# MICROBIOMES OF THE BUILT ENVIRONMENT

## A RESEARCH AGENDA FOR INDOOR MICROBIOLOGY, HUMAN HEALTH, AND BUILDINGS

**SUMMARY FOR BUILDING PROFESSIONALS AND OTHER STAKEHOLDERS**

A report from the National Academies of Sciences, Engineering, and Medicine evaluates research on the complex interactions among indoor environments, the microbial communities inside buildings, and human health. The time people spend in homes and workplaces is shared with diverse microorganisms—viruses, bacteria, fungi, and protozoa—that are found in the air that circulates in buildings, in the plumbing systems that supply water and remove waste, and on surfaces from the most inaccessible space behind a wall to a doorknob that is touched every day. New microorganisms and microbial components are constantly introduced into built environments through pathways such as pets, plants, rodents, an open window, a leaky roof, and dirt tracked indoors on an occupant's shoes.

The composition and viability of indoor microbial communities are influenced by many factors, including the availability of water and nutrients for growth and survival, characteristics and behaviors of building occupants, and the external environment.

Air enters buildings through intentional ventilation such as HVAC systems, windows, and doors, as well as through unintentional ventilation, such as infiltration of the building envelope. Because mechanical ventilation systems often have filtration systems that can capture some microorganisms, these systems are generally regarded as health-promoting. Yet additional research is needed on the potential benefits of increasing the introduction of outdoor air into buildings in locations where outdoor pollution levels are relatively low and the ambient temperature is comfortable for building occupants.

Plumbing systems can serve as microbial reservoirs, and condensation, leaks, and malfunctioning or poorly-maintained equipment can also contribute to sustained microbial growth outside of these systems. Plumbing system characteristics and the ways that humans use these systems can influence microorganisms. For example, water temperature affects microbial viability, and human behaviors such as leaving a toilet seat up or down while flushing can influence the extent to which microorganisms become aerosolized. In addition, microbial growth can affect the integrity of building materials and systems, resulting in corrosion, degradation or biofilm formation.

The report proposes a **systematic research agenda with 12 priority areas** to address knowledge gaps and achieve the goals of characterizing built environment interrelationships, assessing effects of exposures on human health outcomes, exploring non-health impacts of indoor microbial communities, advancing tools and research infrastructure, and translating research into practice. Building professionals can play a role in the effective pursuit of such a research agenda (see Box on back).

Although research offers insights into building-related factors that can influence the indoor microbiome, knowledge gaps remain, including the need to:

- *Improve understanding of how building attributes are associated with microbial communities.* Information is lacking, for example, on how to interpret test results to improve building management practices. Such research could be employed to develop improved guidelines that are test- and climate-specific.
- *Improve understanding of the association between building characteristics and indoor microorganisms that have favorable effects on human health.* Important questions include when outdoor environments and their microbial communities may have beneficial effects indoors, and the impacts of natural and mechanical ventilation on potentially beneficial microorganisms.
- *Develop strategies to improve monitoring and maintenance of built environments to promote healthy indoor microbiomes, including concealed spaces.* Concealed spaces can harbor conditions that promote the growth and transport of microorganisms, but they are not easily accessed and are often unmonitored or poorly maintained. Design advances are needed to address these gaps, and maintenance practices studied to ensure that they do not unintentionally cause problems.

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- *Deepen knowledge on the impact of climate and climate variation on the indoor environment.* Additional studies might explore the impact of factors such as changing temperatures and shifts in humidity on microbial survival, and how human behaviors interact with climate to impact indoor microbial communities. Research on human responses to climate change—use of air conditioning, biocides, humidifiers, and dehumidifiers—will also need to be explored to understand whether there are any unintended health effects or changes to the microbiome.
- *Collect better information on air, water, and surface microbiome sources and reservoirs in the built environment.* Buildings and the indoor microbiomes they contain are part of a dynamic system. Improved information on microbial sources and reservoirs will be needed before effective public health programs or recommendations can be developed.
- *Identify and promote collection of a common set of data elements in future studies of the impact of the indoor microbiome.* This common data set can facilitate cross-study comparison, thereby strengthening scientists' ability to make informed building and public health decisions.

Engaging building science researchers, architects, and engineers in these efforts is an important step in pursuing this ambitious research agenda, but achieving an improved understanding of the nexus of built environments, their associated microbial communities, and their human occupants can help define and promote healthful indoor environments in the future.

## BUILDING AND ARCHITECTURAL COMPONENTS OF THE RESEARCH AGENDA

Architects, engineers, and building scientists can contribute to addressing the knowledge gaps identified in the report, for example by conducting research to:

**Characterize interrelationships among microbial communities and various aspects of the built environment** by studies that aim to:

- Understand relationships among building site selection, design, construction, commissioning, operation, and maintenance; building occupants; and indoor microbial communities.
- Incorporate social and behavioral sciences to better understand how humans interact with their built environments and how these interactions may impact health.

Explore the **Non-Health Impacts of Interventions to Manipulate Microbial Communities** through studies that seek to:

- Understand the energy, environmental, and economic impacts of interventions that aim to modify indoor microbial exposures, and integrate this information into frameworks that assesses the impact of potential interventions.

**Translate Research Into Practice** via efforts that:

- Support communication and stakeholder engagement to convey information about the interrelationships among the built environment and the indoor microbiome to diverse audiences, including professional building design, operation, and maintenance communities, healthcare providers, and building occupants and homeowners.

This document is based on the report *Microbiomes of the Built Environment: A Research Agenda for Indoor Microbiology, Human Health, and Buildings.* The study was sponsored by the Alfred P. Sloan Foundation, the Gordon and Betty Moore Foundation, the National Aeronautics and Space Administration, the National Institutes of Health, and the U.S. Environmental Protection Agency, with additional support from the National Academy of Sciences Cecil and Ida Green Fund.

Copies of the report are available from the National Academies Press at **http://www.nap.edu.**

For more information, visit: **http://nas-sites.org/builtmicrobiome**

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