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UNDERSTANDING & MITIGATING INDOOR AIR POLLUTION

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INTRODUCTION

For decades, Utah's metropolitan areas have struggled with some of the worst air quality episodes in the world.[1] However, most Utahns underestimate and are unaware of the serious short-term and long-term health impacts of poor air quality.[2] During poor air quality episodes, many people retreat to indoor environments to escape the pollution. It is important to guarantee or promote healthy indoor air quality (IAQ) at home because these places become a refuge against hazardous outdoor air. But indoor environments are complex and can be ineffective in providing protection against outdoor air pollutants. Indoor environments can be a source of various pollutants in themselves based on geography and climate, building materials, human behaviors, and allergens. Various counties in Utah with growing metropolitan areas (including but not limited to Salt Lake, Utah, Davis, and Tooele) are in unique physiographic areas that exacerbate air quality hazards. Challenges and strategies to promote healthy indoor air quality in Utah are reviewed throughout this report; major sources of air quality pollutants are divided into four main groups: outdoor sources, housing conditions, human behavior, and socioeconomic factors.

WHAT FACTORS IMPACT INDOOR AIR QUALITY?

OUTDOOR SOURCES

Environmental factors

Environmental factors contribute to poor air quality and can be considered naturally occurring phenomena outside of human control and decision. This includes wildfire smoke and particulate matter pollution (PM) transported by air currents. Atmospheric phenomena called inversions or persistent cold-air pools occur in valleys surrounded by mountains and exacerbate air quality problems associated with anthropogenic emissions in Utah. Major metropolitan areas in Utah are moreover in proximity to or built on the lakebed of an ancient pluvial lake, Lake Bonneville. As a result, the Great Basin is a significant source of PM pollution. The chemical composition of dust and soil emitted from the Great Basin has elevated levels of potentially hazardous elements including lead, arsenic, nickel, and chromium.[3] Sevier Dry Lake is one of numerous defined dust sources downwind of Utah's heavily populated areas. The atmospheric transport of dust and soil locally, regionally, and globally has detrimental effects on human health, ecosystem functions, and biochemical cycles.

Both wildfire smoke and PM are increasing concerns for metropolitan areas in Utah. First, due to the transport of smoke from extreme forest fires in California. And second, due to the drying of the Great Salt Lake (GSL) exposing more dust to the atmosphere.[4] The continuation of a drying GSL would result in another large dust source like Sevier Dry Lake. Megadroughts and climate change throughout the western U.S. could soon amount to local health, and environmental crises in Utah unless state mitigation efforts increase.

Anthropogenic factors

Anthropogenic activities that take place in the built environment result in myriad harmful air pollutants. Sources of anthropogenic air pollution are complex and range from transportation and industry to recreational and cooking fires. The U.S. Environmental Protection Agency (EPA) has identified 188 toxic air pollutants and established national ambient air quality standards (NAAQS) for six of the most common air pollutants–carbon monoxide, lead, ground-level ozone, particulate matter, nitrogen dioxide, and sulfur dioxide—these are known as "criteria air pollutants."[5] In Utah's Metropolitan areas,

anthropogenic emissions vary in space and time. Anthropogenic greenhouse gas (GHG) emissions are mainly a result of the combustion of fossil fuels and come from a variety of sources including automobiles. The combustion of fossil fuels are associated with several air pollutants, including criteria air pollutants and the main culprit of climate change—Carbon Dioxide (CO_2). There are some identified hotspots and peak periods for air pollutants across the Salt Lake Valley associated with the season (e.g., inversions and wildfires), traffic, rush hour, and socioeconomic activities (e.g., 4th of July fireworks).[6] Data about anthropogenic sources can be used to inform stakeholders and help government agencies and policymakers make decisions to meet air pollution mitigation targets.

HOUSING CONDITIONS

Since climate change concerns highlighted the need to promote sustainable development by increasing efficiency in construction systems, building regulations and codes have focused more on energy efficiency and sustainable materials than indoor air quality.[7] Although the US Clean Air Act was implemented in the 70s and has since been revised, the topic and concern about IAQ have never been discussed.[8] Nonetheless, according to the EPA, indoor air pollutants are likely to be up to 100 times higher than outdoor pollutants.[9] From this perspective, built environment composition, particularly housing, as a place of constant interaction becomes relevant when considering sources of contaminants and their implications on health.

Ventilation systems and energy efficiency

Complying with building regulations is the first step to promoting good IAQ. Although discussed by scholars, minimum natural illumination and cross-ventilation in each room reduces air renovation rate and reduces the likelihood of Sick House Syndrome (SHS) or Sick Building Syndrome (SBS).[10] Due to technological advances, this has been modified with heating, ventilation, and air conditioning systems

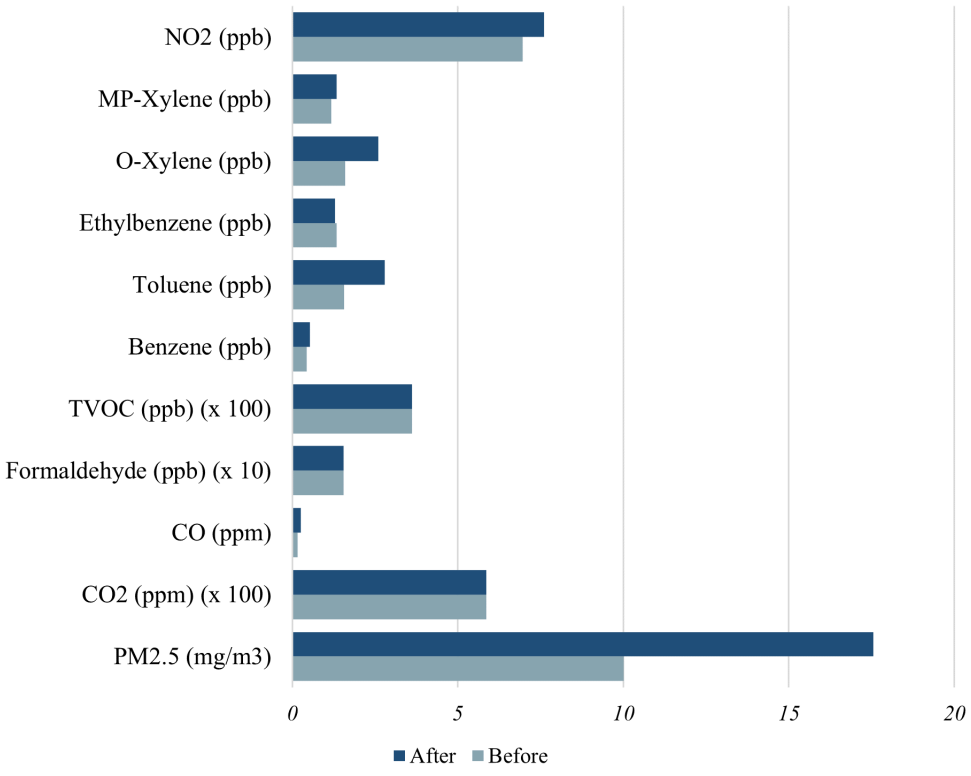

FIGURE 1. Indoor Air Pollutants concentrations before and after the retrofit in housing.[7]

(HVAC) primarily focused on temperature comfort. HVAC equipment follows ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) regulations on ventilation rates without any IAQ consideration. Some HVAC technologies have been developed to target affordable markets where energy efficiency and the generation of pollutants during operation is not considered. This is aggravated by the absence of central ventilation systems or ventilation in bathrooms or kitchens.[11]

On the other hand, HVAC has also diversified towards energy efficiency under the low-carbon emission goal, constantly promoting building retrofitting from private and governmental programs. While high-performance results become a promising way of construction, it also compromises air renovation. This is evident in cases where isolation of walls, roofs, and windows with new ventilation systems reduces building airtightness and exchange rate.[12] In Figure 1, a measure before and after presents the increase on pollutants when airtightness is reduced. Under these conditions, although occupants' satisfaction with temperature comfort is perceived as positive, long-term effects on exposure to different pollutants might suggest a different perception.

Building systems and materials

Pollutants and health relate to several sources and effects. On indoor conditions without adequate filtration system pollutants increase from 2 to 5 times compared with outdoor conditions (see Figure 2). For example, in a wide exposed area like the state of Utah, radon gas can filter in deficient foundations, piping, drainage, walls, and through other materials, exposing occupants to different hazardous levels of this gas, which can have effects such as lung cancer.[13] Leakages in heating and cooling utilities can create carbon monoxide (CO) as a byproduct of fuels, exacerbated when housing is near highly trafficked roads. Ovens for space heating produce nitrogen dioxide (NO_2) and carbon dioxide.[14] Particle pollutants represent a risk to human health through respiratory, skin, and alimentary canals.

Insulation and construction materials also represent a complex measure of impact. In the case of asbestos, its multiple applications for thermal insulation and incombustible properties are hazardous when exposed to humans. Some effects include various types of cancer.[15] Insulation materials also produce

FIGURE 2. Common sources of indoor air pollutants. *Source: www.indoorbreathing.com*

formaldehyde, a flammable gas present in different resins at room temperature, including wood building materials (plywood, fiberboard), textiles, carpets, paints, and plastic.[16] Although present in low quantities, long-term exposure effects can result in asthma and chronic bronchitis. Building materials and IAQ are significant depending on surface properties. Under different environmental conditions, surfaces (photocatalytic, adsorption, absorption) generate mold or accumulate particles, and when experiencing a heating effect, they become a new source of contamination.[17] In Utah's context, surfaces are prone to collect dust and particulate matter. Surfaces that absorb tobacco smoke become a thirdhand smoke source that, added to the previous contaminants, cause rhinitis or pneumonia.[18]

Volatile Organic Compounds (VOCs) are also present in construction materials, mainly in new construction buildings. This is due to the finishing components, including paints, furniture, and new combustion appliances. Although VOC emissions decrease after the construction is finished, the purchase of new furniture and remodeling might create new sources of contaminants. A chart with the most common pollutants and the major sources is included below (see Table 1). Intensive exposure to these chemicals implicates several chronic health effects, including disrupting endocrine functions and altering human genetics.[19]

TABLE 1. MAJOR INDOOR POLLUTANTS AND EMISSION SOURCES[14]

Pollutant	*Major Emission Sources*
Allergens	House dust, domestic animals, insects
Asbestos	Fire retardant materials, insulation
Carbon dioxide	Metabolic activity, combustion activities, motor vehicles in garages
Carbon monoxide	Fuel burning, boilers, stoves, gas or kerosene heaters, tobacco smoke
Formaldehydes	Particleboard, insulation, furnishings
Micro-organisms	People, animals, plants, air conditioning systems
Organic substances	Air conditioning systems
Ozone	Adhesives, solvents, building materials, volatilization, combustion, paints, Photochemical reactions.
Particles	Re-suspension, tobacco smoke, combustion products
Polycyclic aromatic hydrocarbons	Fuel combustion, tobacco smoke
Pollen	Outdoor air, trees, grass, weeds, plants
Radon	Soil, building construction materials (concrete, stone)
Fungal spores	Soil, plants, foodstuffs, internal surfaces
Sulphur dioxide	Outdoor air, fuel combustion

Several strategies are being applied to control and reduce indoor air pollutants in the construction industry. This includes identifying pollutant sources, air ventilation, and filtration systems under physical, chemical, and biological technologies.[20] Further research is required to understand the impacts on first and second sources of pollutants that sometimes are limited by human activities and behaviors.[21]

HUMAN BEHAVIOR

Human behavior and activities are an avenue of exposure that can significantly affect indoor air quality. Everyday behaviors, such as cooking and cleaning, can produce toxic levels of particulate matter, carbon monoxide, nitrogen oxides (NO_x), and volatile organic compounds in residential homes.[22]

Cooking

The type of cooking appliances people use (wood, gas, or electric-powered) and how people prepare their food have variable effects on IAQ.[23] Due to their power supply, electric stoves are proven to be the best cooking appliances because they produce zero indoor emissions. The largest contributors to indoor air pollution while cooking include the method of cooking (i.e., frying, baking, and boiling), use of oil and fat, temperature, and type of pan. For instance, pan-frying meat over high heat will produce larger particles and higher concentrations of pollutants indoors than boiling vegetables in a pot. Residents can significantly reduce their exposure to harmful indoor air pollutants with proper ventilation inside their homes. Turning on a range hood while cooking, for example, is one way to improve IAQ while cooking.

Indoor combustion

Common sources of indoor combustion in a residential setting include burning firewood, candles or incense, and smoking. Indoor combustion releases toxic chemicals such as carbon monoxide, volatile organic compounds, particulate matter, and nitrogen oxides that trigger oxidative stress, which causes irritation and inflammation throughout the body.[24] This may lead to serious health issues such as respiratory disease, heart disease, cancer, and neuropsychological disorders. Limiting the use of combustible products indoors and increasing ventilation inside homes can significantly improve IAQ.

Consumer products

Indoor use of chemical or scented products such as cleaning supplies, diffusers, and skincare products can adversely affect IAQ by releasing high concentrations and mixtures of substances into the air.[25] These chemicals, which are primarily volatile organic compounds, can linger for an extended amount of time, especially in small, enclosed spaces, and interact with other airborne particles, producing an even more unhealthy indoor environment. Even “green”/organic, odor-removing products that are marketed as non-toxic can release harmful chemicals into the air.[26] Short and long-term exposures to scented products have been associated with health problems such as asthma, migraines, skin irritation, and gastrointestinal issues. Eliminating or reducing the use of scented products and having adequate indoor ventilation are ways to improve air quality indoors.

Ventilation

Opening and closing windows is another common behavior that may increase or decrease exposure to unhealthy IAQ levels.[27] For instance, if tenants and homeowners prefer to keep their windows closed while cooking or cleaning even though outdoor air pollution levels are low, they would be more exposed to indoor pollutants over a prolonged period. Establishing better airflow in and out of the home environment or having an air purifier could mitigate the harmful effects of indoor activities. As mentioned in previous sections, having an effective indoor ventilation system can decrease the longevity and number of indoor pollutants in a residential environment.

SOCIOECONOMIC FACTORS

It can be assumed that some of the most vulnerable households experiencing poor IAQ are in areas with poor outdoor air quality. This might be true for most residents in Salt Lake City when experiencing cool air pool events in winter or wildfires in summer. However, poor IAQ can also be dependent upon socioeconomic level.[28] Low-income families are more susceptible to dwelling in rentals or owned homes with precarious conditions with low-quality insulation and filtering systems. This is exacerbated by crowding and deficient utilities.[29] Although regulations are increasingly concerned with energy efficiency, they do not apply to material specifications and long-term health repercussions which generates Sick House Syndrome.[30] In some households, the operation of low-cost HVAC systems becomes the only option to provide temperature comfort for occupants without air renovation, becoming a hazard to physical and mental health.[31] On the west side of the Wasatch Front, where most of the industry is located, a generation of diverse pollutants and proximity to major highways with transportation-related emissions aggravate precarious living conditions followed by bad IAQ.[32] This represents an environmental injustice that impacts individuals' health, such as pulmonary diseases, asthma, and shortened life span. Experiencing illnesses that affect the nuclear family, where children are absent from school and parents call in sick to work, also resonate with economic conditions, medical expenditures, and the likelihood of losing jobs.[33]

POLICIES AND PROGRAMS TO ADDRESS INDOOR AIR POLLUTION

Programs and policies have been employed across Utah and the United States to address indoor air pollution in housing. These initiatives have varied considerably in scope and impact; some focus on preventing pollutants, while others focus on mitigating poor IAQ impacts. Policies and programs related to IAQ and housing are often limited and fail to explicitly address indoor air quality. However, increasingly poor outdoor air conditions (e.g., wildfires, winter inversions), as well as the COVID-19 pandemic, have highlighted the need for more substantial policies and programs in this area.[34]

INDOOR AIR QUALITY PROGRAMS

As Table 2 suggests, most existing IAQ and housing-related programs in Utah are managed by the Utah Department of Environmental Quality (UDEQ). The UDEQ oversees the Utah Division of Air Quality (UDAQ), which is responsible for distributing information about pollutant types, current conditions, and mitigation procedures for both indoor and outdoor pollution. This includes programs that address radon, asbestos, and lead exposure by providing resources to mitigate current pollution and prevent further pollution. The rest of Utah's local initiatives are managed by Salt Lake County through the Green & Healthy Homes initiative (see Table 2). Like the DEQ, Green & Healthy Homes is responsible for education, outreach, and connecting residents to external resources. The initiative directly manages Lead Safe Housing, which provides free health testing and lead cleanup services to households living in homes built before 1978 with young children (under 6 years of age) who have been exposed to lead.

Compared to programs that address outdoor air quality, IAQ initiatives are less common.[35] In Utah's case, IAQ programs overseen by government agencies tend to revolve around the dissemination of information and resources, rather than physical interventions. Additionally, programs that do directly address IAQ often engage with contractors and developers (rather than with tenants or landlords) for demolition, inspection, and renovation activities. Table 3 outlines numerous programs within the Intermountain West that have implemented air filter distribution programs in recent years. These programs were created in response to growing wildfire concerns in the Western United States, and many of these initiatives target

lower-income or otherwise more vulnerable households (e.g., households geographically most impacted by outdoor pollutants that can affect IAQ). The Free Air Purifier Program in Ashland, Oregon, for example, has distributed HEPA-grade portable air filters based on three main qualifications: age, presence of certain health conditions, and socioeconomic status.

TABLE 2. INDOOR AIR QUALITY PROGRAMS IN UTAH

Program Name	*Implementing Agency*	*Scope*	*Project Description*
Green & Healthy Homes	Salt Lake County Regional Development	*county*, Salt Lake County	Part of a national IAQ program, Salt Lake County's Green & Healthy Homes initiative connects residents to resources and information related to indoor air pollution.
Lead Safe Housing	Salt Lake County Regional Development – Green & Healthy Homes	*county*, Salt Lake County	The Lead Safe Housing program is nested within Salt Lake County's Green & Healthy Homes initiative. This program provides lead mitigation and health testing services, specifically targeting older homes (built before 1978) and households with young children (under age 6).
Utah DEQ Radon Program	Utah Department of Environmental Quality – Waste Management and Radiation Control	*state*, Utah	The Utah DEQ Radon Program connects Utah residents to resources and information about radon impacts, test kits, and mitigation options.
Utah DAQ Asbestos Program	Utah DEQ Division of Air Quality	*state*, Utah	Utah DAQ's Asbestos Program works to educate residents and developers about the harms of asbestos and assists with abatement projects, renovations, and inspections to ensure safety and health standards are met.
Utah DAQ Lead-Based Paint Program	Utah DEQ Division of Air Quality	*state*, Utah	Utah DAQ's Lead-Based Paint Program oversees procedures and certification for work activities that require exposure to lead-based paint, such as renovation and demolition, to reduce the impacts of lead exposure.

TABLE 3. IAQ PROGRAMS OUTSIDE OF UTAH

Program Name/ Initiatives	*Implementing Agency*	*Scope*	*Program Description*
Clean Air Filtration Program	Bay Area Air Quality Management District	*region*, San Francisco Bay Area, CA	Enhances filtration in disadvantaged communities by funding ventilation system upkeep and upgrades as well as purchasing portable air filters.
Free Air Purifier Program	City of Ashland	*city*, Ashland, OR	Provides free HEPA-grade portable filters to qualifying Ashland residents. Qualifications can be based on: (a) age vulnerability (children under 15 and adults over 65 years), (b) individuals predisposed to cardiovascular and respiratory illness, and (c) low-income applicants.

Clean Air Rooms – Santa Barbara	Santa Barbara County Air Pollution Control District (APCD)	*county*, Santa Barbara County, CA	Provided Guadalupe and Casmalia residents with HEPA-grade filters one a first-come, first-served basis in response to increase wildfire activity.
Clean Air Rooms – San Luis Obispo County	San Luis Obispo County Air Pollution Control District	*county*, South San Luis Obispo County, CA	Pilot program that provides low-income households with HEPA-grade air filters.
Distribution of portable air filters	The Flathead City-County Health Department	*county*, Flathead Valley, MT	Provided portable air filters to individuals at risk due to specific health conditions (e.g., respiratory and cardiovascular illnesses).
Portside Air Quality Improvement and Relief (PAIR) Program	The San Diego Air Pollution Control District (APCD)	*county*, San Diego County, CA	Provides monitoring systems and portable air filters to qualifying applicants. Applicants of PAIR services are typically geographically more impacted by outdoor air pollution or are burdened in some other way (e.g., low-income households).

INDOOR AIR QUALITY POLICIES

Like public programs, IAQ policies can be a helpful tool to reduce indoor air pollution in housing environments. However, policies related to indoor air quality tend, like IAQ programs, to be limited in their number and scope, especially in Utah. In general, IAQ policies that also impact housing fall into three main categories: housing codes, landlord-tenant laws, and specific IAQ policies.[36]

Housing codes

Housing codes are the most common type of policy used to enforce indoor air quality standards in rental housing units. These codes outline a series of standards that must be met by property owners to maintain a unit's health, safety, and comfort. If housing codes are violated, property owners can face fines, citations, court cases, or other consequences as a result. For Salt Lake City, housing codes are enforced at the local level with the city's Existing Residential Code Title 18.50 (see Table 4). This policy protects rental housing inhabitants by outlining guidelines for IAQ-related conditions, such as ensuring that hazards like household pests and mold are not present in a unit.

Landlord-tenant laws

Landlord-tenant laws are similar to housing codes because they are used to ensure rental properties are safe and well-maintained by outline the duties of both parties—landlord and tenant—in a property agreement. However, these polices differ from housing codes for two key reasons. First, landlord-tenant laws often are the policies that enforce housing codes and other standards. Second, while housing codes are enforced by public agencies, landlord-tenant laws are enforced through private, legal action (e.g., if a renter feels their unit is not being properly maintained to meet housing standards, they can file a lawsuit against their landlord). In Utah, landlord-tenant responsibilities and rights are described in the Utah Fit Premises Act (see Table 4).

IAQ-specific policies

Policies that specifically address IAQ are far less common than landlord-tenant laws and housing codes, both of which are standard in most states and localities. However, unlike these other two policy types which typically address IAQ issues only coincidentally, IAQ-specific policies work to reduce indoor air pollution directly. As Table 4 shows, Utah state laws have categorized secondhand smoke as a nuisance, giving tenants legal recourse if they are experiencing drifting smoke in their home.

TABLE 4. IAQ POLICIES THAT IMPACT SALT LAKE CITY

Policy Name	*Scope*	*Policy Type*	*Description*
Utah Fit Premises Act	State	Landlord-tenant law	Outlines the rights and responsibilities of tenants and landlords in the State of Utah to maintain the health, safety, and wellness of rental units.
Salt Lake City Existing Residential Code Title 18.50	Local	Housing code	Outlines a set of standards housing units in Salt Lake City must be held to that are enforced by the city's Building Services division.
Secondhand Smoke Amendments (SHSA)	State	IAQ-specific policy	Defines secondhand smoke as a nuisance, providing Utah renters with the ability to file a lawsuit if they are negatively affected.

Although Utah and, specifically, Salt Lake City have employed a series of programs and policies to address indoor air quality, these efforts may not be sufficient.[37] This is especially true as certain air quality conditions worsen (e.g., wildfires, winter inversions, summer ozone levels) and in the face of public health crises like the COVID-19 pandemic. In the coming years, the State and City should consider implementing stronger policies or overseeing more IAQ-related programs to address indoor air pollution. This may involve restructuring existing programs to better reach renters and landlords, or modeling new initiatives after ones that have been implemented in other states (e.g., portable air filter distribution, provision of air quality monitoring systems, etc.).

ACTIONS & SOLUTIONS

AIR QUALITY MONITORING

Two primary ways of monitoring indoor air quality include: wireless sensor network (WSN) and Internet of Things (IoT).[38] The Internet of Things (IoT) provides real-time monitoring and transmits data to "a cloud computing-based web server using an IoT sensor network."[39] In contrast, the wireless sensor network (WSN) has been "regarded as the most reliable communication protocol because of its low cost, low consumption, and low data rate."[40] This device also allows data in real time. Air quality monitors can vary significantly in cost, but there are some available on Amazon for under $100. Also, a lot of research from the University of Utah is being conducted to monitor outdoor air quality in different neighborhoods. While not directly helpful for indoor air quality concerns, these monitors can provide a better sense of outdoor air quality concerns within particular areas. Residents, property owners, and landlords should consider partnering with researchers and community groups that work to fundraise and provide these monitors in underserved neighborhoods.

SOURCE CONTROL

The EPA describes source control as one of the best ways to reduce indoor air quality, but this can also be the most expensive and difficult depending on what sources of pollution are causing the problem. The main way to control pollution sources is to use low pollution or pollution free materials within the home.[41] Some overarching recommendations include:

- Use air filtration to prevent outdoor pollutants from impacting indoor air quality
- Check labels of products to look for their government grade
- Clean components that capture dust or liquid drops (such as filters) and replace them if necessary.
- Avoid high strength activities, practice better sanitation, do not smoke indoors, and limit use of cosmetic sprays.[42]
- Clean any humidifiers regularly before use, clean and dry water-damaged carpets, and keep your home clean to reduce other allergens.
- Use exhaust fans when cooking with gas cook stoves. Make sure wood stoves are sized correctly and have EPA certification. If you have a range hood: make sure it can vent outdoors, use it when you use the stove, and if possible, cook on back burners as those areas are better covered by the exhaust. If you do not have a range hood, work to use a ceiling or wall exhaust fan and/or open windows and doors to increase air flow.[43]
- Make sure you check warnings on household products. Some products may recommend you use them in a well-ventilated area. If so, use the products outdoors, near an exhaust fan, or by an open window. Avoid products with "methylene chloride, benzene, perchloroethylene, and formaldehyde" as they are high risk.[44]
- Pesticides should similarly be used in well-ventilated areas. Make sure you also dispose of these by following the "manufacturer's or hazardous waste collector's guidelines."[45] Nonchemical pest controls are preferrable.
- If you encounter any asbestos in your home, do not mess with it, and instead call a professional contractor.
- For lead, you can wipe down all surfaces with a dishwasher detergent and wash all toys and stuffed animals. Make sure your children wash their hands often. Avoid burning painted wood or attempting to remove lead paint. If you work in construction or somewhere where dust is present, make sure you wipe your shoes thoroughly on your door mat before entering your home.
- Hard flooring can help reduce allergens (such as mold spores or dust). If you opt for carpet, make sure you "unroll and air it out in a well-ventilated area, and choose one with low-emitting adhesives. Open windows and turn on fans/mechanical ventilation equipment for 48 to 72 hours after installation. Remember to clean it often."[46]

In Salt Lake, the inversions and wildfires are difficult sources to control. Infrastructure changes like using electric instead of natural gas can be well over 300 dollars and for some homes may not be possible. The EPA, however, describes these measures as sometimes more cost efficient in the long run because ventilation can lower energy efficiency. Here are some further solutions that address sources that are controllable:

Radon is a growing concern because its lack of odor makes it impossible to identify without a test. Many houses can be at risk of radon exposure, regardless of their age. The EPA offers a helpful map that can identify areas most likely to be vulnerable to radon exposure. Testing for Radon is less expensive than other indoor air quality interventions and is strongly encouraged by the EPA for all people to do.[47] Radon tests vary in price, but there are multiple sites that can help one find a radon test and even lower the price.

The University of Kansas offers short term test kits and long-term test kits under 50 dollars and can provide a coupon for those who need additional help.[48] These kits can also be purchased online or through home improvement stores. The state of Utah offers an online website that also makes finding a radon test kit and certified radon professionals more manageable.[49] The main thing to worry about is ensuring the radon test kit has the phrase "Meets EPA Requirement." Should radon be found in the home, the best way to manage it is to hire a radon contractor to make sure you address the problem fully. This is a costly option, but it can be reduced through coupons. Try searching around for reductions in price if you have to mitigate your radon exposure. If you depend upon well water, make sure to have that also tested for radon. For more information, you can contact the EPA Drinking Water Hotline (800-426-4791) or the Utah's radon website.[50]

Biological elements that can reduce indoor air quality according to Tran et al. are divided into allergens, "animal dander and cat saliva, house dust, cockroaches, mites, and pollen," and microorganisms which includes "viruses, fungi, and bacteria."[51] There are a lot of sources of these contaminants, but one of the best ways to reduce some of these is to control the humidity, with 30-50 percent humidity being recommended by the United States Consumer Safety Commission.[52] Several options exist for controlling moisture.

Exhaust fans that vent air outdoors in high moisture places

Replacing an existing fan is around $100, installing a new fan can be anywhere from 350-800$ depending upon what kind of exhaust fan you choose.

Humidifiers

In a dry climate, humidifiers can help increase humidity up to the 30-50 percent range recommended. Some of the different types include Cool Mist, Warm Mist, Evaporative, Vaporizer, and Ultra Sonic.[53] The price varies based on smaller models which range from $10-$500, with full home humidifiers sometimes costing over $1,000. Warm mist, Ultra Sonic, and Vaporizer are better for long term use because you can switch from warm to cool mist. Ultra-Sonic and Cool Mist are more energy efficient and easier to clean. Cool Mist and Evaporators are more child and pet safe than the others. The room size will be the main factor to consider when purchasing one of these. The larger the room, the bigger the humidifier should be. Most range from 25 to 100 feet. You can check this by looking at the gallon size on the packaging.[54] Make sure to clean these thoroughly and refill with clean water each time you use them.

Dehumidifiers $-$$$

While not as useful in the Salt Lake valley, which tends to be very dry, a dehumidifier can help lower humidity levels if that is a problem. These can be particularly helpful in moisture hot spots like bathrooms.[55] Different types are categorized by size and pints of water removed within 24 hours. These include: a mini dehumidifier (1-10 pints) which is best for a small room and costs between $40-70; a small to medium capacity (11-25 pints) which can cost $100-250); and a large capacity (25-70 pints) which helps with large areas like basements and costs from $150-400. You can also purchase large-capacity and low-maintenance ones that range from $800-1,200 and whole-house ones for $1,000-2,500.[56]

IMPROVED VENTILATION & FILTRATION:

Most heating and cooling systems do not bring in fresh air from outside according to the EPA, which can be a good and bad thing in the case of outdoor air quality concerns that can impact indoor air quality. Tran et al. classify ventilation systems into mechanical ventilation (fans or blowers) and natural ventilation which allow outdoor air flow without mechanical equipment.[57] Hybrid ventilation systems

combine natural and mechanical ventilation to decrease energy consumption.[58] Putting in a new ventilation system, however, costs anywhere from $120 to $10,000, with hybrids being on this higher range.[59] When engaging in indoor activities that can reduce indoor air quality, such as painting, cooking, welding, etc., ventilation can be effective and can occur through opening windows and doors, HVACs with outdoor air intakes, and infiltration via house openings, such as joints and cracks in walls. Thus, if you plan to increase ventilation, you need to ensure the pollution is an indoor not an outdoor source and that the outdoor air quality is not a further risk. The seasons most at risk for outdoor air quality in Salt Lake City are winter and summer but you can check the daily air quality at https://air.utah.gov/. The best and most cost-effective way to increase ventilation is through opening doors and windows when there are indoor air quality concerns and the threat of outdoor air quality is low.[60]

Swamp coolers work by pulling warm air from outside, passing it through wet and cool pads, and then sending the cool air out through the room. If indoor air quality pollutants are a concern, these can be helpful because they bring in outside airflow. It can also help with excessive dry conditions. The main concern, however, is that when outside air is also a concern, then these swamp coolers will not be as effective. They are also not as effective in more humid homes as these coolers add humidity, which can make the cool air not feel as cool. For these devices to be effective in situations where outdoor air quality is also a concern, they need to have a good filtration system. Filters need to remove as "much pollen, dust, and other particulates from the atmosphere as possible."[61] An extraction system that can take heat and moisture and put it outside without needing windows to be open is the most effective swamp cooler method in a place with outdoor air quality concerns. This will help reduce the number of outdoor pollutants from entering the home.[62] Swamp coolers can range in price from $150-7,000 with the average being $1,500 - $3,500.[63]

Filtration can be a key component of AC systems. For those who have systems already installed, filtration can be an economical and efficient method. Filters can be especially helpful for removing Ozone, but this can diminish over time. HEPA, or high-efficiency particulate air filters are recommended because they can "remove 99.97% of airborne bacteria, dust, mold, and pollen particles as small as 0.3 microns."[64] Industry HEPA filters are measured with minimum efficiency reporting values (MERV) ratings going from 1 to 16. The higher the value, the better filtration.[65] Yu et al warn, however, that "Despite the fact that air filtration systems represent a good solution for the improvement of IAQ, they could become a source of contamination from micro-organisms harmful to human health."[66] The main concern with filters is making sure you change them often to avoid diminished air flow and further pollution concerns.[67] You also want to make sure your filter has a Minimum Efficiency Reporting Value (MERV) of at least 10 (out of 16), which indicates the filter's efficiency in trapping airborne particles.[68] Some other recommendations include making sure you install the filter correctly, clean out dust monthly, replace the filter around every three months but check it regularly as you may need to remove it sooner, and if you have a central air system, operate it with the fan on. If you can or plan to remodel, then installing a ventilation system that operates separately from forced air heating is encouraged.

AIR PURIFICATION

Air cleaners and purifiers are necessary when the pollution of the source is difficult or impossible to eliminate. According to the EPA, the effectiveness of these devices depends upon "how well it collects pollutants from indoor air (expressed as a percentage efficiency rate) and how much air it draws through the cleaning or filtering element (expressed in cubic feet per minute)."[69] When researching these devices, you should look for both an efficient collector and high circulation rate. The EPA warns further that the strength of the pollutant source can determine how effective these devices are, with table-top air cleaners

in particular not being very effective against strong sources.[70] While the EPA recommends combining these devices with efforts to remove the source, this is not always possible when the source is outdoor air pollution coming inside. The best way to determine the effectiveness of these air purifiers and suitableness for particular rooms is to look for the clean air delivery rate (CADR) score, which should be equal to "two-thirds of the area in the room."[71] The higher the CADR rating, the more particles that will be removed. Thus, when picking an air purifier, determine the size of rooms, avoid air cleaners that generate ozone, and look at industry ratings.

DIY Air Purifiers

If you are unable to purchase an air purifier due to limited stock or the expense of available models, DIY Purifiers can be an effective option. Sarah B. Henderson, a senior scientist in environmental health services at the British Columbia (BC) Centre for Disease Control, conducted a study on homemade purifiers in 2020 and found that they can be a helpful alternative. The recommended filter for these homemade devices is High Efficiency Particulate Air (HEPA) filters, which have the highest efficiency rating of filters on the market. These can range in price from "$16–$95 depending on quality, estimated longevity, and manufacturer."[72] DIY purifiers are best suited for smaller enclosed rooms (10 by 10 feet). There are two types: filter plus fan and the box fan filter. Both require a 20-by-20-inch box fan (about $35) and duct tape. For the filter plus fan, you only need one 20-by-20-inch HEPA or other high-quality filter, whereas for the box fan filter you need two, cardboard, and a utility knife or scarf scissors. The box fan filter is more complicated in terms of putting it together, but it works more efficiently. For directions on how to put these together visit: https://www.healthline.com/health/air-purifiers-sold-out-diy-options#tips. These do pose a fire risk because the motor from the box fan heats up, so make sure you only use these when someone is around, there are no obstructions to the airflow of the purifier, and that you open windows when outside air is clearer in order to release any trapped particles stuck inside the home.[73]

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