cohorts. Although radon may present significant risks, thousands of people annually go to radon-contaminated mines for deliberate exposure to help with the symptoms of arthritis without any serious health effects.

Radon as a terrestrial source of background radiation is of particular concern because, although overall very rare, where it does occur it often does so in high concentrations. Some of these areas, including parts of Cornwall and Aberdeenshire have high enough natural radiation levels that nuclear licensed sites cannot be built there—the sites would already exceed legal limits before they opened, and the natural topsoil and rock would all have to be disposed of as low-level nuclear waste. People in affected localities can receive up to 10 mSv per year background radiation.

This led to a health policy problem: what is the health impact of exposure to radon concentrations (100 Bq/m^3) typically found in some buildings?

Detection methods

When exposure to a carcinogenic substance is suspected, the cause/effect relationship on any given case can never be ascertained. Lung cancer occurs spontaneously, and there is no difference between a "natural" cancer and another one caused by radon (or smoking). Furthermore, it takes years for a cancer to develop, so that determining the past exposure of a case is usually very approximative. The health effect of radon can only be demonstrated through theory and statistical observation.

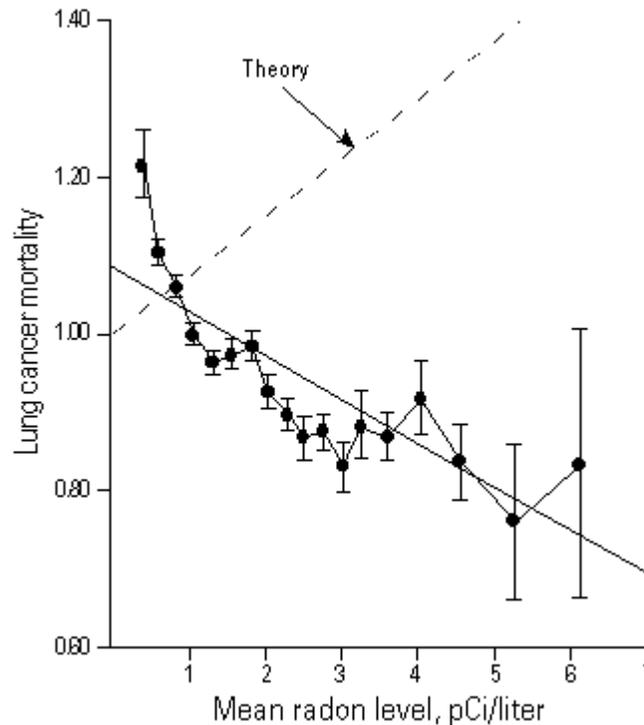
The Study design for epidemiological methods may be of three kinds:

- The best proofs come from observations of cohorts (predetermined populations with known exposures and exhaustive follow-up), such as those on miners, or on Hiroshima and Nagasaki survivors. Such studies are efficient, but very costly when the population needs to be a large one. Such studies can only be used when the effect is strong enough, hence, for high exposures.
- Alternate proofs are case-control studies (the environment factors of a "case" population is individually determined, and compared to that of a "control" population, to see what the difference might have been, and which factors may be significant), like the ones that have been used to demonstrate the link between lung cancer and smoking. Such studies can identify key factors when the signal/noise ratio is strong enough, but are very sensitive to selection bias, and prone to the existence of confounding factors.

- Lastly, ecological studies may be used (where the global environment variables and their global effect on two different populations are compared). Such studies are “cheap and dirty”: they can be easily conducted on very large populations (the whole USA, in Dr Cohen's study), but are prone to the existence of confounding factors, and exposed to the ecological fallacy problem.

Furthermore, theory and observation must confirm each other for a relationship to be accepted as fully proven. Even when a statistical link between factor and effect appears significant, it must be backed by a theoretical explanation; and a theory is not accepted as factual unless confirmed by observations.

Epidemiology studies of domestic exposures



A controversial epidemiological study showing increased cancer risk vs. radon domestic exposure (5 pCi/L \approx 200 Bq/m³). This study lacks individual level controls for smoking and radon exposure, and therefore lacks statistical power to draw conclusions on what would be radiation hormesis. Because of this the error bars (which simply reflect the raw data variability) are probably too small.

Cohort studies are impractical for the study of domestic radon exposure. The expected effect of small exposures being very small, the direct observation of this effect would require huge cohorts: the populations of whole countries.

Several ecological studies have been performed to assess possible relationships between selected cancers and estimated radon levels within particular geographic regions where environmental radon levels appear to be higher than other geographic regions. Results of

such ecological studies are mixed; both positive and negative associations, as well as no significant associations, have been suggested.

The most direct way to assess the risks posed by radon in homes is through case-control studies.

The studies have not produced a definitive answer, primarily because the risk is likely to be very small at the low exposure encountered from most homes and because it is difficult to estimate radon exposures that people have received over their lifetimes. In addition, it is clear that far more lung cancers are caused by smoking than are caused by radon.

Epidemiologic radon studies have found trends to increased lung cancer risk from radon with a no evidence of a threshold, and evidence against a threshold above high as 150 Bq/m³ (almost exactly the EPA's action level of 4 pCi/L). Another study similarly found that there is no evidence of a threshold but lacked the statistical power to clearly identify the threshold at this low level. Notably, the latter deviance from zero at low level convinced the World Health Organization that, "The dose-response relation seems to be linear without evidence of a threshold, meaning that the lung cancer risk increases proportionally with increasing radon exposure."

The most elaborate case-control epidemiologic radon study performed by R. William Field and colleagues identified a 50% increased lung cancer risk with prolonged radon exposure at the EPA's action level of 4 pCi/L. Iowa has the highest average radon concentrations in the nation and a very stable population which added to the strength of the study. For that study, the odds ratio was found to be increased slightly above the confidence interval (95% CI) for cumulative radon exposures above 17 WLM (6.2 pCi/L=230 Bq/m³ and above).

The results of a methodical ten-year-long, case-controlled study of residential radon exposure in Worcester County, Massachusetts, found an apparent 60% *reduction* in lung cancer risk amongst people exposed to low levels (0–150 Bq/m³) of radon gas; levels typically encountered in 90% of American homes—an apparent support for the idea of radiation hormesis. In that study, a significant result (95% CI) was obtained for the 75–150 Bq/m³ category. The study paid close attention to the cohort's levels of smoking, occupational exposure to carcinogens and education attainment. However, unlike the majority of the residential radon studies, the study was not population-based. Errors in retrospective exposure assessment could not be ruled out in the finding at low levels. Other studies into the effects of domestic radon exposure have not reported a hormetic effect; including for example the respected "Iowa Radon Lung Cancer Study" of Field et al. (2000), which also used sophisticated radon exposure dosimetry.

Intentional exposure

"Radon therapy" is an intentional exposure to radon via inhalation or ingestion. Nevertheless, epidemiological evidence shows a clear link between breathing high concentrations of radon and incidence of lung cancer.

Arthritis

In the late 20th century and early 21st century, some "health mines" were established in Basin, Montana which attracted people seeking relief from health problems such as arthritis through limited exposure to radioactive mine water and radon. The practice is controversial because of the "well-documented ill effects of high-dose radiation on the body." Radon has nevertheless been found to induce beneficial long-term effects.

Bathing

Radioactive water baths have been applied since 1906 in Jáchymov, Czech Republic, but even before radon discovery they were used in Bad Gastein, Austria. Radium-rich springs are also used in traditional Japanese onsen in Misasa, Tottori prefecture. Drinking therapy is applied in Bad Brambach, Germany. Inhalation therapy is carried out in Gasteiner-Heilstollen, Austria, in Kowary, Poland and in Boulder, Montana, United States. In the United States and Europe there are several "radon spas," where people sit for minutes or hours in a high-radon atmosphere in the belief that low doses of radiation will invigorate or energize them.

Radiotherapy

Radon has been produced commercially for use in radiation therapy, but for the most part has been replaced by radionuclides made in accelerators and nuclear reactors. Radon has been used in implantable seeds, made of gold or glass, primarily used to treat cancers. The gold seeds were produced by filling a long tube with radon pumped from a radium source, the tube being then divided into short sections by crimping and cutting. The gold layer keeps the radon within, and filters out the alpha and beta radiations, while allowing the gamma rays to escape (which kill the diseased tissue). The activities might range from 0.05 to 5 millicuries per seed (2 to 200 MBq). The gamma rays are produced by radon and the first short-lived elements of its decay chain (^{218}Po , ^{214}Pb , ^{214}Bi , ^{214}Po).

Radon and its first decay products being very short-lived, the seed is left in place. After 12 half-lives (43 days), radon radioactivity is at 1/2000 of its original level. At this stage, the predominant residual activity is due to the radon decay product ^{210}Pb , whose half-life (22.3 year) is 2000 times that of radon (and whose activity is thus 1/2000 of radon's), and its descendants ^{210}Bi and ^{210}Po , totalizing 0.03% of the initial seed activity.

Health policies on public exposure

Dose-effect model retained

Radon has been recognized as carcinogenic to humans at high concentrations, based on miners studies. The highly publicized case of Stanley Watras showed that radon concentration could reach the levels found in mines, where it is considered a health hazard. This led to awareness of radiation resulting from radon.

The only dose-effect relationship available are those of miners cohorts (for much higher exposures), exposed to radon. Studies of Hiroshima and Nagasaki survivors are less informative (the exposure to radon is chronic, localized, and the ionizing radiations are alpha rays). Although low-exposed miners experienced exposures comparable to longterm residence in high-radon dwellings, the mean cumulative exposure among miners is approximately 30-fold higher than that associated with long-term residency in a typical home. It can be concluded from miner studies that when the radon exposure in dwellings compares to that in mines (above 1000 Bq/m³), radon is a proven health hazard; but in the 1980s very little was known on the dose-effect relationship, both theoretically and statistical.

Studies have been made since the 1980s, both on epidemiological studies and in the radiobiology field. In the radiobiology and carcinogenesis studies, progress has been made in understanding the first steps of cancer development, but not to the point of validating a reference dose-effect model. The only certainty gained is that the process is very complex, the resulting dose-effect response being complex, and most probably not a linear one. Biologically based models have also been proposed that could project substantially reduced carcinogenicity at low doses. In the epidemiological field, no definite conclusion has been reached. However, from the evidence now available, a threshold exposure, that is, a level of exposure below which there is no effect of radon, cannot be excluded.

Given the radon distribution observed in dwellings, and the dose-effect relationship proposed by a given model, a theoretical number of victims can be calculated, and serve as a basis for public health policies.

With the BEIR VI model, the main health impact (nearly 75% of the death toll) is to be found at low radon concentration exposures, because most of the population (about 90%) lives in the 0-200 Bq/m³ range. Under this modeling, the best policy is obviously to reduce the radon levels of all homes where the radon level is above average, because this leads to a significant decrease of radon exposure on a significant fraction of the population; but this effect is predicted in the 0-200 Bq/m³ range, where the linear model has its maximum uncertainty. From the statistical evidence available, a threshold exposure cannot be excluded; if such a threshold exists, the real radon health impact would in fact be limited to those homes where the radon concentrations reaches that observed in mines - at most a few percent. If a radiation hormesis effect exists after all, the situation would be even worse: under that hypothesis, suppressing the natural low

exposure to radon (in the 0-200 Bq/m³ range) would actually lead to an increase of cancer incidence, due to the suppression of this (hypothetical) protecting effect. Since the low-dose response is unclear, the choice of a model is very controversial. As the saying goes, “guess if you can, choose if you dare”

No conclusive statistics being available for the levels of exposure usually found in homes, the risks posed by domestic exposures is usually estimated on the basis of observed lung-cancer deaths caused by higher exposures in mines, under the assumption that the risk of developing lung-cancer increases linearly as the exposure increases. This was the basis for the model proposed by BEIR IV in the 1980s. The linear no-threshold model has since been kept in a conservative approach by the UNSCEAR report and the BEIR VI and BEIR VII publications, essentially for lack of a better choice:

Until the [...] uncertainties on low-dose response are resolved, the Committee believes that [*the linear no-threshold model*] is consistent with developing knowledge and that it remains, accordingly, the most scientifically defensible approximation of low-dose response. However, a strictly linear dose response should not be expected in all circumstances.

The BEIR VI committee adopted the linear no-threshold assumption based on its understanding of the mechanisms of radon-induced lung cancer, but recognized that this understanding is incomplete and that therefore the evidence for this assumption is not conclusive.

Death toll attributed to radon

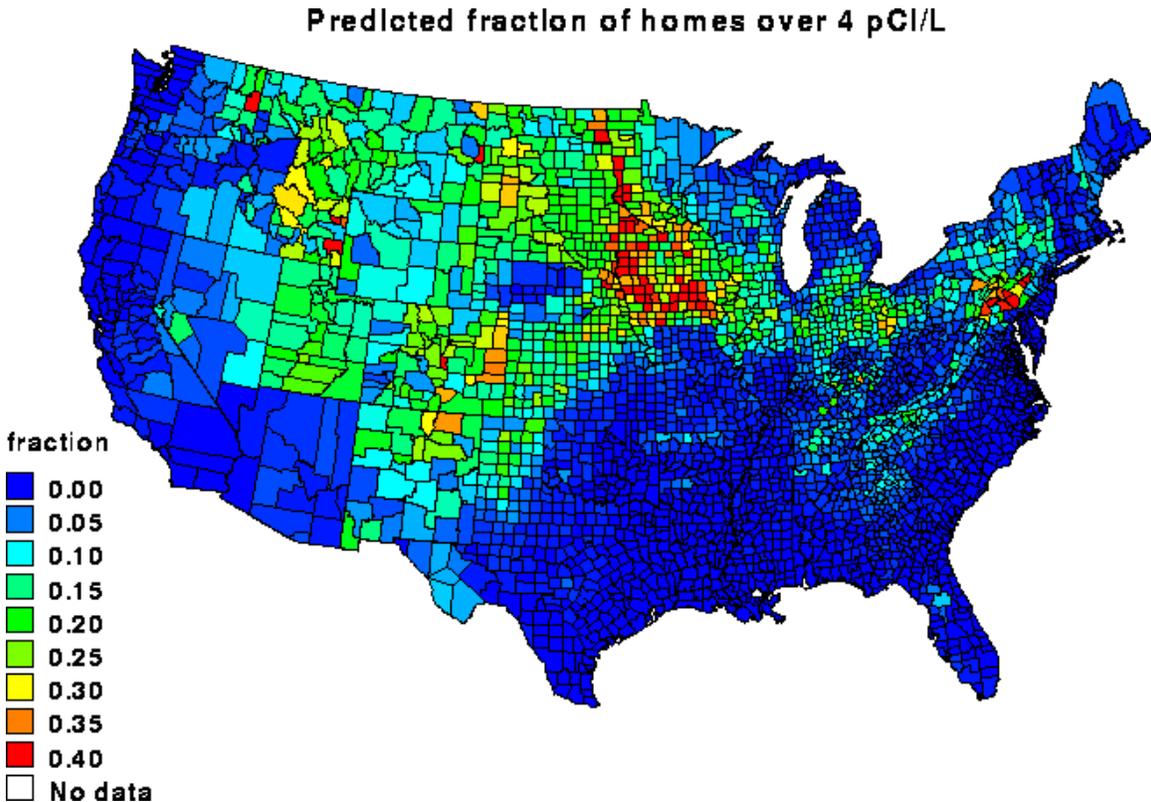
In discussing these figures, it should be kept in mind that both the radon distribution in dwelling and its effect at low exposures are not precisely known, and the radon health impact has to be computed (deaths caused by radon domestic exposure cannot be observed as such). These estimations are strongly dependent on the model retained.

According to these models, radon exposure is thought to be the second major cause of lung cancer after smoking. Iowa has the highest average radon concentration in the United States; studies performed there have demonstrated a 50% increased lung cancer risk with prolonged radon exposure above the EPA's action level of 4 pCi/L.

Based on studies carried out by the National Academy of Sciences in the United States, radon would thus be the second leading cause of lung cancer after smoking, and accounts for 15,000 to 22,000 cancer deaths per year in the US alone. The United States Environmental Protection Agency (EPA) says that radon is the number one cause of lung cancer among non-smokers. The general population is exposed to small amounts of polonium as a radon daughter in indoor air; the isotopes ²¹⁴Po and ²¹⁸Po are thought to cause the majority of the estimated 15,000–22,000 lung cancer deaths in the US every year that have been attributed to indoor radon. The Surgeon General of the United States has reported that over 20,000 Americans die each year of radon-related lung cancer.

In the United Kingdom, residential radon would be, after cigarette smoking, the second most frequent cause of lung cancer deaths: according to models, 83.9% of deaths are attributed to smoking only, 1.0% to radon only, and 5.5% to a combination of radon and smoking.

Radon concentration guidelines



Predicted fraction of homes exceeding the EPA's recommended action level of 4 pCi/L

The World Health Organization has recommended a radon reference concentration of 100 Bq/m³ (2.7 pCi/L). The European Union recommends that action should be taken starting from concentrations of 400 Bq/m³ (11 pCi/L) for older dwellings and 200 Bq/m³ (5 pCi/L) for newer ones. After publication of the North American and European Pooling Studies, Health Canada proposed a new guideline that lowers their action level from 800 to 200 Bq/m³ (22 to 5 pCi/L). The United States Environmental Protection Agency (EPA) strongly recommends action for any dwelling with a concentration higher than 148 Bq/m³ (4 pCi/L), and encourages action starting at 74 Bq/m³ (2 pCi/L).

EPA recommends that all homes should be monitored for radon. If testing shows levels less than 4 picocuries radon per liter of air (160 Bq/m³), then no action is necessary. For levels of 20 picocuries radon per liter of air (800 Bq/m³) or higher, the home owner should consider some type of procedure to decrease indoor radon levels. For instance,

since radon has a half-life of four days, opening the windows once a day can cut the mean radon concentration to one fourth of its level.

The United States Environmental Protection Agency (EPA) recommends homes be fixed if an occupant's long-term exposure will average 4 picocuries per liter (pCi/L) that is 148 Bq/m³. EPA estimates that one in 15 homes in the United States has radon levels above the recommended guideline of 4 pCi/L. EPA radon risk level tables including comparisons to other risks encountered in life are available in their citizen's guide. The EPA estimates that nationally, 8% to 12% of all dwellings are above their maximum "safe levels" (four picocuries per liter—the equivalent to roughly 200 chest x-rays). The United States Surgeon General and the EPA both recommend that all homes be tested for radon.

The limits retained do not correspond to a known threshold in the biological effect, but are determined by a cost-efficiency analysis. EPA believes that a 150 Bq/m³ level (4 pCi/L) is achievable in the vast majority of homes for a reasonable cost, the average cost per life saved by using this action level is about \$700,000.

For radon concentration in drinkable water, the World Health Organization issued as guidelines (1988) that remedial action should be considered when the radon activity exceeded 100 kBq/m³ in a building, and remedial action should be considered *without long delay* if exceeding 400 kBq/m³.

Radon testing



A radon test kit.

There are relatively simple tests for radon gas, but these tests are not commonly done, even in areas of known systematic hazards. Radon test kits are commercially available. The short-term radon test kits used for screening purposes are inexpensive, in many cases free. The kit includes a collector that the user hangs in the lowest livable floor of the dwelling for 2 to 7 days. The user then sends the collector to a laboratory for analysis.

The National Environmental Health Association provides a list of radon measurement professionals.

Long term kits, taking collections for up to one year, are also available. An open-land test kit can test radon emissions from the land before construction begins. The EPA and the National Environmental Health Association have identified 15 types of radon testing. A Lucas cell is one type of device.

Radon levels fluctuate naturally. An initial test might not be an accurate assessment of a home's average radon level. Transient weather can affect short term measurements. Therefore, a high result (over 4 pCi/L) justifies repeating the test before undertaking more expensive abatement projects. Measurements between 4 and 10 pCi/L warrant a long term radon test. Measurements over 10 pCi/L warrant only another short term test so that abatement measures are not unduly delayed. Purchasers of real estate are advised to delay or decline a purchase if the seller has not successfully abated radon to 4 pCi/L or less.

Since radon concentrations vary substantially from day to day, single grab-type measurements are generally not very useful, except as a means of identifying a potential problem area, and indicating a need for more sophisticated testing.

Mitigation

Transport of radon in indoor air is almost entirely controlled by the ventilation rate in the enclosure. Generally, the indoor radon concentrations increase as ventilation rates decrease. In a well ventilated place, the radon concentration tends to align with outdoor values (typically 10 Bq/m³, ranging from 1 to 100 Bq/m³).

Radon levels in indoor air can be lowered in a number of ways, from sealing cracks in floors and walls to increasing the ventilation rate of the building. The five principal ways of reducing the amount of radon accumulating in a dwelling are:

- Improving the ventilation of the dwelling and avoiding the transport of radon from the basement into living rooms;
- Increasing under-floor ventilation;
- Installing a radon sump system in the basement;
- Sealing floors and walls; and
- Installing a positive pressurization or positive supply ventilation system.

The half-life for radon is 3.8 days, indicating that once the source is removed, the hazard will be greatly reduced within a few weeks.

Positive-pressure ventilation systems can be combined with a heat exchanger to recover energy in the process of exchanging air with the outside, and simply exhausting basement air to the outside is not necessarily a viable solution as this can actually draw radon gas *into* a dwelling. Homes built on a crawl space may benefit from a radon collector installed under a "radon barrier" (a sheet of plastic that covers the crawl space).

ASTM E-2121 is a standard for reducing radon in homes as far as practicable below 4 picocuries per liter (pCi/L) in indoor air.

The National Environmental Health Association and the National Radon Safety Board administer voluntary National Radon Proficiency Programs for radon professionals consisting of individuals and companies wanting to take training courses and examinations to demonstrate their competency. A list of mitigation service providers is available. Indoor radon can be mitigated by sealing basement foundations, water drainage, or by sub-slab de-pressurization. In severe cases, mitigation can use air pipes and fans to exhaust sub-slab gases to the outside. Indoor ventilation systems are more effective, but exterior ventilation can be cost-effective in some cases.

Chapter- 5

Indoor Air Quality

Indoor air quality (IAQ) is a term referring to the air quality within and around buildings and structures, especially as it relates to the health and comfort of building occupants.

IAQ can be affected by microbial contaminants (mold, bacteria), gases (including carbon monoxide, radon, volatile organic compounds), particulates, or any mass or energy stressor that can induce adverse health conditions. Indoor air is becoming an increasingly more concerning health hazard than outdoor air. Using ventilation to dilute contaminants, filtration, and source control are the primary methods for improving indoor air quality in most buildings.

Determination of IAQ involves the collection of air samples, monitoring human exposure to pollutants, collection of samples on building surfaces and computer modelling of air flow inside buildings.

Common pollutants

Radon

Radon is an invisible, radioactive atomic gas that results from the radioactive decay of radium, which may be found in rock formations beneath buildings or in certain building materials themselves. Radon is probably the most pervasive serious hazard for indoor air in the United States and Europe, probably responsible for tens of thousands of deaths from lung cancer each year. There are relatively simple tests for radon gas, but these tests are not commonly done, even in areas of known systematic hazards. Radon is a heavy gas and thus will tend to accumulate at the floor level. Building materials can actually be a significant source of radon, but little testing is done for stone, rock or tile products brought into building sites; radon accumulation is greatest for well insulated homes. The half life for radon is 3.8 days, indicating that once the source is removed, the hazard will be greatly reduced within a few weeks. However annually thousands of people go to radon contaminated mines for purposeful exposure to help with the symptoms of arthritis without any serious known health effects, though lung cancer can take many years to develop. Radon mitigation methods include sealing concrete slab floors, basement

foundations, water drainage systems, or by increasing ventilation. They are usually cost effective and can greatly reduce or even eliminate the contamination and the associated health risks.

Molds and other allergens

These biological chemicals can arise from a host of means, but there are two common classes: (a) moisture induced growth of mold colonies and (b) natural substances released into the air such as animal dander and plant pollen. Moisture buildup inside buildings may arise from water penetrating compromised areas of the building envelope or skin, from plumbing leaks, from condensation due to improper ventilation, or from ground moisture penetrating a building part. In areas where cellulosic materials (paper and wood, including drywall) become moist and fail to dry within 48 hours, mold mildew can propagate and release allergenic spores into the air.

In many cases, if materials have failed to dry out several days after the suspected water event, mold growth is suspected within wall cavities even if it is not immediately visible. Through a mold investigation, which may include destructive inspection, one should be able to determine the presence or absence of mold. In a situation where there is visible mold and the indoor air quality may have been compromised, mold remediation may be needed. Mold testing and inspections should be done by an independent investigator to avoid any conflict of interest and to insure accurate results; free mold testing offered by remediation companies is not recommended.

There are some varieties of mold that contain toxic compounds (mycotoxins). However, exposure to hazardous levels of mycotoxin via inhalation is not possible in most cases, as toxins are produced by the fungal body and are not at significant levels in the released spores. The primary hazard of mold growth, as it relates to indoor air quality, comes from the allergenic properties of the spore cell wall. More serious than most allergenic properties is the ability of mold to trigger episodes in persons that already have asthma, a serious respiratory disease.

Mold is always associated with moisture, and its growth can be inhibited by keeping humidity levels below 50%. Moisture problems causing mold growth can be direct such as a water leaks and/or indirect such as condensation due to humidity levels.

Carbon monoxide

One of the most acutely toxic indoor air contaminants is carbon monoxide (CO), a colorless, odorless gas that is a byproduct of incomplete combustion of fossil fuels. Common sources of carbon monoxide are tobacco smoke, space heaters using fossil fuels, defective central heating furnaces and automobile exhaust. Improvements in indoor levels of CO are systematically improving from increasing numbers of smoke-free restaurants and other legislated non-smoking buildings. By depriving the brain of oxygen, high levels of carbon monoxide can lead to nausea, unconsciousness and death.

According to the American Conference of Governmental Industrial Hygienists (ACGIH), the time-weighted average (TWA) limit for carbon monoxide (630-08-0) is 25 ppm.

Volatile organic compounds

Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects. Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. VOCs are emitted by a wide array of products numbering in the thousands. Examples include: paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions.

Organic chemicals are widely used as ingredients in household products. Paints, varnishes, and wax all contain organic solvents, as do many cleaning, disinfecting, cosmetic, degreasing, and hobby products. Fuels are made up of organic chemicals. All of these products can release organic compounds during usage, and, to some degree, when they are stored. Testing emissions from building materials used indoors has become increasingly common for floor coverings, paints, and many other important indoor building materials and finishes.

Legionella

Legionellosis or Legionnaire's Disease is caused by a waterborne bacterium *Legionella* that grows best in slow-moving or still, warm water. The primary route of exposure is aerosolization, most commonly from evaporative cooling towers or showerheads. A common source of *Legionella* in commercial buildings is from poorly placed or maintained evaporative cooling towers, which often release aerosolized water that may enter nearby ventilation intakes. Outbreaks in medical facilities and nursing homes, where patients are immuno-suppressed and immuno-weak, are the most commonly reported cases of Legionellosis. More than one case has involved outdoor fountains in public attractions. The presence of *Legionella* in commercial building water supplies is highly under-reported, as healthy people require heavy exposure to acquire infection.

Legionella testing typically involves collecting water samples and surface swabs from evaporative cooling basins, shower heads, faucets, and other locations where warm water collects. The samples are then cultured and colony forming units (cfu) of *Legionella* are quantified as cfu/Liter.

Legionella is a parasite of protozoans such as amoeba, and thus requires conditions suitable for both organisms. The bacterium forms a biofilm which is resistant to chemical and antimicrobial treatments, including chlorine. Remediation for *Legionella* outbreaks in commercial buildings vary, but often include very hot water flushes (160 °F; 70 °C), sterilization of standing water in evaporative cooling basins, replacement of shower heads, and in some cases flushes of heavy metal salts. Preventative measures include

adjusting normal hot water levels to allow for 120°F at the tap, evaluating facility design layout, removing faucet aerators, and periodic testing in suspect areas.

Asbestos fibers

The U.S. Federal Government and some States have set standards for acceptable levels of asbestos fibers in indoor air. Many common building materials used before 1975 contain asbestos, such as some floor tiles, ceiling tiles, taping muds, pipe wrap, mastics and other insulation materials. Normally significant releases of asbestos fiber do not occur unless the building materials are disturbed, such as by cutting, sanding, drilling or building remodelling. There are particularly stringent regulations applicable to schools.

Inhalation of asbestos fibers over long exposure times is associated with increased incidence of lung cancer.

Asbestos is found in older homes and buildings, but it is most dangerous in schools and industrial settings. It was once widely used in shingles, fireproofing, heating systems and floor and ceiling, tiles in older buildings. When asbestos-containing material is damaged or disintegrates, microscopic fibers are dispersed into the air. The risk of lung cancer from inhaling asbestos fibers is also greater to smokers. The symptoms of the disease do not usually appear until about 20 to 30 years after the first exposure to asbestos. Removal of asbestos-containing materials is not always optimal because the fibers can be spread into the air during the removal process. A management program for intact asbestos-containing materials is often recommended instead.

Carbon dioxide

Carbon dioxide (CO₂) is a surrogate for indoor pollutants emitted by humans and correlates with human metabolic activity. Carbon dioxide at levels that are unusually high indoors may cause occupants to grow drowsy, get headaches, or function at lower activity levels. Humans are the main indoor source of carbon dioxide. Indoor levels are an indicator of the adequacy of outdoor air ventilation relative to indoor occupant density and metabolic activity. To eliminate most Indoor Air Quality complaints, total indoor carbon dioxide should be reduced a difference of less than 600 ppm above outdoor levels. NIOSH considers that indoor air concentrations of carbon dioxide that exceed 1,000 ppm are a marker suggesting inadequate ventilation. ASHRAE recommends that carbon dioxide levels not exceed 700 ppm above outdoor ambient levels. The UK standards for schools say that carbon dioxide in all teaching and learning spaces, when measured at seated head height and averaged over the whole day should not exceed 1,500 ppm. The whole day refers to normal school hours (i.e. 9.00am to 3.30pm) and includes unoccupied periods such as lunch breaks. European standards limit carbon dioxide to 3500 ppm. OSHA limits carbon dioxide concentration in the workplace to 5,000 ppm for prolonged periods, and 35,000 ppm for 15 minutes. Exhaust gas leakages can occur from furnace metal exhaust pipes that lead to the chimney when there are leaks in the pipe and the pipe gas flow area diameter has been reduced.

Ozone

Ozone is produced by ultraviolet light from the Sun hitting the Earth's atmosphere (especially in the ozone layer), lightning, certain electric devices (such as air ionisers), and as a byproduct of other types of pollution.

Ozone exists in greater concentrations at altitudes commonly flown by passenger jets. Reactions between ozone and onboard substances, including skin oils and cosmetics, can produce toxic chemicals as byproducts. Ozone itself is also irritating to lung tissue and harmful to human health. Larger jets have ozone filters to reduce the cabin concentration to safer and more comfortable levels.

Outdoor air used for ventilation may have sufficient ozone to react with common indoor pollutants as well as skin oils and other common indoor air chemicals or surfaces. Particular concern is warranted when using "green" cleaning products based on citrus or terpene extracts as these chemicals react very quickly with ozone to form toxic and irritating chemicals as well as fine and ultrafine particles. Ventilation with outdoor air containing elevated ozone concentrations may complicate remediation attempts.

Developing countries

A major source of indoor air pollution in developing countries is the burning of biomass (e.g. wood, charcoal, dung, or crop residue) for heating and cooking. The resulting exposure to high levels of particulate matter resulted in between 1.5 million and 2 million deaths in 2000.

Effect of indoor plants

Houseplants together with the medium in which they are grown can reduce components of indoor air pollution, particularly volatile organic compounds (VOC) such as benzene, toluene, and xylene. Plants can also remove CO₂, which is correlated with lower work performance, from indoor areas. The effect was investigated in one study by NASA for use in spacecrafts. Plants also appear to reduce airborne microbes, molds, and increase humidity. However the presence of plants indoors has also been associated with higher humidity and airborne fungal concentrations.

When CO₂ concentrations are elevated indoors relative to outdoor concentrations, it is only an indicator that ventilation is inadequate to remove metabolic products associated with human occupancy. Plants require CO₂ to grow and release oxygen when they consume CO₂. A study published by the American Chemical Society on October 6, 2009 considered uptake rates of ketones and aldehydes by the peace lily (*Spathiphyllum clevelandii*) and golden pothos (*Epipremnum aureum*.) Akira Tani and C. Nicholas Hewitt found "Longer-term fumigation results revealed that the total uptake amounts were 30–100 times as much as the amounts dissolved in the leaf, suggesting that volatile organic carbons are metabolized in the leaf and/or translocated through the petiole." It is worth noting the researchers sealed the plants in Teflon bags. "No VOC loss was detected

from the bag when the plants were absent. However, when the plants were in the bag, the levels of aldehydes and ketones both decreased slowly but continuously, indicating removal by the plants"

While results do indicate house plants may be effective at removing some VOCs from air supplies, many studies neglect to consider ventilation, reductions when faced with continuous emission rather than burst, and other real world factors. A review of studies between 1989 and 2006 on the performance of houseplants as air cleaners, presented at the Healthy Buildings 2009 conference in Syracuse, NY, concluded "...indoor plants have little, if any, benefit for removing indoor air of VOC in residential and commercial buildings."

Since high humidity is associated with increased mold growth, allergic responses, and respiratory responses, the presence of additional moisture from houseplants may not be desirable in all indoor settings.

HVAC design

Environmentally Sustainable Design concepts also include aspects related to the commercial and residential heating, ventilation and air-conditioning (HVAC) industry. Among several considerations, one of the topics to attended to is the issue of indoor air quality throughout the design and construction stages of a building's life.

One technique to reduce energy consumption while maintaining adequate air quality, is *demand controlled ventilation*. Instead of setting throughput at a fixed air replacement rate, carbon dioxide sensors are used to control the rate dynamically, based on the emissions of actual building occupants.

For the past several years, there have been many debates among indoor air quality specialists about the proper definition of indoor air quality and specifically what constitutes "acceptable" indoor air quality.

One way of quantitatively ensuring the health of indoor air is by the frequency of effective turnover of interior air by replacement with outside air. In the UK, for example, classrooms are required to have 2.5 outdoor air changes per hour. In halls, gym, dining, and physiotherapy spaces, the ventilation should be sufficient to limit carbon dioxide to 1,500 ppm. In the USA, and according to ASHRAE Standards, ventilation in classrooms is based on the amount of outdoor air per occupant plus the amount of outdoor air per unit of floor area, not air changes per hour. Since carbon dioxide indoors comes from occupants and outdoor air, the adequacy of ventilation per occupant is indicated by the concentration indoors minus the concentration outdoors. The value of 615 ppm above the outdoor concentration indicates approximately 15 cubic feet per minute of outdoor air per adult occupant doing sedentary office work where outdoor air contains 385 ppm, the current global average atmospheric CO₂ concentration. In classrooms, the requirements in the ASHRAE standard 62.1, Ventilation for Acceptable Indoor Air Quality, would typically result in about 3 air changes per hour, depending on the occupant density. Of

course the occupants aren't the only source of pollutants, so outdoor air ventilation may need to be higher when unusual or strong sources of pollution exist indoors. When outdoor air is polluted, then bringing in more outdoor air can actually worsen the overall quality of the indoor air and exacerbate some occupant symptoms related to outdoor air pollution. Generally, outdoor country air is better than indoor city air. Exhaust gas leakages can occur from furnace metal exhaust pipes that lead to the chimney when there are leaks in the pipe and the pipe gas flow area diameter has been reduced.

The use of air filters can trap some of the air pollutants. The Department of Energy's Energy Efficiency and Renewable Energy section wrote "[Air] Filtration should have a Minimum Efficiency Reporting Value (MERV) of 13 as determined by ASHRAE 52.2-1999." Air filters are used to reduce the amount of dust that reaches the wet coils. Dust can serve as food to grow molds on the wet coils and ducts and can reduce the efficiency of the coils.

Moisture management and humidity control requires operating HVAC systems as designed. Moisture management and humidity control may conflict with efforts to try to optimize the operation to conserve energy. For example, Moisture management and humidity control requires systems to be set to supply Make Up Air at lower temperatures (design levels), instead of the higher temperatures sometimes used to conserve energy in cooling-dominated climate conditions. However, for most of the US and many parts of Europe and Japan, during the majority of hours of the year, outdoor air temperatures are cool enough that the air does not need further cooling to provide thermal comfort indoors. However, high humidity outdoors creates the need for careful attention to humidity levels indoors. High humidities give rise to mold growth and moisture indoors is associated with a higher prevalence of occupant respiratory problems.

The "dew point temperature" is an absolute measure of the moisture in air. Some facilities are being designed with the design dew points in the lower 50's °F, and some in the upper and lower 40's °F. Some facilities are being designed using desiccant wheels with gas fired heater to dry out the wheel enough to get the required dew points. On those systems, after the moisture is removed from the make up air, a cooling coil is used to lower the temperature to the desired level.

Commercial buildings, and sometimes residential, are often kept under slightly-positive air pressure relative to the outdoors to reduce infiltration. Limiting infiltration helps with moisture management and humidity control.

Dilution of indoor pollutants with outdoor air is effective to the extent that outdoor air is free of harmful pollutants. Ozone in outdoor air occurs indoors at reduced concentrations because ozone is highly reactive with many chemicals found indoors. The products of the reactions between ozone and many common indoor pollutants include organic compounds that may be more odorous, irritating, or toxic than those from which they are formed. These products of ozone chemistry include formaldehyde, higher molecular weight aldehydes, acidic aerosols, and fine and ultrafine particles, among others. The higher the outdoor ventilation rate, the higher the indoor ozone concentration and the

more likely the reactions will occur, but even at low levels, the reactions will take place. This suggests that ozone should be removed from ventilation air, especially in areas where outdoor ozone levels are frequently high. Recent research has shown that mortality and morbidity increase in the general population during periods of higher outdoor ozone and that the threshold for this effect is around 20 parts per billion (ppb).

Institutional programs

The topic of IAQ has become popular due to the greater awareness of health problems caused by mold and triggers to asthma and allergies. Awareness has also been increased by the involvement of the United States Environmental Protection Agency. They have developed an "IAQ Tools for Schools" program to help improve the indoor environmental conditions in educational institutions.

The National Institute for Occupational Safety and Health conducts Health Hazard Evaluations (HHEs) in workplaces at the request of employees, authorized representative of employees, or employers, to determine whether any substance normally found in the place of employment has potentially toxic effects, including indoor air quality.

A variety of scientists work in the field of indoor air quality including chemists, physicists, mechanical engineers, biologists, bacteriologists and computer scientists. Some of these professionals are certified by organizations such as the American Industrial Hygiene Association and the American Indoor Air Quality Council.

On the international level, the International Society of Indoor Air Quality and Climate (ISIAQ), formed in 1991, organizes two major conferences, the Indoor Air and the Healthy Buildings series. ISIAQ's journal *Indoor Air* is published 6 times a year and contains peer-reviewed scientific papers with an emphasis on interdisciplinary studies including exposure measurements, modeling, and health outcomes.

Chapter- 6

Indoor Bioaerosol

Bioaerosols are natural or artificial particles of biological (microbial, plant, or animal) origin suspended in the air. These particles are also referred to as organic dust. Bioaerosols may consist of bacteria, fungi (and spores and cell fragments of fungi), viruses, microbial toxins, pollen, plant fibers, *etc.* Size of bioaerosol particles varies from below 1 μm to 100 μm in aerodynamic diameter; viable bioaerosol particles can be suspended in air as single cells or aggregates of microorganism as small as 1-10 μm in size. Since bioaerosols are potentially related to various human health effects and the indoor environment provides a unique exposure situation, concerns about **indoor bioaerosols** have increased over the last decade.

Sources and Influencing Factors

Sources for indoor environments

Indoor bioaerosols may originate from outdoor air and indoor reservoirs. Although outdoor bioaerosols cannot easily migrate into large buildings with complex ventilation systems, certain categories of outdoor bioaerosols (i.e., fungal spores) do serve as major sources for indoor bioaerosols in naturally ventilated buildings at specific periods of time (i.e., growing seasons for fungi). Major indoor sources for bioaerosols at residential homes include human occupants, pets, house dust, organic waste, as well as the heating, ventilation and air-conditioning (HVAC) system. Several studies have identified human activities as an important source for indoor bioaerosols. Human bodies can generate bioaerosols directly through activities like talking, sneezing, and coughing, while other residential activities (i.e., washing, flushing toilet, sweeping floor) can generate bioaerosols indirectly. Since microorganisms can accumulate and grow on dust particles, house dust is a potential source of bioaerosols. In a study by Wouters *et al.*, they investigated the effects of indoor storage of organic household waste on microbial contamination among 99 households in the Netherlands in the summer of 1997, and indicated that “increased microbial contaminant levels in homes are associated with indoor storage of separated organic waste”, which might elevate “the risk of bioaerosol-related respiratory symptoms in susceptible people”. However, the analysis by Wouters *et al.* was based on the collected samples of settled house dust, which might not serve as a strong indicator for bioaerosols suspended in the air. Other materials in residential

buildings, such as food stuffs, house plants, textiles, wood material and furniture stuffing can also become bioaerosol sources when water content is appropriate for microorganisms to grow. For non-residential buildings, some specific indoor environments, such as hospitals, wastewater treatment plants, composting facilities, certain biotechnical laboratories, have been revealed to have bioaerosol sources related to their particular environmental characteristics.

Factors influencing indoor bioaerosol generation

According to previous studies, major indoor environmental factors influencing bioaerosol concentration include relative humidity, characteristics of air ventilation systems, seasonal variation, temperature, and chemical composition of the air. Other factors, such as the type of home, building material, geographical factors, do not seem to have significant impacts on respirable fungi and bacteria (important constituents of bioaerosols). Relative humidity is one of the most widely studied influencing factors for indoor bioaerosols. Concentrations of two categories of bioaerosols, endotoxin and airborne fungi, are both positively related to indoor relative humidity (higher concentration associated with higher relative humidity). Relative humidity also affects the infectivity of airborne viruses. Regarding the characterization of air ventilation system, increased use of central air conditioning is found to be associated with lower fungal bioaerosol concentration.

Human Health Effects

Adverse health effects/diseases related to indoor bioaerosol exposure can be divided into two categories: those confirmed to be associated with bioaerosol and those suspected but not confirmed to be associated with bioaerosol. Bioaerosols have been revealed to cause certain human diseases, such as tuberculosis, Legionnaires' disease and different forms of bacterial pneumonia, coccidioidomycosis, influenza, measles, and gastrointestinal illness. Bioaerosols are also associated with some noninfectious airway diseases, such as allergies and asthma. As a known component of indoor bioaerosol, $\beta(1\rightarrow3)$ -glucan (cell wall components of most fungi) is proposed to be the causative agent of mold-induced nonallergic inflammatory reactions. It is reported that 25%-30% of allergenic asthma cases in industrialized countries are induced by fungi, which has been the focus of concerns about human exposure to airborne microorganisms in recent years.

Some other human diseases and symptoms have been proposed to be associated with indoor bioaerosol, but no deterministic conclusions could be drawn due to the insufficiency of evidence. One example is the well-know sick building syndrome (SBS). SBS refers to non-specific complaints, such as upper-respiratory irritative symptoms, headaches, fatigue, and rash, which cannot be related to an identifiable cause but are building related. Over the last two decades, there have been many studies indicating association of indoor bioaerosol with sick building syndrome. However, most of the related studies based their conclusions on statistical correlation between concentrations of certain types of bioaerosols and incidence of complaints, which has various drawbacks methodologically. For example, some studies have a small sample size, which critically

undermines the validity of speculations based on the statistical results. Also, many studies were not able to exclude the influences of other factors beside bioaerosol in their analysis, which makes the statistical correlation theoretically inappropriate to support association of SBS with bioaerosols. Additional studies revealed that bioaerosol is unlikely to be the cause of SBS. Recent epidemiological and toxicological studies continued to suggest a possible link between bioaerosol exposure and sick building syndrome, but methodological limitations remained in these studies.

The ability of bioaerosols to cause human disease depend not only on their chemical composition and biological characteristics, but also on the quantity of bioaerosol inhaled and their size distribution, which determines the site of bioaerosol deposition to human respiratory systems. Bioaerosols larger than 10 μm in aerodynamic diameter are generally blocked by the nasal region of the respiratory tract, those between 5-10 μm mainly deposit in the upper respiratory system and usually induce symptoms like allergic rhinitis, and particles with aerodynamic diameter less than 5 μm can reach the alveoli and hence lead to serious illnesses such as allergic alveolitis.

Because of the confirmed and potential adverse health effects associated with indoor bioaerosol, some concentration limits for total number of bioaerosol particles are recommended by different agencies and organizations as follow: 1000 CFUs/m³ (National Institute of Occupational Safety and Health (NIOSH)), 1000 CFUs/m³ (American Conference of Governmental Industrial Hygienists (ACGIH)) with the culturable count for total bacteria not exceeding 500 CFUs/m³. Note that for certain types of indoor bioaerosols, it might be hard to establish a specific concentration limit or acceptance level, due to the differences on sampling and analysis method.

Sampling and Detection Methods

Bioaerosol sampling techniques

To enable subsequent identification and quantification, bioaerosols need to be captured from the air first. Different air sampling techniques have been used to realize the goal of capturing indoor bioaerosols.. Important characteristics of bioaerosol sampling include: representativeness of sampling, sampler performance, and compatibility with subsequent analysis. Long-term sampler theoretically has a better representiveness of sampling than short-term sampler, but may not have a good temporary resolution. Performance of samplers (i.e., limit of detection and upper limit of range) has a significant impact on the reliability of results. Different characterizations of samplers can also limit the possibilities for further analysis (identification and quantification). Major bioaerosol sampler types and their possible subsequent analysis are summarized in Table 1. A frequently used sampler in previous studies is the Andersen impactor.

Table 1 Major types of bioaerosol samplers (adapted from).

Sampler	Example of Device	Possible Subsequent Analysis
Impactors and Sieve Samplers	Anderson impactor; SAS; Burkard sampler	Cultivation; Microscopic analysis

Impingers	AGI-30; Shipe sampler; Midget, multi-stage and micro-impingers	Cultivation; Microscopic analysis; Biochemical analysis; Immunoassays
Centrifugal Samplers	RCS; Aerojet cyclone	Cultivation; Microscopic analysis; Biochemical analysis; Immunoassays
Filter Cassette	Glass fiber; Teflon filters; Polycarbonate	Cultivation; Microscopic analysis; Biochemical analysis; Immunoassays

Certain limitations exist for commonly used bioaerosol samplers. For most of the samplers, nonbiological environmental particles such as dust must be separated from bioaerosols prior to detection. The diluted nature of bioaerosol in the air also poses challenges to samplers. While total microorganism concentrations are on the order of $10^6/\text{cm}^3$ or greater, bioaerosol concentrations are commonly less than $1/\text{cm}^3$, and often less than $1/\text{m}^3$ in the case of infectious aerosols. Moreover, many commercially available bioaerosol samplers haven not been investigated on their collection efficiencies for particles with different aerodynamic diameters, which makes it impossible to get the size-resolved bioaerosol information.

Identification/quantification methods

In previous research on indoor bioaerosol in residential environments, microorganisms have been quantified by conventional culture-based techniques, in which colony forming units (CFU) on selective media are counted. Cultivating methods have several disadvantages. Culture-based methods are known to underestimate environmental microbial diversity, based on the fact that only a small percentage of microbes can be cultivated in the laboratory. This underestimation is likely to be signified for the quantification of bioaerosol, since colony counts of airborne microbes are typically quite different from direct counts. Culture-based methods also need relatively long incubation times (over 24 hours) and are labor intensive. Consequently, culture-based methods are no longer suitable for effective and rapid identification and quantification of bioaerosol, and non-culture based methods, such as immunoassays, molecular biological tests, and optical, and electrical methods, have been developing over the past few decades.

Major culture-independent identification/quantification methods adopted in previous bioaerosol studies include polymerase chain reaction (PCR), quantitative polymerase chain reaction (qPCR), microarray (PhyloChip), fluorescent in situ hybridization (FISH), flow cytometry and solid-phase cytometry, immunoassay (i.e., enzyme-linked immunosorbent assay (ELISA)). The well-known PCR is a powerful tool in identifying and even quantifying the biological origin of bioaerosols. PCR alone cannot accomplish all the tasks related to bioaerosol detection; instead it usually serves as the preparation tool for subsequent processes like DNA sequencing, microarray, and community fingerprinting techniques. A typical procedure for PCR-based bioaerosol analysis is shown in Figure 1.

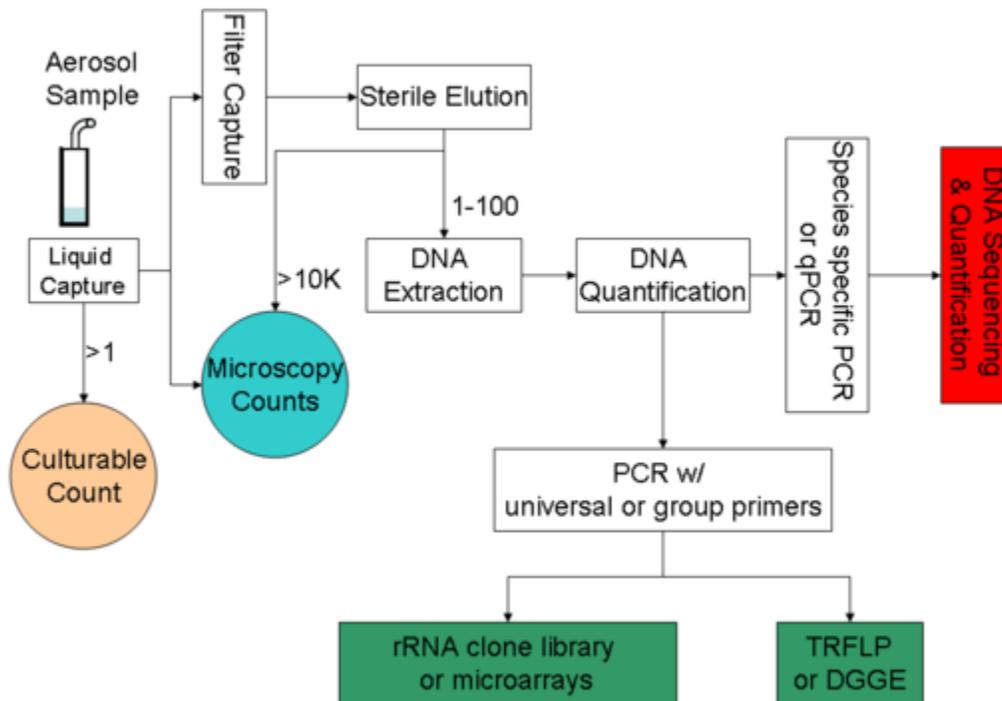


Figure 1 Pathways to PCR-based bioaerosol analysis (adapted from). The numbers listed indicate the quantities of bioaerosols required for successful analysis.

Molecular biological methods for bioaerosol are significantly faster and more sensitive than conventional culture-based methods, and they are also able to reveal a larger diversity of microbes. Targeting the variation in the 16S rRNA gene, a microarray (PhyloChip) was used to conduct comprehensive identification of both bacterial and archaeal organisms in bioaerosols. New U.S. EPA methods have been developed to utilize qPCR to characterize indoor environment for fungal spores. In a study by Lange *et al.*, FISH method successfully identified eubacteria in samples of complex native bioaerosols in swine barns. Nonetheless, molecular biological tools have limitations. Since PCR methods target DNA, viability of cells could not be confirmed in some cases. When qPCR technique is used for bioaerosol detection, standard curves need to be developed to calibrate final results. One study indicated that “curves used for quantification by qPCR needs to be prepared using the same environmental matrix and procedures as handling of the environmental sample in question” and that “reliance on the standard curves generated with cultured bacterial suspension (a traditional approach) may lead to substantial underestimation of microorganism quantities in environmental samples”. Microarray techniques also face the challenge of natural sequence diversity and potential cross-hybridization in complex environmental bioaerosols).

Concentration Levels in Different Geographical Regions

Concentration levels of indoor bioaerosols in different regions of the world recorded in published literatures are summarized as Table 2.

Table 2 Concentration of indoor bioaerosols in different regions of the world

Geographical Region	Study Period	Sampling/Survey Size	Average Concentration Level (CFU/m ³)	Major Microbes Present
Midwestern area, USA	April-September, 1991	27 (noncomplaint homes)	Viable bacteria: 970; Culturable fungi: 1200.	N/A
Taipei area, Taiwan	July 1996	40 daycare centers (DC), 69 office buildings (OB), 22 homes (H)	Bacteria: 7651(DC), 1502(OB), 2907(H); Fungi: 854(DC), 195(OB), 695(H).	N/A
25 states of USA	1994-1998	100 large office buildings	Total bacteria (average): 101.9; Total bacteria (90th percentile): 175.	<i>Mesophilic bacteris</i>
Upper Silesia, Poland	1996-1998	70 dwellings	Bacterial aerosol in homes: 1000; Bacterial aerosol in offices: 100.	<i>Micrococcus spp</i> ; <i>Staphylococcus epidermidis</i>
The city of Boston, USA	May 1997- May 1998	21 offices	Fungi: 42.05 (Standard deviation=69.60)	N/A
Hong Kong, China	About 1 week	2 offices	Highest bacteria concentration: 2912; Highest fungi concentration: 3852.	<i>Cladosporium</i> ; <i>Penicillium</i>
The city of Daegu, Republic of Korea	June 2003- August 2004	41 bars, 41 internet cafes, 44 classrooms, 20 homes	Total bacteria and total fungi: 10-1000.	N/A

Approaches to Control Indoor Bioaerosols

Based on the sources and the influencing factors for indoor bioaerosols discussed in the section on **Sources and Influencing Factors**, corresponding remedial actions could be taken to control related contamination. Potentially effective strategies include: 1) limiting entrance of outdoor aerosols; 2) keeping the relative humidity level below high levels (<60%); 3) installing appropriate filtration devices to air ventilation system to inlet filtered outdoor air into indoor environment; 4) reducing/removing contaminant sources

(i.e., indoor organic waste). As in the U.S., due to the increase in tuberculosis in the mid-1980s, indoor air treatment has developed substantially during the past two decades. Current or developing indoor air purification technologies include filtration, aerosol ultraviolet irradiation, electrostatic precipitation, unipolar ion emission, and photocatalytic oxidation.

Chapter- 7

Mold Growth, Assessment and Remediation

Mold assessment and **mold remediation** are techniques used in occupational health: mold assessment is the process of identifying the location and extent of the mold hazard in a structure, and mold remediation is the process of removal and/or cleanup of mold from an indoor environment.

Health effects

Molds are ubiquitous in nature, and mold spores are a common component of household and workplace dust. However, when spores are present in large quantities, they are a health hazard to humans, potentially causing allergic reactions and respiratory problems.

Some molds also produce mycotoxins that can pose serious health risks to humans and animals. The term "toxic mold" refers to molds that produce mycotoxins, such as *Stachybotrys chartarum*, not to all molds. Exposure to high levels of mycotoxins can lead to neurological problems and in some cases death. Prolonged exposure, e.g. daily workplace exposure, can be particularly harmful.

Causes & growing conditions

Molds are found everywhere inside and outside, and can grow on almost any substance when moisture is present. Molds reproduce by spores, which can be carried by air currents. When these spores land on a moist surface that is suitable for life, they begin to grow. Mold is normally found indoors at levels that do not affect most healthy individuals.

Because common building materials are capable of sustaining mold growth, and mold spores are ubiquitous, mold growth in an indoor environment is typically related to water or moisture indoors. Mold growth may also be caused by incomplete drying of flooring materials such as concrete. Flooding, leaky roofs, building maintenance problems, or indoor plumbing problems can lead to mold growth inside homes, schools, or office buildings.

For significant mold growth to occur, there must be a source of water (which could be invisible humidity), a source of food, and a substrate capable of sustaining growth. Common building materials, such as plywood, drywall, furring strips, carpets, and carpet padding are food for molds. In carpet, invisible dust and cellulose are the food sources. After a single incident of water damage occurs in a building, molds grow inside walls and then become dormant until a subsequent incident of high humidity; this illustrates how mold can appear to be a sudden problem, long after a previous flood or water incident that did not produce such a problem. The right conditions reactivate mold. Studies also show that mycotoxin levels are perceptibly higher in buildings that have once had a water incident.



Although this home suffered only minor exterior damage from Hurricane Katrina, small leaks and inadequate air flow permitted this mold infestation.

Spores need three things to grow into mold:

- Nutrients: Cellulose is a common food for spores in an indoor environment.
- Moisture: Moisture is required to begin the decaying process caused by the mold.
- Time: Mold growth begins between 24 hours and 10 days from the provision of the growing conditions. There is no known way to date mold.

Mold colonies can grow inside building structures. The main problem with the presence of mold in buildings is the inhalation of mycotoxins. Molds may produce an identifiable smell. Growth is fostered by moisture. After a flood or major leak, mycotoxin levels are higher in the building even after it has dried out.

Food sources for molds in buildings include cellulose-based materials, such as wood, cardboard, and the paper facing on both sides of drywall, and all other kinds of organic matter, such as soap, fabrics, and dust containing skin cells. If a house has mold, the moisture may be from the basement or crawl space, a leaking roof, or a leak in plumbing pipes behind the walls. People residing in a house also contribute moisture through normal breathing and perspiration. Insufficient ventilation can further enable moisture build-up. Visible mold colonies may form where ventilation is poorest, and on perimeter walls, because they are coolest, thus closest to the dew point.

If there are mold problems in a house only during certain times of the year, then it is probably either too air-tight, or too drafty. Mold problems occur in airtight homes more frequently in the warmer months (when humidity reaches high levels inside the house, and moisture is trapped), and occur in drafty homes more frequently in the colder months (when warm air escapes from the living area into unconditioned space, and condenses). If a house is artificially humidified during the winter, this can create conditions favorable to mold. Moving air may prevent mold from growing since it has the same desiccating effect as lowering humidity. Keeping indoor air temperature higher than 74 °F (23 °C) also has an inhibiting effect on mold growth.

Because common building materials are capable of sustaining mold growth, and mold spores are ubiquitous, mold growth in an indoor environment is typically related to an indoor water or moisture problem. Leaky roofs, building maintenance problems, or indoor plumbing problems can lead to mold growth inside homes, schools, or office buildings. Another common cause of mold growth is flooding.

Removing one of the three requirements for mold reduces or eliminates the new growth of mold. These three requirements are 1) Moisture, 2) Food source for the mold spores (dust, dander, etc), and 3) Warmth (mold generally does not grow in cold environments).

HVAC systems can create all three requirements for significant mold growth. The A/C system creates a difference in temperature that allows/causes condensation to occur. The high rate of dusty air movement through an HVAC system may create ample sources of food sources for the mold. And finally, since the A/C system is not always running - the

ability for warm conditions to exist on a regular basis allows for the final component for active mold growth.

Because the HVAC system circulates air contaminated with mold spores and sometimes toxins, it is vital to prevent any three of the environments required for mold growth. A) Highly effective return air filtration systems are available that eliminate up to 99.9% of dust accumulation (as compared to 5% elimination by typical HVAC air filters). These newer filtration systems usually require modification to existing HVAC systems to allow for the larger size of electrostatic 99.9% filters. However, thorough cleaning of the HVAC system is required before usage of high efficiency filtration systems will help. Once mold is established, the mold growth and dust accumulation must be removed. B) Insulation of supply air ducts helps to reduce or eliminate the condensation that ultimately creates the moisture required for mold growth. This insulation should be placed externally on the air ducts, because internal insulation provides a dust capture and breeding ground for mold.

Assessment

The first step in an assessment is to determine if mold is present. This is done by visually examining the premises. If mold is growing and visible this helps determine the level of remediation that is necessary. If mold is actively growing and is visibly confirmed, sampling for specific species of mold is unnecessary.

These methods, considered non-intrusive, only detect visible and odor-causing molds. Sometimes more intrusive methods are needed to assess the level of mold contamination. This would include moving furniture, lifting and/or removing carpets, checking behind wallpaper or paneling, checking in ventilation duct work, opening and exposing wall cavities, etc.

Careful detailed visual inspection and recognition of moldy odors should be used to find problems needing correction. Efforts should focus on areas where there are signs of liquid moisture or water vapor (humidity) or where moisture problems are suspected. The investigation goals should be to locate indoor mold growth to determine how to correct the moisture problem and remove contamination safely and effectively.

The basic goals of any mold investigation are always twofold: 1) find the locations of mold growth, and 2) determine the sources of the moisture. If these can be answered by simpler or more cost-effective methods, mold testing is probably not a wise use of resources.

Sampling

In general the EPA does not recommend sampling unless an occupant of the space is symptomatic. When sampling is necessary it should be performed by a trained professional who has specific experience in designing mold-sampling protocols, sampling methods, and the interpretation of findings. Sampling should only be conducted to answer

a pertinent question: examples "what is the spore concentration in the air", or "is a particular species of fungi present in the building." The additional question should be asked before sampling "what action can or should a person take upon obtaining data."

The sampling and analysis should follow the recommendations of Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health (NIOSH), Environmental Protection Agency (EPA), and the American Industrial Hygiene Association (AIHA). Most importantly, when a sample is taken the proper chain of custody should be adhered to. The AIHA offers lists of accredited laboratories that submit to required quarterly proficiency testing.

Three types of air sampling include but are not limited to:

- **Air sampling:** the most common form of sampling to assess the level of mold. Sampling of the inside and outdoor air is conducted and the results to the level of mold spores inside the premises and outside are compared. Often, air sampling will provide positive identification of the existence of non-visible mold.
- **Surface samples:** sampling the amount of mold spores deposited on indoor surfaces (swab, tape, and dust samples)
- **Bulk samples:** the removal of materials from the contaminated area to identify and determine the concentration of mold in the sample.

When sampling is conducted, all three types are recommended by the AIHA, as each sample method alone has specific limitations. For example, air samples will not provide proof a hidden source of mold. Nor would a swab sample provide the level of contamination in the air.

Though it may not be recommended, air sampling following mold remediation is usually the best way to ascertain efficacy of remediation, when conducted by a qualified third party.

Remediation

The first step in solving an indoor mold problem is stopping the source of moisture. Next is to remove the mold growth. Common remedies for small occurrences of mold include:

- Sunlight
- Ventilation
- Wall insulation
- Non-porous building materials
- Household cleansers

Significant mold growth may require professional mold remediation and removal of affected building materials. A conservative strategy is to discard any building materials saturated by the water intrusion or having visible mold growth.

There are many ways to prevent mold growth heating, ventilating, improved insulation and air conditioning, and dry fog.

In extreme cases of mold growth in buildings, it may be easier to condemn the building rather than clean the mold to safe levels. Alternatively, look into the possibility of applying external wall insulation. This has the benefit of increasing the wall temperature above the dew-point, thus helps prevent internal condensation which results in mould-growth.

Certain contractors are capable of repairing mold damage - usually by removing the affected areas and eliminating the cause of the excess moisture.

There are also cleaning companies that specialize in fabric restoration - a process by which mold and mold spores are removed from clothing to eliminate odor and prevent further mold growth and damage to the garments.

New technology also allows some mold remediation companies to fill a room with a dry fog that kills the mold and stops its growth. This fog uses a chemical that is EPA approved and does not harm or damage the physical well being of persons or animals.

Improper methods for cleaning mold include exposure to high heat, dry air, sunlight (particularly UV light), ozone, and application of fungicides. These methods may render the mold non-viable, however, the mold and its by-products can still elicit negative health effects. As noted in following sections, the only proper way to clean mold is to use detergent solutions that physically remove mold. Many commercially available detergents marketed for mold clean-up also include an anti-fungal agent. The most effective way at this point is formal *Mold Remediation*.

The goal of remediation is to remove or clean contaminated materials in a way that prevents the emission of fungi and dust contaminated with fungi from leaving a work area and entering an occupied or non-abatement area, while protecting the health of workers performing the abatement.

Cleanup and removal methods

The purpose of the clean-up process is to eliminate the mold and fungal growth and to remove contaminated materials. As a general rule, simply killing the mold with a biocide is not enough. The mold must be removed since the chemicals and proteins, which cause a reaction in humans, are still present even in dead mold.

Dry ice freeze blasting

Recently, some companies have begun using dry ice freeze blasting to remove mold from suitable surfaces, such as wood and cement.

Dry Fog

New technology is pointing to a dry chemical fog that fills a room and kills the mold throughout a specified area. This procedure allows mold to be remediated without the destruction or damage of the facility in question. It is also safe and far less expensive than older and more traditional remediation methods.

Vacuum

Wet vacuum cleaners are designed to remove water from floors, carpets and other hard surfaces where water has accumulated. Wet vacuuming should only be used on wet materials, as spores may be exhausted into the indoor environment if insufficient liquid is present. After use this equipment must be thoroughly cleaned and dried as spores can adhere to the inner surfaces of the tank, hoses, and other attachments.

Damp wipe

Damp wipe is the removal of mold from non-porous surfaces by wiping or scrubbing with water and a detergent. Care must be exercised to make sure the material is allowed to quickly dry to discourage any further mold growth. With surfaces such as metal, glass, hardwood, plastics, and concrete, mold should be scraped off as much as possible. Then, scrub the surface with a moldicide or fungicide cleaner.

HEPA vacuum

High Efficiency Particulate Air filtered vacuum cleaners are used in the final cleanup of remediation areas after materials have been thoroughly dried and all contaminated materials have been removed. HEPA vacuum cleaners are recommended for the cleanup of the outside areas surrounding the remediation area. During this process the workers wear proper personal protective equipment (PPE) to prevent exposure to mold and other contaminants. The collected debris and dust should be stored in impervious bags or containers in a manner to prevent any release of debris.

Disposal of debris and damaged materials

Building materials and furnishings contaminated with mold should be placed into impervious bags or closed containers while in the remediation area. These materials can usually be discarded as regular construction waste.

Equipment

Several types of equipment may be used in the remediation process and may include:

- **Moisture meter:** a tool that measures the moisture level in building materials. It can also be used to measure the progress of the drying of damaged materials. Pin

moisture meters have a small probe that is inserted into the material. Pinless moisture meters usually have a flat sensing area that is pressed directly against the material's surface. Moisture meters can be used on carpet, wallboard, woods, brick, and other masonry.

- **Humidity gauge:** measures the amount of humidity in the indoor environment. Often gauges are paired with a thermometer to measure the temperature.
- **Borescope:** a hand-held tool that allows the user to see potential mold problems inside walls, ceilings, crawl spaces, and other tight spaces. It consists of a camera on the end of a flexible “snake”. No major drilling or cutting of dry wall is required.
- **Digital camera:** used to document findings during assessment.
- **Personal protective equipment (PPE):** includes respirators, gloves, impervious suit, and eye protection. These items can be used during the assessment and remediation processes.
- **Thermographic camera :** Infrared thermal imaging cameras are often used (and effective) in addition to moisture meters to double check moisture meter findings, and look at the broader picture. They help mainly in identifying auxiliary points of moisture intrusion.
- **Dehumidifier :** If you have high humidity in your home from things like aquariums or house plants, a dehumidifier can help bring down the level of moisture in the air. This in turn will reduce the chances that mold can build up within these areas of your home.

Protection levels

During the remediation process, the level of contamination dictates the level of protection for the remediation workers. The levels of contamination are described as Levels I, II, and III. Each has specific requirements for worker safety. The levels are as follows:

Level I

Small Isolated Areas (10 sq. ft or less) for example, ceiling tiles, small areas on walls.

- Remediation can be conducted by the regular building staff as long as they are trained on proper clean-up methods, personal protection, and potential hazards. This training can be performed as part of a program to comply with the requirements of OSHA Hazard Communication Standard (29 CFR 1910.1200).
- Respiratory protection (for example, N-95 disposable respirator) is recommended. Respirators must be used in accordance with the OSHA respiratory protection standard (29 CFR 1910.134). Gloves and eye protection should also be worn.
- The work area should be unoccupied. Removing people from spaces adjacent to the work area is not necessary, but is recommended for infants (less than 12 months old), persons recovering from recent surgery, immune-suppressed, or people with respiratory diseases.
- Containment of the work area is not necessary. However, misting and dust suppression is recommended.

- Contaminated materials that cannot be cleaned should be removed from the building in sealed impermeable plastic bags and disposed of as ordinary waste.
- The work area/areas used by workers for access/egress should be cleaned with a damp cloth or mop and a detergent.
- All areas should be left dry and visibly free of contamination and debris.

Level II

Mid-sized Isolated Areas (10-30 sq ft) – for example, individual wallboard panels.

- Remediation can be conducted by the regular building staff as long as they are trained as for Level I. Respiratory protection, occupation of the work and adjacent areas, and handling of contaminated materials are the same as for Level I.
- Surfaces in the work area that could become contaminated should be covered with sheet(s) of plastic that are secured in place. This should be done prior to any remediation process to prevent further contamination.
- Dust suppression methods, such as misting (not soaking) surface prior to remediation, are recommended.
- The work area/areas used by workers for access/egress should be HEPA vacuumed and cleaned with a damp cloth or mop and a detergent.
- As with Level I, all areas should be left dry and visibly free of contamination and debris.

Level III

Large Isolated Areas (30-100 sq ft) – e.g., several wallboard panels

- Industrial hygienists or other environmental health and safety professionals with experience performing microbial investigations and/or mold remediation should be consulted prior to remediation activities to provide oversight for the project.
- It is recommended that personnel be trained in the handling of hazardous materials and equipped with respiratory protection (N-95 disposable respirator). Respirators must be used in accordance with OSHA respiratory protection standard (29 CFR 1910.134) Gloves and eye protection should also be worn.
- Surfaces in the work area and areas directly adjacent that could become contaminated should be covered with a secured plastics sheet(s) before remediation to contain dust/debris and prevent further contamination.
- Seal ventilation ducts/grills in the work area and areas directly adjacent with plastic sheeting.
- The work area and areas directly adjacent should be unoccupied. Removing people from spaces adjacent to the work area is not necessary, but is recommended for infants (less than 12 month old), persons recovering from recent surgery, immune-suppressed or people with respiratory diseases.
- Dust suppression methods, such as misting (not soakings) surface prior to remediation, are recommended.

- Contaminated materials that cannot be cleaned should be removed from the building in sealed impermeable plastic bags and disposed of as ordinary waste.
- The work area/areas used by workers for access/egress should be HEPA vacuumed and cleaned with a damp cloth or mop and a detergent.
- All areas should be left dry and visibly free from contamination and debris.

Level IV

Extensive Contamination (greater than 100 contiguous sq. ft in an area).

- Personnel trained in handling of hazardous materials and equipped with:
 - Full face respirators with HEPA cartridges
 - Disposable protective clothing covering the entire body including the head, shoes and hands
- Containment of the affected area:
 - Complete isolation of the work area from occupied spaces using plastic sheeting sealed with duct tape (including ventilation duct/grills, fixtures, and other openings
- The use of an exhaust fan with a HEPA filter to generate negative pressurization, a decontamination room, and airlocks
- Contaminated materials that cannot be cleaned should be removed from the building in sealed impermeable plastic bags and disposed of as ordinary waste.
- The contained area and decontamination room should be HEPA vacuumed and cleaned with a damp cloth or mopped with a detergent solution and be visibly clean prior to the removal of any isolation barrier.

In conclusion, after the moisture source has been eliminated and the mold growth removed, the premises should be revisited and then re-evaluated to ensure the mold growth and the remediation process was successful. The premises should be free of any moldy smells or visible growth.

Chapter- 8

Underfloor Air Distribution and Superinsulation

Underfloor air distribution

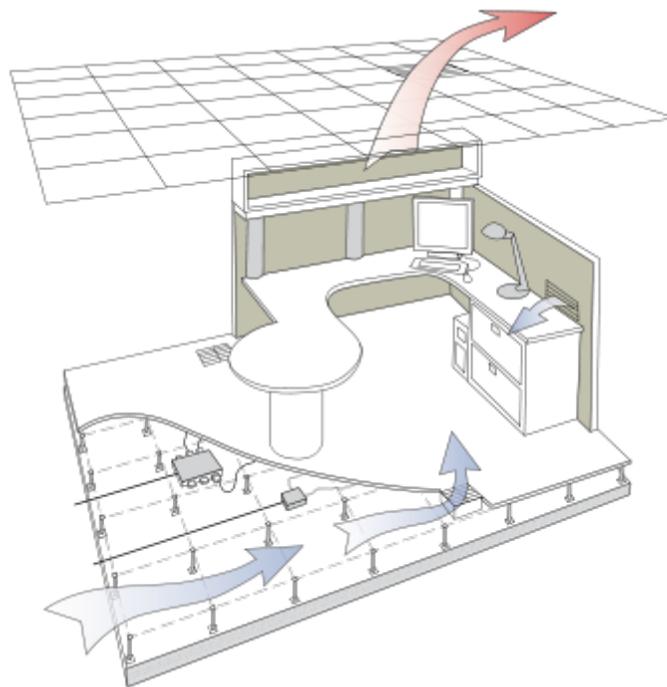


Diagram of air movement in a underfloor air distribution system

Underfloor air distribution (UFAD) is an air distribution strategy for providing ventilation and space conditioning in buildings as part of the design of an HVAC system. UFAD systems use the air plenum beneath a raised floor to provide conditioned air through diffusers directly to the occupied zone.

Applications

Underfloor air distribution is frequently used in office buildings, particularly highly-reconfigurable and open plan offices where raised floors are desirable for cable management. UFAD is also common in command centers, IT data centers and computer rooms which have large cooling loads from electronic equipment and requirements for routing power and data cables. The ASHRAE Underfloor Air Distribution Design Guide suggests that any building considering a raised floor for cable distribution should consider UFAD.

System description

Like other HVAC systems, UFAD systems rely on air handling units to filter and condition air to the appropriate supply conditions so it can be delivered to the occupied zone. While overhead systems typically use ducts to distribute the air, UFAD systems use the plenum formed by installation of a raised floor. The plenum generally sits 0.3-0.48 m (12-18 in) above the structural concrete slab, although lower heights are possible. Specially designed floor diffusers are used as the supply outlets. The most common UFAD configuration consists of a central air handling unit delivering air through a pressurized plenum and into the space through floor diffusers. Other approaches may incorporate fan powered thermal units at the outlets, underfloor ducts, desktop vents or connections to Personal Environmental Control Systems.

UFAD air distribution and stratification

UFAD systems rely on the natural stratification that occurs when warm air rises due to thermal buoyancy. In a UFAD design, cold, fresh air stays in the lower, occupied part of the room, while heat sources such as occupants and equipment generate thermal plumes, which carry the warm air and pollutants towards the ceiling where they are exhausted through the return air ducts. The optimal ventilation strategy controls the supply outlets to limit the mixing of supply air with room air to just below the breathing height of the space. Above this height, stratified and more polluted air is allowed to occur. The air that the occupant breathes will have a lower concentration of contaminants compared to conventional uniformly mixed systems.

Many factors, including the ceiling height, diffuser characteristics, number of diffusers, supply air temperature, total flow rate, cooling load and conditioning mode affect the efficacy of the UFAD system. Swirl diffusers and perforated-floor-panel diffusers have been shown to create a low air velocity in the occupied zone, while linear diffusers created the highest velocity in the occupied zone, disturbing thermal stratification and posing a potential draft risk.

UFAD and energy

The energy efficiency of UFAD systems is a not fully solved issue, currently generating numerous research projects within the building science and mechanical engineering

community. Proponents of UFAD point to the lower fan pressures required to deliver air in a building via the plenum as compared to through ducts. Typical plenum pressures are 0.1 in. H₂O (25 Pa) or less. The improvements in cooling-system efficiency inherent in operation at higher temperatures save energy, and relatively higher supply air temperatures allow longer periods of economizer operation. However, an economizer strategy is highly climate-dependent and necessitate careful control of humidity to avoid condensation. Critics, on the other hand, cite the shortage of rigorous research and testing to account for variations in climate, system design, thermal comfort and air quality to question whether UFAD is able to deliver improved energy efficiency in practice. Limited simulation tools, the shortage of design standards and relatively scarcity of exemplar projects compound these problems.

Thermal decay

Thermal decay is the temperature increase of the conditioned air due to convective heat gain as it travels through the underfloor supply plenum from the plenum inlet to the floor diffusers. This is caused by cool supply air coming into contact with the concrete slab and raised floor warmed by heat gains, for example from the story below. Modeling studies have shown that for a range of typical operating conditions the total supply plenum heat gain can amount to 30-40% of the total system heat gain.

UFAD compared to other distribution systems

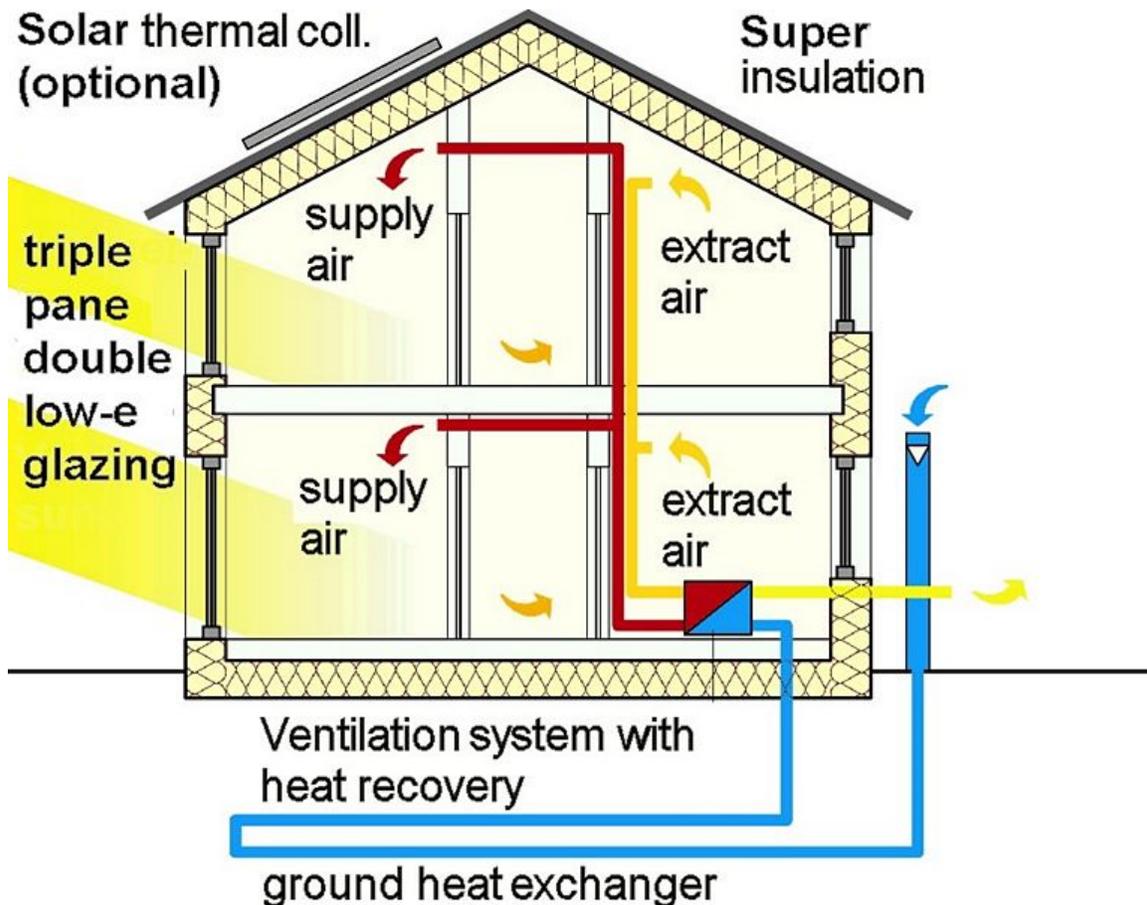
Overhead (mixing)

Conventional *overhead mixing systems* usually locate both the supply and return air ducts at the ceiling level. Supply air is supplied at velocities higher than typically acceptable for human comfort and the air temperature may be lower, higher or the same as desired room temperature depending on the cooling/heating load. High speed turbulent air jets mix incoming supply air with the room air.

Displacement ventilation

Displacement Ventilation systems (DV) work on similar principals as UFAD systems. DV systems deliver cool air into the conditioned space at or near the floor level and return air at the ceiling level. This works by utilizing the natural buoyancy of warm air and the thermal plumes generated by heat sources as cooler air is delivered from lower elevations. While similar, UFAD tends to encourage more mixing within the occupied zone. The major practical differences are that in UFAD, air is supplied at a higher velocity through smaller sized supply outlets than in DV, and the supply outlets are usually controlled by the occupants.

Superinsulation



The passivhaus standard combines superinsulation with other techniques and technologies to achieve ultra-low energy use.

Superinsulation is an approach to building design, construction, and retrofitting that dramatically reduces heat loss (and gain) by using much higher levels of insulation and airtightness than normal. A superinsulated house is intended reduce heating needs very significantly and may even be heated predominantly by intrinsic heat sources (waste heat generated by appliances and the body heat of the occupants) with very small amounts of backup heat. This has been demonstrated to work even in very cold climates but requires close attention to construction details in addition to the insulation.

Superinsulation is one of the ancestors of the passive house approach. A related approach to efficient building design is zero energy building.

There is no set definition of superinsulation, but superinsulated buildings typically include:

- Very high levels of insulation (typically $R_{ip}40$ walls and $R_{ip}60$ roof)

- Details to ensure insulation continuity where walls meet roofs, foundations, and other walls
- Airtight construction, especially around doors and windows
- a Heat recovery ventilation to provide fresh air
- No large windows facing any particular direction
- Much smaller than conventional heating system, sometimes just a small backup heater

Nisson & Dutt (1985) suggest that a house might be described as "superinsulated" if the cost of space heating is lower than the cost of water heating.

History

The term "superinsulation" was coined by Wayne Schick at the University of Illinois at Urbana-Champaign. In 1976 he was part of a team that developed a design called the "Lo-Cal" house, using computer simulations based on the climate of Madison, Wisconsin. Several houses, duplexes and condos based on Lo-Cal principles were built in Champaign-Urbana, Illinois in the 1970s.

In 1978 the "Saskatchewan House" was built in Regina, Saskatchewan by a group of several Canadian government agencies. It was the first house to publicly demonstrate the value of superinsulation and generated a lot of attention. It originally included some experimental evacuated-tube solar panels, but they were not needed and were later removed.

In 1979 the "Leger House" was built by Eugene Leger, in East Pepperell, Massachusetts. It had a more conventional appearance than the "Saskatchewan House", and also received extensive publicity.

Publicity from the "Saskatchewan House" and the "Leger House" influenced other builders, and many superinsulated houses were built over the next few years, but interest declined as energy prices fell. Many US builders now use more insulation than will fit in a traditional 2x4 stud wall (either using 2x6 studs or by adding rigid foam to the outside of the wall), but few would qualify as "superinsulated".

Numerous custom homes and demonstration superinsulated homes continue to be built Westford House.

Retrofits

It is possible, and increasingly desirable, to retrofit superinsulation to an existing older house or building. The easiest way is often to add layers of continuous rigid exterior insulation, and sometimes by building new exterior walls that allow more space for insulation. A vapor barrier can be installed on the outside of the original framing but may not be needed. An improved continuous air barrier is almost always worth adding, as older homes tend to be leaky, and such an air barrier can be important for energy savings

and durability. Care should be exercised when adding a vapor barrier as it can reduce drying of incidental moisture, or even cause summer (in climates with humid summers) condensation and consequent mold and mildew. This may cause health problems for the occupants and damage the existing structure. Many builders in northern Canada use a simple 1/3 to 2/3 approach, placing the vapor barrier no further out than 1/3 of the R-value of the insulated portion of the wall. This method is generally valid for interior walls that have little or no vapor resistance (e.g. they use fibrous insulation) and controls air leakage condensation as well as vapor diffusion condensation. This approach will ensure that condensation does not occur on or to the inside of the vapor barrier during cold weather. The 1/3:2/3 rule will ensure that the vapor barrier temperature will not fall below the dew point temperature of the interior air, and will minimize the possibility of cold-weather condensation problems. For example, with an internal room temperature of 20°C (68°F), the vapor barrier will then only reach 7.3 °C (45 °F) when the outside temperatures is at -18°C (-1°F). Indoor air dewpoint temperatures are more likely to be in the order of around 0 °C (32 °F) when it is that cold outdoors, much lower than the predicted vapor barrier temperature, and hence the 1/3:2/3 rule is quite conservative. For climates that do not often experience -18°C, the 1/3:2/3 rule should be amended to 40:60% or 50:50. As the interior air dewpoint temperature is an important basis for such rules, buildings with high interior humidities during cold weather (e.g., museums, swimming pools, humidified or poorly ventilated airtight homes) may require different rules, as can buildings with drier interior environments (such as highly ventilated buildings, warehouses). The 2009 International Residential Code (IRC) embodies more sophisticated rules to guide the choice of insulation on the exterior of new homes, which can be applied when retrofitting older homes.

A vapor permeable building wrap on the outside of the original wall helps keep the wind out, yet allows the wall assembly to dry to the exterior. Asphalt felt and other products such as permeable polymer based products are available for this purpose, and usually double as the Water Resistant Barrier / drainage plane as well.

Interior retrofits are possible where the owner wants to preserve the old exterior siding, or where setback requirements don't leave space for an exterior retrofit. Sealing the air barrier is more difficult and the thermal insulation continuity compromised (because of the many partition, floor, and service penetrations), the original wall assembly is rendered colder in cold weather (and hence more prone to condensation and slower to dry), occupants are exposed to major disruptions, and the house is left with less interior space. Another approach is to use the 1/3 to 2/3 method mentioned above — that is, to install a vapor retarder on the inside of the existing wall (if there isn't one there already) and add insulation and support structure to the inside. This way, utilities (power, telephone, cable, and plumbing) can be added in this new wall space without penetrating the air barrier. Polyethylene vapor barriers are risky except in very cold climates, because they limit the wall's ability to dry to the interior. This approach also limits the amount of interior insulation that can be added to a rather small amount (e.g., only R6 can be added to a 2x4 R12 wall).

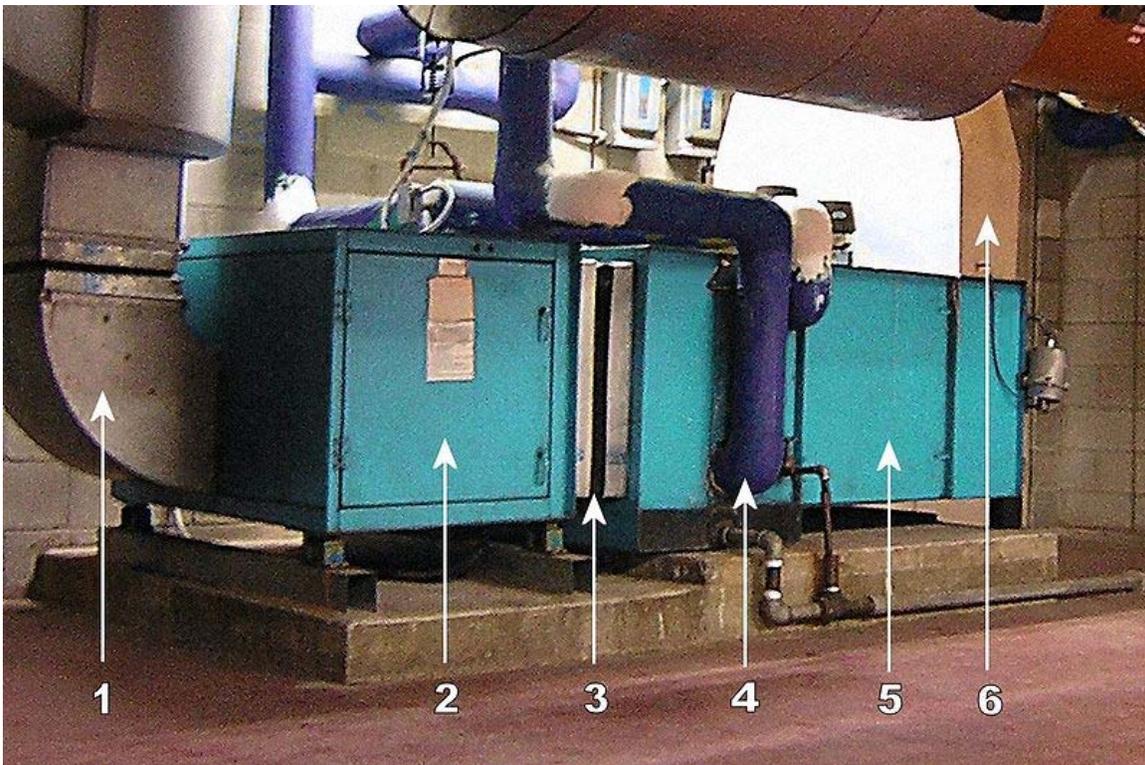
Costs and benefits

In new construction, the cost of the extra insulation and wall framing may be offset by not requiring a dedicated central heating system. In homes with numerous rooms, more than one floor, air conditioning or large sized, a central furnace is often justified or required to ensure sufficiently uniform thermal conditions. Small furnaces are not very expensive and some ductwork to every room is almost always required to provide ventilation air in any case. Because the peak demand and annual energy use is low, sophisticated and expensive central heating systems are not often required. Hence, even electric resistance heaters may be used. Electric heaters are typically only used on the coldest winter nights when overall demand for electricity is low. Other forms of backup heater are widely used, such as wood pellets, wood stoves, natural gas boilers or even furnaces. The cost of a superinsulation retrofit may need to be balanced against the future cost of heating fuel (which can be expected to fluctuate from year to year due to supply problems, natural disasters or geopolitical events), the desire to reduce pollution from heating a building, or the desire to provide exceptional thermal comfort.

A superinsulated house takes longer to cool in the event of an extended power failure during cold weather, for example after a severe ice storm disrupts electric transmission because heat loss is much less than normal buildings, but the thermal storage capacity of the structural materials and contents is the same. Adverse weather may hamper efforts to restore power, leading to outages lasting a week or more. When deprived of their continuous supply of electricity (either for heat directly, or to operate gas-fired furnaces), conventional houses cool more rapidly during cold weather, and may be at greater risk of costly damage due to freezing water pipes. Residents who use supplemental heating methods without proper care during such episodes, or at any other time, may subject themselves to risk of fire or carbon monoxide poisoning.

Chapter- 9

Ventilation (architecture)



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

Ventilating (the *V* in HVAC) is the process of "changing" or replacing air in any space to provide high indoor air quality (i.e. to control temperature, replenish oxygen, or remove moisture, odors, smoke, heat, dust, airborne bacteria, and carbon dioxide). Ventilation is used to remove unpleasant smells and excessive moisture, introduce outside air, to keep interior building air circulating, and to prevent stagnation of the interior air.

Ventilation includes both the exchange of air to the outside as well as circulation of air within the building. It is one of the most important factors for maintaining acceptable

indoor air quality in buildings. Methods for ventilating a building may be divided into *mechanical/forced* and *natural* types.

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

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

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

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

Definition

Ventilation is the intentional movement of air from outside a building to the inside. **Ventilation air**, as defined in ASHRAE Standard 62.1 and the *ASHRAE Handbook*, is that air used for providing acceptable indoor air quality. It mustn't be confused with *vents* or *flues*; which mean the exhausts of clothes dryers, and combustion equipment such as water heaters, boilers, fireplaces, and wood stoves. The vents or flues carry the products of combustion which have to be expelled from the building in a way which does not cause harm to the occupants of the building. Movement of air between indoor spaces, and not the outside, is called **transfer air**.

An example of closed ventilation

In commercial, industrial, and institutional (CII) buildings, and modern jet aircraft, return air is often recirculated to the air handling unit. A portion of the supply air is normally exfiltrated through the building envelope or exhausted from the building (e.g., bathroom or kitchen exhaust) and is replaced by outside air introduced into the return air stream. The rate of ventilation air required, most often provided by this mechanically-induced outside air, is often determined from *ASHRAE Standard 62.1* for CII buildings, or *62.2* for low-rise residential buildings, or similar standards.

Necessity

When people or animals are present in buildings, ventilation air is necessary to dilute odors and limit the concentration of carbon dioxide and airborne pollutants such as dust, smoke and volatile organic compounds (VOCs). Ventilation air is often delivered to spaces by mechanical systems which may also heat, cool, humidify and dehumidify the space. Air movement into buildings can occur due to uncontrolled **infiltration** of outside air through the building fabric or the use of deliberate **natural ventilation** strategies. Advanced air filtration and treatment processes such as *scrubbing*, can provide ventilation air by cleaning and recirculating a proportion of the air inside a building.

Types of ventilation

- **Mechanical or forced ventilation:** through an **air handling unit** or direct injection to a space by a fan. A local exhaust fan can enhance infiltration or natural ventilation, thus increasing the ventilation air flow rate.
- **Natural ventilation** occurs when the air in a space is changed with outdoor air without the use of mechanical systems, such as a fan. Most often natural ventilation is assured through operable windows but it can also be achieved through temperature and pressure differences between spaces. Open windows or vents are not a good choice for ventilating a basement or other below ground structure. Allowing outside air into a cooler below ground space will cause problems with humidity and condensation.
- **Mixed Mode Ventilation** or **Hybrid ventilation:** utilises both mechanical and natural ventilation processes. The mechanical and natural components may be used in conjunction with each other or separately at different times of day. The natural component, sometimes subject to unpredictable external weather conditions may not always be adequate to ventilate the desired space. The mechanical component is then used to increase the overall ventilation rate so that the desired internal conditions are met. Alternatively the mechanical component may be used as a control measure to regulate the natural ventilation process, for example, to restrict the air change rate during periods of high wind speeds.
- **Infiltration** is separate from *ventilation*, but is often used to provide *ventilation air*.

Ventilation rate

The **ventilation rate**, for CII buildings, is normally expressed by the volumetric flowrate of outside air being introduced to the building. The typical units used are cubic feet per minute (CFM) or liters per second (L/s). The ventilation rate can also be expressed on a per person or per unit floor area basis, such as CFM/p or CFM/ft², or as *air changes per hour*.

For residential buildings, which mostly rely on infiltration for meeting their ventilation needs, the common ventilation rate measure is the number of times the whole interior volume of air is replaced per hour, and is called **air changes per hour** (*I* or *ACH*; units of 1/h). During the winter, ACH may range from 0.50 to 0.41 in a tightly insulated house to 1.11 to 1.47 in a loosely insulated house.

ASHRAE now recommends ventilation rates dependent upon floor area, as a revision to the 62-2001 standard whereas the minimum ACH was 0.35, but no less than 15 CFM/person (7.1 L/s/person). As of 2003, the standards have changed to an addition of 3 CFM/100 sq. ft. (15 l/s/100 sq. m.) to the 7.5 CFM/person (3.5 L/s/person) standard.

Ventilation standards

- In 1973, in response to the 1973 oil crisis and conservation concerns, ASHRAE Standards 62-73 and 62-81) reduced required ventilation from 10 CFM (4.76 L/S) per person to 5 CFM (2.37 L/S) per person. This was found to be a primary cause of sick building syndrome.
- Current ASHRAE standards (Standard 62-89) states that appropriate ventilation guidelines are 20 CFM (9.2 L/s) per person in an office building, and 15 CFM (7.1 L/s) per person for schools. In commercial environments with tobacco smoke, the ventilation rate may range from 25 CFM to 125 CFM.

In certain applications, such as submarines, pressurized aircraft, and spacecraft, ventilation air is also needed to provide oxygen, and to dilute carbon dioxide for survival. Batteries in submarines also discharge hydrogen gas, which must also be ventilated for health and safety. In any pressurized, regulated environment, ventilation is necessary to control any fires that may occur, as the flames may be deprived of oxygen.

ANSI/ASHRAE (Standard 62-89) sets maximum CO₂ guidelines in commercial buildings at 1000 ppm, however, OSHA has set a limit of 5000 ppm over 8 hours.

Ventilation guidelines are based upon the minimum ventilation rate required to maintain acceptable levels of bioeffluents. Carbon dioxide is used as a reference point, as it is the gas of highest emission at a relatively constant value of 0.005 L/s. The mass balance equation is:

$$Q = G/(C_i - C_a)$$

- Q = ventilation rate (L/s)
- G = CO₂ generation rate
- C_i = acceptable indoor CO₂ concentration
- C_a = ambient CO₂ concentration

Ventilation equipment

- Fume hood
- Biological safety cabinet
- Dilution ventilation
- Room air distribution
- Heat recovery ventilation

Natural ventilation

Natural ventilation involves harnessing naturally available forces to supply and removing air through an enclosed space. There are three types of natural ventilation occurring in buildings: wind driven ventilation, pressure-driven flows, and stack ventilation. The pressures generated by 'the stack effect' rely upon the buoyancy of heated or rising air. Wind driven ventilation relies upon the force of the prevailing wind to pull and push air through the enclosed space as well as through breaches in the building's envelope. Natural ventilation is generally impractical for larger buildings, as they tend to be large, sealed and climate controlled specifically by HVAC systems. Both are examples of passive engineering and have applications in renewable energy.

Demand-controlled ventilation (DCV)

DCV makes it possible to maintain proper ventilation and improve air quality while saving energy. ASHRAE has determined that: "It is consistent with the Ventilation rate procedure that Demand Control be permitted for use to reduce the total outdoor air supply during periods of less occupancy." CO₂ sensors will control the amount of ventilation for the actual number of occupants. During design occupancy, a unit with the DCV system will deliver the same amount of outdoor air as a unit using the ventilation-rate procedure. However, DCV can generate substantial energy savings whenever the space is occupied below the design level.

Local exhaust ventilation

Local exhaust ventilation addresses the issue of avoiding the contamination of indoor air by specific high-emission sources by capturing airborne contaminants before they are spread into the environment. This can include water vapor control, lavatory bioeffluent control, solvent vapors from industrial processes, and dust from wood- and metal-working machinery. Air can be exhausted through pressurized hoods or through the use of fans and pressurizing a specific area.

A local exhaust system is composed of 5 basic parts

1. A hood that captures the contaminant at its source
2. Ducts for transporting the air
3. An air-cleaning device that removes/minimizes the contaminant
4. A fan that moves the air through the system
5. An exhaust stack through which the contaminated air is discharged

Ventilation and combustion

Combustion (e.g., fireplace, gas heater, candle, oil lamp, etc.) consumes oxygen while producing carbon dioxide and other unhealthy gases and smoke, requiring ventilation air. An open chimney promotes infiltration (i.e. natural ventilation) because of the negative pressure change induced by the buoyant, warmer air leaving through the chimney. The warm air is typically replaced by heavier, cold air.

Ventilation in a structure is also needed for removing water vapor produced by respiration, burning, and cooking, and for removing odors. If water vapor is permitted to accumulate, it may damage the structure, insulation, or finishes. When operating, an air conditioner usually removes excess moisture from the air. A dehumidifier may also be appropriate for removing airborne moisture.

Smoking and ventilation

ASHRAE standard 62 states that air removed from an area with **environmental tobacco smoke** shall not be recirculated into ETS-free air. A space with ETS requires more ventilation to achieve similar perceived air quality to that of a non-smoking environment.

The amount of ventilation in an ETS area is equal to the amount of ETS-free area plus the amount V , where:

$$V = DSD \times VA \times A/60E$$

- V = recommended extra flow rate in CFM (L/s)
- DSD = design smoking density (estimated number of cigarettes smoked per hour per unit area)
- VA = volume of ventilation air per cigarette for the room being designed (ft³/cig)
- E = contaminant removal effectiveness

Problems

In hot, humid climates, unconditioned ventilation air will deliver approximately one pound of water each day for each cubic foot per minute of outdoor air per day, annual average. This is a great deal of moisture, and it can create serious indoor moisture and mold problems.

- Ventilation efficiency is determined by design and layout, and is dependent upon placement and proximity of diffusers and return air outlets. If they are located

- closely together, supply air may mix with stale air, decreasing efficiency of the HVAC system, and creating air quality problems.
- System imbalances occur when components of the HVAC system are improperly adjusted or installed, and can create pressure differences (too much circulating air creating a draft or too little circulating air creating stagnancy).
 - Cross-contamination occurs when pressure differences arise, forcing potentially contaminated air from one zone to an uncontaminated zone. This often involves undesired odors or VOCs.
 - Re-entry of exhaust air occurs when exhaust outlets and fresh air intakes are either too close, or prevailing winds change exhaust patterns, or by infiltration between intake and exhaust air flows.
 - Entrainment of contaminated outside air through intake flows will result in indoor air contamination. There are a variety of contaminated air sources, ranging from industrial effluent to VOCs put off by nearby construction work.

Air Quality Procedures

Ventilation Rate Procedure is rate based on standard, and “prescribes the rate at which ventilation air must be delivered to a space and various means to condition that air.” Air quality is assessed (through CO₂ measurement) and ventilation rates are mathematically derived using constants.

Indoor Air Quality Procedure “uses one or more guidelines for the specification of acceptable concentrations of certain contaminants in indoor air but does not prescribe ventilation rates or air treatment methods.” This addresses both quantitative and subjective evaluation, and is based on the Ventilation Rate Procedure. It also accounts for potential contaminants that may have no measured limits, or limits are not set (such as formaldehyde offgassing from carpet and furniture).

Chapter- 10

Air Purifier



A Sharp FU-888SV Plasmacluster air purifier.



The same air purifier, cover removed.

An **air purifier** is a device which removes contaminants from the air. These devices are commonly marketed as being beneficial to allergy sufferers and asthmatics, and at reducing or eliminating second-hand tobacco smoke. Commercial grade air purifiers are manufactured as either small stand-alone units or larger units that can be affixed to an air handler unit (AHU) or to an HVAC unit found in the medical, industrial, and commercial industries.

Use and benefits of purifiers

Dust, pollen, pet dander, mold spores, and dust mite feces can act as allergens, triggering allergies in sensitive people. Smoke particles and volatile organic compounds (VOCs)

can pose a risk to health. Exposure to various components such as VOCs increases the likelihood of experiencing symptoms of sick building syndrome. Additionally, with the advancement in technology, air purifiers are becoming increasingly capable of capturing a greater number of bacterial, virus, and DNA damaging particulates. Air purifiers are used to reduce the concentration of these airborne contaminants and are very useful for people who suffer from allergies and asthma. Technological and scientific studies are also finding that poor air quality can be a contributing factor of some forms of cancer, respiratory illnesses, COPD, and other pulmonary infections and illnesses.

Air purifiers also reduce the need for frequent room and area cleaning of dust.

Purifying techniques

Several different processes of varying effectiveness can be used to purify air. Different processes may remove different contaminants, so there is advantage in using more than one process in a purifier.

- Ultraviolet germicidal irradiation - UVGI can be used to sterilize air that passes UV lamps via forced air. Air purification UVGI systems can be freestanding units with shielded UV lamps that use a fan to force air past the UV light. Other systems are installed in forced air systems so that the circulation for the premises moves micro-organisms past the lamps. Key to this form of sterilization is placement of the UV lamps and a good filtration system to remove the dead micro-organisms. For example, forced air systems by design impede line-of-sight, thus creating areas of the environment that will be shaded from the UV light. However, a UV lamp placed at the coils and drainpan of cooling system will keep micro-organisms from forming in these naturally damp places. The most effective method for treating the air rather than the coils is in-line duct systems, these systems are placed in the center of the duct and parallel to the air flow.
- Filter - based purification traps airborne particles by size exclusion. Air is forced through a filter and particles are physically captured by the filter.

HEPA filters remove at least 99.97% of 0.3-micrometer particles, and are usually more effective for particles which are larger or slightly smaller. They are effective down to 0.01 micrometers in many cases, but become ineffective for particles smaller than 0.01 micrometer. HEPA purifiers which filter all the air going into a clean room must be arranged so that no air bypasses the HEPA filter. In dusty environments, a HEPA filter may follow an easily cleaned conventional filter (prefilter) which removes coarser impurities so that the HEPA filter needs cleaning or replacing less frequently. HEPA filters do not generate ozone or harmful byproducts.

Filter for HVAC at MERV 14 or above are rated to remove airborne particles of 0.3 micrometers or larger. A high efficiency MERV 14 filter has a capture rate of at least 75% for particles between 0.3 to 1.0 micrometers. Although the capture rate of a MERV filter is lower than that of a HEPA filter, a central air system can

move significantly more air in the same period of time. Using a high-grade MERV filter can be more effective than using a high-powered HEPA machine at a fraction of the initial capital expenditure. Unfortunately, most furnace filters are slid in place without an airtight seal, which allows air to pass around the filters. This problem is worse for the higher-efficiency MERV filters because of the increase in air resistance. Higher-efficiency MERV filters are usually denser and increase air resistance in the central system, requiring a greater air pressure drop and consequently increasing energy costs.

- Activated carbon is a porous material that can adsorb volatile chemicals on a molecular basis, but does not remove larger particles. The adsorption process when using activated carbon must reach equilibrium thus it may be difficult to completely remove contaminants. Activated carbon is merely a process of changing contaminants from a gaseous phase to a solid phase, when aggravated or disturbed contaminants can be regenerated in indoor air sources. Activated carbon can be used at room temperature and has a long history of commercial use. It is normally used in conjunction with other filter technology, especially with HEPA. Other materials can also absorb chemicals, but at higher cost.
- Photocatalytic Oxidation (PCO)' is an emerging technology in the HVAC industry. In addition to the prospect of Indoor Air Quality (IAQ) benefits, it has the added potential for limiting the introduction of unconditioned air to the building space, thereby presenting an opportunity to achieve energy savings over previous prescriptive designs. As of May 2009 there was no more disputable concern raised by the Lawrence Berkeley National Laboratory data that PCO may significantly increase the amount of formaldehyde in real indoor environments. As with other advanced technologies, sound engineering principles and practices should be employed by the HVAC designer to ensure proper application of the technology. Photocatalytic oxidation systems are able to completely oxidize and degrade organic contaminants. For example, Volatile Organic Compounds found low concentrations within a few hundred ppmv or less are the most likely to be completely oxidized.(PCO) uses short-wave ultraviolet light (UVC), commonly used for sterilization, to energize the catalyst and oxidize bacteria and viruses. PCO in-duct units can be mounted to an existing forced-air HVAC system. PCO is not a filtering technology, as it does not trap or remove particles. It is sometimes coupled with other filtering technologies for air purification. UV sterilization bulbs must be replaced about once a year; manufacturers may require periodic replacement as a condition of warranty. Photocatalytic Oxidation systems often have high commercial costs.
- Ionizer purifiers use charged electrical surfaces or needles to generate electrically charged air or gas ions. These ions attach to airborne particles which are then electrostatically attracted to a charged collector plate. This mechanism produces trace amounts of ozone and other oxidants as by-products. Most ionizers produce less than 0.05 ppm of ozone, an industrial safety standard. There are two major subdivisions: the fanless ionizer and fan-based ionizer. Fanless ionizers are

noiseless and use little power, but are less efficient at air purification. Fan-based ionizers clean and distribute air much faster. Permanently mounted home and industrial ionizer purifiers are called electrostatic precipitators.

- Liquid Ioniser purifiers use a capillary to feed liquid into an ionisation field that creates electrically charged liquid ions. Liquid ions only retain a small enough charge so that they are able to float on the wind whilst still effectively purifying the air. Liquid ions attach themselves to airborne particles in a similar way to air ionizer purifiers. However as liquid is charged rather than air/gas they absorb the pollutants in the air. In the process of creating Liquid ions there are no by-products produced such as ozone or oxidants. Liquid ions can be seen by the naked eye under the correct lighting conditions unlike plasma which cannot.
- Ozone generators produce ozone, and are sometimes sold as whole house air cleaners. Unlike ionizers, ozone generators are designed to produce significant amounts of ozone, a strong oxidant gas which can oxidize many other chemicals. The only safe use of ozone generators is in unoccupied rooms, utilising "shock treatment" commercial ozone generators that produce over 3000 mg of ozone per hour. Restoration contractors use these types of ozone generators to remove smoke odors after fire damage, musty smells after flooding, mold (including toxic molds), and the stench caused by decaying flesh which cannot be removed by bleach or anything else except for ozone. However, it is not healthy to breathe ozone gas, and one should use extreme caution when buying a room air purifier that also produces ozone.
- Titanium dioxide (TiO₂) technology - nanoparticles of TiO₂, together with calcium carbonate to neutralize any acidic gasses that may be adsorbed, is mixed into slightly porous paint. Photocatalysis initiates the decomposition of airborne contaminants at the surface.

Consumer concerns

Other aspects of air cleaners are: hazardous gaseous by-products, noise level, frequency of filter replacement, electrical consumption, and visual appeal. Ozone production is typical for air ionizing purifiers. Although high concentration of ozone is dangerous, most air ionizers produce low amounts (<0.05 ppm). The noise level of a purifier can be obtained through a customer service department and is usually reported in decibels (dB). The noise levels for most purifiers are low compared to many other home appliances. Frequency of filter replacement and electrical consumption are the major operation costs for any purifier. There are many types of filters; some can be cleaned by water, by hand or by vacuum cleaner, while others need to be replaced every few months or years. In the United States, some purifiers are certified as ENERGY STAR and are energy efficient.

HEPA technology is used in portable air purifiers as it removes common airborne allergens. The US Department of Energy has requirements manufacturers must pass to meet HEPA requirements. The HEPA specification requires removal of at least 99.97%

of 0.3 micrometers airborne pollutants. Products that claim to be "HEPA-type", "HEPA-like", or "99% HEPA" do not satisfy these requirements and may not have been tested in independent laboratories.

Air purifiers may be rated on: CADR; efficient area coverage; air changes per hour, which indicates how frequently the air purifier can exchange all the air in a given room; the clean air delivery rate, which determines how well air has been purified; energy usage; and the cost of the replacement filters.

Potential ozone hazard

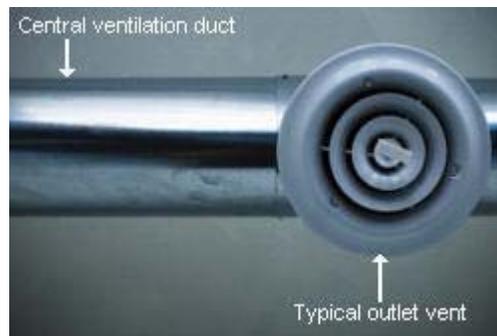
As with other health-related appliances, there is controversy surrounding the claims of certain companies, especially involving ionic air purifiers. Many air purifiers generate some ozone, an energetic allotrope of three oxygen atoms, and in the presence of humidity, small amounts of NO_x. Because of the nature of the ionization process, ionic air purifiers tend to generate the most ozone. This is a serious concern, because ozone is a criteria air pollutant regulated by health-related federal and state standards. In a controlled experiment, in many cases, ozone concentrations were well in excess of public and/or industrial safety levels established by U.S. Environmental Protection Agency, particularly in poorly ventilated rooms.

Ozone can damage the lungs, causing chest pain, coughing, shortness of breath and throat irritation. It can also worsen chronic respiratory diseases such as asthma and compromise the ability of the body to fight respiratory infections -- even in healthy people. Ironically, people who have asthma and allergy are most prone to the adverse effects of high levels of ozone. For example, increasing ozone concentrations to unsafe levels can increase the risk of asthma attacks. Due to the below average performance and potential health risks, Consumer Reports has advised against using ozone producing air purifiers. Ozone generators used for shock treatments (unoccupied rooms) which are needed by smoke, mold, and odor remediation contractors as well as crime scene cleanup companies to oxidize and permanently remove smoke, mold, and odor damage are however considered a valuable and effective tool when used correctly for commercial and industrial purposes.

In September 2007, the California Air Resources Board announced a ban of in-home ozone producing air purifiers. This law, which took effect in 2009, will require testing and certification of all types of air purifiers to verify that they do not generate excessive ozone. This ban does not affect shock treatment ozone generators however for commercial and industrial use. Studies indicate that some ionic air purifiers produce ozone at 3.3 to 4.3 mg/h. Ozone generators used for shock treatments on the other hand produce over 3000 mg/h, the amount of ozone needed to create a "shock treatment" over a 6 hour period in a 100-200 sq ft room. The ozone generators which are subject to this ban use ceramic Mica plates that produce 300–400 mg/h of ozone and are intended to be used indoors in occupied rooms.

Chapter- 11

HVAC

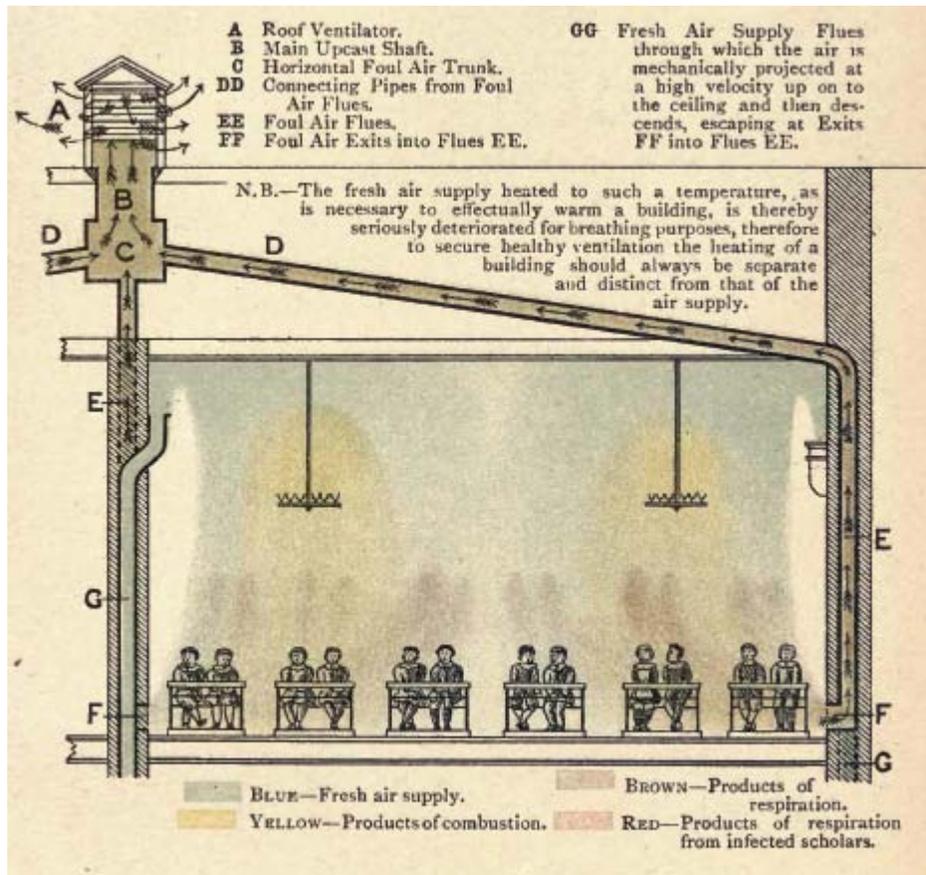


HVAC systems use ventilation air ducts installed throughout a building that supply conditioned air to a room through rectangular or round outlet vents, called diffusers; and ducts that remove air through return-air grilles

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

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

Background



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

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

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

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

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

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

Design of the HVAC system.

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

Heating



Central heating unit

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

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

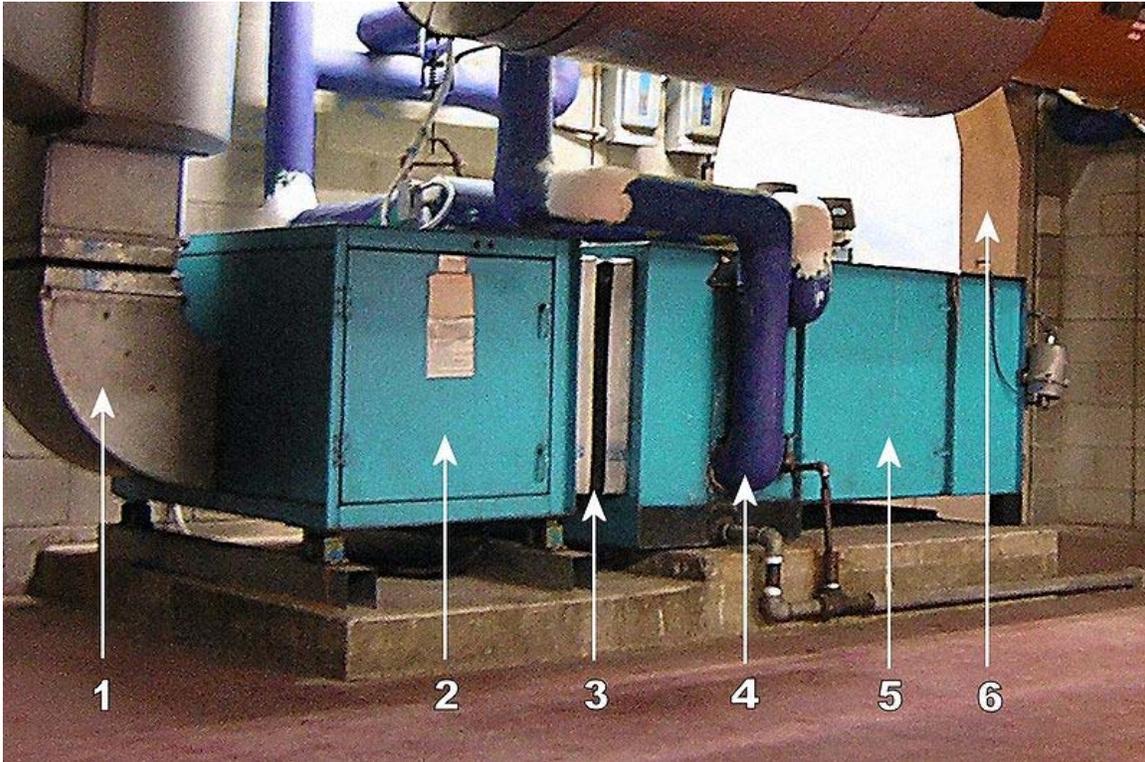
Forced air systems send heated air through ductwork. During warm weather the same ductwork can be used for air conditioning. The forced air can also be filtered or put through air cleaners.

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

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

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

Ventilating



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

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

Mechanical or forced ventilation

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

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

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

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

Natural ventilation

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

Air conditioning

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

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

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

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

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

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

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

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

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

Energy efficiency

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

Heating energy

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

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

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

Geothermal Heat Pump

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

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

Ventilation energy recovery

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

Air conditioning energy

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

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

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

HVAC industry and standards

North America

USA

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

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

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

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

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

Europe

United Kingdom

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

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

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

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

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

Australia

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

Asia

India

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

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

Pakistan

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