INDOOR ENVIRONMENTAL EXPOSURES

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ABSTRACT

The majority of the world's population now spends most of their time in indoor environments. The design and ecology of these spaces consequently has a significant impact on human health. Despite being our primary habitat, until recently little was known about how indoor environments are shaping our bodies. Recent research across the life sciences is revealing numerous ways that indoor exposures are contributing to the emergence of particular health conditions and diseases. These findings expose health outcomes that reflect existing socio-economic disparities along geographic, gendered, economic and racial lines. This entry outlines the key indoor environmental exposures that are relevant to human health and how social scientists are helping to highlight the relationships between these exposures and other socio-economic variables. It also covers the approaches developed within the social sciences to help mitigate harm and some of the key methodologies employed to investigate complex indoor socio-ecological systems.

Keywords: environmental health; indoor environment; hazardous chemicals; indoor microbiome; citizen sensing; environmental justice

INTRODUCTION

Indoor spaces are the sites in which the majority of people around the world now spend the majority of their time. The types of substances one is exposed to in these places consequently has a significant influence over their health. In many industrialised nations, including most of Europe, North America and Australia, it is often estimated that the majority of people are spending 90% of their time in the indoors.[i.] By 2050 it is expected that two thirds of the world's population will be spending the majority of their time in urban indoor environments (UN, 2014).

The types of health-relevant environmental exposures that people are subject to indoors differs significantly depending on a range of geographic and socio-economic factors. Across low-income countries, around 2.6 billion people are exposed to indoor smoke from cooking on open fires or stoves fuelled by kerosene, biomass or coal (WHO, 2021). In many places the effects of smoke inhalation are exacerbated by traffic and industrial fumes that become trapped indoors. As a result, indoor air pollution has been estimated to cause 3% of deaths globally, and 6% in low-income countries (Dicker et al., 2018). Conversely, in high income countries, harmful indoor environmental exposures are more likely to be caused by the off gassing of particular chemicals from products and building materials, traffic and other forms of pollution that become trapped indoors, and the microbial ecologies of buildings. As more of the world's population moves into urban centres, indoor environmental exposures are coming to impact on health in new ways.

Research over the last three decades has provided some insight into the degree to which our bodies and environments continuously transform one another; from the way we react to pollutants, to the way we smell, and the expression of our genes (Meloni et al., 2021; Prior et al., 2019). The mounting evidence that bodies are porous to their environments in manifold ways has raised a number of pertinent questions that are being explored by social scientists. In particular, researchers have turned their attention to the relationship between factors such as geography, socio-economic status, race and ethnicity, design and planning and governance structures in determining the type and distribution of harmful indoor environmental exposures.

This entry is divided into two sections. The first outlines some of the health impacts associated with environmental exposures in indoor environments, and their causes and distribution. The second provides an overview of the ways that social scientists have endeavoured to understand and address how indoor environments come to shape the bodies of occupants.

HOW DO ENVIRONMENTAL EXPOSURES INDOORS AFFECT HEALTH?

The way that indoor environments affect human health depends on a number of factors. While some pollutants (such as lead) produce relatively consistent effects on exposed bodies, others are much more contingent on the characteristics of the body exposed and the other attributes of the environment. Some examples of the key sources of indoor exposures relevant to human health are described below:

Smoke and airborne particulate matter

The key source of indoor smoke exposure around the world is from burning fuels such as kerosene, biomass or coal associated with indoor cooking and heating. Although this type of exposure is diminishing as alternative fuel and heating sources become available, it is still responsible for the majority of deaths associated with indoor air pollution from various chronic diseases, such as stroke, ischaemic heart disease, lung cancer and chronic obstructive pulmonary disease (Adamkiewicz et al., 2011; Yin et al., 2020). The other key source of indoor smoke emanates from bush or wildfires, which are increasing in prevalence (Reid et al., 2016). While this form of indoor air pollution had previously been restricted to areas in which biomass commonly burned, the scale and distribution of fires is changing as the climate warms, exposing many urban areas to dangerous levels of smoke.

Air pollution associated with traffic and industrial activities is also a primary source of harmful indoor environmental exposures. For example, in China concentrations of Particulate Matter 2.5 (PM2.5) exceed the WHO Air Quality Guideline for the entire population, with 81% still living in places that exceeded safe air pollution levels set by the WHO in 2017 (Yin et al., 2020). While these forms of pollution are harmful in both indoor and outdoor environments, particulate matter can become trapped in buildings, which can expose occupants hours after outdoor air pollution has cleared.

Hazardous chemicals

Since the 1950s there have been significant changes in building materials and consumer products used indoors and ways that buildings are used. Many of the new chemicals that have entered living and workspaces over the past 70 years have been classified as carcinogenic, mutagenic, endocrine disrupting and are associated with a range of health effects from respiratory disease to metabolic, hormonal and neurological disorders and certain types of cancer (Bergman et al., 2013; Mitro et al., 2016; Steinemann, 2015; Wilson et al., 2003). Materials such as polymeric flooring, composite wood, synthetic carpets, foam cushioning, plastics, and electrical appliances have become ubiquities, while a range of new devices and products have come to be used, including fragranced cleaning and personal care products, antimicrobials and non-stick cookware (Weschler, 2009). These products emit a vast range of chemicals including solvents, unreacted monomers, and additives. Changes in building use practices have also influenced toxic chemical exposures. Buildings are generally less ventilated, and air-conditioning has become increasingly ubiquitous around the world (Zalasiewicz et al., 2017). Practices such as cooking, cleaning and showering are now accompanied by a range of products that emit numerous Volatile Organic Compounds (VOC) and other chemicals (Biesterbos et al., 2013).

These cumulative changes have altered the kind and concentrations of chemicals that occupants are exposed to indoors. Levels of certain toxicants (e.g. aromatic and chlorinated solvents, formaldehyde, and chlorinated pesticides,) have risen and fallen, but not disappeared, while levels of other toxicants have increased and remain high (e.g. brominated flame-retardants, phthalate esters, nonionic surfactants, and their degradation products) (Weschler, 2009).

Microorganisms

Indoor fungi are common and often pernicious allergens, triggering severe skin, eye, and lung inflammation and exacerbating conditions such as asthma. Each building material – like paperboard, wallpaper, wood, plastic and cement - has its own associated set of microbes that like to live in and feed off it. Rook and Knight (2015) found that when modern structures degrade, or become damp, they become colonised with types of microorganisms that we have not historically lived with.

A number of studies have now revealed that various strains of pathogenic or allergenic fungi dwell in buildings. For example, the fungus *Neosartorya hiratsukae*, implicated in the range of causes of Parkinson's disease, *Chaetomium globosum*, an allergen and sometimes pathogen, and the toxic black mould *Stachybotrys chartarum* have been found embedded in plasterboard sued to construct interior walls (Andersen et al., 2017; Dunn, 2018) embedded in plasterboard during manufacturing.

The types of pathogens present indoors are also dependant on the types of building materials and practices conducted indoors. Perhaps ironically, many of the antimicrobial cleaning products employed to mitigate the potential emergence of pathogens are driving microbial evolution to create more dangerous microbes. The use of antimicrobials indoors has been directly linked to the rise and spread of antimicrobial resistance (Fahimipour et al., 2018; Hartmann et al., 2016). People are also more likely to be affected by airborne pathogens indoors, particularly in poorly ventilated spaces.

Absence of exposure

In addition to health impacts associated with exposure to pollutants and microorganisms, the absence of particular organisms within indoor spaces has also been associated with certain diseases, and allergic and autoimmune disorders in particualr.

Around the 1950s public health institutions began to recognise an increasing prevalence of chronic inflammatory conditions in wealthy, urbanised regions of the world (Isolauri et al., 2004; Okada et al., 2010). These allergic and autoimmune diseases number between 80-100 types. Based on the 'biodiversity hypothesis' individuals who spend the majority of their time in indoor spaces in urban areas lack exposure to biodiversity in outdoor natural landscapes, including environmental microbiota, which results in inadequate stimulation of important immunoregulatory circuits in people, and particularly children (Fyhrquist et al., 2014; Hanski et al., 2012; Stamper et al., 2016).

Cumulative and combinative exposures

Exposures to particular organisms or contaminants in indoor environments do not affect people in uniform or consistent ways. The way one's body reacts to a particular substance is contingent on what that substance is combined with, the amount, the prior exposures of the person, their age, their immune system, their sex and a range of other factors. This is the case for both microbial and toxicant exposures. For example, if a person experiences asthma in early life to do a lack of exposure to biodiverse microbes and high exposure to toxicants and allergens, such as cockroaches, which may trigger it, they will respond to indoor environments differently to those with a different exposure history. They me be more adversely affected by mould or dust mites, for instance. As a result, adverse health effects caused by indoor environmental conditions are not experienced evenly across society. Children from disadvantaged backgrounds experience far higher rates of asthma in high income countries Exposures to certain substances in early life can alter how one's body responds to other types of exposures later in life (Keet et al., 2015; Skinner et al., 2020). Similarly, exposure to chemical toxicants can influence how one's immune system responds to pathogens. For example, research has found that prior exposure to air pollution and flame retardant chemicals can result in more severe responses to the Covid 19 virus (ATSDR, 2020; Xiao et al., 2020).

The non-linearity of responses to indoor allergens and hazardous chemicals in indoor spaces has provided a significant challenge for those advocating for regulatory change to adequately protect people from these exposures. In the following section I will look at some of the ways that social scientists have come to research indoor exposures, often with the intention of improving advocacy approaches.

How are environmental exposures indoors investigated?

Understanding health-relevant exposures in indoor spaces requires not only sampling and testing for what is present in the environment, but the normative cultural practices that determine how buildings are used, and the larger socio-political and economic drivers that influence how a building is designed and built and where.

The primary areas in which social scientists are contributing to research into indoor environmental exposures and their consequences are linked to: 1) understanding the drivers and effects of exposures on peoples' lives, 2) their experiences of those effects and 3) in helping to generate new forms of evidence that can be used to appropriately reassign responsibility and advocate for healthier environments.

Social scientists, including geographers, sociologists and anthropologists, have engaged in assessing how housing inequality contributes to indoor contaminant exposure in different regions (Adamkiewicz et al., 2011; Lea & Pholeros, 2010). There has been a particular focus on how exposures associated with poor housing contribute to adverse health outcomes for marginalised groups such as immigrants or racial minorities. Some examples include mould associated with damp walls and increased asthma rates (Keet et al., 2015; Skinner et al., 2020), formaldehyde off-gassing from cheap building materials and incidence of cancer (Shapiro, 2015), or chemical toxicants that enter drinking water and food through contaminated land, resulting in manifold adverse health outcomes (Pauli, 2019).

Workplace exposures in different industries, including textiles (Singh, 2015) cleaning (Rosenman et al., 2020) office work (Murphy, 2006) and various other types of factory and industrial professions (refs) have also been investigated. Sociologists and geographers have also played a role in assessing the adequacy of regulatory, governance and other standards and classification systems that determine how healthy environments are defined and measured (Hepler-Smith, 2019; Liboiron, 2015).

A growing body of research has also emerged that looks at how responsibility for managing indoor environmental exposures is allocated (e.g. to individuals, parents, industry or governments) and the implications of this for action and health outcomes in different contexts. The gendered nature of responsibility for managing the environmental exposures of families in the home has been a particular focus (Altman et al., 2008; Mackendrick, 2014).

Sociologists and psychologists have also explored the psychological and physical effects of the anxiety and fear associated with the risk of indoor environmental contaminants that one's children or self are exposed to (Bass et al., 2003; Edelstein, 2018) and the disproportionate experience of these risks for first nations and other marginalised communities (Arquette et al., 2002; Hoover et al., 2015; Wiebe, 2016).

In addition to researching the drivers and effects of indoor environmental exposures, social scientists are increasingly collaborating with scientists and engineers to develop practices that can help affected communities advocate for healthier environments. One way this has been done is through biomonitoring and other sensing practices, in which people from a certain group collect samples from a local environment – such as indoor air or tap water – or from themselves – such as urine, blood, breast milk or hair – to be tested for the presence of particular contaminants (Brody et al., 2009; Matz et al., 2017). The evidence is then linked to other data, such as poor housing stock or disadvantage, to raise awareness of the problem, and advocate to government and industry to restrict polluting activities. Often, these protocols are designed to enable communities to collect their own data with low-cost and low-tech sensing devices that enable groups to design the collection practices based on their knowledge of the problem (for e.g. Gabrys et al., 2016; Morawska et al., 2018; Pritchard et al., 2018).

Biomonitoring practices have also been central to debates around how concepts such as risk, pollution and toxicity have been used in public health and regulatory settings and whether they need to be revised (Daemmrich, 2008; Hoover et al., 2015). While biomonitoring has been used to effectively advocate for the rights of communities, there is also a risk that biomonitoring data can further entrench existing ways of measuring harm exclusively in relation to the presence of particular molecules in an environment or body – a reductive approach which fails to capture the high degree of biological and social complexity which link exposure and harm (Murphy, 2008). An increasing number of researchers are consequently promoting approaches that place responsibility on known producers of polluting substances over approaches that focus on demonstrating the presence of toxic molecules in bodies (Davies, 2019; Liboiron, 2021; Roberts et al., 2008).

Research approaches

A range of methodological approaches have been employed by social scientists to investigate the drivers and effects of indoor environmental exposures. Ethnographic research methods are particularly common among anthropologists and geographers investigating environmental exposures. In addition to more traditional ethnographic approaches, new forms of ethnographic investigation have emerged to account for the bio-physical aspects of human-environment interactions, including: bio-ethnography, which combines ethnographic and biological data to generate improved understandings of how life circumstances and histories shape health and inequality (Roberts & Sanz, 2018); sensory ethnography, an approach that takes account of the sensory experience and perception that shape experiences of everyday life (Pink, 2015); and multi-species and chemo-ethnography, which focus on how new forms of relationships (economic, personal, political) have emerged with new encounters across species and with modern chemistry, respectively (Kirksey & Helmreich, 2010; Shapiro & Kirksey, 2017)

Examples of some other notable approaches for health research include: Participatory action research (PAR), which includes iterative cycles of reflection, data collection, and action with participants with the intention of transforming health outcomes through the research process (Baum et al., 2006; Nix et al., 2019); "Following the thing", which traces the journey of a given thing (e.g. goods, chemicals, people, energy, data), and the dynamic transformations it creates and is subject to throughout its life (Cook, 2006; Evans, 2018); Visual and spatial methodologies, which utilise tools such as Geographic Information Systems (GIS) to provide data of relationships between variables such as traffic pollution occurrence, indoor air quality and different social groups (Zhao et al., 2018); and social practice research, which involves an examination of normative everyday practices in a particular time and place to understand how concepts such as risk and responsibility manifest and are reproduced in everyday actions, and also how the dynamics of daily life can structure environmental exposures in particular ways (Heidenstrøm, 2021; Wakefield-Rann et al., 2018).

As new forms of contaminates, including novel building materials, circulated chemicals, increasingly polluted environments, new forms of air pollution move indoors, social scientific approaches to understanding the health risks of indoor environmental exposures will become increasingly important. While some cross-disciplinary collaborations have emerged around issues associated with indoor environmental exposures and health (see Wakefield-Rann & Fam, 2018), further inter- and transdisciplinary collaborations will be required to address emerging health problems.

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