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Occupant Behavior and Comfort

Pacific Northwest
NATIONAL LABORATORY

Advancing human outcome analytics to build confidence in indoor environmental quality investment

Learning Objectives

- Discuss the variety and complexity of human outcome metrics in buildings.
- Understand the value of advancing healthy building analytics and M&V in an applied way.

Acknowledgements

- Erik Mets – PNNL
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- Luke Troup – PNNL

Background

Programmatic Goal

Quantify occupant benefits to improve confidence in indoor environmental quality (IEQ) investments.

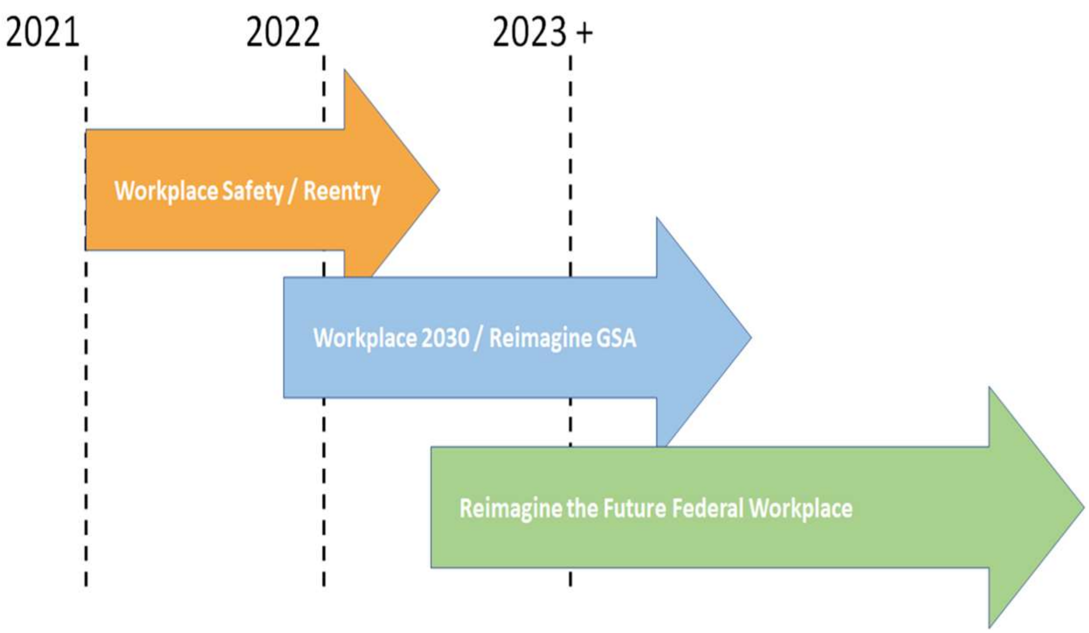
Topic Areas and Challenges

Data Collection: It can be expensive and labor intensive to comprehensively evaluate IEQ in a building.

Predicting Occupant Benefits: Limited and incongruent data from field studies mean less confidence in predictions of occupant benefits for a specific building.

Measurement + Verification: Many human measurements are often expensive and not scalable or suitable for non-research applications.

Health and the Future of Work



Objectives of this Research:

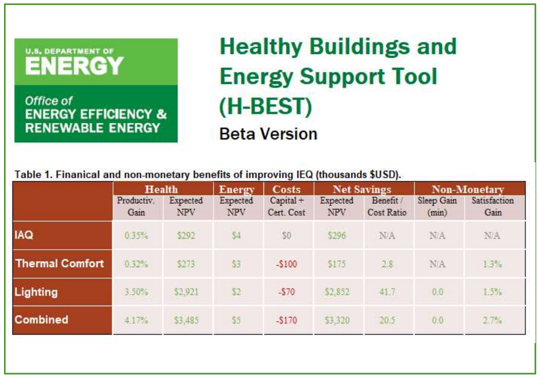
Leverage GSA's large portfolio to gather significant data from field studies starting with Workplace 2030 and Reimagine GSA

Develop a standardized approach to evaluate human benefits in decision making that is replicable at scale and able to be validated

Create a feedback loop to create and validate predictions, fine-tune healthy strategies, and build confidence in investments in occupant health and wellbeing

Healthy Buildings Toolkit Overview

Healthy Buildings and Energy Support Tool (H-BEST)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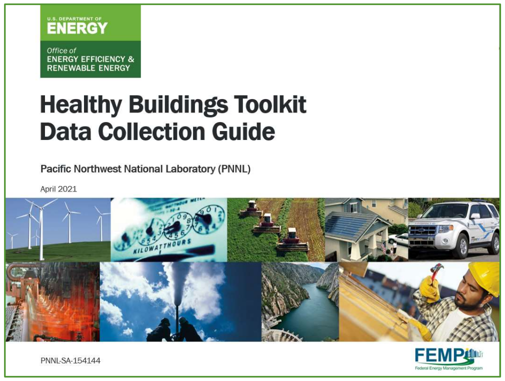
Healthy Buildings and Energy Support Tool (H-BEST)
Beta Version

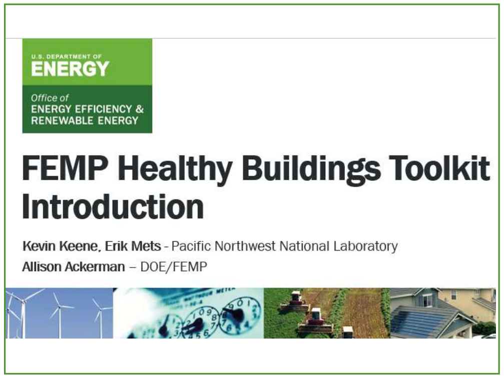
Table 1. Finanical and non-monetary benefits of improving IEQ (thousands $USD).

	Health		Energy	Costs	Net Savings		Non-Monetary	
	Productiv. Gain	Expected NPV	Expected NPV	Capital + Cert. Cost	Expected NPV	Benefit / Cost Ratio	Sleep Gain (min)	Satisfaction Gain
IAQ	0.35%	$292	$4	$0	$296	N/A	N/A	N/A
Thermal Comfort	0.32%	$273	$3	-$100	$175	2.8	N/A	1.3%
Lighting	3.50%	$2,921	$2	-$70	$2,852	41.7	0.0	1.5%
Combined	4.17%	$3,485	$5	-$170	$3,320	20.5	0.0	2.7%

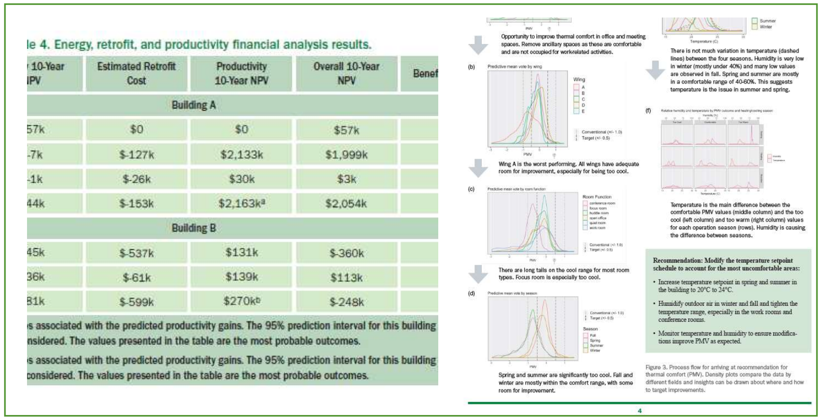
Data Collection Guide



On-Demand Training



Pilot Case Studies


le 4. Energy, retrofit, and productivity financial analysis results.

10-Year IPV	Estimated Retrofit Cost	Productivity 10-Year NPV	Overall 10-Year NPV	Benef
Building A				
57k	$0	$0	$57k	
-7k	$-127k	$2,133k	$1,999k	
-1k	$-26k	$30k	$3k	
44k	$-153k	$2,163k[a]	$2,054k	
Building B				
45k	$-537k	$131k	$-360k	
36k	$-61k	$139k	$113k	
31k	$-599k	$270k[b]	$-248k	

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Equipment Lending Library

Making IEQ Evaluation More Accessible

The purpose of the Healthy Buildings Toolkit is to provide decision support for energy managers, sustainability managers, building managers, operators, and owners to improve IEQ and energy efficiency in their building.

How to comprehensively evaluate the IEQ performance of a building at a low-cost, effort, and required expertise?

- Measurement duration
- Sample size
- Number of metrics

Pilot Tests

Building A

Vintage: 2017
Size: 26,000 sq.ft.
Location: Northwest
Occupants: 92

Building B

Vintage: 1970
Size: 29,000 sq.ft.
Location: Northwest
Occupants: 80

Building C

Vintage: 1940's
Size: 110,000 sq.ft.
Location: South Central
Occupants: 250

Building D

Vintage: 1917
Size: 764,000 sq.ft.
Location: Mid-Atlantic
Occupants: 2,200

Building E

Location: South Central
Size: ~96,000 sq.ft.
Occupants: 478

Building F

Location: Mid-Atlantic
Size: ~38,000 sq.ft.
Occupants: 188

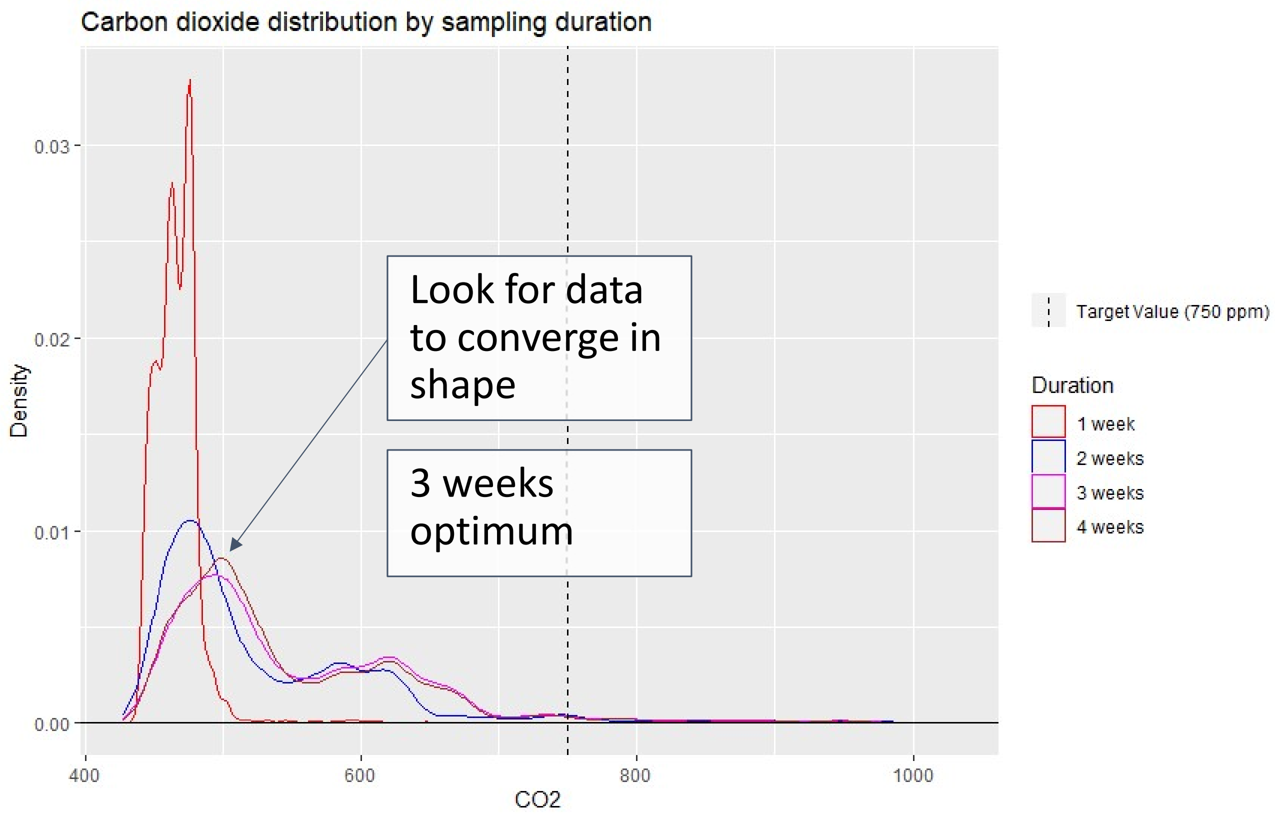
Building G

Location: Mid-Atlantic
Size: ~115,000 sq.ft.
Occupants: 575

Note

Seven samples is not enough to make sweeping conclusions but offers valuable observations

Identifying Optimal Sample Duration (CO_2)



Observations

Measurement duration:

- Recommend 2 weeks of CO_2 collection
- Recommend 2-3 weeks of temperature and humidity monitoring and sampling in each season

Number of optimum sensor locations depends on size of building:

- Buildings less than 50,000 sq.ft.
  - Temperature and humidity one sensor per 8,000 sq.ft
  - CO_2 one sensor per 20,000 sq.ft.
- Buildings greater than 50,000 sq.ft.
  - Temperature and humidity one sensor per 40,000 sq.ft
  - CO_2 one sensor per 70,000 sq.ft.

Streamlining IEQ Analytics

H-BEST streamlines an IEQ evaluation from raw data to help users quickly draw insights on their building's performance and areas for improvement.

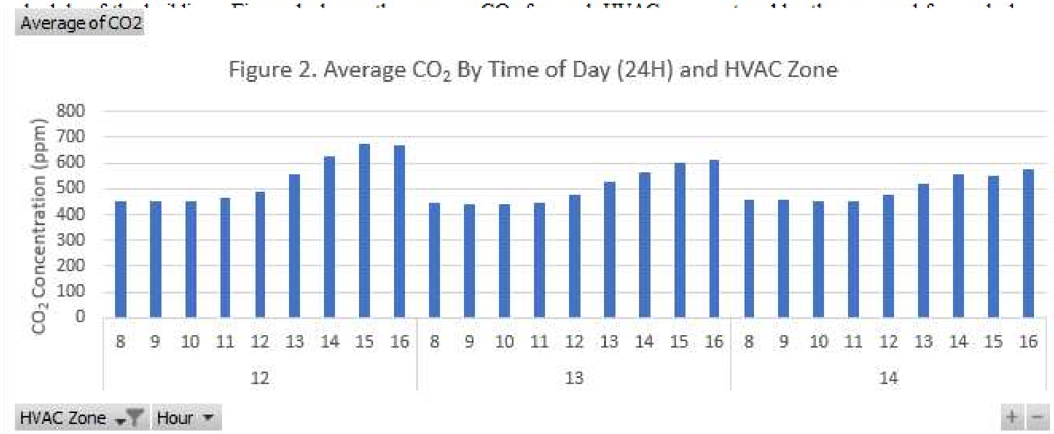
Example

Carbon Dioxide

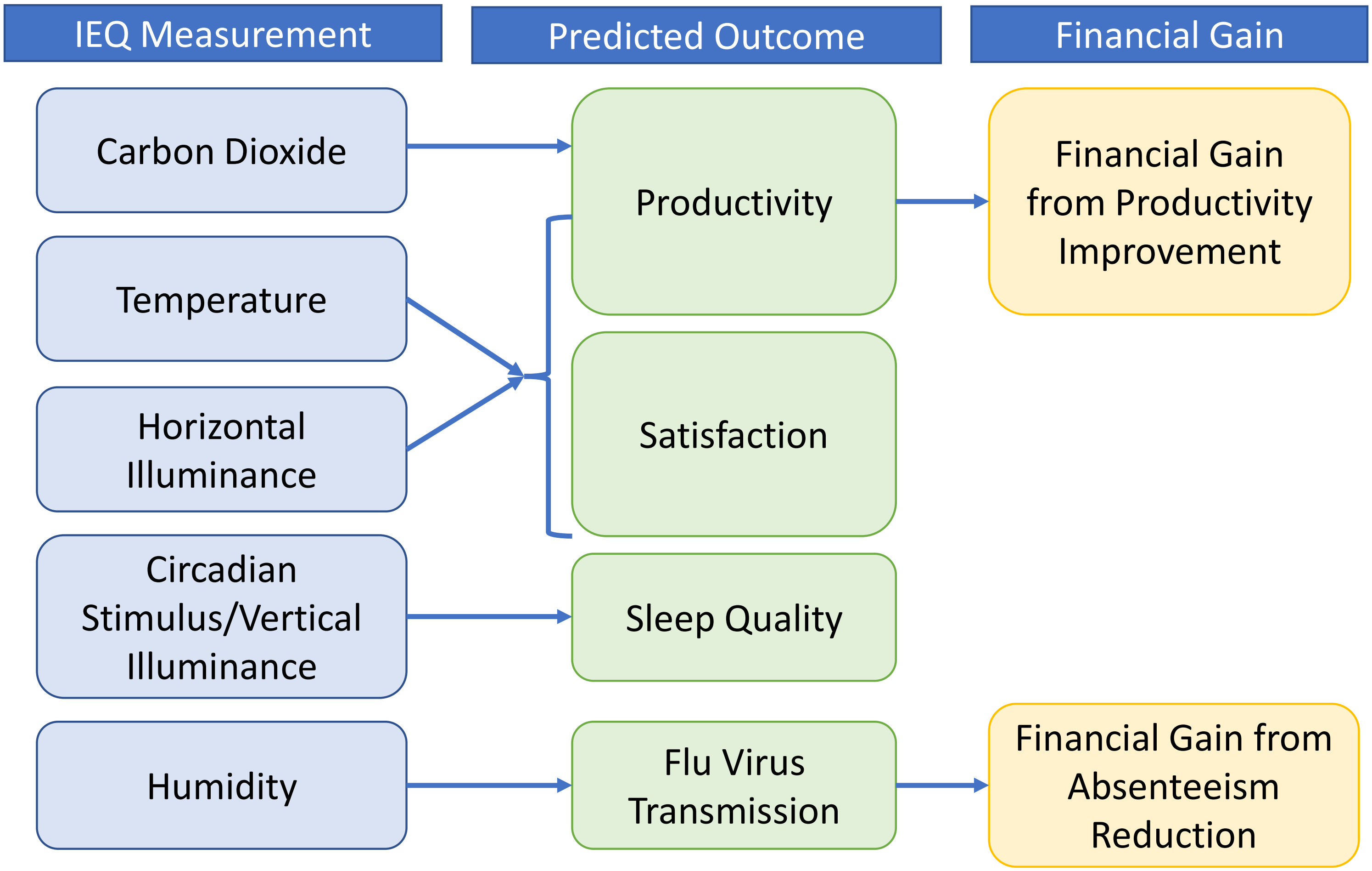
Carbon dioxide (CO_2) is a common IAQ indicator. Some studies have found that CO_2 itself may not be harmful to occupants at the levels typically found in buildings, rather it is a proxy for other IAQ pollutants. This is because CO_2 is an indicator of other human bioeffulents that can reduce air quality and has a strong correlation to ventilation rate, which is the principle driver for reducing IAQ pollutants. Studies that introduce artifical CO_2 to a space rather than human-produced CO_2 have not found as good correlations to human health outcomes.[12],[13] For this reason, only human-produced CO_2 studies are included in the regression models used in this tool.

This tool uses a target of 350 ppm above outdoor concentration, or approximately 750 ppm, which is the WELL v2 credit A06 Option 2 two-point threshold for demand controlled ventilation.[14] The common benchmark for acceptable CO2 levels in a building is the ASHRAE 62.1-2016 Addendum d guidance of 700 ppm above outdoors, or approximately 1,000 ppm. This tool encourages users to go beyond the acceptable conditions to push for 750 ppm as a target.

CO_2 levels are often a concern during certain times of the day or days of the week, depending on the occupancy

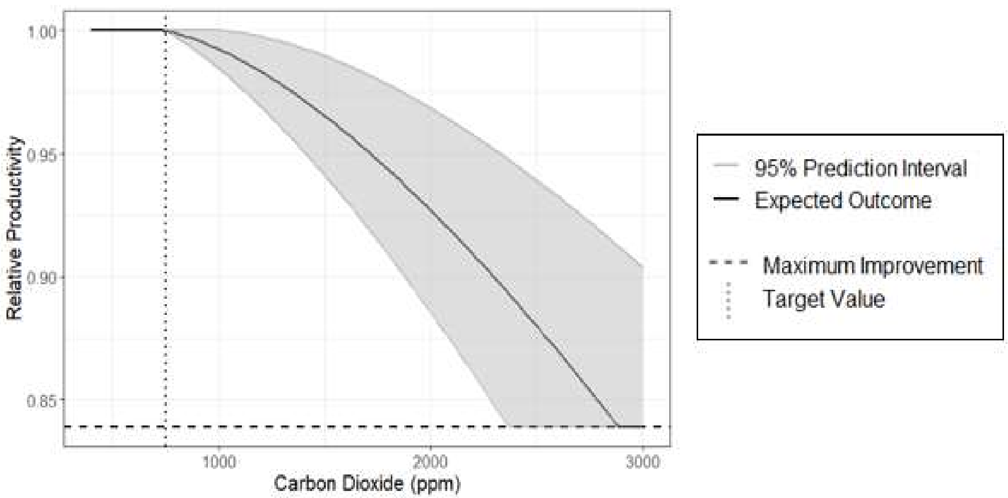


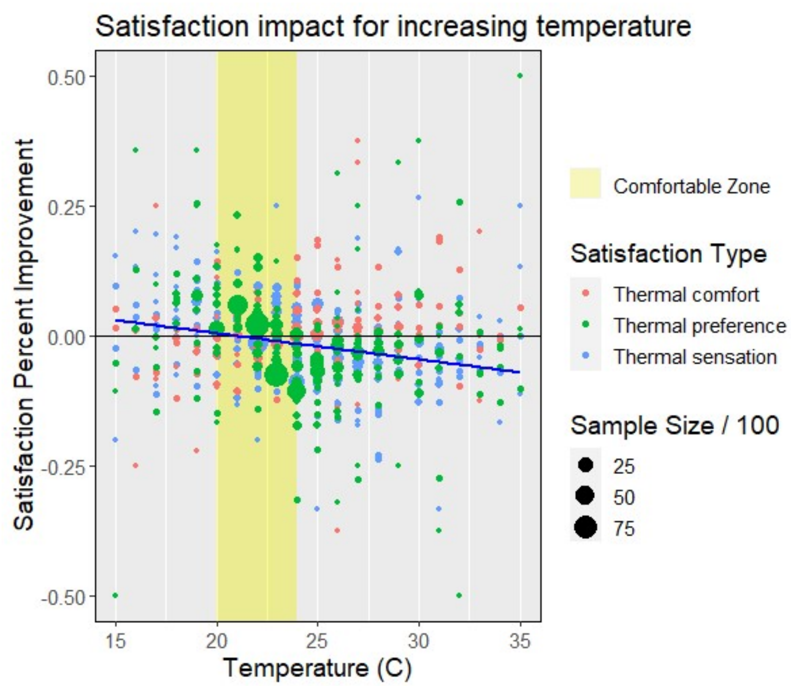
IEQ Regression Models in H-BEST



H-BEST Regression Models

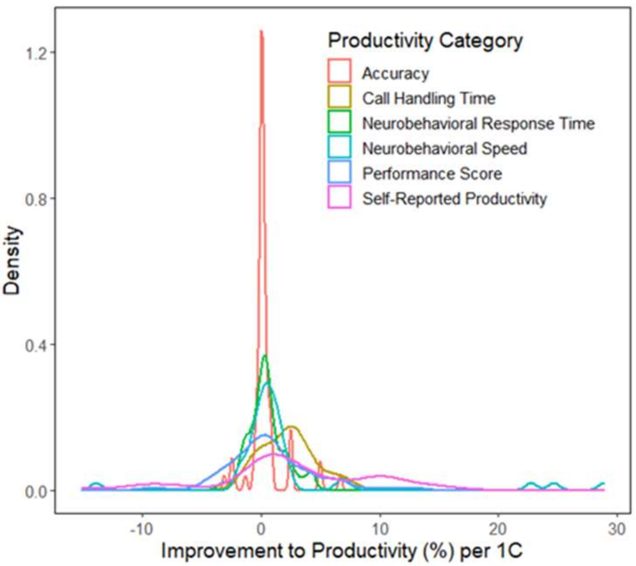
Conducted literature review for thermal comfort, lighting, and air quality to create meta-analysis regression models to predict the improvement potential of human outcomes for any building based on IEQ parameters.

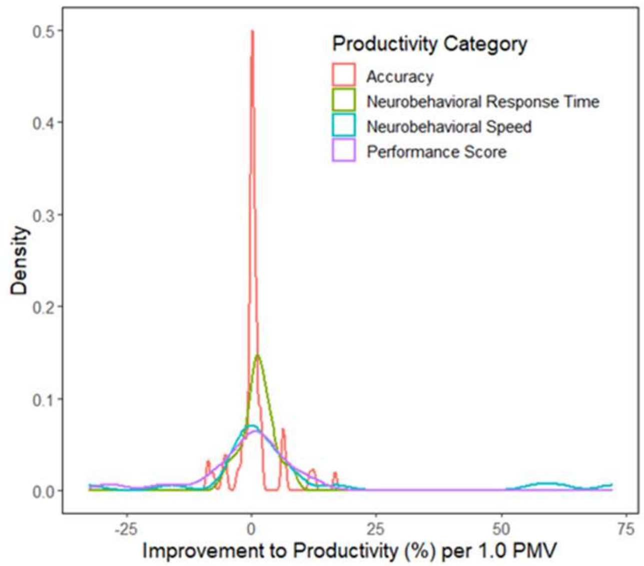




Advancing Productivity Research

One challenge with conducting a meta-analysis on productivity is the variety of metric types that can be used to define productivity. Used a pairwise t-test evaluation and summary statistics to compare the results of these metrics to see if they can be combined in a meta-analysis.





All the p-values for **call handling time, neurobehavioral response time, and self-reported productivity** showed no significant differences when compared to **neurobehavioral speed** (suggesting that the effects are of the same magnitude and can be combined directly).

Most of the p-values for **accuracy** and **performance score** showed significant difference compared to neurobehavioral speed.

Empowering Project Business Cases

Compare IEQ categories and get an idea of the magnitude of savings potential

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Providing Automated Decision Support

Solutions development tab contains 63 possible improvement measures

H-BEST will filter out the ones that are not applicable and the user can read the provided information to select the best options

Step 7. Improvement Opportunities | Return to Instructions | Energy and Cost | Results

7. Use the filter in the "Suggested" to select rows with "YES". The YES and NO values are automatically filled based on the data entered in other tabs. Read through the information provided for each improvement measure and then choose u in the "Selected" column. These improvement measures will then populate into your report on the "Results" tab.

Improvement Measure	Suggested	IEQ Category	Selected	Issue and Solution	Applicability	Guidance
Ventilation schedule	NO	Carbon Dioxide	NO	CO_2 could be improved during certain hours of day/week in at least one HVAC zone.		Install modulation damper at outdoor air intake (if not al ventilation schedule according to problematic times or us position (DCV).
Re-tune HVAC controls						
Test and balance HVAC system for air circulation	YES	Carbon Dioxide	NO	CO2 could be improved in at least one HVAC zone. Important to test controls and verify their functionality before trying other solutions. The air distrubtion effectiveness can be improved and the HVAC has not been tested in some time. If the static fan pressure is too low or the distribution nozzle type/damper position limits flow too much, the air won't be discharged at a velocity in the space to facilitate effective air distribution and if the pressure is too high or the nozzle type/damper position ejects air to rapidly, it can affecting their thermal comfort of occupants (too cold).		Improve air distrubtion by removing obstructions blocki diffuser type (increasing air velocity) or increasing fan sp better throughout space.
Increase outdoor air	YES	Carbon Dioxide	NO	CO2 could be improved in at least one HVAC zone. The ventilation may be below par.		Increase outdoor air fraction at indoor airtake to 30-60% CFM/person). Note that this could have impacts to PM sufficient and maintained.
Improve air circulation in select zones	YES	Carbon Dioxide	NO	CO2 could be improved in at least one user-defined zone. The air distrubtion effectiveness can be improved and the HVAC has not been tested in some time.		Improve air distrubtion by removing obstructions blocki diffuser type (increasing air velocity) so that air can circu Note that other zones may have opportunity for improv distribution as well but good CO2.
Demand-control ventilation	NO	Carbon Dioxide	NO	CO_2 could be improved during certain hours of day/week in at least one user-defined zone.	Reliable return air on floor CO2 sensors, fully modulating economizers	DCV uses feedback from indoor air quality sensors to de outdoor air damper position. Make a corresponding lowe outdoor air damper commands or airflow setpoints. CO2 faulty. Implement a fault tolerant strategy—don't imple the outdoor air dampers to 0% or 100% indefinitely. Pla

Improving Regression Models in Partnership With GSA

Objectives

- Identify the human metrics that provide greatest value at lowest cost and difficulty
- Improve predictions in H-BEST to build confidence
- Collecting potential confounding factors to understand the complex relationship between environmental and organization attributes and human performance and comfort

Indoor Environmental Quality

- Space design features
- Indoor environmental conditions

Human Outcome Metrics

- Organizational attributes
- Survey responses
- Physiological responses
- Occupancy and location tracking

IEQ Metrics in GSA Research

Lighting:

- Environmental conditions: Circadian stimulus, horizontal illuminance, vertical illuminance
- Space features: window proximity, task lighting, glare prevention

Biophilic design:

- Space features: Access to biophilic elements (indoor plants, natural patterns, and views of the outdoors)

Indoor air quality:

- Environmental conditions: CO_2, TVOC, particulate matter
- Space features: ventilation rate, filtration, sources of contamination, HVAC maintenance, etc.

Thermal comfort:

- Environmental conditions: temperature, humidity, predicted mean vote (PMV)
- Space features: thermal controls, insulation, etc.

Acoustics:

- Environmental conditions: sound level
- Space features: acoustic privacy, sound absorption of materials

Human Outcome Metrics Focus Group

We interviewed researchers and professionals in the healthy buildings field to identify metrics that provide high value to decision makers while reducing cost and difficulty of collection. Consideration was given to avoid redundancy and maximize coverage of our research hypotheses.

Metric	Value Score	Difficulty Score	Cost Score	Combined Score
Satisfaction surveys	1.00	0.73	0.78	1.75
SBS symptom surveys	0.95	0.63	0.88	1.70
Turnover	0.60	0.80	0.95	1.48
Absenteeism/sick time	0.70	0.60	0.90	1.45
Reported illness	0.70	0.60	0.90	1.45
Steps, actigraphy	0.69	0.75	0.65	1.39
Number of calls made (job specific)	0.32	0.88	1.00	1.25
Self-reported productivity	0.39	0.78	0.89	1.23
Stress/mood surveys	0.55	0.61	0.72	1.22
Other cognitive tests	0.80	0.40	0.33	1.17
Sleep quality surveys	0.45	0.55	0.72	1.09
Time online/on computer	0.28	0.61	0.84	1.00
SMS	0.75	0.30	0.20	1.00
Skin temperature	0.38	0.50	0.50	0.88
Heart rate	0.50	0.32	0.27	0.79
Sleep biofeedback (e.g., sleep time, latency, efficiency)	0.35	0.32	0.27	0.64
Cortisol levels	0.50	0.00	0.00	0.50
Eye flicker/pupil dilation	0.38	0.00	0.13	0.44

Advanced Focus Areas

The human outcome metrics vary by focus area based on our hypotheses from existing work

Research Focus	Survey	Organizational Attributes	Physiological/ Performance
Circadian Lighting	Sleep survey		Actigraphy, number of steps, sleep duration
Biophilic Design	Satisfaction, stress survey		
Ventilation / Filtration	SBS symptoms, self-reported productivity	Absenteeism	Cognitive test
Thermal Comfort	Satisfaction with thermal, self-reported productivity	Absenteeism, flu cases	Cognitive test
Acoustic Comfort	Satisfaction with acoustic, self-reported productivity		Cognitive test

Next Steps

- First project underway (postponed due to pandemic and limited occupancy)
  - Alcohol, Tobacco and Firearms (ATF) Headquarters
- GSA Region 10 office to begin next calendar year, followed by other regions
- Take lessons learned to create a concrete protocol for healthy buildings projects

QUESTIONS?

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