Microbiomes of the Built Environment: From Research to Application

Meeting 2 | June 20-21, 2016
20 F Street, NW
Washington, DC 20001

The National Academies of
SCIENCES · ENGINEERING · MEDICINE

Microbiomes of the Built Environment: From Research to Application: Meeting 2

Understanding Microbial Communities in Built Environments

20 F Street Conference Center
20 F Street NW, Washington DC 20001
June 20-21, 2016

Monday, June 20

Light breakfast will be available

8:45am **Welcome and Introductions**
Joan Bennett, Committee Chair

Committee member introductions (name and affiliation)
Goals of the study and open sessions

9:15 **Opening Session: Perspectives on Microbial Interactions in Built Environments**

- **Jo Handelsman,** Office of Science and Technology Policy
- **Brent Stephens,** Illinois Institute of Technology
- Discussion

10:15 **Break**

10:30 **Public Engagement on the Implications of Built Environment Microbiomes**
How will the public engage in understanding built environment microbiomes and interact with the information that results from such studies? How is the public likely to respond to the implications, and can any lessons be derived from experiences with citizen science and risk assessment communication?

- **Lee Ann Kahlor,** University of Texas at Austin
- **Rob Dunn,** North Carolina State University (remote)
- Discussion

11:45 **Lunch**

1:00 **Linking Human Occupants and Built Environment Microbiomes**
What interactions occur between built environment microbiomes and human occupants, including human microbiomes? What are the consequences of these interactions?

- **Jack Gilbert,** University of Chicago
- **Elizabeth Grice,** University of Pennsylvania
- **Susan Lynch,** University of California, San Francisco
- **Gary Adamkiewicz,** Harvard T.H. Chan School of Public Health

- **Donald Milton,** University of Maryland (remote)
- **Chuck Haas,** Drexel University
- **Joanne Sordillo,** Brigham and Women's Hospital and Harvard T.H. Chan School of Public Health
- **Discussion**

3:30 **Break**

3:45 **Parallel Breakout Discussions: What do we really need to know about built environment microbiomes in order to move toward application?**

(note: colored sticker on your nametag will denote your group)

Identify key questions that would need to be answered to understand the functions of microbiomes in built environments. What information would need to be obtained in order to move from basic microbiome research and characterization to application in building design and operation?

5:15 **Reconvene in Plenary - Recap of Day 1 and Preliminary Key Points Raised in Breakouts**

5:30 **Adjourn Day 1**

6:00 **Dinner for committee, speakers and sponsors**

Art and Soul, 415 New Jersey Avenue NW, Washington DC 20001

Tuesday, June 21

Light breakfast will be available

8:30 **Welcome and Goals for Day 2**

8:45 **Reporting from Breakouts**

What questions does the field need to answer and what are the most critical types of information that need to be collected to answer these questions?
(1 rapporteur per group)

- Group A
- Group B
- Group C
- Discussion

9:45 **Break**

10:00 **Building Systems: Impacts and Characterization**

What do we know about various building systems, their relevant features, and links between building science and indoor microbial environments?

- **Andrew Persily,** National Institute of Standards and Technology
- **Terry Brennan,** Camroden Associates
- **Dennis Stanke,** Trane Ingersoll Rand (retired)
- **Jeffrey Siegel,** University of Toronto

12:15 **Concluding Remarks**

12:30 **Public Meeting Adjourns**

1:00 **CLOSED SESSION - Committee Members and Academy Staff Only**

4:00 **Closed Session Adjourns**

PROJECT PROSPECTUS

Humans spend roughly 90 percent of each day indoors in environments built for shelter and environmental control. Recent research has shown that within these built environments there exist a vast number and diversity of species of bacteria, viruses, fungi and protozoa in the air, water, and heating, ventilation, and air conditioning (HVAC) systems, and on surfaces. These constitute dynamic microbial communities or "microbiomes." The nature, composition, diversity, evolution, and growth of these microbiomes are influenced by interactions with humans, animals and plants, and by factors such as air flow, temperature, humidity, chemical exposures and building materials. These factors are, in turn, shaped by the design, construction, operation, occupation, and use of the built environments.

Although the world of living things is dominated by microbes, very little is known about the vast majority of them. Until recently there have been few systematic efforts to collect and describe the microbes living in or on soil, seawater, freshwater lakes and streams, plants, in the guts and on the bodies of humans and other animals, and in the constructed environments in which we spend most of our time. Our ability to move from identification of genes to a functional understanding of microbial communities and their interaction with ecological conditions remains limited.

Microbial communities in built environments have been shown to affect human health both positively and negatively, influencing our susceptibility to allergies and infectious diseases. The potential health effects from exposure to mold growing in damp environments, for example, are well-recognized. Until relatively recently, most microorganisms in built environments were regarded as pollutants that should be reduced or eliminated from indoor reservoirs. It is now understood, however, that the vast majority of the millions of microbes contained in every glass of water we pour or every breath of air we inhale indoors is non-pathogenic. Many questions remain about the ways in which human occupants shape complex indoor microbiomes and, reciprocally, how the indoor microbiomes to which we are exposed influence the formation and composition of own internal microbiome and what that might mean.

Similarly, "building science" to inform the dynamic between microbiomes and built environments is itself underdeveloped. For example, building materials are poorly characterized in terms of physical structure and chemical composition, factors believed to influence the nature of resident microbial communities and their growth rates. Accordingly, our understanding of how microbial communities respond to changes in building environmental conditions, materials, operation, and maintenance practices is even more limited. We are beginning to understand that microbiomes can have positive and negative effects on the longevity, energy efficiency, and maintenance of the built environments they inhabit, accelerating or decelerating corrosion and degradation of materials, structures, and infrastructural systems. For example, it is estimated that U.S. industries spend $276

billion per year repairing damage to water infrastructure and approximately 50 percent of this cost can be attributed to corrosion influenced by microorganisms. Yet it is believed that the majority of microbes in water systems do no physical harm, and some microbial communities might actually protect pipes from chemical and physical stresses.

A number of investigations are being carried out to better understand microbiomes in buildings such as homes, workplaces, and hospitals, in transit systems, and in unusual environments such as those that support human space exploration. But it is not always obvious which types of complex biological, chemical, and physical data are most important to collect to help answer key research questions, how to design and standardize methods and data interpretation, and which tools from diverse disciplines are available to help address these challenges. For example, information on microbial metabolic activity or factors linked to allergenicity or pathogenicity may be needed to supplement measures of overall composition and diversity such as 16S sequencing. Further discussion may be useful on the types of building data that can be collected and the spatial and temporal resolution that is required from environmental sampling.

Currently, standards pertaining to microbes in the built environment are limited and focus on specific adverse human and material effects or, to some extent, performance. A building's performance can be measured in terms of its indoor environmental quality (e.g., quality of air, ventilation, lighting, comfort of occupants), its use of materials, energy, and other natural resources, and its emissions into the air and water. In some cases, voluntary consensus and other widely recognized standards have been adopted for the design of mechanical and other building systems (e.g., HVAC systems) or for their performance (e.g., energy efficiency standards). Some infrastructure design takes into account positive chemical reactions, such as oxidation on weathering steel, which develops a "patina" of rust to produce a protective barrier that impedes further access of oxygen and moisture. However, there is, in general, limited knowledge on the complex effects of microbes for in-situ construction materials or design.

Integrating expertise from microbial ecologists, building scientists and engineers, and environmental and public health researchers may help refine the design of studies on microbiomes in diverse built environments, enabling results to more effectively inform our understanding of the indoor habitats in which we spend the majority of our time, how these interactions affect us, and whether we can use the results of such investigations to inform improved design and operation of built environments or to support occupant health and well-being. The question facing us is not whether or not we will shape the microbiomes of built environments, but whether we will do so intentionally and in a manner that is socially responsible, applying new knowledge as it becomes available and as its systemic and health implications are more clearly understood.

The purposes of the proposed study are to assess the current state of knowledge regarding microbiomes of the built environment; identify the scientific, technical, engineering, and

health-related knowledge gaps; map out basic and applied research agendas and priorities to guide practical and actionable knowledge to facilitate improving the microbiome/built environment interface; and provide information for government agencies considering whether to include research on the microbiome/built environment interface in their research plans, with the research agenda developed by the study serving as a guide to key issues and questions. The 20-month project will be overseen by an ad hoc committee of approximately 12-14 experts representing various disciplinary and sectoral perspectives.

STATEMENT OF TASK

The National Academies' Board on Life Sciences, working in partnership with the NAE, IOM, and Board on Infrastructure and the Constructed Environment will assess the current state of knowledge regarding microbial communities (bacteria, viruses, fungi, etc.), or "microbiomes" of the built environment, and the implications for human health, sustainability, security, and the design, construction, and operation of physical infrastructural systems and other elements of built environments. The committee will:

- Assess needs, opportunities, and challenges for the practical application of what is currently known about microbiome/built environment interactions.
- Determine if the knowledge developed to date is adequate to assess the impacts of existing policies and practices (e.g., energy efficiency, air quality, building standards and regulations, standards for the design of infrastructural systems, voluntary systems for rating green buildings, etc.) on the microbiomes of the built environment; the resulting implications for human health, sustainability and security; and in cases where the knowledge is found to be adequate, summarize the impacts and implications.
- Identify the scientific, technical, engineering, and health-related knowledge gaps and map out basic and applied research agendas and priorities for built environments with regard to microbiome and microbial-oriented research, building and infrastructure-oriented research, health-oriented research, and tools and method development.
- Consider the economic, legal, and regulatory implications of intentional design and maintenance of built environments to influence microbiomes, as well as social, ethical, and public engagement dimensions thereof.

The committee may also recommend additional actions to advance understanding of microbiome-built environment interactions and accelerate the application of existing and new knowledge in this area to improve the design of built environments for human health, economy, sustainability, and other dimensions of built environment performance.

STUDY COMMITTEE

JOAN WENNSTROM BENNETT, PHD *(Chair)*
Distinguished Professor of Plant Biology
and Pathology
Rutgers University

JONATHAN ALLEN, PHD
Bioinformatics Scientist
Lawrence Livermore National Laboratory

JEAN COX-GANSER, PHD
Research Team Supervisor, Field Studies Branch
Respiratory Health Division
National Institute for Occupational Safety and Health

JACK GILBERT, PHD
Professor, Department of Surgery
University of Chicago

DIANE GOLD, MD
Professor, Department of Environmental Health
Harvard T. H. Chan School of Public Health

JESSICA GREEN, PHD
Alec and Kay Keith Professor of Biology
Founding Director, Biology and the Built
Environment (BioBE) Center
University of Oregon

CHARLES HAAS, PHD
LD Betz Professor of Environmental Engineering
Head, Department of Civil, Architectural and
Environmental Engineering
Drexel University

MARK HERNANDEZ, PHD, PE
Professor
Department of Civil, Environmental and
Architectural Engineering
University of Colorado, Boulder

ROBERT HOLT, PHD
Eminent Scholar
Arthur R. Marshall, Jr. Chair in Ecological
Studies
University of Florida

RONALD LATANISION, PHD
Senior Fellow
Exponent

HAL LEVIN, BArch
Research Architect
Building Ecology Research Group

VIVIAN LOFTNESS, MA, FAIA, LEED AP
University Professor
School of Architecture
Carnegie Mellon University

KAREN NELSON, PHD
President
J. Craig Venter Institute

JORDAN PECCIA, PHD
Associate Professor of Chemical and
Environmental Engineering
Yale University

ANDREW PERSILY, PHD
Chief, Energy and Environment Division
National Institute of Standards and Technology

JIZHONG ZHOU, PHD
George Lynn Cross Research Professor
Department of Microbiology and Plant Biology
Director, Institute for Environmental Genetics
University of Oklahoma

NATIONAL ACADEMIES OF SCIENCES, ENGINEERING, AND MEDICINE STAFF

KATHERINE BOWMAN *(Study Director)*
Senior Program Officer
Board on Life Sciences
(P) (202) 334-2638
(E) kbowman@nas.edu

ELIZABETH BOYLE
Program Officer
Board on Environmental Studies and Toxicology
(P) (202) 334-2228
(E) eboyle@nas.edu

DAVID BUTLER
Scholar
Institute of Medicine
(P) (202) 334-2524
(E) dbutler@nas.edu

ANDREA HODGSON
Christine Mirzayan Fellow (until 4/9/2016)
Board on Life Sciences
(P) (202) 334-3142
(E) ahodgson@nas.edu

JENNA OGILVIE
Research Associate
Board on Life Sciences
(P) (202) 334-1348
(E) jogilvie@nas.edu

CAMERON OSKVIG
Director
Board on Infrastructure and the Constructed Environment
(P) (202) 334-2663
(E) coskvig@nas.edu

PROCTOR REID
Director
National Academy of Engineering Program Office
(P) (202) 334-2467
(E) preid@nae.edu

FRANCES SHARPLES
Director
Board on Life Sciences
(P) (202) 334-2187
(E) fsharples@nas.edu

SPEAKER BIOGRAPHIES

Gary Adamkiewicz

Gary Adamkiewicz is an environmental health specialist with more than twenty years of experience. He is currently Assistant Professor of Environmental Health and Exposure Disparities at the Harvard T. H. Chan School of Public Health, where much of his work focuses on the connections between housing and health, especially within low-income communities. His research has included studies of indoor environmental conditions within the homes of children with asthma, and studies that aim to understand the factors that contribute to specific exposures such as: pesticides and other chemicals, allergens, secondhand smoke and combustion by-products. He has worked with national, state and local agencies the on projects that aim to reduce the burden of disease from indoor environmental issues. Dr. Adamkiewicz is a member of the Science Advisory Committee for the National Center for Healthy Housing, and has served on EPA's Environmental Justice Technical Guidance Review Panel, under the auspices of the agency's Science Advisory Board. He has served as an advisor to the World Health Organization's effort to establish indoor air quality guidelines. Dr. Adamkiewicz also serves as the Healthy Cities Program Leader at the Harvard Center for Health and the Global Environment. Dr. Adamkiewicz holds a Ph.D. in chemical engineering from the Massachusetts Institute of Technology and a Master of Public Health from the Harvard School of Public Health.

Terry Brennan

Terry is a building scientist and educator. He is on the editorial boards of Environmental Building News and Heating Piping and Air Conditioning Magazine. He currently chairs the USACE committee developing new air leakage protocols. Past work includes consulting on a research project to restore three homes in the Seventh Ward of New Orleans after Hurricanes Katrina and Rita, teaching healthy housing courses for the National Center for Healthy Housing and working on a research project to study unplanned airflows in commercial buildings in New York State. He is a member of ASHRAE 62.2 Ventilation and Air Quality Committee and served as consultant to the National Academy of Sciences Committee on Dampness and Health in Buildings. He holds a Bachelors degree in Physics and a Masters degree in Environmental Studies.

Rob Dunn

Rob Dunn is a biologist and writer in the Department of Biological Sciences at North Carolina State University. The science Dunn mentors attempts to use many different approaches to understand the stories of the species all around us and how they have changed or might change in the future. Often those species are ants and their societies, other times mosquitoes and the diseases they vector or rare carnivores and the parasites they host. Central to all of this work is the sense that much of what we assume someone else knows (such as which species live around us in cities) is totally unknown. The unknown is large and wonderful and Dunn and his collaborators, students, postdocs and other researcher scientists, love to spend their days in it. Dunn's writing focuses on the stories of the scientists behind the science, who they are, what they do and how and why they did it. Dunn's writing has appeared in Natural History, BBC Wildlife Magazine, Scientific American, Smithsonian Magazine, National Geographic and other magazines. His first book, Every Living Thing, was awarded the National Outdoor Book Award for Natural History writing. His new book, out in the spring of 2011, The Wild Life of Our Bodies, examines the long human relationship with other species (be they tapeworms or tigers) and how changes in those relationships are affecting our health and well being.

Jack Gilbert

Jack Gilbert earned his PhD from Unilever and Nottingham University, UK in 2002, and received his postdoctoral training at Queens University, Canada. He subsequently returned to the UK in 2005 to Plymouth Marine Laboratory at a senior scientist until his move to Argonne National Laboratory and the University of Chicago in 2010. Currently, Professor Gilbert is in Department of Surgery at the University of Chicago, and is Group Leader for Microbial Ecology at Argonne National Laboratory. He is also Associate Director of the Institute of Genomic and Systems Biology, Research Associate at the Field Museum of Natural History, and Senior Scientist at the Marine Biological Laboratory. Dr. Gilbert uses molecular analysis to test fundamental hypotheses in microbial ecology. He has authored more than 200 peer reviewed publications and book chapters on metagenomics and approaches to ecosystem ecology. He is currently working on generating observational and mechanistic models of microbial communities in natural, urban, built and human ecosystems. He is on the advisory board of the Genomic Standards Consortium (www.gensc.org), and is the founding Editor in Chief of mSystems journal. In 2014 he was recognized on Crain's Business Chicago's 40 Under 40 List, and in 2015 he was listed as one of the 50 most influential scientists by Business Insider, and in the Brilliant Ten by Popular Scientist.

Elizabeth Grice

Elizabeth Grice, PhD is an Assistant Professor of Dermatology and Microbiology in the Perelman School of Medicine at the University of Pennsylvania. She received her B.A. in Biology from Luther College, and her Ph.D. in Human Genetics from Johns Hopkins University. Dr. Grice then did her post-doctoral fellowship at the National Institutes of Health (NIH) under the direction of Dr. Julia Segre, where her work revealed the vast topographic and temporal diversity of the skin microbiome. She has received several awards including the K99-R00 Pathway to Independence Award, an NIH Award of Merit for her work establishing the skin component of the Human Microbiome Project, and the Luther College Young Alumni Award. Research in the Grice laboratory, which is funded by NIH and industry grants, integrates microbiology, dermatology, genomics, bioinformatics, and immunology towards the general objective of examining host-microbe interactions of the skin. Areas of focus include the microbiome in chronic and traumatic wounds, consequences of perturbing the skin microbiome, and microbiome-innate immune interactions.

Charles Haas

Charles Haas is the L.D. Betz Professor of Environmental Engineering and Head of the Department of Civil, Architectural and Environmental Engineering at Drexel University. His broad research interests include the estimation of human health risks from environmental exposures to pathogens and their control using engineering interventions and drinking water treatment. Specific research activities include assessment of risks from exposures to deliberately released agents; engineering analysis and optimization of chemical decontamination schemes; microbiological risks associated with pathogens in drinking water, biosolids, and foods; novel kinetic models for disinfection processes and process control; and use of computational fluid dynamics for process modeling. Dr. Haas was co-director of the Center for Advancing Microbial Risk Assessment that which was jointly funded by the U.S. Department of Homeland Security and the U.S. Environmental Protection Agency, and has received funding from various sources including NSF, EPA, research foundations and local government agencies. He received his MS from the Illinois Institute of Technology and his PhD in environmental engineering from the University of Illinois at Urbana-Champaign.

Jo Handelsman

Jo Handelsman is the Associate Director for Science at the White House Office of Science and Technology Policy, appointed by President Obama and confirmed by the Senate in June of 2014. Dr. Handelsman helps to advise President Obama on the implications of science for the Nation, ways in which science can inform U.S. policy, and on Federal efforts in support of scientific research. Prior to joining OSTP,

Dr. Handelsman was the Howard Hughes Medical Institute Professor and Frederick Phineas Rose Professor in the Department of Molecular, Cellular and Developmental Biology at Yale University. She previously served on the University of Wisconsin-Madison faculty as a Professor in Plant Pathology from 1985 to 2009 and as Professor and Chair of the Department of Bacteriology from 2007 to 2009. In 2013, she served as President of the American Society for Microbiology. Dr. Handelsman is an expert in communication among bacteria that associate with soil, plants, and insects and helped pioneer the field of metagenomics, bridging agricultural and medical sciences. Handelsman is also recognized for her research on science education and women and minorities in science, and received the Presidential Award for Excellence in Science Mentoring in 2011. Dr. Handelsman also co-chaired the PCAST working group that developed the 2012 report, "Engage to Excel," which contained recommendations to the President to strengthen STEM education to meet the workforce needs of the next decade in the United States. Dr. Handelsman co-founded the Wisconsin Program for Scientific Teaching, the Yale Center for Scientific Teaching, and the National Academies Summer Institute on Undergraduate Education, programs focused on teaching principles and practices of evidence-based education to current and future faculty at colleges and universities nationwide. Dr. Handelsman received a B.S. from Cornell University and a Ph.D. in Molecular Biology from the University of Wisconsin-Madison.

Lee Ann Kahlor

Lee Ann Kahlor, an associate professor of advertising and public relations at the University of Texas at Austin, researches science and health communication with an emphasis on information seeking and sharing. Her primary theoretical contribution is the planned risk information-seeking model (PRISM). Her work spans risk topics ranging from cancer to induced seismicity. She has looked at seeking and sharing behaviors among the public and within scientific communities, specifically indoor microbiologists and nano-scientists. Kahlor has more than 30 publications including work in *Science Communication, Public Understanding of Science, Risk Analysis, Nature Nanotechnology, Indoor and Built Environment, Health Communication, Journal of Health Communication, Communication Research,* and *Media Psychology*. She has edited two books: *New Agendas in Strategic Communication* (co-ed. with Anthony Dudo) and *Communicating Science: New Agendas in Communication* (co-ed. with Patricia Stout). In 2015, Kahlor won her college's highest teaching award for her dedication to undergraduate teaching. Her work is funded by the National Science Foundation, the Alfred P. Sloan Foundation, St. David's Center for Health Promotion and Disease Prevention Research, and the UT Center for Integrated Seismicity Research.

Susan Lynch

Dr. Susan Lynch received her undergraduate degree in Microbiology from University College Dublin, Ireland. She completed her graduate studies in the same department, where she identified and characterized the gene cluster responsible for biosynthesis of the polyketide antifungal, Amphotericin B. Dr. Lynch's postdoctoral research was performed at the Department of Microbiology and Immunology, Stanford University, where she was awarded a Dean's Fellowship. In June 2006, Dr. Lynch joined the faculty as an Assistant Professor at the University of California San Francisco, where she initiated multiple studies of the human airway and gastrointestinal microbiome. She is currently an Associate Professor of Medicine, in the Division of Gastroenterology, where she also Directs the Colitis and Crohn's Disease Microbiome Research Core and acts as Associate Director of the Microbiome in Inflammatory Disease Program. Her research program focuses primarily on culture-independent studies of human microbiota in both respiratory and gastrointestinal niches, particularly in the role of the gastrointestinal microbiome in chronic inflammatory diseases. As a natural extension of these studies Dr. Lynch has developed a robust research program on the relationship between the microbiology of the built environment, human microbiome and host health, with a specific emphasis on childhood allergic asthma. Dr. Lynch has been awarded the Rebecca Buckley Lectureship by the American Academy of Allergy, Asthma and Immunology, featured in International Innovation: Women in Healthcare, and received an Irish Health and Science 100 award. She is extensively published with over 100 peer-reviewed publications, a large majority in the emergent field of human microbiome research.

Donald Milton

Donald Milton earned a BS in Chemistry from the University of Maryland Baltimore County (Cum Laude), an MD from Johns Hopkins University and a DrPH (Environmental Health) from Harvard University. Dr. Milton trained clinically in medicine at Emory and Boston Universities and Occupational and Environmental Medicine at Harvard. He previously served on the faculties of the Department of Environmental Health, Harvard School of Public Health and the Department of Work Environment, University of Massachusetts Lowell School of Health and Environment. Currently, he is Professor and Director of the Maryland Institute for Applied Environmental Health, University of Maryland School of Public Health and Professor of Medicine, University of Maryland School of Medicine, Adjunct Senior Lecturer on Occupational and Environmental Health at Harvard School of Public Health, and Honorary Professor, Department of Community Medicine, University of Hong Kong. He is board certified in internal and occupational medicine and has 20 years of experience in occupational medicine referral practice. He teaches courses on environmental and occupational hygiene, aerobiology, toxicology, indoor air quality, respiratory epidemiology, physiology, pathology, and pathophysiology. He is a past chair of the ACGIH Bioaerosols committee and a member of the editorial boards of Indoor Air and BMC Public Health, and for 10 years of Applied Environmental Microbiology. He is a recipient of the Lloyd Hyde Research Award of Emory University, the Harriet Hardy Award for Lifetime Achievement from the New England College of Occupational and Environmental Medicine, and was elected a Fellow of the International Society for Indoor Air Quality and Climate in 2008.

Andrew Persily

Andrew Persily has performed research into indoor air quality and ventilation since the late 1970s. His work has included the development and application of measurement techniques to evaluate airflows and indoor air contaminant levels in a variety of building types, including large, mechanically ventilated buildings and single-family dwellings. These evaluation procedures include tracer gas techniques for measuring air change rates and air distribution effectiveness, contaminant concentrations measurements, and envelope airtightness. He has contributed to the development and application of multi-zone airflow and contaminant dispersal models. Dr. Persily was a vice-president of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) from 2007 to 2009, and is past chair of ASHRAE SSPC 62.1, responsible for the revision of the ASHRAE Ventilation Standard 62. He is currently chair of Standard 189.1, Design of High-Performance Green Buildings. He is a past chair of ASTM Subcommittee E6.41 on Air Leakage and Ventilation Performance and past vice-chair of subcommittee D22.05 on Indoor Air Quality. He was named an ASTM Fellow and an ISIAQ Fellow in 2002, and an ASHRAE Fellow in 2004.

Jeffrey Siegel

Jeffrey Siegel, PhD is Professor of Civil Engineering at the University of Toronto and a member of the university's Building Engineering Research Group. His research interests including healthy and sustainable buildings, ventilation and indoor air quality in residential and commercial buildings, control of indoor particulate matter, the indoor microbiome, and moisture interactions with indoor chemistry and biology. Dr. Siegel is an active member of ISIAQ and ASHRAE and is an associate editor for the journal *Building and Environment.* He teaches courses in indoor air quality, sustainable buildings, and sustainable energy systems. Prior to his position at the University of Toronto, Dr. Siegel was an Associate Professor at the University of Texas. He holds an MS and PhD in Mechanical Engineering from the University of California, Berkeley (2002).

Joanne Sordillo

Dr. Joanne Sordillo is an epidemiologist and clinical laboratory scientist with a background in environmental epidemiology and exposure assessment. Her research has focused on exposures to microbes and development of asthma and allergic disease in children. Her early work focused on broad biomarkers of bacteria (endotoxin, peptidoglycan) and fungi (ergosterol, (1→3) Beta D-glucan)

as metrics for exposure. She developed an internal standard for GC/MS analysis of ergosterol, an indicator of total fungal biomass used in epidemiological studies to assess mold exposure in homes. Her epidemiological longitudinal study on multiple environmental microbial exposures and incidence of childhood allergic disease was one of the first to simultaneously consider exposure to gram positive and gram negative microbes. Her current ongoing research uses metagenomic tools to examine the health effects of environmental and human bacterial and fungal communities as well as their specific taxonomic members. Her most recent exposure assessment study characterized the indoor microbiome (bacterial and fungal communities) in dust samples collected from the home and school environments.

Dennis Stanke

With a BSME from the University of Wisconsin, Dennis joined Trane in 1973, as a controls development engineer. He retired from Trane as Staff Applications Engineer specializing in airside systems including controls, ventilation, indoor air quality, and dehumidification. He has written numerous applications manuals and newsletters, has published many technical articles and columns, and has appeared in many Trane Engineers Newsletter Live broadcasts. An ASHRAE Fellow and Life Member, Dennis is a former member of the USGBC LEED Technical Advisory Group for Indoor Environmental Quality (the EQ TAG) and former Chairman for ASHRAE Standard 62.1, "Ventilation for Acceptable Indoor Air Quality," and most recently, former Chairman for ASHRAE Standard 189.1, "Standard for the Design of High-Performance Green Buildings."

Brent Stephens

Brent Stephens, PhD, is an Associate Professor of Architecture Engineering at the Illinois Institute of Technology (IIT). He is an expert in the fate and transport of indoor pollutants, building energy and environmental measurements, HVAC filtration, human exposure assessment, building energy simulation, and energy efficient building design. Dr. Stephens runs the Built Environment Research Group at IIT, which conducts research on energy efficiency and indoor air quality in buildings. His research has been funded by the U.S. Environmental Protection Agency; American Society of Heating, Refrigerating, and Air Conditioning Engineers; Alfred P. Sloan Foundation; National Air Filtration Association; and the Air Conditioning, Heating, and Refrigeration Institute. Dr. Stephens holds a PhD in Civil Engineering and an MSE in Environmental and Water Resources Engineering from the University of Texas at Austin. Within the area of Microbiomes of Built Environment, his recent projects include: (1) making long-term measurements of building environmental and operational parameters in the Hospital Microbiome Project, which collected microbial samples from surfaces, air, staff, and patients over the course of one year in a new hospital pavilion both before and after it was occupied; (2) hosting a workshop to engage building scientists in advancing a research agenda for future studies of the microbiology of the built environment; (3) developing a suite of inexpensive, open-source devices based on the Arduino platform for measuring and recording long-term indoor environmental and building operational data for built environment microbiome studies; (4) developing and applying an experimental apparatus for investigating the transport and control of indoor bioaerosols from simulated human respiratory activities; and (5) conducting controlled chamber experiments to understand the metabolic succession of microbes on built environment surfaces.