Energy and Health Nexus

Pacific Northwest NATIONAL LABORATORY

MAKING THE CASE FOR BUILDING ENERGY EFFICIENCY CONSIDERATIONS OF OCCUPANT HEALTH AND PRODUCTIVITY

March 2020

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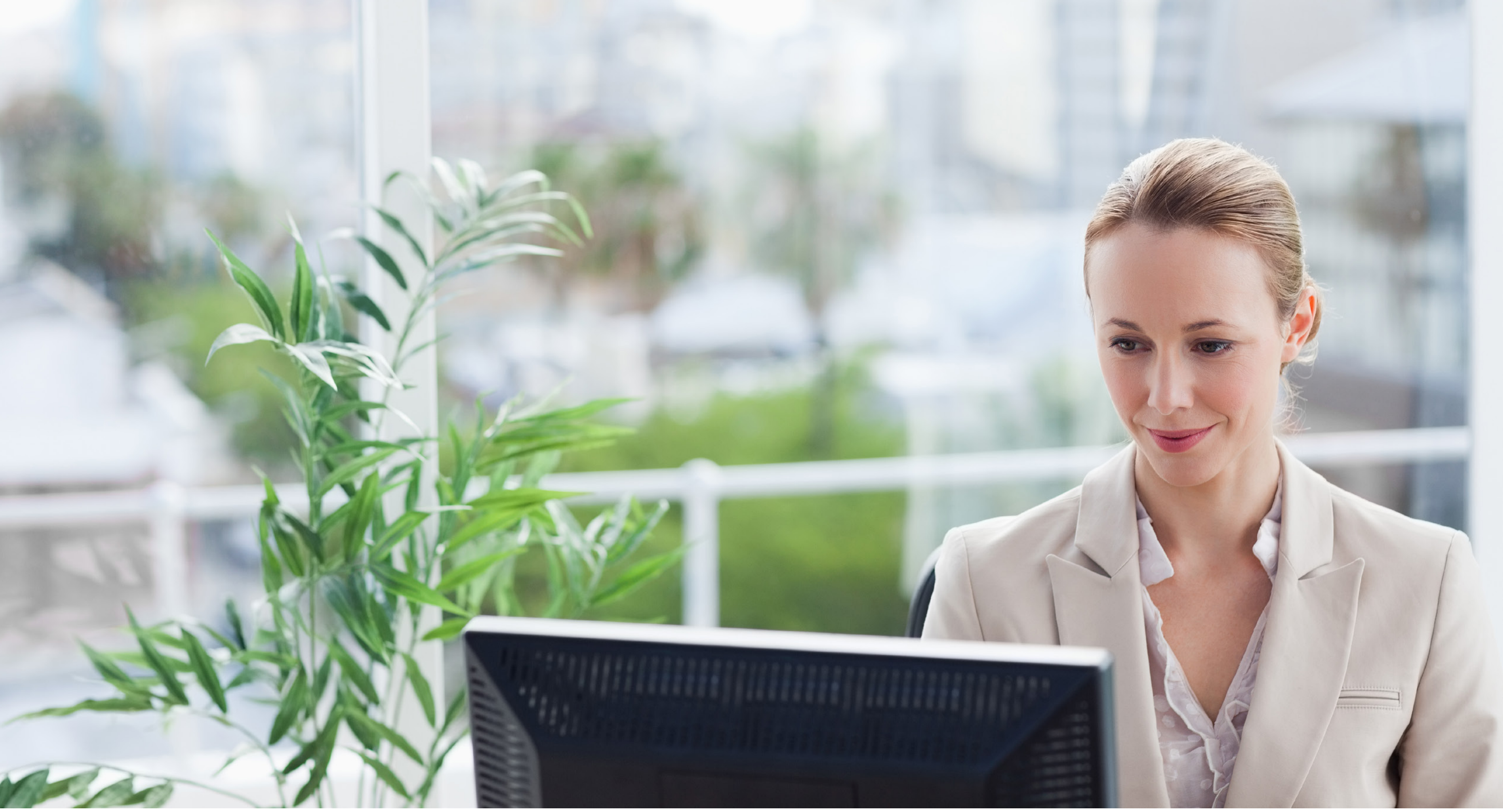

The built environment plays a major role in American lives; it is where we spend 90 percent of our time and accounts for over 40 percent of U.S. energy consumption. Traditionally, building energy efficiency technologies, systems, and design have focused on the economic benefits from reduced energy consumption; however, recent research and efforts have sought to leverage the capabilities of buildings (residential, commercial, and federal) to improve non-energy benefits to occupants and the broader economy. This article explores the opportunities of energy and health research across the building sector.

VALUE PROPOSITIONS: AN ACCELERATED PATH TO ACHIEVE AGGRESSIVE ENERGY REDUCTION GOALS

Many energy efficiency projects have non-energy benefits, such as improved occupant productivity, decreased illness from indoor air quality problems, and reduced environmental pollution. Non-energy benefits, such as health and productivity improvements, can have large economic benefits—which are currently unaccounted for in energy efficiency project valuation methodologies. With increasingly higher performance goals for both new construction and building retrofits, the ability to finance these projects through energy cost savings is becoming increasingly more difficult. As a result, fewer qualifying projects are found economically feasible in traditional benefit-cost calculations. However, the value of these non-energy benefits is not included in cost-benefit calculations; if they were, more projects would find the benefits outweighed the costs, accelerating the deployment of energy efficiency in the built environment.

Funded by the US Department of Energy's Federal Energy Management Program, PNNL conducted a meta-analysis of empirical studies that have examined how indoor environment impacts occupant outcomes (e.g., productivity, turnover, absenteeism, cognitive abilities, satisfaction, stress) to better understand the quantification opportunities for non-energy benefits. Our review of 63 high-quality publications shows a 5.7 percent average improvement in productivity (n=63) and a 37 percent reduction in absenteeism (n=14) when indoor air quality and thermal comfort is improved. Acknowledging this health benefit value from energy efficiency measures links to areas most important to those in the commercial sector—occupants.

The 3-30-300 rule states that, on average, companies spend $3 in utilities, $30 in rent, and $300 in payroll per square foot per year.[1] A recent report by Stok found that owner-occupants and tenants could gain $115 per square foot 10-year net present value from productivity, retention, and wellness by implementing general healthy building retrofits in a typical office building; savings are even higher ($129 per square foot over ten years) once savings from utility and maintenance are included.[2] Similarly, a report by Muldavin found a $27.8 per square foot five-year net present value for obtaining WELL healthy building certification.[3] Thus, measures that can help address payroll concerns (e.g., occupant health and productivity) are extremely important to the commercial sector. Facility cost saving decisions should not consider physical space in isolation.

Leveraging buildings to achieve broader building sector goals requires occupant consideration. Grid modernization, grid-integrated building, energy management information system, digitalization/cybersecurity and internet of things (IoT) technologies have enabled buildings to interact with the grid more efficiently and intelligently. However, buildings are largely designed to provide certain functions while meeting the minimum requirements for public health and safety. Demand response and other grid services have been primarily designed for grid benefits. Smart grid, cities, or buildings are introducing disruptive innovations that can turn buildings from passive objects that consume resources and energy to living objects that promote optimal outcomes and resilience. If the impacts of these types of building-level interventions on building occupants is unknown—or worse, not considered—then their achievement of broader economic or sector goals will be limited. Inadequate considerations of how changing "normal" building operations would impact occupants' comfort, health, and productivity results in reluctance or resistance to any interventions in building operations due to the perceived risks associated with these "disruptions." To overcome the resistance to changes and to turn risks into opportunities, we need to gain knowledge and develop measurement of human outcomes that represent the best interests of building owners, business owners, and building occupants. We can turn such knowledge into a decision framework that compares personnel benefits and grid service benefits, and evaluates the tradeoffs when conflicts occur.

1 https://www.us.jll.com/en/trends-and-insights/workplace/a-surprising-way-to-cut-real-estate-costs

2 Attema JE, SJ Fowell, MJ Macko, and WC Neilson. 2018. The Financial Case For High Performance Buildings. San Francisco: stok, LLC.

3 Muldavin S, CR Miers, and K McMackin. 2017 "Buildings emerge as drivers of health and Profits." *Corporate Real Estate Journal* 7(2): 177–193. https://static1.squarespace.com/static/5a00a5ad90bade3bd62dbaa1/t/5aff64bf758d46bedbd90862/1526686912747/Buildings+Emerge+as+Drivers+of+Health+%26+Profits_Corp+RE+Journal_Dec+2017.pdf

WHITE SPACE: PROPERLY ACCOUNTING FOR HEALTH BENEFITS IN THE CONTEXT OF ENERGY EFFICIENCY

Environmental psychology, medical research, and building technology studies have revealed correlations on the impact of lighting, comfort, and air quality on human circadian rhythm, the immune system, stress, mood, cognitive function, and other health functions. However, this knowledge has yet to be fully utilized to guide technology and strategy development in the building energy sector to promote positive human outcomes. The major challenge is how to quantify occupant benefits in the context of energy efficiency decision making. Correlations between indoor environmental quality (IEQ) metrics and human performance (e.g., measured by cognitive, speed, or accuracy tests) that are derived from empirical studies and mostly published in academic journals have not been directly translated to building system design and operation.

Take building ventilation as an example. There is plenty of research showing the benefits of improved indoor air quality. The question is how this knowledge can be used to enhance ventilation system design and operation in a specific building. For example, a Harvard study showed that a 400-ppm increase in CO_2 was associated with a 21 percent decrease in a typical participant's cognitive scores across all domains, and a 20-cubic feet per minute (cfm) increase in outdoor air per person was associated with an 18

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percent increase in these scores.[4] However, most ventilation systems in commercial buildings are designed based on ASHRAE Standard 62.1, which specifies a minimum ventilation rate of 5 cfm/person and 0.06 cfm/ft^2 with a default occupant density of 5 people/ft^2 in office space. This approximates to 1,000 ppm, which is the same value as what is recommended in the Mechanical Engineers Handbook published in 1916 and the 1929 New York City Building Code.[5] While the energy society has put much effort in promoting reduced unnecessary heating and cooling through demand control ventilation, energy recovery ventilation, variable air volume systems, and tighter envelope construction, the ventilation standard has not kept up with the technology advancements. How these energy efficiency measures impact occupants has not been fully studied. Understanding the tradeoffs and finding the synergies can stir investment in technologies that can deliver sufficient fresh air to occupants with minimum energy use.

Additionally, many case studies and publications on healthy buildings use different metrics and indicators (e.g., ventilation rate, CO_2, VOC, indoor air temperature, window accessibility) to characterize IEQ, making apples-to-apples comparisons difficult. Without a method for tracking and comparing results, the building community has not been able to effectively capitalize on past experience. **Moreover, interaction of building systems and diversity of the existing installations makes it more challenging to copy healthy building strategies from one building to another.** For example, windows increase daylighting—which entrains circadian rhythms—and also introduce thermal gains at the same time. Forced-air central HVAC

4 Harvard Study

5 Lionel S Marks ed. 1916. Published by McGraw-Hill Book Company, Inc.

systems are controlled by indoor temperature setpoints, which affects the amount of air delivered to the occupants at the same time. An energy model can optimize building design or operation based on the energy benefits, but there is no equivalent optimization for occupants' health benefits. Particular effort is needed to bridge the energy efficiency and human health and physiology communities. This effort can help align the energy reduction goal with that of the building/business owner, and therefore accelerate technology deployment.

R&D OPPORTUNITIES: A CROSS-CUTTING PARADIGM ENABLED BY NEW TECHNOLOGIES

Building technologies adoption has been driven by cost and market demand, which is associated with consumer value propositions. An example can be found in lighting technologies. The cost of light emitting diodes (LEDs) has dramatically decreased in recent years, making them a great candidate for lighting retrofits. LED lighting is more energy efficient than fluorescent lighting, up to 28.5 percent in one study.[6] In addition, LEDs provide greater control over the amount and spectral quality of the lighting,[7] which can improve occupant satisfaction and have a positive impact on circadian rhythms, and therefore, increase the health and productivity of building occupants. Considering the savings together (energy reduction and health benefits, if quantified) can accelerate lighting retrofit and motive building owners to go above and beyond basic lamp upgrade.

Other high-cost building technologies can benefit from quantified non-energy benefits to accelerate their deployment in the market. For example, electrochromic windows can be automated to reduce glare while balancing natural light transmission. One study found a 10 percent electricity savings when using automated electrochromic windows to control for visual comfort compared to conventional blinds.[8] However, the energy savings alone often does not justify the high installation cost of electrochromic windows. Similarly, a high-performance building envelop can decrease direct heat transfer to occupants sitting close to the building enclosure and increase their comfort while saving energy. If noise reduction is considered during window upgrades, the potential benefits from improved sleep quality may outweigh the energy savings. Quantifying these benefits can help justify a building upgrade opportunity that would have otherwise gone unrecognized.

The high-performance building movement has expanded in recent years to promote occupant health and well-being, alongside energy efficiency, as a major consideration to drive building design and technology development. The Energy and Health Nexus is neither a traditional occupant satisfaction survey, nor a one-off IEQ case study.

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6 LRC – Lighting Research Center. 2016. Results Report: Measuring Personal Light Exposures, Health, and Wellbeing Outcomes: Federal Center South, Seattle, Washington. Troy, NY. https://www.lrc.rpi.edu/programs/lightHealth/pdf/GSA/FCS_Human.pdf.

7 PNNL – Pacific Northwest National Laboratory.2017. Energy and Environment Directorate Research Highlight: Flexible Lighting Evaluated in Mental Health Facility. https://energyenvironment.pnnl.gov/highlights/highlight.asp?id=2891.

8 DiLaura D, K Houser, R Mistrick, and G Steffy. 2011. The Lighting Handbook. IESNA – Illuminating Engineering Society of North America.

Rather, it aims to create a new cross-cutting research paradigm that utilizes new technologies and techniques and leverages emerging public- and private-sector investments in health and well-being. Ubiquitous IoT technologies have enabled us to better measure and track indoor and outdoor environmental characteristics, building system performances, and human biometrics and activities. New capabilities in data processing and analytics can help us to better understand the interactions between humans and their physical environment, and ensure the continued deployment of building energy efficiency technologies to promote positive human outcomes.

Recommended Research Areas

- **Review current research landscape to identify gaps and develop required framework to bridge occupant health and productivity with energy efficiency approaches.** Such a framework will address the dynamics between energy systems and indoor environmental quality in terms of energy savings and health benefits. The findings from empirical studies need to be translated to building system design and operation strategies. The framework can further guide the development of an optimization model to inform energy efficiency decision making.

- **Collaborate with private industry (e.g., manufacturers, energy service companies) to develop consistent methods to quantify the non-energy benefits of building systems and services, and establish a data collection and analytical platform accordingly.** The complexity of human health and behaviors increases the uncertainty of measuring and verifying non-energy outcomes. Some benefits can only be observed from long-term trends or with a large quantity of data. A consistent approach supported by an interoperable platform across manufacturers and service providers is critical to establish credibility and utilize crowd-sourcing mechanisms to accumulate knowledge and evidence at a faster pace.

- **Collaborate with private industries (e.g., insurance, real estate, utilities, software service companies) to develop the business case, pilot tests, and technologies to advance human-centered building systems.** With a structured decision framework and a consistent method to quantify occupants' benefits, opportunities for new technology development or validation will be revealed. In addition, one percent productivity gain or improved cognitive function has a different economic value for different types of businesses and buildings. The cost benefit analysis is beyond the traditional net present value from energy savings; therefore, integrating technology development with a business case study through collaborative efforts is even more important.

- **Consider broader, public good impacts of integrated energy/building services within the framework of human and community service organizations.** While the broader perspective of the benefits buildings can provide to occupants and society is outside the scope of a typical building upgrade decision, properly capturing the collective impact these decisions could have is within the scope of many human and community service organizations (e.g., public health, city planning, community resilience). Currently, the societal impacts from poor or inefficient building design are not captured in a broader economic cost-benefit analysis when considering high performing buildings. Rather, the costs are born elsewhere in catastrophic property damages during extreme weather events or by the public health programs facing populations with illnesses exacerbated by sub-optimal housing. Expanding stakeholder engagement efforts outside traditional building stakeholder groups could yield major benefits. By developing cross-cutting and integrated research and deployment efforts that bring in the broader human and community service sector, we may offer an accelerated path to better design and deploy new energy and building technologies to the existing buildings stock, which can normally take a century to completely turnaround. Additionally, this cross-cutting partnership would be an opportunity to fundamentally improve occupant lives. Energy/building researchers must take a more holistic view, advancing their knowledge in how the built environment affects occupants' health (such as buildings systems to alleviate heat stress or shelter occupants), and how they may develop crosscutting strategies to fully leverage the resources beyond energy/building sectors.

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U.S. DEPARTMENT OF ENERGY

PNNL-SA-151589 | Updated March 17, 2020