U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Healthy Buildings Initiative: Pacific Northwest National Laboratory Pilot Study

Photo credit: Pacific Northwest National Laboratory

The U.S. Department of Energy's Federal Energy Management Program (FEMP), in partnership with the General Services Administration, is currently investigating how traditional building energy efficiency measures can impact health in the federal sector through the Healthy Buildings Initiative (HBI).

FEMP is currently funding research at Pacific Northwest National Laboratory (PNNL) to develop a framework for evaluating indoor environmental quality (IEQ) metrics and quantifying the potential financial costs and gains related to improving occupant productivity in federal buildings. The goal of this initiative is to facilitate more holistic decision making. In fiscal year 2019, PNNL piloted this framework at their Richland, Washington campus to investigate how integrated energy and health analysis could benefit building retrofit and operation strategies.

Background

The concept of green buildings describes the large umbrella of sustainability, which includes energy efficiency, carbon emissions, environmental protection, human health, and financial equity. The human health aspect of green buildings is beginning to emerge as an area of larger focus in the building industry and in the context of energy efficiency. There is growing recognition that building occupant health could provide significant cost savings to employers in the form of greater productivity, cognitive performance, satisfaction, job retention, and reduced absenteeism. Occupant health and energy efficiency are both impacted by building systems and therefore benefit from being considered holistically.

A major challenge in addressing building occupant health is how to quantify occupant benefits in the context of energy efficiency decision-making. Although there is an abundance of information and tools on how to quantify energy benefits, health and productivity are the more challenging to quantify. Correlations between IEQ metrics and productivity from laboratory and empirical studies have not been fully translated to building system design and operation.

The PNNL team is developing a research tool being used to bridge occupant health and productivity outcomes with energy efficiency approaches. This is the first case study in a series to evaluate the components of the framework. This case study explores how the framework can yield meaningful outcomes when conducted in conjunction with an energy audit.

Framework Overview

The methodology developed by PNNL (outlined in Figure 1) estimates the potential financial gains from occupant

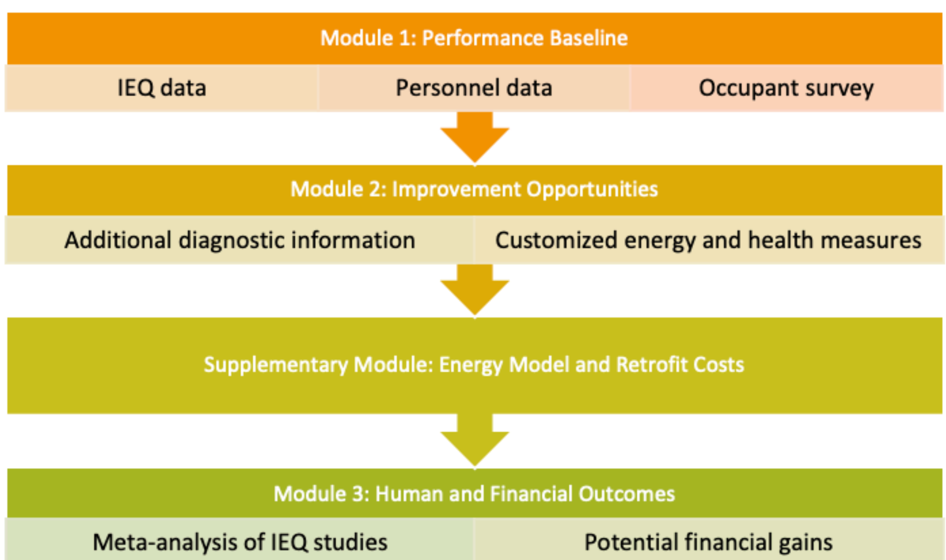

Figure 1. Modules comprising the HBI framework methodology.

productivity improvements and identifies specific modifications customized for a building. There are three modules within the overall methodology framework.

Module 1 collects baseline IEQ data by monitoring parameters such as carbon dioxide, temperature, humidity, and light levels, and administering an occupant survey.

Module 2 uses the baseline IEQ data to guide the collection of additional building characteristic, operation, and asset information needed to understand the reasons for any IEQ issues. This information is used to identify specific improvement actions to help achieve the IEQ targets.

An optional component of the framework is to create an energy model and provide estimated retrofit costs. This information is included in this case study but is not streamlined within the framework.

Data from Module 1 are also used in Module 3 to estimate the potential productivity improvement for a building. PNNL developed a series of correlations between IEQ metrics and human productivity from a meta-analysis of 51 experimental conditions from peer-reviewed academic studies. The potential productivity gains between the baseline IEQ values and the target IEQ values are converted to financial gains using the cost of employees in the building.

Table 1. Features of Pilot Building A and B.

Building Name	A	B
Vintage	2017	1965
Total floor area (sq. ft.)	26,190	29,416
Number of workstations	118	80
Number of floors	2	1
Wall Type	8” concrete wall with 1” stucco	100 mm brick on steel frame
Window Type	Glazed double-pane windows	Glazed single-pane windows
Heating System	VAV[a] reheat with natural gas-fired boiler plant	VAV[a] reheat with natural gas-fired boiler plant
Cooling System	District chilled-water plant	Electric chiller plant
Ventilation System	Schedule-based demand-controlled ventilation	Adjustable outdoor air dampers fixed at about 10% outdoor air ratio

[a]VAV = variable air volume

Case Study Design

Module 1: Performance Baseline

The PNNL team collected data over a two-week period in two PNNL buildings in Richland, Washington. These buildings are referred to as Building A and Building B to protect sensitive information. Building A is a recently constructed, energy-efficient building, and Building B is a legacy building that was constructed over 50 years ago. The information in Table 1 describes the distinguishing features of Buildings A and B. Both buildings are located in ASHRAE Climate Zone 5B (i.e., dry, cold).

As part of the Performance Baseline module, the PNNL team collected carbon dioxide, temperature, and humidity measurements at 15-minute intervals for three weeks in August 2019. The team measured this data at four locations in each building (two open office areas, one private office, and one cubicle). The team also measured horizontal illuminance at 40 locations throughout each building. Horizontal illuminance was taken in the absence of daylight to evaluate electric lighting. Building A had historical data on carbon dioxide and temperature available through the building automation system.

The team engaged PNNL Human Resources and managers for data on the employees who sit in each building. These data included the average cost of the employee (average salary and average PNNL benefits multiplier) and number of employees in the building.

The team administered a short occupant survey for one week to collect information about thermal satisfaction (i.e., percentage of occupants satisfied with temperature) and satisfaction with lighting (i.e., percentages of occupants satisfied that the lighting level was appropriate in terms of dimness, brightness, and glare/contrast). The survey contained additional questions designed to elicit qualitative responses for further diagnosis and understanding of issues.

Module 2: Improvement Opportunities

The information collected in Module 1 informed the subsequent modules. After baselining the current building performance based on occupant health, the team identified issues in building systems and operations and developed recommendations on how to improve occupant health while balancing energy efficiency. The team compiled and used a list of health improvement and retrofit strategies based on industry and literature research.

Supplementary Module: Energy Model and Retrofit Costs

An energy model for each building was created using EnergyPlus to identify the energy impacts of the IEQ measures identified. The retrofit cost data was taken from the Department of Energy's Scout Tool to provide approximations for the pilot test purpose.

Module 3: Human and Financial Outcomes

Based on the correlations between IEQ and improved productivity developed for Module 3, productivity gains were converted to financial gains based on the cost of employees in the building. The details of the regression models and financial calculations will be documented in a separate technical resource. The net present value (NPV) of the measures is determined based on the estimated investment costs required to attain those improvements, energy cost/savings, and personnel (health) gains. A 10-year NPV with a typical discounted rate of 3% is used to compare the results.

Results

Recommended Improvements

Based on the IEQ measurements and survey results from Module 1, the research team identified improvements for the two pilot buildings in Module 2. The results are detailed in Table 2.

Energy Simulation Results

The energy impact of the recommendations for both buildings are shown in the Table 3. The energy use intensity before retrofitting is 58.3 kBtu/sq.ft (Building A) and 73.4 kBtu/sq.ft (Building B); it is reduced to 43.2 kBtu/sq.ft (Building A) and 48.7 kBtu/sq.ft (Building B) after retrofitting.

Cost/Benefit Analysis

Table 4 shows the economic analysis considering both energy and human benefits. If all IEQ metrics reach the target values for healthy buildings, the estimated personnel gains in 10-year NPV are $2.16 million for Building A and $270 thousand for Building B. The envelope retrofit for Building B shows a negative overall cost/benefit ratio because of the high capital cost. The personnel satisfaction gains from the improved lighting environment helps justify the cost of retrofitting the lighting, which is higher than the 10-year energy cost savings. However, the personnel

Table 2. Recommendations for pilot buildings based on issues identified in baseline performance data.

Category	Building	Issues	Recommendations
Thermal Comfort	A	Mostly too cool in open offices. Survey shows some complaints of too warm in afternoons, especially during spring and summer. Lack of thermal control in open offices.	Increase temperature setpoint in open offices 1°F in morning year-round and monitor the predicted mean vote. Provide supplemental thermal control devices (e.g., heated chairs) to individuals as needed in open office spaces. Add automated shading to windows to reduce solar heat gain.
	B	Too warm in some areas. Envelope is poorly insulated leading to high energy use for space heating and cooling.	Retrofit envelope with more insulation for walls, windows, and roof.
Air Quality	A	No health-related issue. The building seems to be over-ventilated.	Confirm whether the building is occupied as designed. Check economizer functions and damper positions. Reduce outdoor airflow (up to 40% based on energy model) with continuing monitoring to keep the carbon dioxide level below 750 ppm.
	B	No health- or energy-related issues.	None.
Electric Lighting	A	Some spaces are underlit.	Add task lighting to underlit workstations.
	B	Survey complaints of glare. Some spaces are overlit and some spaces are underlit.	Replace T8 overhead lights with light-emitting diode (LED) lighting and ensure consistent horizontal illuminance within the comfort range. Add light-toned colors to walls and furniture to reduce contrast.

Table 3. Modeled energy use for the recommendations from the EnergyPlus simulations.

	Electricity (kBtu/ft^2)	Natural Gas (kBtu/ft^2)	Chilled Water (kBtu/ft^2)	Total Energy Use (kBtu/ft2)	Percent Reduction Energy	Energy Cost Savings ($/yr)
Building A						
Calibrated baseline	20.7	19.2	18.3	58.3		
Recommission ventilation system and reduce outdoor air flow (up to 40%)	20.1	9.3	11.8	41.3	29.2%	$6,633
Add personal thermal comfort devices and window shading	22.1	18.7	18.3	59.1	-1.3%	-$794
Add LED task lighting to workstations	20.9	19.2	18.3	58.3	-0.1%	-$68
All measures combined	21.7	9.1	12.5	43.2	25.9%	$5,209
Building B						
Calibrated baseline	41.3	32.1	0	73.4		
Envelope retrofit	38.1	15.1	0	53.2	27.5%	$5,276
Replace overhead lighting with LED lighting	34.5	34.3	0	68.8	6.3%	$4,175
All measures combined	31.3	17.4	0	48.7	33.7%	$9,477

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

Category	Energy 10-Year NPV	Estimated Retrofit Cost	Productivity 10-Year NPV	Overall 10-Year NPV	Benefit/Cost ratio
Building A					
Indoor Air Quality	$57k	$0	$0	$55k	N/A
Thermal Comfort	$-7k	$-124k	$2,133k	$1,941k	15.7
Lighting	$-1k	$-25k	$30k	$3k	0.1
Combined	$44k	$-149k	$2,163k[a]	$1,995k	13.4
Building B					
Thermal Comfort	$45k	$-522k	$131k	$-350k	-0.7
Lighting	$36k	$-60k	$139k	$110k	1.8
Combined	$81k	$-581k	$270k[b]	$-240k	-0.4

[a] Note that there are uncertainties associated with the predicted productivity gains. The 95% prediction interval for this building is from $0 to $4,720 if all uncertainties are considered. The values presented in the table are the most probable outcomes.

[b] Note that there are uncertainties associated with the predicted productivity gains. The 95% prediction interval for this building is from $70k to $471k if all uncertainties are considered. The values presented in the table are the most probable outcomes.

satisfaction gains from improved thermal comfort are inadequate to generate an appealing benefit/cost ratio. The testing period occurred during the summer so it is possible that poor envelope insulation causes further discomfort in the winter. The personnel financial gains could potentially justify an envelope retrofit with an additional round of data collection in the winter.

Building A has smaller energy savings opportunities than Building B but greater health gains opportunities. Looking at individual categories, thermal comfort improvement in Building A has the highest benefit/cost ratio.

Conclusion and Future Research

The HBI framework applied to the two buildings in this case study gives an estimate of the potential monetary gain from improving IEQ. The intent of the HBI program is to incorporate healthy building evaluations with traditional energy audit and energy-efficiency analyses. Similar to predicted energy savings, it is difficult to predict if a specific retrofit would result in meeting the target IEQ performance, so the IEQ parameters should be re-evaluated (using Module 1) after the intervention to verify that actions led to the desired results and monitoring should be contined thereafter to verify that positive results are maintained. It is expected that as more buildings track IEQ data and personnel satisfaction gains in a standardized and structured framework, the cause-and-effect relationships between IEQ parameters and the corresponding human outcomes will become clearer and more accurate prediction models can be developed.

This research presents multiple avenues for application and further expansion of the HBI framework. For example, while the economic analysis in this methodology is intended for existing government office buildings, the study shows potential for structuring similar methodologies for multi-family residential, educational, industrial (e.g., manufacturing, factory), health care, and other use types and functions. In addition, this research considers healthy buildings in terms of energy efficiency; however, resiliency is another key topic area that could be considered in more holistic programs and decision-making. ■

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