Indoor Air Quality Protection Pathways for Health, Climate, Equity and Economic Benefits

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ABSTRACT

Indoor air pollution is an overlooked issue in US policy tightly linked to health, climate, equity, and economic outcomes. People spend nearly 90% of their time indoors where some pollutant concentrations can be five times higher than outdoors and can be even higher in buildings that use combustion fuels. Sensitive groups such as children and disadvantaged communities bear some of the greatest health burdens exacerbated by poor indoor air quality. Despite these pressing risks, building industry decision makers and policy makers have yet to recognize the pivotal role of addressing indoor air quality in unlocking numerous intersectional benefits.

Identifying and reducing sources of indoor air pollution encourages the uptake of high-efficiency, non-emitting appliances, and high-performing building systems. Doing so supports occupant health by directly limiting indoor pollutant exposure; reduces emissions in line with climate goals; alleviates long standing environmental inequities; and avoids pollution-related financial burdens.

This project calls attention to the opportunity for indoor air quality to unlock numerous health, climate, equity, and economic benefits. We identify indoor air quality protection pathways that offer policymakers accessible and effective ways to improve indoor air. Built upon extensive scientific research, global examples, and existing U.S. programs, these pathways are defined in two groups: market transformation strategies, including voluntary standards and advancements in IAQ monitoring technology; and policy pathways, including increased IAQ guidance, inspection protocols, and regulations. Applications range from monitoring and regulation of pollutants indoors to health-driven building policy and practice such as building codes, standards, regulations, and certification programs.

1. Introduction

Protecting indoor air quality (IAQ) is a key lever to protect health, improve building performance, and advance clean energy goals at a pace that matches the urgency for action. Decades of ambient air regulations have decreased emissions in other sectors, while "an important air quality challenge remains: the majority of human exposure to airborne pollutants occurs in the indoor environment," as reported by the EPA (EPA 2018). People spend nearly 90% of their time indoors, where pollutant concentrations are often two to five times higher than outdoors (EPA 2023a; Adgate et al. 2004). Combustion fuel use further exacerbates indoor air pollution; homes with gas stoves have concentrations of nitrogen dioxide (NO_2) 50-400% higher than homes with electric stoves (Seals and Krasner 2020; EPA 2008). Despite these health risks, there are no US federal and very few state IAQ guidelines, and no comprehensive regulations

that place a limit on common indoor air pollutants (Prescott et al. 2023).This gap in guidance is "not negligible," according to the EPA; IAQ guidelines, standards, and legislation have been adopted outside of the US to address the well-evidenced economic, medical, and public health consequences of indoor air pollution (EPA 2018).

Current IAQ measures are not enough. Ventilation standards only set a minimum baseline for performance, do not refer to health-based guidelines to set their design limits, and are not mandatory unless adopted by an authority (Bahnfleth 2024; Prescott et al. 2023). Additionally, indoor source control is not uniformly enforced; many building codes in the US do not require range hoods on gas stoves, nor are range hoods uniform in performance quality, even though peak emissions from gas stoves can reach levels beyond US outdoor and global indoor air quality limits (Seals and Krasner 2020).

As IAQ policy is nascent, building owners, manufacturers, and industry experts can use market-driven strategies to lead by example. The changes needed to align our building sector with climate goals will need to be initiated through a diverse mix of regulations, investments, incentives, and education. This paper summarizes the benefits of improved IAQ for public health, building performance, and equity; provides actionable steps to embed IAQ management into market and policy pathways; and examines learning opportunities from proposed legislation in New York City to inform efficient, scalable IAQ management.

2. IAQ considerations benefit public health, building performance, and equity

Given its encompassing nature, the indoor environment is an opportune venue to expand beyond traditional industry silos and address broader intersectional issues. In a 2018 report, EPA stated that "through epidemiological, toxicological, and exposure science research, it is well-established that these indoor air pollutants produce significant (and often inequitable) economic, medical, and public health costs to society" (EPA 2018). Additionally, EPA has stated that indoor air pollution will likely worsen with climate change (EPA 2023b). Strategies that protect IAQ have been shown to provide significant public health benefits, encourage electrification in line with climate goals, and alleviate long standing inequities. Considerations for these myriad benefits can help prioritize health-protective measures in the market and in policy development.

2.a. Improve Public Health and Wellbeing

Indoor air pollution has been consistently ranked among the top five environmental risks to public health (EPA 2014). Indoor pollutant concentrations may be two to five times – and occasionally more than 100 times – higher than outdoor levels (Wallace et al. 1986). Specifically, combustion activities emit pollutants such as NO_X, carbon monoxide (CO), fine particulate matter ($PM_{2.5}$), ultrafine particles (UFPs) and formaldehyde (CH_20). Exposure to these pollutants has long been linked to a range of adverse health outcomes, including respiratory conditions, hospital visits, school and work absenteeism, shorter lifespans, and serious conditions such as heart disease, stroke, and cancer (Cincinelli and Martellini 2017; WHO 2022; Prescott et al. 2023).

Fortunately, air quality protections can result in potentially hundreds of avoided mortalities and billions of dollars in better health outcomes for Americans. Limits on outdoor air

pollutants achieved through the Clean Air Act (CAA) have led to decreases in respiratory illness cases, absences from school and work, emergency room visits, and mortality rates (EPA 2023c). The benefits of pollution control under the CAA outweigh costs by 30 to 1, with $2 trillion in avoided health costs in 2020 alone (EPA 2023d; Price et al. 2020; Mui and Levin 2020; Colmer and Voorheis 2021). In New York City, a 7% reduction in $PM_{2.5}$ concentrations avoided between 160 and 390 premature deaths and 460 hospitalizations and emergency department visits for respiratory and cardiovascular disease each year, valued at $3.4 billion annually (Johnson et al. 2020). Successes from the reduction of outdoor air pollutants suggest that policies to protect indoor air too have major potential to set significant health benefits in motion.

2.b. Support Well-Sequenced Clean Energy Solutions in Buildings

Strategies that limit indoor air pollution can simultaneously reduce greenhouse gas emissions, supporting the case for electrification. Efficiency and energy conservation are necessary but insufficient; expedited efficiency, emissions reductions, and renewable energy scaling together provide 80% of the emissions reductions needed by 2030 to stay below 1.5 degrees of warming (IEA 2023). For meaningful emissions reductions aligned with the urgency of US climate goals, electrification is key. Strong market transformation signals are needed to advance electrification solutions at speed and scale, especially in states with little existing market for emerging technologies such as heat pumps.

Fossil fuel equipment and appliances in our buildings that emit health-harming criteria pollutants contribute to 13% of greenhouse gas emissions in the U.S. (EPA 2023e). Pollution reduction strategies encourage efficient technology, control devices, and fuel switching, including appliance and equipment electrification (Buonocore et al. 2021).[1] Air-source heat pumps reduce GHG emissions by ~25% compared to dual fuel systems (Tan and Fathollahzadeh 2021). Analysis found that transitioning 41,874 Connecticut homes from natural gas furnaces to heat pumps would avoid roughly 126 tons of NOx and 100,331 tons of CO_2 per year (Karambelas and Cooper 2021). Further, analysis has shown that even when properly installed and maintained, ventilation systems do not significantly change levels of NO_2 indoors, countering the misconception that ventilation is enough to address the health impacts of combustion appliances (Bland et al. 2022).

Properly sequencing building upgrades while simultaneously considering IAQ is necessary to avoid unintended energy and health consequences. Effectively and efficiently meeting IAQ needs with all-electric equipment is also linked to the building envelope and ventilation system. It is best practice to assess and improve envelope performance before sizing the mechanical systems (including heating, cooling and ventilation). The goal is a high-performing envelope with right-sized electric mechanical systems, thus minimizing costs and maximizing health and environmental benefits. For example, simply running a ventilation system at higher rates will significantly increase energy load. A day-care facility with efficiency and IAQ in mind opted for a load-reducing ventilation system and high efficiency filters, resulting in

[1] Building strategies work as powerful allies to achieve a decarbonized electric grid and our emissions goals and decarbonization scenarios are tied to assumptions of a simultaneously decarbonizing grid. Further, pre-existing deficiencies such as structural issues, asbestos, mold, leaking combustion appliances and other factors that impact indoor air quality and how complete decarbonization is pursued merit study and policy attention, but are beyond the scope of this paper.

70% lower outside air usage and over $4,600 energy savings annually (enVerid 2021). Studies modeling weatherization found that efforts to solely tighten the building envelope increased serious asthma events by 20%, but eliminating indoor emission sources and repairing exhaust hoods mitigated this effect and electrifying the gas stove resulted in the highest health cost savings (Seals and Krasner 2020). Considering IAQ and efficiency in advance and properly sequencing building improvements can minimize health risk and optimize energy efficiency.

Detailed and extensive accounting for air pollution-related benefits can be used to support climate policies and other environmental goals, as doing so may well validate the adoption of electrification policies at speed and scale. In 2024, $5 billion dollars in federal funding will be available for reducing climate pollution (EPA 2024a). This funding and other US resources related to emissions are as much of an opportunity to improve IAQ as they are to address climate change.

2.c. Reduce Long Standing Systemic Inequities

The burden of air pollution is not evenly shared; low-income households and those facing systemic racism generally experience poorer IAQ (Ferguson et al. 2020; Tessum et al. 2021). Low-income communities and communities of color are more likely to live in older and smaller homes with inadequate ventilation and less efficient appliances, and are closer to outdoor air pollution sources, all of which can contribute to higher indoor air pollution (Jbaily 2022; Tessum et al. 2021). For instance, people in households making <$10,000 per year, are exposed to twice as much long-term NO_2 from gas and propane stoves as people in households making >$150,000 per year (Kashtan et al. 2024). Fortunately, improvements in air quality have been shown to directly benefit affected communities and their future generations. Populations that experienced lower outdoor air pollution exposure (because of CAA mandates) were richer and healthier than those that were born before its introduction. These benefits were enduring; grandchildren of women who were exposed to lower levels of air pollution during pregnancy were more likely to attend college and less likely to drop out of high school 40 years later (Colmer and Voorheis 2021). These linkages demonstrate the important role that air pollution protections can play in increasing upward mobility and economic opportunity, the persisting nature of these benefits as they propagate from one generation to the next, and the potential for indoor air protections to have similar successes.

While emissions reductions since CAA-enactment have been drastic with beneficial results, research shows that racial and socioeconomic disparities persist in air pollution reduction, necessitating more just air quality policies that target reductions for overburdened communities (Nunez et al. 2024). Strong, equitable, targeted air-pollution-reduction strategies are important for reducing overall air-pollution levels, improving measures of equity, and ensuring the wellbeing of all people living in America.

3. Pathways to advance IAQ protections

Defining ‘good’ IAQ is necessary to protect human health, but just as crucial are the steps to embed IAQ considerations into practice. This can be accomplished via two pathways: market drivers to advance IAQ technology and proven solutions, and policy drivers to cohesively bring all buildings to a health-based, high-performance standard of quality.

3.a. Market Transformation Pathways

As IAQ policy is in early development stages across the US, successful market examples are crucial. Consumer interest in IAQ solutions has grown since the COVID-19 pandemic; in 2012, only 9% of U.S. consumers thought IAQ was a health threat, while in 2022, 60% were at least mildly concerned, and 19% were very concerned about IAQ (Consumer Reports 2012; Will 2022). While biological contaminant control differs from the scope of this report, a growing awareness among consumers indicates increased market demand for IAQ solutions and products, according to a 2023 U.S. IAQ Market report (BBC Research 2023). IAQ solutions implemented in voluntary, market-based pathways will act as scaffolding for additional health-protective measures, technological and market advancements, and ultimately policy development.

3.a.i. Voluntary certifications and standards[2]

Voluntary standards incentivize leading building owners to implement IAQ-protective strategies that the broader building industry can follow. However, many standard setting organizations including the American National Standards Institute, American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), American Society for Testing and Materials, do not adhere to IAQ guidelines in their design limits, and may have outdated design limits (Prescott et al. 2023). Updating these design limits in accordance with indoor-specific guidelines can improve their efficacy in protecting IAQ.

Voluntary building certification programs, such as EPA Indoor AirPLUS, LEED, WELL, and Enterprise Green Communities can also drive competition and innovation in the market. Most programs do not refer to indoor-specific, health-protective guidelines, rely on self-reported IAQ measures, and rarely relate to chemical measurements of IAQ (Licina and Langer 2021; Prescott et al. 2023). This results in relatively little change to physical conditions of IAQ in buildings after adopting certification measures (Licina and Langer 2021). Incorporating health-based measures of IAQ into these certification programs will yield additional benefits to occupant health and wellbeing, in addition to resilience from climate change. For instance, architecture firm Skidmore, Owings & Merrill installed indoor air monitors in their New York City office in 2019 and spoke to the benefits of being able to adjust building controls as needed to ensure adequate IAQ for building occupants, including during the 2023 wildfire smoke events in New York City (Sigal Shemesh 2023).

To pair IAQ and electrification objectives, voluntary certifications and standards could further identify electric appliances as solutions to mitigate combustion-related appliances in buildings, or enforce differentiating requirements based on fuel type to account for heightened emissions from combustion appliances.

3.a.ii. Affordable IAQ monitoring technology

To understand whether IAQ is safe, we need to make the invisible visible. Like smoke or carbon monoxide detectors, IAQ monitors can alert building occupants of high pollutant levels they would otherwise not perceive (Berkeley Lab 2024). IAQ monitoring programs have been successfully established for some pollutants. For instance, schools in Boston and Colorado have

[2] Voluntary standards are enforceable minimum requirements for IAQ that are not mandatory unless adopted by an authority (Bahnfleth 2024). Voluntary building certification programs are used to incentivize, assess, and recognize buildings that meet certain requirements or standards outlined in a given program (World GBC 2024).

partnered with manufacturers to measure IAQ, IAQ-worsening activities or sources, and issues with the HVAC systems (Boston Public Schools 2023; PR Newswire 2023). EPA has stated that these devices should be present in every home, school, and other buildings, but that current technology is limited in accuracy and precision (EPA 2024b). Affordable, market-ready IAQ monitors that can measure a suite of indoor air criteria pollutants, including those associated with combustion, will allow additional building types like residential homes to identify sources and mitigate pollution accordingly.

EPA also acknowledges the lack of a widely accepted air concentration limit for most indoor pollutants that limits individuals' ability to interpret IAQ monitor readings (EPA 2024b). Developing affordable, comprehensive IAQ monitors and adhering to a standard set of IAQ guidelines will help standardize IAQ monitoring and mitigation practices and increase general understanding of IAQ.

3.b. Policy Pathways

While policy action is in its infancy, IAQ is being recognized at the national scale: experts have urged the White House to create a task force and "Indoor Air Quality Act" mirroring U.S. outdoor air policy, and the White House voiced the importance of improving IAQ during a summit convening in October of 2022 (Colwell 2022; White House 2022). But additional guidance and actions are needed to appropriately scale and shape equitable, health-based, high-impact IAQ protections and achieve intersectional benefits. Federal, state, and local policies should weave IAQ considerations into existing agency protocols and establish mandatory, health-based codes and standards for IAQ. As disadvantaged communities and sensitive groups are more likely to face health risks from indoor air pollution, adopting mandatory IAQ protections provides a high-impact opportunity to address systemic inequities. These policy actions can be achieved at various tiers of enforcement: from voluntary guidelines to building-specific protocols, to regulatory standards and codes.

3.b.i. Foundational guidance

IAQ guidelines are voluntary health- or risk-based limits on safe pollutant levels for the general public (Prescott et al. 2023). The need for guidelines is well recognized at the federal level; in 2018, an EPA-funded report recommended that EPA develop a "strategy exploring the viability of the federal government establishing national indoor air quality guidelines and/or standards." Currently, California and Illinois are the only US jurisdictions with IAQ guidelines. Since California's original publication of guidelines in 2005, they have informed emissions limits on products and building materials as well as California's building energy code ventilation and filtration requirements (CARB 2024a). CARB has also begun incorporating new scientific information into their guidance, including healthy building practices, impacts from extreme environmental events, and solutions that reduce greenhouse gasses and opt for clean energy. Jurisdictions can adopt existing guidelines from established institutions like CARB, Health Canada and the World Health Organization (CARB 2002, Health Canada 2022, WHO 2021). For instance, CARB IAQ guidelines cite Health Canada's residential IAQ guidelines, and in turn Canada's guidelines refer to the World Health Organization (Prescott et al. 2023).

3.b.ii. Embed into existing agency protocols: product safety, building inspections

Federal and state agencies can incorporate health-based indoor air quality considerations into their existing protocols like product safety assessment and building inspections.

Federal and state product safety agencies can set health-based limits on source emissions, as understanding sources helps control air pollution (EPA 2019). US consumers care about the health harms of combustion fuel use that is currently not accounted for in appliance guidance. After learning about the health harms of the health harms of gas stove emissions, US consumers were less likely to prefer gas over electric stoves. Additionally, 67% of Americans support allowing CPSC to set regulations on gas appliances due to these health harms (Sabrina Jacobs 2023). The Federal Consumer Product Safety Commission (CPSC) can embed IAQ guidelines into existing protocols, distribute health-based guidance on sources of indoor air pollution, and develop mandatory product emissions standards under their authority (Figueroa and Lienke 2022). For example, Health Canada previously developed an IAQ guideline-based product emissions standards for air cleaners and wood products (Wille and Moore 2023). Additionally, CARB set health-based ozone emission limits on indoor air cleaners (CARB 2024b).

Regarding building inspections, federal and state agencies can enact proactive, health-based building policies and inspection protocols. For example, the U.S. Department of Housing and Urban Development (HUD) developed a smoke-free housing policy for public housing, which could be paralleled for other emissions sources like combustion appliances (Prescott et al. 2023). HUD could also adopt established IAQ guidelines into their National Standards for the Physical Inspection of Real Estate (NSPIRE) model, evaluating IAQ and sources of pollutants in new and existing housing (Prescott et al. 2023). The Federal Housing Finance Agency (FHFA) enacted radon testing requirements in multifamily Enterprise properties, which could be extended to inspect levels of other health-harming pollutants (FHFA 2023).

3.b.iii. Establish regulatory codes and standards[3]

With no single authority over indoor air and few precedent policies in the U.S. and beyond, indoor air can become nobody's problem (Morawksa, Marks, and Monty 2022). Where towns, cities, and counties are the primary providers of key government services, their authority over local affairs and public policy can be limited: only possessing policymaking power consistent with state constitutions and state laws, as well as the federal Constitution and federal laws (Mattison 2022). While a lack of structured authority on indoor air is a challenge, adjacent policies addressing health risks indoors can be models when developing standards for other indoor air pollutants.

States can embed health-based pollutant limits in new building standards, codes, and requirements for efficiency, performance, and ventilation. Not all appliances that run on gas are required to exhaust outdoors, and combustion pollutants from these systems are still able to leak indoors or infiltrate from outdoor air (Seals 2020). Even when ventilation is properly installed and maintained, studies have found that exhaust hoods are not uniformly removing pollutants (Seals 2020). As there are limited policies directly addressing indoor air pollutants, successes in the private sector and voluntary programs should be referenced when determining mandatory measures.

[3] IAQ regulations, such as building codes or mandatory standards, are mandatory rules set by authorities that are enforced as law (Bahnfleth 2024).

Building code requirements can be specific to fuel type, as combustion fuel use produces more emissions than non-emitting fuel types, and other factors that may impact IAQ. For instance, Washington's building code set differentiated ventilation requirements for gas stoves versus electric stoves in single family and multifamily residential buildings, requiring 250 CFM for gas stoves and 150 CFM for electric (State of Washington 2023a; State of Washington 2023b). California's energy code includes single family and multifamily home ventilation requirements based on dwelling size (CEC 2022).

At the state and federal level, policymakers should not see the lack of existing overt regulatory oversight on IAQ in the U.S. as an impediment. Recent advancements in proposed policies limiting indoor air pollution may serve as models, including New York City's proposed IAQ standards bill and the Model Indoor Air Quality Act developed by Johns Hopkins Center for Health Security (JHCHS 2023). This model law provides foundational evidence for state authority to improve IAQ, and future adoption of this law by states can indicate methods for tailoring the law to the specifications of a given regional or local jurisdiction.

4. Lessons Learned: New York IAQ Bills

There are multiple examples of policymakers taking steps to protect IAQ in the U.S. and beyond that may be replicated or modeled after (EIA 2023a; Abdul-Wahab et al. 2015). However, few IAQ-related policies include pollutant limits (ELI 2023b; Prescott et al. 2023). New York City recently proposed a precedent-setting set of bills to monitor and regulate IAQ. While these bills have not been enacted, they serve as an example of policy solutions to establish healthy IAQ.

4.a. New York City's Indoor Air Quality Standards and Monitoring Bill

New York City councilmember Keith Powers proposed legislation in the fall of 2023 to improve and standardize IAQ in schools, municipal buildings, and a subset of commercial and privately-owned properties. At the time of its proposal, the bills were (and continue to be as of spring 2024) a first-of-its-kind comprehensive IAQ standard for key pollutants across multiple building types. The proposed legislation includes measures to install and maintain air quality monitoring devices for various pollutants and metrics such as ambient temperature, ambient humidity level, air changes per hour, CO_2 levels, CO levels, and fine and ultrafine particulate levels. Further, there are inclusions of a pilot program to monitor IAQ in certain residential and commercial buildings with the goal to inform future rulemaking.

4.b. Public Reception and Support

While the legislation has yet to pass as of spring 2024, early reception from both the public and scientific community has been overwhelmingly positive, especially from health and children advocates. Both live testimony and submissions to the public comment docket reveal alignment in public opinion – one that recognizes the importance of standardizing and protecting IAQ and its critical role in promoting a healthier, more prosperous, and equitable society (Shemesh 2023). Influential health professionals and organizations testified in support of the bills, including the New York State Public Health Association, American Academy of Pediatrics (New York State), Asthma and Allergy Foundation of America and the Icahn School of

Medicine at Mount Sinai Children's Environmental Health Center. The groundswell of health professionals validating such policy emphasizes the critical opportunity at hand to protect public health. Examination of the public comment docket also revealed support of passing these bills with parents, building-sector professionals and the United Federation of Teachers (Shemesh 2023). Of particular significance was the multiple intentional nods to passing protective standards in New York City's schools, underscoring a shared concern and desire for better protections and environments for some of society's most vulnerable — children.

4.c. Limitations and Recommendations

The supposed implementing agency of these bills, NYC's Department of Health and Mental Hygiene (DOHMH), raised concerns on the efficacy of available air quality monitoring technology and the burden of resources necessary to implement such an extensive program. Additionally, DOHMH offered feedback on the lack of guidance on sampling and pathways to meaningful health-based standards. We recommend entities that pursue similar programs to consider the availability of appropriate air quality monitoring technology as recommended by subject-matter experts, while establishing clearly defined, informed and generalizable sample sizes. This will enable stakeholders to tap into available resources most efficiently for scientifically sound and representative policy. Furthermore, DOHMH cast doubts on their own standing in promulgating rules pertaining to IAQ, as a direct outcome of the lack of comparative health-based standards. As mentioned in earlier sections, policymakers can still act in the absence of overt regulatory mechanisms. We urge the New York City Council to continue to work closely with implementing agencies and subject-matter experts to develop air quality protections that maximize benefits for residents while complimenting the local policy making landscape.

Finally, these bills lacked the monitoring and standardization of ozone- and particulate-forming NO_X, a group of toxic gasses including NO_2, and nitric oxide (NO) commonly associated with combustion. We recommend that policymakers include the monitoring and standardization of NO_X levels indoors to reflect the best available science and strengthen any air quality programs by maximizing air pollution reduction and human health benefits.

5. Conclusion

IAQ is an underdeveloped and crucial component of preparing for a warming climate, transitioning to clean energy, and improving health outcomes for all. Addressing IAQ is a leadership opportunity; the following are recommendations for leaders:

- **Support market transformation pathways that will pave the way for policy.** Implementing IAQ-protective industry practices, protocols, and safety measures can build precedent for stronger action and lead to strong policy development. Building owners, operators, designers, and other industry decision makers can install sensors, perform IAQ monitoring pilot programs, educate peers on the health and climate harms of indoor pollution, and replicate model examples of IAQ management in their buildings. These strategies will help innovate IAQ management strategies and increase demand for IAQ monitoring technology. Further, building industry members can enroll their buildings in voluntary certification programs and comply with voluntary standards that require IAQ management. IAQ considerations allow building industry decisionmakers to

better sequence new construction and building upgrades, encouraging the uptake of electric, efficient, high-performing building systems.

- **Call for expanded guidance, protocols, and policies to limit indoor air pollution.** Improved guidance at all levels of government will help prioritize IAQ in the building industry and beyond. Federal and state governments can publish indoor air quality guidelines as a first step to standardize the national understanding of what levels of pollutants indoors are safe. These guidelines can be woven into protocols like building inspections and product safety assessments. Finally, federal, state, and city governments can enact regulatory measures to equitably address indoor air pollution in buildings, including the development of standards and enactment of standards into building code.

There is no single pathway for improving IAQ; these improvements should be pursued at every level of decision making. Further, partnerships between building industry members, governmental decision makers, and experts in IAQ can strengthen these protective measures beyond traditional, observation-based or complaint-based methods of regulating IAQ. As climate change may worsen IAQ and introduce new problems (EPA 2023b), strategies to improve IAQ will become more urgent and closely linked to both health and climate outcomes. Considering IAQ at every step of the way – from construction, to operation, to retrofit – leads to healthier, more efficient, more high-performing, and more equitably-resourced buildings.

References

Adgate, J.L., Church, T.R., Ryan, A.D., Ramachadran, G., Fredrickson, A.L., Stock, T.H., Morandi, M.T., and Sexton, K. 2004. "Outdoor, Indoor, and Personal Exposure to VOCs in Children." *Environmental Health Perspectives*, 112 (4): 1386-1392. https://doi.org/10.1289/ehp.7107

Bahnfleth, B. 2024. *Standards, Guidelines, & Regulations Matter. Where We Are & What We Need.*https://www.nationalacademies.org/documents/embed/link/LF2255DA3DD1C41C0A42D3BEF0989ACAECE3053A6A9B/file/DEA0BC556C23FA6A7A0EFB142E07BC6BB9F76B6989EC?noSaveAs=1. National Academies Indoor Air Chemistry Matters Workshop 3: Reaching Communities for Action.

BBC Research. 2023. "U.S. Indoor Air Quality Market." BBC Publishing. https://www.bccresearch.com/market-research/environment/us-indoor-air-quality-market.html

Berkeley Lab. 2024. "Air Quality Sensors." Lawrence Berkeley National Laboratory. https://indoor.lbl.gov/air-quality-sensors

Bland et al. 2022. "Studying the Optimal Ventilation for Environmental Indoor Air Quality." *National Center for Healthy Housing.* https://nchh.org/resource-library/report_studying-the-optimal-ventilation-for-environmental-indoor-air-quality.pdf

Boston Public Schools. 2023. "Indoor Air Quality (IAQ) Sensor Dashboard." https://www.bostonpublicschools.org/Page/8810

Buonocore, J., Salimifard, P., Michanowicz, D.R. and Allen, J.G. 2021. "A Decade of the U.S. Energy Mix Transitioning Away from Coal: Historical Reconstruction of the Reductions in the Public Health Burden of Energy." *Environmental Research Letters*, 16, (5). https://iopscience.iop.org/article/10.1088/1748-9326/abe74c/pdf.

CARB (California Air Resources Board). 2002. *Indoor Air Pollution in California*. State of California. https://ww2.arb.ca.gov/sites/default/files/2020-05/rpt0705.pdf

———. 2024a. "Progresses and Challenges on Indoor Air Quality in California." CARB. https://ww2.arb.ca.gov/resources/documents/progresses-and-challenges-indoor-air-quality-california

———. 2024b. "Air Cleaner Regulation (AB 2276)." CARB. https://ww2.arb.ca.gov/our-work/programs/air-cleaners-ozone-products/air-cleaner-regulation-ab-2276

CEC (California Energy Commission). 2022. "Building Energy Efficiency Standards for Residential and Nonresidential Buildings." Title 24, Part 6. State of California. https://www.energy.ca.gov/sites/default/files/2022-12/CEC-400-2022-010_CMF.pdf

Cincinelli, A. and Martellini, T. 2017. "Indoor Air Quality and Health," *International Journal of Environmental Research and Public Health* 14, (11):1286, https://doi.org/10.3390/ijerph14111286

Colmer, J. and Voorheis, J. 2021. "The Grandkids Aren't Alright: The Intergenerational Effects of Prenatal Pollution Exposure," Washington Center for Equitable Growth. https://equitablegrowth.org/working-papers/the-grandkids-arent-alright-the-intergenerational-effects-of-prenatal-pollution-exposure/

Colwell, S. 2022. "Engineering Dean Corsi Clears the Air at White House." University of California, Davis. https://www.ucdavis.edu/news/engineering-dean-corsi-clears-air-white-house

Consumer Reports. 2012. "Is Poor Indoor Air Quality Making You Sick?" Consumer Reports. https://www.consumerreports.org/cro/magazine/2012/06/is-poor-indoor-air-quality-making-you-sick/index.htm

EIA (Environmental Law Institute). 2023a. "Recent Developments in Indoor Air Quality Policy." ELI. https://www.eli.org/buildings/recent-developments-iaq

———. 2023b. "Environmental Law Institute Database of State Indoor Air Quality Laws." ELI. https://www.eli.org/buildings/database-state-indoor-air-quality-laws

enVerid (enVerid Systems). 2021. "Broadcasters' Child Development Center: Optimizing Indoor Air Quality for Children and Teachers While Saving Space and Energy." https://enverid.com/resources/case-studies/broadcasters-child-development-center-optimizing-indoor-air-quality-for-children-and-teachers-while-saving-space-and-energy/

EPA. 2008. “Integrated Science Assessment For Oxides Of Nitrogen – Health Criteria (Final Report, July 2008).” EPA. 2–38. https://cfpub.epa.gov/ncea/isa/recordisplay.cfm?deid=194645

———. 2014. “Reference Guide for Indoor Air Quality in Schools,” https://www.epa.gov/iaq-schools/reference-guide-indoor-air-quality-schools

———. 2016. “Integrated Science Assessment (ISA) for Oxides of Nitrogen - Health Criteria,” https://www.epa.gov/isa/integrated-science-assessment-isa-oxides-nitrogen-health-criteria.

———. 2018. “The 50th Anniversary of the Clean Air Act: Clean Air Act Advisory Committee Report to the EPA.” https://www.epa.gov/caaac/final-caa-50th-anniversary-workgroup-report-findings-and-recommendations-us-epa

———. 2019. “Our Nation’s Air: Understanding Emission Control Sources Helps Control Air Pollution.” https://gispub.epa.gov/air/trendsreport/2019/#sources

———. 2023a. “Indoor Air Quality.” https://www.epa.gov/report-environment/indoor-air-quality

———. 2023b. “Indoor Air Quality and Climate Change.” https://www.epa.gov/indoor-air-quality-iaq/indoor-air-quality-and-climate-change

———. 2023c. “Progress Cleaning the Air and Improving People’s Health,” https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health

———. 2023d. “Overview of the Clean Air Act and Air Pollution.” https://www.epa.gov/clean-air-act-overview

———. 2023e. “Sources of Greenhouse Gas Emissions,” https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions.

———. 2024a. “Climate Pollution Reduction Grants.” https://www.epa.gov/inflation-reduction-act/climate-pollution-reduction-grants#:~:text=The%20Climate%20Pollution%20Reduction%20Grants,and%20other%20harmful%20air%20pollution.

———. 2024b. “Low–Cost Air Pollution Monitors and Indoor Air Quality.” EPA. https://www.epa.gov/indoor-air-quality-iaq/low-cost-air-pollution-monitors-and-indoor-air-quality

———. 2024c. “Federal Interagency Committee on Indoor Air Quality.” EPA. https://www.epa.gov/indoor-air-quality-iaq/federal-interagency-committee-indoor-air-quality

———— . 2024d. “Radon Standards of Practice.” EPA. https://www.epa.gov/radon/radon-standards-practice

Ferguson, L., Taylor, J., Davies, M., Shrubsole, C., Symonds, P. and Dimitroulopoulou, S. 2020. “Exposure to indoor air pollution across socio-economic groups in high-income countries: A scoping review of the literature and a modelling methodology,” *Environment International*, 143. https://doi.org/10.1016/j.envint.2020.105748

FHFA (Federal Housing Finance Agency). 2023. “FHFA Increases Radon Testing Requirements at Enterprise-Backed Multifamily Properties.” FHFA. https://www.fhfa.gov/Media/Blog/Pages/FHFA-Increases-Radon-Testing-Requirements-at-Enterprise-Backed-Multifamily-Properties.aspx

Figueroa, L. and Lienke, J. 2022. *The Emissions in the Kitchen: How the Consumer Product Safety Commission Can Address the Risks of Indoor Air Pollution from Gas Stoves*. New York University School of Law, Institute for Policy Integrity. https://policyintegrity.org/publications/detail/the-emissions-in-the-kitchen

Health Canada. 2022. “Indoor Air Quality Resources for Professionals.” Government of Canada. https://www.canada.ca/en/health-canada/services/air-quality/residential-indoor-air-quality-guidelines.html

JHCHS (Johns Hopkins Center for Health Security). 2023. “Model State Indoor Air Quality Act.” Johns Hopkins Center for Health Security. https://centerforhealthsecurity.org/sites/default/files/2023-08/230801-msiaqa-final.pdf

IEA (International Energy Agency). *World Energy Outlook 2023.* https://www.iea.org/reports/world-energy-outlook-2023

Jacobs, S. 2023. “After Learning About Their Toxic Emissions, Americans Support Regulating Gas Stoves.” Data for Progress. https://www.dataforprogress.org/blog/2023/1/31/after-learning-about-their-toxic-emissions-americans-support-regulating-gas-stoves.

Jbaily, A., Zhou, X., Liu, J. et al. 2022. “Air pollution exposure disparities across U.S. population and income groups.” *Nature* 601, 228–233. https://doi.org/10.1038/s41586-021-04190-y

Johnson, S et al. 2020. “Assessing Air Quality and Public Health Benefits of New York City’s Climate Action Plans,” *Environmental Science & Technology* 54, (16): 9804–13, https://doi.org/10.1021/acs.est.0c00694.

Karambelas, A and Cooper, C. 2021. “Estimating the Emissions Benefits of Switching to Heat Pumps for Residential Heating”. NESCAUM. https://otcair.org/upload/Documents/Reports/nescaum-otc-emission-reduction-analysis-for-residential-heating-202106.pdf

Kashtan, Y., Nicolson, M., Finnegan, C., Ouyang, Z., Garg, A., Lebel, E., Rowland, S., Michanowicz, D., Herrera, J., Nadeau, K., Jackson, R. 2024. "Nitrogen dioxide exposure, health coutomes, and associated demographic disparities due to gas and propane combustion by U.S. stoves." *Science Advances.* 10, https://www.science.org/doi/full/10.1126/sciadv.adm8680

Licina, D. and Langer, S. 2021. "Indoor air quality investigation before and after relocation to WELL-certified office buildings." *Building and Environment*, 204, 108182, https://www.sciencedirect.com/science/article/pii/S0360132321005837

Mattison, N.R. 2022. "Beyond Gas Bans: Alternative Pathways to Reduce Building Emissions in Light of State Preemption Laws." New York University School of Law, Guarini Center on Environmental, Energy, & Land Use Law. https://guarinicenter.org/wp-content/uploads/2022/11/2022-11-10-Mattison-Beyond-Gas-Bans.pdf

Morawksa, L., Marks, G.B., Monty, J. 2022. "Healthy Indoor Air is Our Fundamental Need: The Time to Act is Now." *Medical Journal of Australia*, 217, (11): 578-581. https://doi.org/10.5694/mja2.51768

Mui, S. and Levin, A. 2020. *Clearing the Air: The Benefits of the Clean Air Act*. NRDC (Natural Resources Defense Council). https://www.nrdc.org/sites/default/files/benefits-clean-air-act-ib.pdf#page=8

New York City Council. 2023. "Int 1127, 1128, 1129, 1130" New York, NY: Committee on Health. https://legistar.council.nyc.gov/MeetingDetail.aspx?ID=1118235&GUID=C76C4223-29AA-4D84-9547-5F6D4566435D&Options=&Search=

Nunez, Y., Benavides, J., Shearston, J.A., Krieger, E.M., Daouda, M., Henneman, L.R.F., McDuffie, E.E., Goldsmith, J., Casey, J.A. and Kioumourtzoglou, M. 2024. "An Environmental Justice Analysis of Air Pollution Emissions in the United States from 1970 to 2010." *Nature Communications*, 15, 268. https://doi.org/10.1038/s41467-023-43492-9

Prescott, N., Henchen, M., Hines, E., Seals, B. 2023. *The Need for U.S. Indoor Air Quality Guidelines: Advancing Policy for Healthy Buildings at the Federal and State Level*. RMI. https://rmi.org/the-need-for-us-indoor-air-quality-guidelines/

Price, J., Gulati, S., Lehr, J. and Penn, S. 2020. *The Benefits and Costs of U.S. Air Pollution Regulations*. IEc (Industrial Economics, Incorporated). https://www.nrdc.org/sites/default/files/iec-benefits-costs-us-air-pollution-regulations-report.pdf

PR Newswire. 2023. "Attune partnered with 45 Colorado school districts, The University of Colorado Boulder and The Colorado Department of Health and Environment to expand indoor air quality monitoring systems statewide." https://www.prnewswire.com/news-releases/attune-partnered-with-45-colorado-school-districts-the-university-of-colorado-

boulder-and-the-colorado-department-of-health-and-environment-to-expand-indoor-air-quality-monitoring-systems-statewide-301995573.html

Seals, B. and Krasner, A. 2020. Gas Stoves: *Health and Air Quality Impacts and Solutions*. RMI. https://rmi.org/insight/gas-stoves-pollution-health

Seals, B., and Louis-Prescott, L. 2021. *Uncovering the Deadly Toll of Air Pollution from Buildings*. RMI. https://rmi.org/uncovering-the-deadly-toll-of-air-pollution-from-buildings/

Shemesh, S. 2023. Introductions 1127, 1128, and 1130, New York City Council Committee on Health. p. 125. https://legistar.council.nyc.gov/View.ashx?M=F&ID=12343470&GUID=537BB7F0-D747-4F75-BCEB-B49B2EF17335

State of Washington. 2023a. "WSR 23-02-058." State of Washington Building Code Council. https://www.sbcc.wa.gov/sites/default/files/2023-01/WSR_23-02-058_OTS4043.5_Combined.pdf

———. 2023b. "WSR 23-02-055." State of Washington Building Code Council. https://sbcc.wa.gov/sites/default/files/2023-01/2021%20IMC_CR103_combined.pdf

Tan, L., Fathollahzadeh, M. H. 2021. *Why Heat Pumps Are the Answer to Heat Waves.* RMI. www.rmi.org/why-heat-pumps-are-the-answer-to-heat-waves/.

Tessum, C. W., Paolella, D. A., Chambliss, S. E., Apte, J. S., Hill, J. D., Marshall, J. D. 2021. "PM $_{2.5}$ Polluters disproportionately and systematically affected people of color in the United States." *Science Advances*, 7(18). https://doi.org/10.1126/sciadv.abf4491

Wallace, L., Pellizzari, E.D., Hartwell, T.D., Whitmore, R., Sparacino, C. and Zelon, H. 1986. "Total Exposure Assessment Methodology (Team) Study: Personal Exposures, Indoor-Outdoor Relationships, and Breath Levels of Volatile Organic Compounds in New Jersey." *Environment International* 12, (1-4): 369–87, https://doi.org/10.1016/0160-4120(86)90051-6.

White House. 2022. "Readout of the White House Summit on Improving Indoor Air Quality." United States White House. https://www.whitehouse.gov/briefing-room/statements-releases/2022/10/12/readout-of-the-white-house-summit-on-improving-indoor-air-quality/

WHO (World Health Organization). 2021. "WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide." WHO. https://www.who.int/publications/i/item/9789240034228

———. 2022. "Household Air Pollution," https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health

Will, J. 2022. “How to Protect Yourself From Indoor Air Pollution and Other Hidden Home Hazards.” Consumer Reports. https://www.consumerreports.org/appliances/indoor-air-quality/protect-yourself-from-indoor-air-pollution-and-home-hazards-a1085509595/

Wille, S. and Moore, J. 2023. “Indoor Air Quality Exposure Limits at Health Canada: Development and Use.” Health Canada. https://ww2.arb.ca.gov/sites/default/files/2023-06/Moore_IACAS_guidelines.pdf

World GBC (World Green Building Council). 2024. “Sustainable Building Certifications.” World GBC. https://worldgbc.org/sustainable-building-certifications/