Overview

September 2018
As the pioneer of Wellness Real Estate™ and founder of the WELL Building Standard™, Delos™ is transforming our homes, offices, schools and other indoor environments by placing health and wellness at the center of design, construction, facilities and operations decisions.
Mayo Clinic treated 1.8 million patients in all 50 states and 143 countries in 2016, is the first and largest integrated nonprofit medical practice in the world, and is ranked #1 in more specialties than any other hospital globally.

Mayo’s mission statement is “To inspire hope and contribute to health and well-being by providing the best care to every patient through integrated clinical practice, education and research.”
The Well Living Lab connects building science and health science to discover ways to improve human health in the indoor environment.
What is a “Living Lab”?

A “living lab” is a bridge between chamber and field studies, allowing researchers to accurately measure how people interact with their environment. These labs may include highly controlled spaces that people occupy and use as they would in a typical real-world environment, or comprehensive data collection of information from users in the real-world.
### Research Approach

<table>
<thead>
<tr>
<th>Areas of Study</th>
<th>Outcomes of Interest</th>
<th>Types of Simulated Spaces</th>
<th>Methods of Measurement</th>
<th>Study Populations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal/Air</td>
<td>Sleep</td>
<td>Bedroom</td>
<td>Wearable sensors</td>
<td>Healthy individuals</td>
</tr>
<tr>
<td>Light</td>
<td>Performance</td>
<td>Bathroom</td>
<td>Cognitive tests</td>
<td>Working adults</td>
</tr>
<tr>
<td>Acoustics</td>
<td>Reduced exposure</td>
<td>Kitchen</td>
<td>Environmental sensors</td>
<td>Students</td>
</tr>
<tr>
<td>Ergonomics</td>
<td>Stress</td>
<td>Office</td>
<td>Observation and ethnography</td>
<td>Recovering pts.</td>
</tr>
<tr>
<td>Behavior/Physiol.</td>
<td>Fitness</td>
<td>Classroom</td>
<td>Auto-ethnography and self reports</td>
<td>Seniors</td>
</tr>
<tr>
<td>Physical activity</td>
<td>Comfort</td>
<td>Hotel room</td>
<td></td>
<td>At-risk groups</td>
</tr>
</tbody>
</table>

Copyright © 2017 by Delos Living LLC. All Rights Reserved. – Confidential Information
Well Living Lab
Dynamic Environment Inside the Lab
A novel methodology to realistically monitor office occupant reactions and environmental conditions using a living lab

Anja Jamrozik a, 2, 3, Christian Ramos a, b, e, Jie Zhao a, b, e, Joleen Bernau a, c, Nicholas Clements a, e, Tracee Vetting Wolf c, Brent Bauer a, d

- Participants in an open-office configuration.
- Deployed environmental and wearable sensors.
- Varied combinations of temperature, lighting, sound.
- Participants’ reactions to the environment were evaluated through surveys and interviews.

Do varying environmental conditions affect occupant experience in the lab?
# Experimental Design

<table>
<thead>
<tr>
<th>Scene Number</th>
<th>Lamp Color Temp (K)</th>
<th>EC Tint</th>
<th>Sheer Shades (Black-Out)</th>
<th>Temp (°F)</th>
<th>Audio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3500</td>
<td>Clear</td>
<td>Open, Controllable (Open)</td>
<td>71</td>
<td>Off</td>
</tr>
<tr>
<td>2</td>
<td>4200</td>
<td>Intelligent</td>
<td>Open, Controllable (Open)</td>
<td>71</td>
<td>Off</td>
</tr>
<tr>
<td>3</td>
<td>2700</td>
<td>Dark</td>
<td>Closed, Not Controllable (Closed)</td>
<td>67</td>
<td>White Noise – Low Volume</td>
</tr>
<tr>
<td>4</td>
<td>2700</td>
<td>Clear</td>
<td>Open, Controllable (Open)</td>
<td>75</td>
<td>Simulated Speaking I</td>
</tr>
<tr>
<td>5</td>
<td>6500</td>
<td>Dark</td>
<td>Closed, Not Controllable (Closed)</td>
<td>67</td>
<td>White Noise – High Volume</td>
</tr>
<tr>
<td>6</td>
<td>6500</td>
<td>Intelligent</td>
<td>Open, Controllable (Open)</td>
<td>75</td>
<td>Simulated Speaking II</td>
</tr>
</tbody>
</table>

**Scene Sequence (x2):**

1, 2, 3, 4,
1, 2, 5, 6, 2...
Cohort Description and Survey Data Collection

Cohort
• N = 7 (1 excluded)
• Age Range = 18 to 65; Avg. Age = 46.9
• Medical records workers at the Mayo Clinic
• Completed usual work tasks (20-40 hours per week)
• Completed surveys at end of day

Surveys
• Baseline – demographics; work; health behaviors
• Daily – satisfaction with environmental conditions (noise level, lighting, and temperature); overall work experience for the day; mood, health behaviors

Questions:
• How much did your work environment make it easy for you to get your work done? 1-5 scale; 1: Not at all, 5: Very much
• Today, how satisfied are you with the __ in the work environment? 1-5 scale; 1: Very dissatisfied; 5: Very satisfied
Sensor and Data Collection

**Temperature/Relative Humidity (RH)**
- Desk-level wireless temperature and humidity sensors, collecting at 5-min intervals (Wireless Humidity Sensor - Monnit Corp.)

**Illuminance**
- Desk-level wireless horizontal illuminance sensors, collecting at 10-min intervals (Lux1000 Light Level Sensor - Wovyn LLC)

**Sound Level Meter**
- Single sound level meter located at desk 5, collecting every 10 seconds (XL2 Audio and Acoustic Analyzer with M2211 Microphone - NTiAudio Inc.)
Conclusions

- **Living labs** can be used to identify the environmental conditions predictive of higher self-reported satisfaction with overall workplace quality, and with specific workplace ambient conditions.

- **Temperature, noise, and light** are important, predictive factors of occupant satisfaction, consistent with prior studies.

- **Future studies** should examine more combinations of environmental parameters in a real-world setting, to generate evidence that may guide and optimize building design and management decisions to best serve occupants.

Future studies should examine the interactions among different environmental conditions and their impact on occupants collectively.
Well Living Lab Lighting Study Summaries
Do different kinds of light benefit different kinds of work?
Improved satisfaction, well-being, performance

Windows provide daylight and view

But also… discomfort and eyestrain from glare
Measuring the Impact of Daylight and View on Satisfaction, Performance, and Productivity

• Study goal: Compare the efficacy of two modern ways of providing access to daylight and view in the office
  • Shading
  • Tinted glass

• Measure the effects on occupants
  • Satisfaction
  • Performance
  • Productivity
Methods

• Participants in an open-office configuration
• 3 conditions varied in daylight/view
• 12 weeks of active conditions:
• 2 iterations x 2 weeks/condition (June – Sept)
• Network of environmental sensors

**Blackout shades**
Motorized mesh **shades w/ manual control**
Automated glass **tint w/ override**

Human outcomes:
• Performance
• Productivity
• Satisfaction
• Eyestrain
• Mood

Environmental outcomes:
• Illuminance
• Color temperature

4000K 300 lux
73-76°F (based on occupant preference)
No sound added

Copyright© 2018 by Delos Living LLC All Rights Reserved – Confidential Information
Cohort Description and Behavioral Data Collection

Cohort
• \( N = 10 \) in lab, \( N = 10 \) control
• Medical records workers
• 6:30AM – 5PM (end work by ~4PM)
• Completed usual work tasks
• Cognitive tests during the day
• Surveys at the end of the day

Performance
Cognitive function (Daily)

Productivity
Objective – from work unit (Daily)
Subjective – evaluated by participant (Daily)

Satisfaction
Satisfaction with light and view (Daily)
Environmental satisfaction (Daily)

Secondary measures
Alertness (Daily)
Affect (Daily)
Headache and eye strain (Daily)
## Daylight and view effects

<table>
<thead>
<tr>
<th>Performance</th>
<th>Productivity</th>
<th>Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inhibition</td>
<td>Environmental conditions support my personal productivity</td>
<td>Tint &amp; Shades: Overall light quality</td>
</tr>
<tr>
<td>Task switching</td>
<td>Eyeestrain</td>
<td>Light for computer work</td>
</tr>
<tr>
<td>Improved in Tint &amp;</td>
<td>- Less eyeestrain</td>
<td>Light on the desk for paper-based</td>
</tr>
<tr>
<td>&amp; Shades</td>
<td>- Less eye fatigue</td>
<td>tasks</td>
</tr>
<tr>
<td>No difference</td>
<td>- Less eye discomfort</td>
<td>Access to view</td>
</tr>
<tr>
<td>Improved in Tint &amp;</td>
<td>- Less blurred vision</td>
<td>Aesthetic appearance</td>
</tr>
<tr>
<td>&amp; Shades</td>
<td>- Less irritability</td>
<td>Overall environmental satisfaction</td>
</tr>
<tr>
<td>Working memory</td>
<td>- Less difficulty focusing</td>
<td>Shades: Background noise</td>
</tr>
<tr>
<td>updating</td>
<td>- Less difficulty concentrating</td>
<td>Size of work area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tint: Air quality</td>
</tr>
</tbody>
</table>
Impact of Daytime Exposure to Blue-Enriched LED Lighting on Office Workers Cognitive Performance and Sleep Behaviors

- Previous findings from WLL showed blue-enriched electric light improved perceived sleep quality

- Goal: Measure the effects of daytime exposure to blue-enriched white light in the office on:
  - Performance
  - Sleep Quality
  - Satisfaction
  - Mood
Study Overview

**Procedure**
- Participants worked in semi open-office configuration
- Deployed environmental and wearable sensors
- Varied electric lighting
- Performance and sleep quality was measured through wearables, surveys, and cognitive tasks

**Cohort**
- 19 office workers (8 females)
- Average age: 37.21 years
- 12 week study (8AM to 5PM)
Electric light testing

Timeline of Experiment:

Control group (N= 9, remains in existing office)
- Pre-experiment: Acclimating to Think It Out app
- Baseline
- Baseline

Experimental group (N=10, move to WLL)
- Pre-experiment: Acclimating to space and Think It Out App
- 4 weeks
- Baseline
- 4 weeks
- Blue-enriched white light
- 4 weeks

Human outcomes:
- Performance
- Sleep
- Satisfaction
- Eyestrain
- Mood
Occupant and Environmental Measurements

Occupant Measurements:

**Performance**
- Cognitive tests
- Perceived productivity survey
- Alertness ratings

**Sleep Quality**
- Sleep wearable
- Sleep diary
- Sleep quality survey

**Perceptions of Environment**
- Satisfaction ratings
- Mood ratings
- Headache and eye strain symptoms

Environmental Measurements:

**Electric Light**
- Illuminance sensors on desks
- CCT sensors on desks
- Light measurements at seated position at each workstation to calculate melanopic lux

Other environmental sensors
Electric lighting effects

**Performance**
- Inhibition: No difference
- Task switching: Improved in blue light conditions
- Working memory updating: No difference

**Productivity**
- Environment supports my personal productivity

**Satisfaction**
- No differences in overall satisfaction or satisfaction with any individual environmental elements
- No differences in headache or eye-strain symptoms

**Sleep**
- **Wearable data:**
  - Sleep duration
  - Bedtime
  - Sleep onset
  - Sleep latency
  - Awakenings
  - Sleep efficiency
- **Surveys/Diaries:**
  - Sleep quality
  - Alertness
  - Sleep duration
  - Bedtime

Copyright © 2018 by Delos Living LLC All Rights Reserved – Confidential Information
Conclusions

- **Lighting matters! It can:**
  - **Improve cognitive performance**
    - Different types of lighting impact different cognitive skill sets
  - **Improve comfort and satisfaction**
    - People prefer having access to windows or light that reflects natural lighting patterns
    - Less discomfort with natural light
  - **Impact behaviors outside of the office**
    - Blue light during the day positively impacts sleep at night
3-YEAR RESEARCH PLAN

CENTRAL HYPOTHESIS

By altering the indoor environment, we can enhance occupants’ health, sleep, stress & resiliency, comfort and performance
Impacts of Dynamic LED Lighting on the Well-being and Experience of Office Occupants
Introduction

Background

- Lighting’s Non-image Forming Effects
  - physiological and psychological functioning
  - circadian rhythms, alertness, cognition, heart rate, and emotional activity

- Dynamic LED Lighting Technology
  - an innovative lighting solution
  - simultaneously vary CCT and illuminance
  - mimic the daily variations of natural light

- Previous lighting study across static conditions

Study Purpose

- Quantify the effect of dynamic LED lighting on the well-being and experience of the occupants at office environment.
Method: Human Outcome Measurement

- Stress
  - Continuous objective meas.
  - Daily subjective meas.
  - Monthly subjective meas.: perceived stress & job stress

- Sleep
  - Continuous objective meas.
  - Daily subjective meas.: sleep diary & alertness
  - Monthly subjective meas.: sleep quality

- Productivity
  - Daily subjective productivity meas.
  - Daily subjective effect of environment

- Secondary Analysis
  - Satisfaction
  - Comfort
  - Naturalness
  - Mood
Method: Lighting Design and Control

Study Operation Space
- 3 modules combined into a 124 m² open office
- Customized design and control of the Panasonic lighting system
- Reconfigured desk layout & various building technologies for the desired lighting environment

Study Operation Schedule
- Acclimation – 1/29/18-2/9/18
- Condition 1 (JP-T) – 2/12/18-3/9/18
- Daylight Saving – 3/10/18-3/18/18
- Condition 2 (JP-D) – 3/19/18-4/13/18
- Condition 3 (US-T) – 4/16/18-5/11/18
- Condition 4 (US-D) – 5/14/18-6/08/18

From Universal Lighting Technologies and Douglas Lighting Controls (owned by Panasonic)
Result: Overview of the Study Operation

Environmental sensor data collection
- No. of Env sensors: 144
- Data collection rate (horizontal lighting): 95%

Subject participation
- No. of subjects recruited: 15
- Expected participation: 1,410 subject*days
- Actual participation: 1,213 subject*days

Occupant sensor data collection
- No. of stress sensors: 15 Empatica E4
- No. of sleep sensors: 15 EarlySense
- Data collection rate: 98% (based on actual participation)

Subjective survey collection
- No. of surveys distributed: 8,700+
- Survey response rate: 88% (based on actual participation)

Further data analysis
- In process
A Delos™ and Mayo Clinic collaboration

Biophilic Office Design Study
Components of biophilic design?

Varying definitions: ¹,²

➢ Direct vs. indirect biophilic implementation

➢ Physical vs. non-physical

➢ Spatial vs. sensory stimuli


Methods/outcomes

• Nature in the space

- Visual
- Acoustics (or other non-visuals)
- Thermal control and airflow
- Presence of water
- Connection to natural systems

Hypothesis:

➢ Stress
➢ Mood
➢ Perceived productivity
➢ Connectedness to nature
Indoor Air Quality in Skyways and Subways
Motivation

- Sources of air pollution are often adjacent to indoor walkways, e.g. restaurants, parking garages, hair salons, and have varying types of pollutant control.

- Sensitive populations (e.g. young, elderly, infirm) are likely to use indoor walkways, increasing the importance of ensuring environmental exposures in these areas are within healthy ranges.
Methods – Instrumentation & Planning

Top View

Konica CL500A (Light Levels)
MetOne BT-645 (PM2.5)
Q-Trak 982 (CO2, CO, Temp, RH)

Computer
ppbRAE 3000 (TVOC)
Monitor

Side View

Teledyne Inlet
Battery and Inverter

Teledyne T640 (PM2.5, PM10-2.5)
Mobile Well Living Lab
## Environmental Sensing

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>CO₂</td>
</tr>
<tr>
<td>Relative Humidity</td>
<td>PM 2.5</td>
</tr>
<tr>
<td>Sound</td>
<td>PM 10</td>
</tr>
<tr>
<td>Thermal Imaging</td>
<td>Light Spectrum</td>
</tr>
<tr>
<td></td>
<td>CCT</td>
</tr>
<tr>
<td></td>
<td>Illuminance</td>
</tr>
</tbody>
</table>
Physiological and Behavioral Sensing

- Motion
- Heart Rate
- Skin Conductance
- Skin Temperature

Custom surveys

Location

Real-time E4 data stream

Complete integration with cloud

Copyright© 2018 by Delos Living LLC All Rights Reserved – Confidential Information
The path forward

Prototype complete

December 2018

In-house and Field Testing

June 2019

Production Ready

January 2020
Well Living Lab Domain Experts

Sara Aristizabal, PhD
Biomedical Engineering/Wearables

Carolina Campanella, PhD
Behavioral Sciences/Sleep

Nicholas Clements, PhD
Building Sciences/Indoor Air Quality

Syed Shabih Hasan, PhD
Computer Sciences/Mobile Sensing Technology

Anja Jamrozik, PhD
Behavioral Sciences/Cognition

Rongpeng Zhang, PhD
Building Sciences/Building Simulation

Jie Zhao, PhD
Building Sciences/Lighting
Well Living Lab Research and Operations Team

Joleen Bernau
Innovation and Subject Coordinator

Kevin Hovde
Senior Project Manager

Christian Ramos
Budget/IRB Management

Chi Lam
Technology Director

Jeyakumar Raman
Information Technology

Sarang Shah
Information Technology

Brant Staven
Information Technology

Linhao Li
Building Science/Research Associate

Shaun Ly
Building Science/Research Analyst

Paige Porter
Behavioral Science/Research Analyst

Suzanne Leaf-Brock
Communications Director

Carole Wolfe
Administrative Assistant
Well Living Lab Leadership Team

Brent A. Bauer, MD
- Medical Director, Well Living Lab
- Professor of Medicine, Mayo Clinic College of Medicine
- Research Director, Mayo Clinic Integrative Medicine Program

Barbara Spurrier
- Managing Director, Well Living Lab
- Senior Vice President, Delos
The office experiment: Can science build the perfect workspace?

Windows, desks and employees are being wired up in a quest to create healthy, evidence-based environments.

Emily Anthes

…”Experts know that indoor spaces can pose health risks. Excessive noise is thought to contribute to high blood pressure and heart disease. Artificial light can disrupt circadian rhythms and may increase the risk of certain cancers”…
Think It Out App

1. Updating

2. Inhibition

3. Switching

4. Surveys/Questionnaires

10 MINUTES/DAY
Next Steps

• Reach out to your own medical community
  • C-suite
  • Individuals

• Find collaborators
  • Academic Consortium for Integrative Medicine and Health
Academic Consortium for Integrative Medicine and Health

“Advancing integrative medicine and health through academic institutions and health systems.”

WHO WE ARE

We’ve changed our name! The Consortium of Academic Health Centers for Integrative Medicine is now the Academic Consortium for Integrative Medicine & Health (The Consortium)

As an organization we are committed to sharing information and ideas, meeting challenges together in a process grounded by the values of integrative medicine, supporting member institutions, and providing a national voice for the advancement of integrative principles.

WHAT WE DO

The mission of the Consortium is to advance integrative medicine and health through academic institutions and health systems.
Next Steps

• Reach out to your own medical community
  • C-suite
  • Individuals
• Find collaborators
  • Academic Consortium for Integrative Medicine and Health
• Design/Build/Use what you already know
“Perhaps we don’t need such rigorous evidence when it comes to nature contact… Maybe we don’t know everything there is to know about human benefits of nature contact, but we have a pretty fair idea, and we know a lot about designing nature into the built environment. And given the pace at which decisions are being made and places built, there is a pressing need to implement what we know. **We can’t wait for the research.**”

Howard Frumkin, 2008

Nature Contact and Human Health, *Biophilic Design*
"The best interest of the patient is the only interest to be considered, and in order that the sick may have the benefit of advancing knowledge, union of forces is necessary."

Dr. W. J. Mayo
Conclusion Slide
bauer.brent@mayo.edu
New methods provide daylight and view while limiting glare.

What are their impact on occupants’ comfort, performance, and eyestrain?
Behavioral Findings

Do varying environmental conditions affect occupant experience in the lab? Yes!

Lower measured *illuminance* associated with…
- Greater workplace quality satisfaction
- Greater satisfaction with sound levels

Greater measured overall *volume* associated with…
- Greater workplace quality satisfaction
- Greater satisfaction with sound levels
- Greater satisfaction with temperature

Higher measured *temperature* associated with…
- Greater satisfaction with temperature

No associations for reported satisfaction with lighting