WELL LIVING LAB

annual report

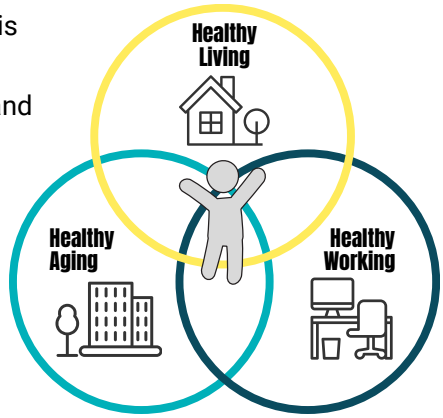
2021

WELL LIVING LAB™

Healthy Living.
Healthy Working.
Healthy Aging.

Dear Colleagues,

We are pleased to share the 2021 Well Living Lab Annual Report, highlighting the past year's accomplishments and our path ahead. This past year we rolled out a new mission and three research themes, grounding our work around scientific inquiry in indoor human health and well-being:



Our Mission

Advance health and well-being through science-based solutions that improve how we live, work, learn, and play.

We are honored and thrilled to be on this journey of discovery in indoor health and well-being with you - our Scientific Advisory Council, Alliance members, and academic collaborators. You are leaders and creators, shaping indoor health and well-being trends across multiple sectors and inspiring our work.

Now that we are emerging from the pandemic, we are excited to conduct more research in the field beyond the walls of our Lab - workplaces, home residences, college dorm rooms, and senior living environments. This work will bring us closer to the individual in our pursuit of applying science-based solutions to improve the human condition.

Cheers to 2022 and continued partnerships with all of you to learn, connect, collaborate, and, most importantly, positively impact the lives of those we serve.

Sincerely,

Barbara Spurrier, MHA
Executive Director, Well Living Lab; Executive Vice President, Delos

Bruce Johnson, PhD
Research Director, Well Living Lab; Professor of Medicine & Physiology, Department of Cardiovascular Diseases, Mayo Clinic College of Medicine; Director of the Mayo Clinical Research Unit's Energy Balance Core Laboratory and the Human Integrative and Environmental Physiology Lab

Nick LaRusso, MD
Chair, Well Living Lab Scientific Advisory Council; Charles H. Weinman Professor of Medicine, Biochemistry and Molecular Biology; Distinguished Investigator of The Mayo Foundation

Table of Contents

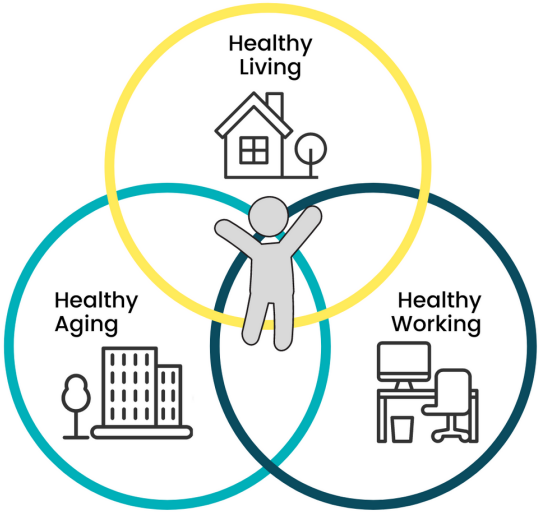
Well Living Lab: By the Numbers

23 Multidisciplinary Team Members

21 Completed Research Studies **&** **19** Peer-Reviewed Publications

5500 Square Feet of Reconfigurable Space

3 Research Themes



25 Well Living Lab Global Alliance Members

1 Formal Academic Affiliation

UNIVERSITY OF MINNESOTA
Driven to Discover®

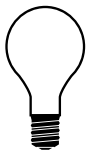
About the Well Living Lab

How much time do you spend indoors?
For the average American, it's more than 21 hours a day, so it's critical that the indoor environments where we live, work, learn, and play positively contribute to our health, well-being, performance, and more.

We spend about
90%
of our time indoors.

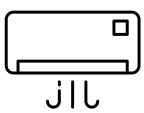
Why It Matters

Buildings and everything in them can affect our health and well-being. When we're healthy, we perform better in all aspects of life - as employees, employers, spouses or partners, parents, friends, and family members. Throughout our lifespan, indoor environments can affect our quality of life in many ways. As informed by Well Living Lab research, we have learned:



Lighting, temperature, and sound can impact sleep and cognitive function.

Natural lighting and biophilia can reduce stress and enhance mood, satisfaction, and productivity.



Automated, sensor-based filtration devices can significantly reduce exposure to harmful indoor air pollutants.

What We Do

The Well Living Lab (WLL) is the first scientific research center exclusively applying human-centered research to understand the interaction between health, well-being, and indoor environments. Our real-world research spans healthy living, healthy working, and healthy aging.

The Lab, founded in 2016 as a collaboration of Delos and Mayo Clinic, is located in the Minnesota BioBusiness Center adjacent to the Mayo Clinic campus in downtown Rochester, Minnesota.

Our multidisciplinary research approach combines environmental, clinical, biomedical, and human behavior expertise with engineering and technology.

The Lab's unique, reconfigurable facility offers spaces to study residential, workplace, and classroom settings. It features advanced sensor technology and remote monitoring, allowing study participants to move freely, unencumbered by wires and monitors.

The need for more focused study of the connection between health and well-being and the indoor environment is real and immediate.

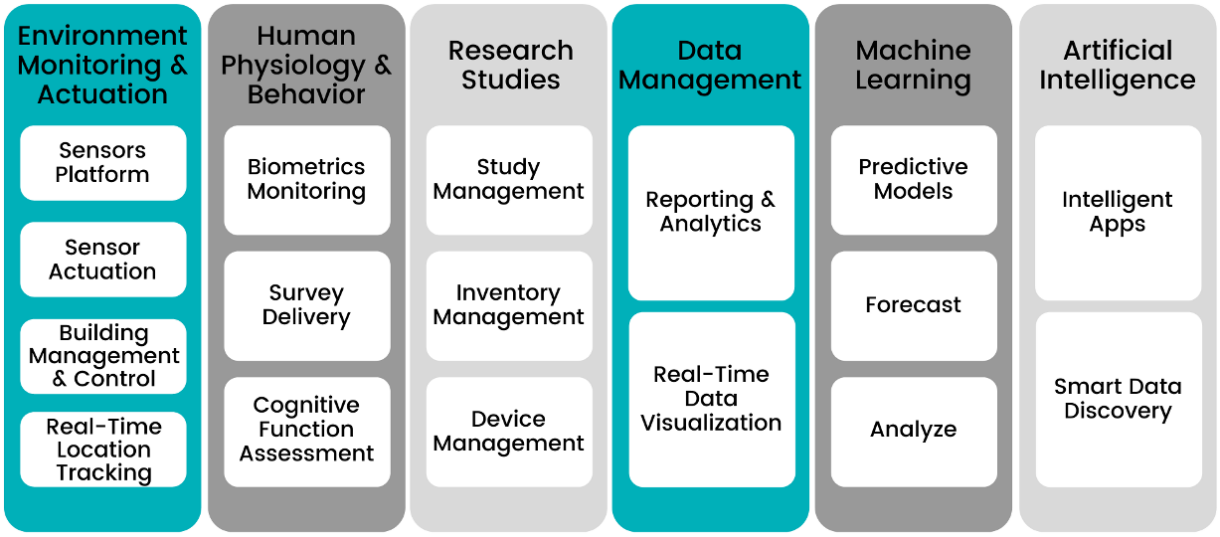
About the Well Living Lab (cont'd)

The only way to understand how
INDOOR ENVIRONMENTS
contribute to **HEALTH & WELL-BEING**
is to scientifically study them.

Research Approach

- Discovery > Translation > Application Framework
- Frequent coordination with Mayo Clinic research community and Institutional Review Board
- Single and multi-cohort studies with volunteer study participants
- Controlled studies and field studies
- Mixed methods approach, such as cognitive tests, surveys, wearable and environmental sensors, observation, and self-reports

Capabilities



Be Informed. Get Involved.

The movement to create healthy indoor spaces is growing rapidly as leaders from science, medicine, technology, architecture, real estate, and more recognize the connection between the indoor environment and health and well-being. Learn more about the Well Living Lab and become part of the movement.

delos™

The Well Living Lab is a subsidiary of Delos, a wellness real estate and technology company. Built on a ground-breaking collaboration between experts across the health sciences and building sciences, Delos helps transform indoor environments into vehicles for health, well-being, performance, and resilience.

About the Research

The Well Living Lab's long-term research objective is to improve human health and well-being across the lifespan. Our research plan sets the stage for achieving this objective by examining specific environmental interventions.

MISSION

Advance health and well-being through science-based solutions that improve how we live, work, learn, and play.

CENTRAL QUESTION

What if the places we live, work, learn, and play improved health and well-being across the lifespan?

FRAMEWORK

Discovery

Translation

Application

PRIORITIES

DESIRABLE

Anchored around scientific exploration and human needs

VIABLE

Informed by assets and capabilities of Delos, Mayo Clinic, and partner organizations

POSSIBLE

Bolstered by technology

Strategic Objectives 2021-2023

1

Advance the science by conducting translational studies relevant to human health.

2

Expand scientific collaborations with Mayo Clinic & select academic centers.

3

Optimize research operations & expand capabilities.

4

Enhance communications with the scientific community & key stakeholders.

2021 Peer-Reviewed Publications

Peer review is critical as a quality control measure for scientific articles. The process involves having other experts in the same field check the validity of a paper, ensuring the integrity of the science. The Well Living Lab would like to see its studies not only published in peer-reviewed scientific journals but also translated into real-world practices to promote healthy environments across an individual's lifespan.

1. Biophilic Office Design: Impact of a Multisensory Approach on Human Wellbeing (Biophilia), Journal of Environmental Psychology.
2. The Feasibility of Wearable and Self-Report Stress Detection Measures in a Semi-Controlled Lab Environment (High Stress), Institute of Electrical and Electronics Engineers.
3. Inactivation of the Replication-Competent VSV Virus Sars-Cov-2 Surrogate on Common Surfaces by Disinfectants (COVID Surface #1), International Journal of Environmental Research and Public Health.
4. Inactivation of the Replication-Competent SARS-CoV-2 on Common Surfaces by Disinfectants (COVID Surface #2), Infection Control & Hospital Epidemiology.
5. Psychosocial and Behavioral Outcomes and Transmission Prevention Behaviors: Working during the COVID-19 Pandemic (CAPTURE Baseline), Mayo Clinic Proceedings: Innovations, Quality & Outcomes.
6. Characterization of Exhaled Particle Deposition and Ventilation in an Indoor Setting (COVID Air #1), Atmospheric Environment.
7. Healthy Home Interventions: Distribution of PM2.5 Emitted during Cooking in Residential Settings (Res IAQ Pilot), Building and Environment.
8. Development of a Testing and Evaluation Protocol for Occupancy Sensing Technologies in Building HVAC Controls: A Case Study of Representative People Counting Sensors (ARPA-E #1), Building and Environment.
9. HVAC Energy Savings, Comfort and Air Quality for Occupancy-Based Control by Side-by-Side Experimental Study (ARPA-E #2), Applied Energy.

The Research Team

The Well Living Lab's multidisciplinary ecosystem consists of experts in biomedical engineering, building, behavioral, and data science, human physiology, technology, operations, communications, and more. By merging these diverse areas of expertise, we can conduct original, translational research that better addresses the complex interaction between health and the indoor environment.

The Scientists

Sara Aristizabal, Ph.D., Research Scientist, Biomedical Engineering and Physiology

Dr. Aristizabal holds a Ph.D. degree in Biomedical Engineering and Physiology from the Mayo Clinic Graduate School of Biomedical Sciences. She has a keen interest in developing new techniques and biometric indicators to assess the health and wellness of the human body, specializing in signal processing, biological modeling, and clinical research. Her knowledge of the wearables research field helps us use the power of digital physiological signals to further understand the effect of the indoor environment on human health and well-being.

Meng Kong, Ph.D., Research Scientist, Building Science, Mechanical & Aerospace Engineering

Dr. Kong has more than ten years of research experience in built environmental and energy systems. He earned his Ph.D. in Mechanical and Aerospace Engineering from Syracuse University, where he then worked as a postdoc and research assistant professor for two years. Dr. Kong's Ph.D. work focused on developing a micro-environmental control system for improving thermal comfort, indoor air quality, and building energy efficiency. He has led research projects on indoor and outdoor air quality control, including the airborne transmission of SARS-CoV-2.

Kevin Mazurek, Ph.D., Research Scientist, Electrical Engineering & Neuroscience

Dr. Mazurek earned his M.S. and Ph.D. in Electrical Engineering from Johns Hopkins University, where he developed prototype hardware systems for restoring walking to individuals with spinal cord injury. Dr. Mazurek completed a postdoc in Neuroscience at the University of Rochester, NY, where he worked as a Research Assistant Professor in Neuroscience. He is applying his interdisciplinary training to understand how individuals perceive and process different features of their environment and how these features could be optimized to improve quality of living and overall health.

The Research Team

The Scientists (cont'd)

Jovan Pantelic, Ph.D., Research Scientist, Building Science, Mechanical Engineering

Dr. Pantelic earned his Bachelor of Mechanical Engineering and his M.S. from the Department of Thermal Engineering at the University of Belgrade (Serbia). He earned his Ph.D. from the National University of Singapore where he studied in the School of Design and Environment, Department of Building. He has spent the last 17 years researching indoor air quality. His research on air spans from the airborne spread of infectious diseases in the built environment to the impact of large-scale episodic pollution events, such as wildfires. For the past seven years, Dr. Pantelic has worked in the field on Internet of Things (IoT) sensing and is considered a leading expert in the field.

Zachary Pope, Ph.D., Research Scientist, Human Physiology & Behavior

Dr. Pope is a physiologist with additional expertise in behavioral science. Dr. Pope was previously a National Heart, Lung, and Blood Institute T32 Postdoctoral Fellow within the University of Minnesota's School of Public Health, Division of Epidemiology and Community Health. He earned his Ph.D. in kinesiology, with a minor in public health, at the University of Minnesota. His master's and undergraduate degrees are from Boise State University, where he studied exercise physiology. Pope is skilled in the assessment of cardiometabolic, physiological, and psychological health outcomes as well as clinical trial design and implementation.

Young Joo Son, Ph.D., Research Scientist, Building Science, Architecture & Building Performance

Dr. Son is a building scientist in the Well Living Lab. She earned her B.S. and M.S. in Interior Architecture and Built Environment from Yonsei University in South Korea and her Ph.D. in Building Performance and Diagnostics from Carnegie Mellon University. Her prior research experience identified the impact of indoor environmental quality on occupant satisfaction and comfort, focusing on thermal and lighting environments. She designed and conducted human subject experiments in laboratory and field settings and collected human physiological and psychological responses.

The Research Team

The Analysts

Kunjoon Byun, M.A. Senior Research Analyst, Behavioral Science

Mr. Byun earned his M.A. degree in Experimental Psychology from the College of William and Mary and a B.A. degree in Psychology from the University of Wisconsin – Madison. He assists in designing and executing research studies at the Well Living Lab and also participates in collecting and analyzing behavioral data. He has research experience in various fields of psychology with an emphasis on judgments and the decision-making process.

Linhao Li, M.S., Senior Research Analyst, Building Science

Mr. Li received his Master of Architecture degree from the Building Performance and Diagnostics program at Carnegie Mellon University. He holds a Bachelor's degree in Built Environment and Facilities Engineering from Tongji University in China. He supports design and execution of research studies, contributes to our understanding of the interactions between building environments and human health, wellness, and performance, and is proficient in a variety of computational simulation tools.

Qingyang Liu, M.S., Senior Research Analyst, Building Science

Ms. Liu obtained her M.S. degree in Building Performance and Diagnostics from Carnegie Mellon University and B.E. degree in Architectural Environment Engineering from University of Nottingham Ningbo, China. She helps maintain and enhance the Lab's infrastructure and technical capabilities, conducts performance evaluations of building systems and sensing equipment, assists with designing, preparing, and executing human subject-centered building science research studies, and collects and analyzes data.

Araliya Senerat, M.P.H., P.M.P., Senior Research Analyst, Behavioral Science

Ms. Senerat earned an M.P.H. degree in Health Promotion and Disease Prevention from the Icahn School of Medicine at Mount Sinai in New York and holds a B.S. in Health Studies from the University of Waterloo in Waterloo, Ontario. She assists in developing and executing research studies and the collection and analysis of data. Her interests and experience include public health, the built environment, active living, cancer, and obesity research.

Completed Studies

2016

ENVIRONMENTAL COMFORT (OFFICE)

2017

DAYLIGHT-COGNITIVE FUNCTION (OFFICE)
BLUE ENRICHED LED SLEEP (OFFICE)
HIGH STRESS MEASUREMENTS (PILOT)
SCENT DIFFUSION IAQ (PILOT)

2018

DYNAMIC LIGHTING (OFFICE)
SLEEP MICROCLIMATE (RESIDENTIAL)

2019

COGNITIVE FUNCTION IN CONSTRUCTION (FIELD)
COGNITIVE FUNCTION DURING HYPOXIA (FIELD)
BIOPHILIC OFFICE DESIGN (OFFICE)
IAQ IN SKYWAYS AND SUBWAYS (FIELD)
AUTOMATED WAKE-UP (RESIDENTIAL)
MOBILE ENVIRONMENTAL SENSOR DEPLOYMENT (FIELD)

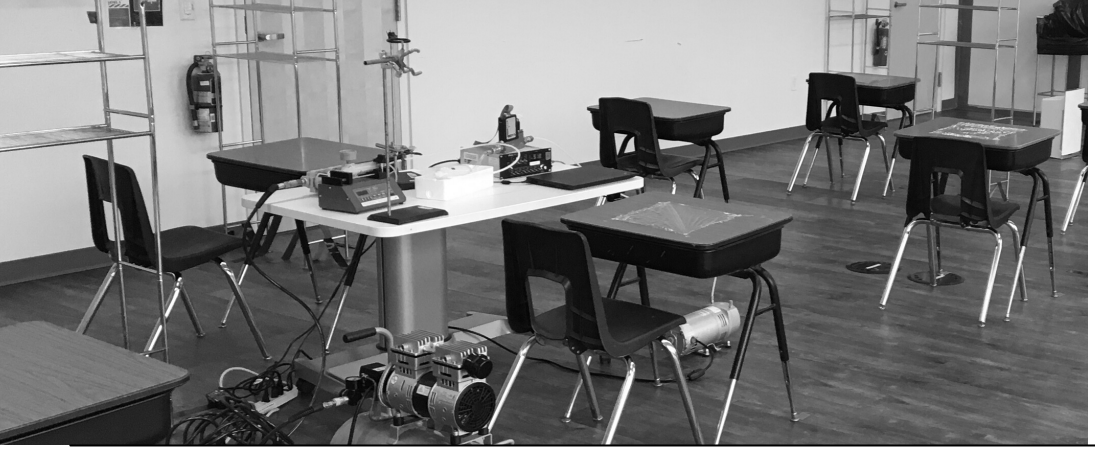
2020

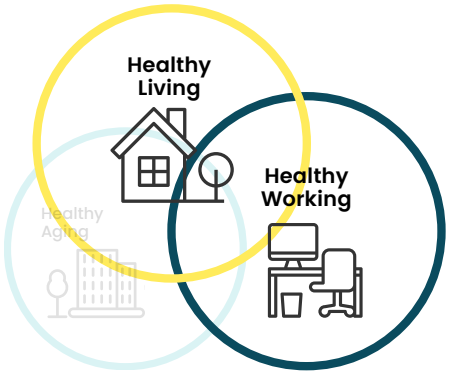
OCCUPANCY SENSOR TESTING (OFFICE)
ARPA-E (OFFICE)
SURFACE: VSV DISINFECTION (COVID)

2021

AIR: CONFERENCE ROOM AIR PURIFICATION (COVID)
AIR: OFFICE SPACE TRANSMISSION (COVID)
AIR: CLASSROOM AIR PURIFICATION (COVID)
SURFACE: SARS-COV-2 DISINFECTION (COVID)
BEHAVIOR: CAPTURE SURVEY BASELINE (COVID)

Current Studies





COVID-19 & Beyond: Safe Indoor Environment Program

The Research Question

How can we optimize the physical and psychosocial conditions of indoor environments in the COVID-19 era?

Why It Matters

COVID-19, the infectious disease caused by the virus SARS-CoV-2, led to millions of deaths globally during the recent pandemic. Like other respiratory infections, the virus can spread directly during breathing, speaking, and other human respiratory activities or indirectly through contact with contaminated surfaces. Effective transmission control measures were needed to stop the spread and subsequent impact of the virus. Relatedly, little information exists about the effect of the pandemic on the mental and behavioral responses of non-healthcare workers during the pandemic. This information will help inform best practices as workplaces reopen in the new COVID-19 era.

What We Studied

More than 20 multidisciplinary researchers collaborated on six interrelated studies to evaluate virus transmission via air and surface and explore the behavioral impact on non-healthcare workers.

Lead Scientist: Dr. Zachary C. Pope
Collaborators: University of Minnesota, Mayo Clinic
Study Locations: Well Living Lab (Air), Mayo Clinic (Surface), Field (Behavior)
Research Themes: Healthy Living and Healthy Working

- Office Study (Air)
- Conference Room (Air)
- Classroom Air Purification (Air)
- Replication-Competent Vesicular Stomatitis Virus (Surface)
- Replication-Competent SARS-CoV-2 (Surface)
- CAPTURE Employee Survey (Behavior)

COVID-19 & Beyond (cont'd)

What We've Learned

AIR

Improving a building's ventilation and filtration rates can help ensure clean air delivery to a space, potentially reducing the likelihood of airborne virus transmission. Portable air filtration units can cost-effectively supplement ventilation and filtration systems when actions such as opening windows or upgrading systems are not a feasible option. Distancing and masking are still encouraged when appropriate.

SURFACE

Common disinfectants can adequately kill viruses on surfaces with economical use, suggesting one could better allocate resources to other mitigation strategies.

BEHAVIOR

Prioritizing employee health and well-being is more critical now than ever, given the stressors of COVID-19. Therefore, stress-, anxiety-, and fatigue-reducing wellness programs should be prioritized along with education about proper health behaviors.

The Health Impact of Automated Indoor Air Pollutant Controls in a Simulated Apartment

The Research Question

How can automated air pollution control improve cardiopulmonary health, air quality, and sleep quality compared to standard residential ventilation?

Why It Matters

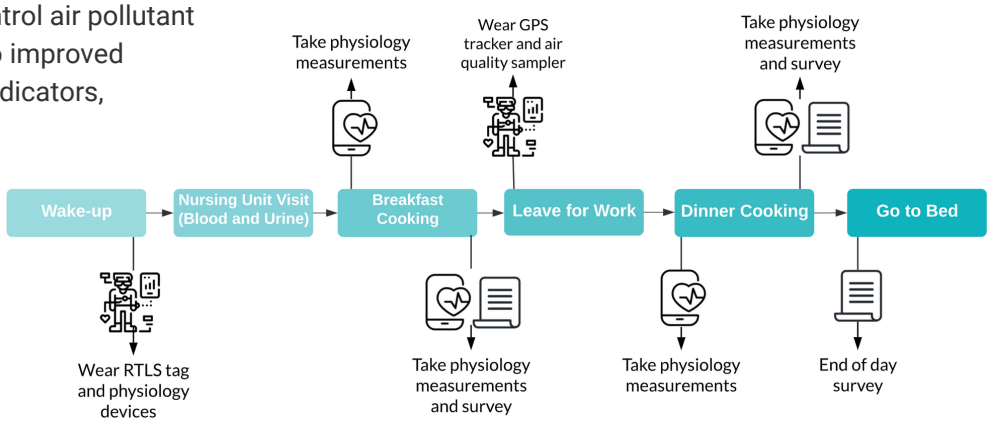
Cooking and cleaning in homes, offices, schools, and other indoor environments can generate harmful particles that may negatively impact the health and performance of inhabitants. Research has shown that stove hoods, portable air purifiers, and exhaust fans can reduce airborne particles, but often, homeowners neglect to activate them when they are most needed.

What We Are Studying

We strive to understand the health effects of indoor air pollution sources and understand if automating filtration and ventilation systems to control air pollutant concentrations will lead to improved cardiopulmonary health indicators, comfort, and better sleep.

Lead Scientist: Dr. Jovan Pantelic
Study Location: Well Living Lab
Research Themes: Healthy Living

Sponsored Research Study



Automated Indoor Air Controls (cont'd)

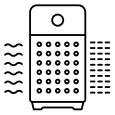
What We've Learned

This study is currently in progress as we investigate whether reduced particle exposure will impact cardiorespiratory health, sleep quality, and perceived environmental quality. Advanced air pollution control may improve indoor air quality and potentially reduce harmful effects on human health.

Based on early results, we have observed that:

Airflow patterns disperse cooking-generated particles quickly across residential spaces.

Stove hoods can effectively reduce emissions during cooking.



Portable air purifiers - when properly sized - are effective in removing cooking-generated particles from the air.

Technology Integration

- This study leverages Well Living Lab-developed, advanced IoT automation that relies on multiple indoor air quality data inputs and automatically triggers air ventilation interventions, such as the stove hood and portable air purifiers.
- A proprietary mobile application connects the Lab with study participants through calendaring, task lists, notifications, and training videos, ultimately simplifying the participant experience, critical to the study's outcome.

Acute Stress Recovery

The Research Question

How can indoor environment features help individuals recover from acutely stressful situations?

Why It Matters

Stress can bring about a variety of mental and behavioral reactions to new, uncertain, and unpredictable situations. Healthy individuals usually recover relatively quickly from acutely stressful events. However, prolonged or repeated exposure to acute stress can adversely affect a person's physical and mental health. Optimizing indoor environmental features could be beneficial for mitigating and helping individuals recover from stress.

What We Are Studying

In this study - which began late in 2021 - researchers are investigating how visual and auditory features of a relaxation room called MindBreaks™ affect an individual's ability to recover after acute stress.

Lead Scientist: Dr. Kevin Mazurek
Study Location: Well Living Lab
Research Themes: Healthy Living

Sponsored Research Study

Technology Integration

This study required the design of a new cognitive task to assess how performance is affected by stress. The WLL tech team developed an efficient platform for the rapid development of this new task, positioning the Lab for similar capabilities in future experiments.

The Lab also incorporated five new wearable devices, expanding the capabilities of the Lab for future studies.

What We've Learned So Far

Immersive, multi-sensory features of relaxation rooms may enable individuals to recover more efficiently after acutely stressful events.

Understanding how each sensory feature of the MindBreaks™ room promotes recovery of physiological measures, cognitive function, and perceived stress can provide vital information about how to individualize recovery from stress.

Clinician Burnout

The Research Question

Can workplace stress and burnout be reduced and job satisfaction be improved when physicians use relaxation rooms that incorporate elements of nature to promote calmness?

Why It Matters

Professional burnout among physicians is relatively common and can negatively impact patient-physician relationships, worker productivity, quality and safety of care, and clinician turnover. Existing research suggests both individual and organizational strategies can reduce burnout among healthcare workers. One approach being promoted is relaxation rooms; however, few research studies have been conducted to demonstrate their effectiveness.

What We Are Studying

In this study - launched at the close of 2021 - researchers are examining whether the use of a relaxation room, called a MindBreaks™ room, is an effective intervention for reducing work-related stress among physicians and clinicians.

Lead Scientist: Dr. Kevin Mazurek
Study Location: Mayo Clinic
Research Themes: Healthy Working

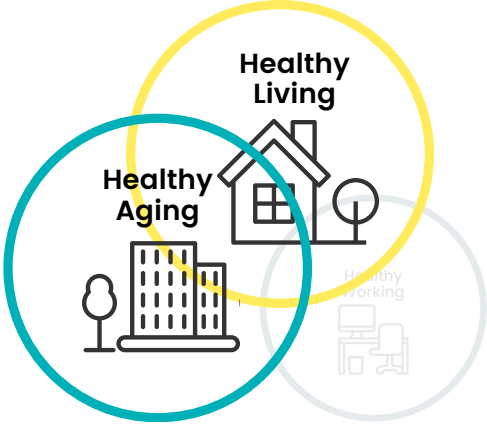
Sponsored Research Study

Technology Integration

To tailor and integrate the MindBreaks™ mobile application with our Well Living Lab infrastructure, we collaborated with the Delos technology team to meet the specific needs of stress-related studies.

What We've Learned So Far

Relaxation rooms may represent an important area of respite for clinicians, which might have downstream benefits on rates of clinician burnout and the quality of medical care provided by clinicians.



Portable Air Filtration in Senior Living Environments

The Research Question

How can we improve indoor air quality in senior living facilities to help protect the health of older adults?

Why It Matters

Indoor air quality can be significantly worse than outdoor air quality. Pollutants can cause complications in individuals with heart disease, diabetes, and breathing problems, each of which can be prevalent in older adults. Recommendations to improve indoor air quality by enhancing or upgrading a building's heating, ventilation, and air conditioning (HVAC) systems are not always feasible, so one must consider other alternatives.

What We Are Studying

In this study, researchers will examine how ventilation and filtration conditions with and without portable air filtration units decrease both the number of particles in the air and those accumulating on surfaces. Planning for this study began in 2021, with the actual research starting in 2022.

Lead Researcher: Mr. Linhao Li
Collaborators: University of Minnesota
Study Location: Senior Living Facility
Research Themes: Healthy Living and Healthy Aging

Sponsored Research Study

What We've Learned So Far

We will apply findings from our previous studies to the forthcoming senior living community study, including:

- Office Spaces: Enhancing a building's HVAC system can reduce the amount of potentially infectious particles that travel and deposit on surfaces.
- Small Conference Rooms: Portable air filtration dramatically increases effective air exchange when used to supplement a building's HVAC system.
- Classrooms: Portable air filtration, as a supplement to a building's HVAC system, reduces the concentration of airborne particles in a room and the number of particles that accumulate on surfaces.

Upcoming Studies

Studies Planned for 2022 + Beyond

Office Worker Performance + Energy and Ventilation (Healthy Working In-Lab Study)

In office settings, indoor air quality is an essential factor affecting workers' cognitive function and, thus, their ability to be productive and contribute to a company's bottom line. In this study, the WLL intends to evaluate how enhanced ventilation and filtration technology may impact health outcomes in office workers.

Interventions in a Tiny Home Environment (Healthy Aging and Healthy Living Field Study)

Individuals spend more than 90% of their time indoors, and levels of indoor air pollutants can be 2-5 times higher than outdoors, underscoring the importance of indoor air quality (IAQ) as a contributor to health and well-being. In this study, the WLL plans to explore how to improve indoor environmental quality for better human health.

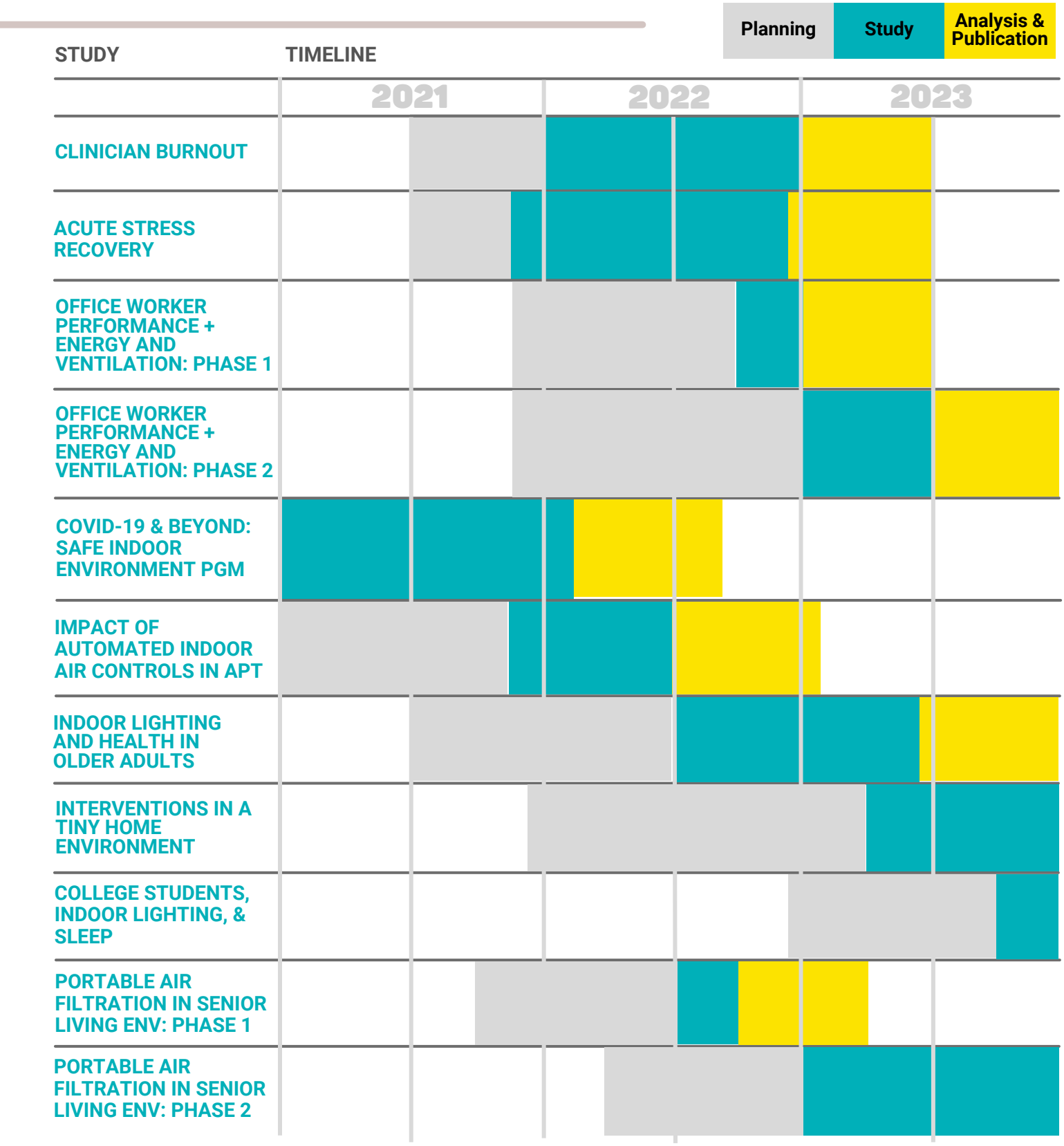
College Students' Indoor Lighting Environment and Sleep (Healthy Living In-Lab Study)

The National Sleep Foundation recommends 7-9 hours of sleep for young adults. Getting the proper amount of quality sleep is vital given that inadequate sleep duration and poor sleep quality are associated with several psychological and cognitive impairments. In this study, the WLL will investigate how elements of a dorm room affect the health and well-being of college students.

Indoor Lighting and Health in Older Adults (Healthy Aging Field Study)

Around 55 million individuals live with dementia worldwide, and this number is expected to rise to 139 million by 2050. Multiple factors play a role in improving older adult health and well-being. In this study, the WLL will look at indoor environmental features, such as lighting, as they relate to the health and well-being of older adults.

Research Study Timeline



About the Well Living Lab Alliance

The Well Living Lab Alliance is a global consortium of more than 20 leading organizations across a variety of industries - real estate, building, technology, design, housing, transportation, and more - that are committed to advancing science and generating evidence-based findings that can be practically applied for societal benefit.

Alliance Membership

Alliance membership is an impactful way for an organization to demonstrate its leadership, involvement, and commitment to the indoor health and well-being movement. Benefits of membership include early access to Well Living Lab study outcomes, opportunities to network and collaborate with the team and other Alliance members, and member-only educational events, such as webinars and an Annual Summit.

Founding and Current Members

Contact

Well Living Lab
221 1st Ave SW, Suite 100
Rochester, MN 55902
507-258-7592
www.welllivinglab.com
info@welllivinglab.com

WELL LIVING LAB™