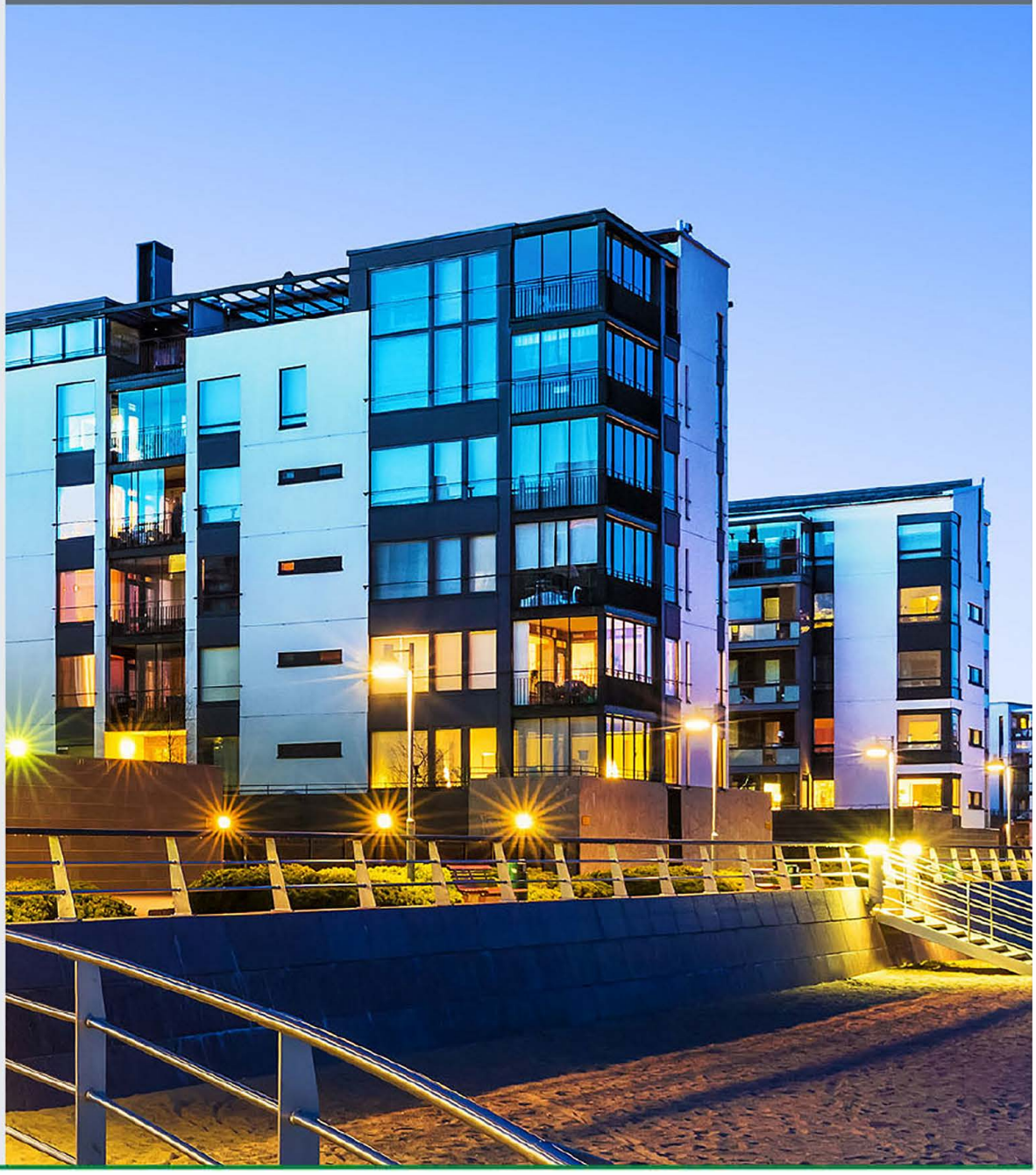
U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Integrating Health and Energy Efficiency in Multi-Family Buildings

June 2021



FEMP
Federal Energy Management Program

INTEGRATING HEALTH AND ENERGY EFFICIENCY IN MULTI-FAMILY BUILDINGS

The 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 Toolkit.

Acknowledgments

This report was prepared by Julia Rotondo, Kevin Keene, and Nora Wang of Pacific Northwest National Laboratory (PNNL) under contract to the U.S. Department of Energy (DOE). The work was supported by FEMP led by Jefferey Murrell. The authors would like to express gratitude to Andy Eidan of Portland General Electric, Michael Freedberg of U.S. Department of Housing and Urban Development (HUD), and Erik Mets of PNNL who have reviewed this case study and provided feedback.

Background

The intersection between health and the built environment has long been known. Since the 18th century, public health officials have been targeting building issues, such as crowding, poor sanitation, and inadequate ventilation in efforts to reduce infectious diseases and fire hazards.[1] More recently, federal agencies, such as the U.S. Environmental Protection Agency (EPA), the Centers for Disease Control and Prevention, HUD, and the DOE have been working to reduce or eliminate indoor building factors that are known to have adverse health impacts on Americans, including reducing lead in housing and indoor air pollution that causes respiratory disease, and ensuring access to adequate heating, cooling, and moisture control.

PNNL, in support of FEMP's Healthy Buildings Toolkit, undertook a review of literature and existing best practices to identify current activities and research on the intersection between traditional energy-efficiency measures and occupant health within multi-family buildings. While the Toolkit methodology has focused on traditional office building spaces, it is now expanding into additional building use types. This overview explores some of the most impactful resources to help property owners and managers understand more about multi-family residential buildings that are both healthy and energy efficient. The federal government provides direct oversight and operation across several types of multi-family residential housing, including dormitories, barracks, and senior community living centers.

Healthy Buildings Toolkit

The methodology developed by PNNL (outlined in Figure 1) estimates the potential financial gains from occupant productivity improvements and identifies specific modifications customized for that building. The Healthy Buildings Toolkit currently evaluates commercial and public office buildings but may be expanded to include multi-family buildings in subsequent editions. There are three modules within the overall methodology framework:

1. The ***Performance Baseline Module*** collects baseline indoor environmental quality (IEQ) data by monitoring parameters such as carbon dioxide, temperature, humidity, and light levels, and administering an occupant survey;
2. The ***Improvement Opportunities Module*** 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; and

3. The ***Productivity Financial Gains Module*** uses the data collected in Module 1 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.

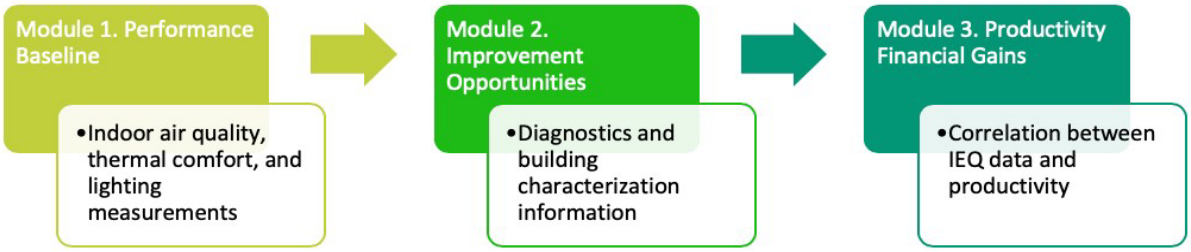


Figure 1. Modules comprising the Healthy Buildings Toolkit.

Multi-family Buildings: Opportunity Space

This case study reviews existing literature and program areas that target multi-family buildings. In the U.S., one in five people, approximately 80 million, live in some type of multi-family building.[2] It is estimated that comprehensive and cost-effective energy-efficiency upgrades could improve the efficiency of multi-family residential buildings by 15-30%, saving $3.4 billion in utility costs across the U.S.[3] With 24% of Americans doing some or all of their work at home,[4] this represents an important opportunity space when reviewing the connection between health and energy—especially given potential productivity impacts on occupants.

HUD STRATEGIC PLANNING TOOLS

A Capital Needs Assessment (CNA) is an evaluation strategy for Public Housing Authorities (PHA) to prioritize HVAC, structural, electrical, and site improvements and leverage funds for all PHA units. A CNA will identify improvements to the building envelope and HVAC system which can lead to reducing energy consumption and creating healthier public living environments.

HUD-assisted housing assessors can manage the project with the CNA e-Tool released in 2016. The CNA e-Tool is mandatory for properties seeking Federal Housing Association (FHA) insurance. The FHA Green Mortgage Insurance Premium gives a 44-58% reduction to borrowers on their mortgage premium for meeting qualifications in one of the designated green building certifications.[5]

HUD's strategic planning tools have enabled energy efficiency and indoor environment upgrades in many multi-family buildings; however, there is an opportunity to expand the health considerations and strategies beyond what is currently available in these programs for millions of U.S. residents.

The definition of a multi-family building differs slightly depending on the agency or code consulted. For example, ASHRAE/IES 90.1 and 90.2 defines mid- and high-rise multi-family buildings as having more than three stories above grade and low-rise multi-family buildings as three stories or fewer above grade containing three or more individual units. HUD defined multi-family buildings as five or more units, regardless of stories. Definitions across state codes or energy-efficiency programs may similarly vary.

Multi-family residential buildings face distinct challenges to maintain or improve indoor air quality compared to single-family homes. Spaces, equipment, building operations, and purchasing power often have conflicting incentives and can depend on the leasing and ownership structure. Additionally, these buildings can be mixed-use, including both residential units and commercial space, such as retail units or office spaces. Mixed spaces can introduce contaminants not typically found in single residential units, generating a broader range of indoor pollutants.[6]

The U.S. Department of Defense (DoD) provides housing for its service members and military families. While the majority of military families utilize housing allowances in privatized housing, approximately 10% are housed in DoD owned and operated units.[7] On-base housing has an

average age of 33 years old, and approximately a quarter is over 40 years old. Single, junior-enlisted service members are required to live in barracks, which are often "sub-standard, inadequately maintained, or obsolete." DoD has found a connection between quality housing and personnel retention, noting that the proportion of personnel remaining in service from bases with high quality housing is about 15% higher than those stated at places with low quality housing.[8] According to a 2014 U.S. Government Accountability Office report, the majority of the U.S. Department of State's overseas leased properties are multi-family residences, spending an estimated $500 million on leases in 2013.[9] Only 15% of these overseas residential properties are federally owned.

As of 2017, HUD annually spends $6.9 billion per year on energy and water subsidies and allowances across its almost 5 million units of public and assisted housing and Section 8 housing choice vouchers (a form of government rent assistance).[10] Energy expenditures have declined an estimated 16.3% over seven years, with energy upgrades in 128,000 units in 2017 and new Energy Performance Contracts financing an estimated $400 million in savings across 64,000 units. With the expansion of the Rental Assistance Demonstration by Congress in 2015, HUD and other public housing owners have been able to take on more debt, which has enabled energy efficiency and health upgrades that were previously not feasible in 185,000 units.[11]

Multi-family Energy Efficiency Measures with Health Impacts

Within the energy efficiency sector, much has been written about non-energy benefits driving consumer uptake of energy efficiency technologies and systems.[12] In a previous case study, HBI discussed certification programs that promote health in commercial and multi-family buildings focusing on Facility Innovations Toward Wellness Environmental Leadership (Fitwel) certification and the International WELL Building Institute's WELL Building Standard, among others. Both programs have developed special modules for multi-family residential buildings and Fannie Mae's Healthy Housing Rewards program provides discounts to multi-family affordable housing providers on capital loans for investing in healthy building improvements and obtaining Fitwel certification.[13] Enterprise Green Communities is another certification program that is very common for affordable housing projects. This section reviews health considerations and linkages between energy efficiency measures in multi-family buildings.

Noise

Studies have increasingly recognized noise as having an impact on health, affecting not only the auditory system but also resulting in annoyance, sleep disturbance, and increased risk of hypertension, heart attack, and stroke.[14,15] The World Health Organization Regional Office for Europe estimated that in Western Europe, the disability-adjusted life-years (number of years lost due to ill-health, disability, or early death) lost annually from environmental noise include 61,000 due to heart disease, 45,000 for cognitive impairment of children, and 903,000 from noise-induced sleep disturbance.[16,17]

Noise Measures: Windows and Envelope

Windows can provide valuable health benefits, such as exterior noise reduction when double- or triple-paned glass is used, or an insulated window film is applied.[18] Sound requires air to travel through, meaning even basic weatherization and efficiency measures, such as air sealing with caulk, can also reduce noise. Fitwel, Enterprise Green Communities, and WELL have noise control measures that can reduce noise from both exterior sources and interior sources. Fitwel acoustical control measures include sealing windows and doors to reduce exterior noise[19] and WELL recommends sound barriers, absorption, and masking technologies and construction practices.[20] Fitwel also references sound and vibration-absorption materials, such as fiberglass thermal insulation material, which can enhance thermal comfort in addition to the sound reduction benefits. Enterprise Green Communities offers three options for compliance: testing that noise levels do not exceed continuous and single-event thresholds; provide a noise abatement plan; or make sure walls, windows, ceilings, floors, and doors meet sound transmission class rating thresholds.[21]

Lighting

The average U.S. household spends about 5% of its energy budget on lighting.[22] Traditional energy efficiency approaches to lighting include switching from conventional lighting to highly-efficient bulbs (e.g., LEDs), which the DOE estimated enabled 1.1 quads of energy savings in 2017, resulting in $12 billion in savings for U.S. consumers.[23] Additionally, energy-efficient lighting design includes maximizing the use of daylighting to reduce the need for artificial lighting entirely during daylight hours.

In addition to energy consumption, lighting can have major impacts on occupant satisfaction within a space. For example, one survey of occupants within multi-family residential buildings found that the levels of satisfaction with lighting improved with better quality and longer duration of daylighting.[24] Humans naturally produce melatonin during the dark hours and stop production upon optic exposure to daylight; when exposed to sunlight (or blue or white artificial light with sufficient intensity) in the morning and midday, natural melatonin production can occur sooner in the evening and reduce sleep latency (time to fall asleep) and sleep efficiency (time in bed spent sleeping) at night.[25] While daylighting is the best option to regulate sleep cycles, LEDs with a tunable color spectrum can provide an alternative when daylighting is inadequate. This concept of using light to cater to humans' biological sleep cycles is called circadian-rhythm lighting design. Its health impact has been observed in studies in nursing homes, with one study finding residents slept better and had a decrease in agitated behaviors (yelling and crying) after a color-tuning LED system replaced fluorescent bulbs.[26]

Multiple certification systems provide daylighting measures within their multi-family programs. For example, the U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED) v4 for multi-family residential buildings requires minimum access to daylight in living spaces across 90% of floor area in residential units in addition to daylight for the building, or should provide "quality views."[27] Both Fitwel and WELL healthy building certification programs also include requirements for daylight access, with WELL specifying measures for occupant control of lighting environments, as well as daylight simulation, circadian lighting design, and electric light quality.[28] Enterprise Green Community requires meeting minimum illumination levels from overhead lighting and recommends including daylight in design.[29]

Indoor Air Quality

Residential activities can result in the creation of indoor pollutants, such as nitrogen dioxide produced from cooking on a gas stove, indoor gas heaters, or smoking. Pediatric asthma can be exacerbated by such pollutants, including both particulate matter and nitrogen dioxide (NO_2).[30] Indoor NO_2 concentration can adversely impact asthmatic children even at levels well below EPA outdoor standards across urban and suburban homes. Research has demonstrated that even a 5 part-per billion (ppb) increase in NO_2 exposure above a threshold of 6 ppb can result in increased risk of severe asthma symptoms that can lead to increased hospital treatment in children.[31]

Indoor Air Quality Measures: Windows and Envelopes

A simple method of decreasing the concentration of indoor pollutants is to increase natural ventilation by opening windows and doors.[32] Both Fitwel and WELL multi-family residential building certification programs include measures for operable windows in all dwelling units. However, for multi-family buildings in high-density urban centers, there can be a trade-off between opening windows to address indoor air pollutants and introducing exterior pollutants (e.g., pollutants from nearby traffic or construction). An efficient exhaust or ventilation system with particle filtration becomes more critical in these locations.

As the building envelope is tightened and less outdoor air can leak in, indoor air quality problems can be exacerbated due to lack of overall ventilation supplied to the building, although thermal comfort and moisture control is benefited.[33] On the other hand, under-sealing in multi-family residential buildings face unique challenges in terms of indoor air quality, including outdoor pollutants entering the building without filtration and indoor pollutants moving from unit to unit. Residents often can seal or caulk their unit but have limited

ability to make changes to the building structure itself,[34] making it a responsibility of the building operator to increase ventilation to over-sealed spaces to reduce buildup of indoor air pollutants.

Indoor Air Quality Measures: Ventilation System and Pollutants

ANSI/ASHRAE Standard 62.2 provides standards for ventilation and acceptable indoor air quality in residential buildings and was most recently updated in 2019. Enterprise Green Communities, Fitwel, and WELL multi-family residential building certification programs include measures related to air quality. WELL focuses on effective and enhanced ventilation, including:

- giving credit for increased outdoor air supply 30% above ASHRAE 62.2, and an additional credit for 60% above;
- demand-controlled ventilation targeting CO_2 thresholds with increasing credits of 900 ppm, 750 ppm, and 600 ppm;
- and meeting thresholds for particulate matter, organic gases, and inorganic gases.[35]

Fitwel includes testing requirements for indoor air quality, requiring certified buildings to comply with a minimum of five measures of the following list:

- particulate matter (less than 25 $\mu g/m^3$);
- carbon dioxide (less than 1100 ppm or 700 ppm over ambient);
- total volatile organic compounds (less than 500 $\mu g/m^3$);
- carbon monoxide (less than 9 ppm);
- formaldehyde (less than 27 ppb); and
- relative humidity (between 30-60%).[36]

Enterprise Green Communities requires conforming to ASHRAE 62.1 mechanical ventilation system and direct exhaust requirements and verifying that the ventilation rate meets the design specifications and recommends installing mechanical efficiency rating value (MERV) 13 particle filters.[37]

Thermal Comfort

In multi-family residential buildings, heating and cooling is either controlled by the resident via individual controls (e.g., thermostat), the building operator centrally, or some combination of the two (e.g., heating or air conditioning controlled centrally, but occupant has some control over the temperature in their unit). Public housing agencies operating in states or localities have minimum heating requirements in public housing. If no local standards exist, they are required to follow guidance issued by HUD, which requires minimum unit temperatures of 68 degrees Fahrenheit and the requirement that indoor temperatures should not drop below 55 degrees Fahrenheit as outdoor temperature approaches the design temperature of equipment.[41] ANSI/ASHRAE

NON-ENERGY BENEFITS FROM RESIDENTIAL WEATHERIZATION

Oak Ridge National Laboratory (ORNL) led a multi-year evaluation of the DOE's Weatherization Assistance Program covering program years 2008 and 2010. Typical weatherization measures could include mechanical measures (heating and/or cooling systems, programmable thermostats, water heaters), building shell measures (insulation, air sealing, window/door repair or replacement), and electric and water measures (efficient lighting).[38]

ORNL found that for every $1 invested in weatherization, participants received $2.78 in non-energy benefits; after weatherization, families had "more livable" homes, missed fewer days of work, and decreased out-of-pocket medical expenses by an annual average of $514.12 of the 11 health-related non-energy benefits evaluated,[39] five link to measures included in the HBI methodology, including: reduced thermal stress on occupants, reduced asthma-related medical care and costs, increased productivity at work due to improvements in sleep, increased productivity at home due to improvements in sleep, and fewer missed days at work. The evaluation also found over 30% of respondents reported improved health benefits and found statistically significant drops in visiting the emergency room and being hospitalized after weatherization for those with severe asthma.[40]

55-2017 provides standards for thermal environmental conditions for human occupancy, specifying a threshold and methodology for calculating thermal comfort based on a variety of environmental factors (e.g., temperature and humidity) and personal factors (e.g., activity, clothing).

Beyond the immediate life and safety impacts from thermal conditions, there are benefits of further improving thermal comfort. For example, research has shown a connection between thermal comfort and sleep quality.[42] Research has shown a connection between poor sleep and numerous health outcomes, including depression, suicide, anxiety and disability,[43,44,45] diabetes, obesity, and hypertension.[46,47,48] Those who report excessive daytime sleepiness due to disturbed sleep also report impacts on activities, mood, and acuity.[49] Research has similarly shown a linkage between sleep quality and productivity in the workplace, with one experiment showing a decrease in productivity related to tiredness or sleepiness up to 6.1%, resulting in an estimated cost per employee linked to an annual productivity decrease of $3,156.[50] Increasing occupant control of the temperature in sleeping spaces, such as bedrooms, may help improve the quality of sleep and increase positive health and productivity outcomes.

THE BRIGHT STUDY

From 2011 to 2014, funded by the HUD 2010 Healthy Homes Technical Studies grant, the Boston Housing Authority teamed up with the Harvard T.H. Chan School of Public Health to investigate the effects of IEQ on resident health, satisfaction, and comfort.[51] The study established three groups of occupants: a control group living in old, conventional housing units for two years, an experimental group of occupants switching from old units to redeveloped units after one year, and a group who lived in new, healthy units for the two years of the study.

The study confirmed the IEQ improvement between the old units and the new units: 65% lower NO2, 57% lower PM2.5, and 93% lower nicotine.[52] They found that this IEQ difference correlated to 47% fewer sick building syndrome symptoms, school absences, and hospital visits in asthmatic children.[53]

Thermal Comfort Measures: Windows and Envelope

Typically, energy efficiency and weatherization programs seek to upgrade windows in existing buildings as inefficient windows can be responsible for 25-30% of residential heating and cooling use.[54] When inefficient or damaged windows let in excess heat or cold air, residents must rely on heating and cooling systems to make up the difference; this can result in extra charges in energy bills or, if the system's capacity cannot handle the load, uncomfortable occupants potentially to the point of life, health, and safety implications.

Associations of adverse health outcomes with excessively hot and excessively cold weather are well documented, resulting in increased prevalence of death and hospitalizations.[55] Extreme temperature can especially impact vulnerable populations; extreme heat, for example, often disproportionately impacts the elderly, pregnant women, and infants. People with cardiovascular or respiratory disease, diabetes, obesity, and conditions, such as asthma, are at greater risk from heat exposure.[56] Increased envelope insulation and reduced infiltration not only save energy, but also make sure a safe and healthy shelter for residents.

Both WELL and Fitwel include thermal comfort measures, with Fitwel requiring access to thermal comfort control devices (such as, thermostat controls, building management systems that allow for temperature requests, or stand-alone fans)[57] and WELL recommending thermal comfort ranges, occupant satisfaction levels, humidity control, and individual control of thermal comfort.[58] Enterprise Green Communities requires designing to maintain relative humidity below 60% or monitoring relative humidity and infrastructure for dehumidification if needed.[59]

Conclusions

Traditionally, multi-family buildings represent a challenging building type for many in the energy-efficiency sector given competing definitions, ownership issues, and multiple stakeholders. Implementing energy efficiency upgrades may become more feasible if the non-energy benefits, in the form of positive health outcomes for occupants, are included in calculations. The existing multi-family research links IEQ

components, such as thermal comfort, noise, lighting, and air quality to health impacts, such as sleep quality and various illnesses and disease. These health gains could be quantified by healthcare costs or equivalent years of life lost.

The IEQ categories studied in multi-family buildings are similar to those used in the Toolkit methodology (electric light, daylight, thermal comfort, and indoor air quality). The current methodology only quantifies health benefits related to employee productivity and financial incentives for employers. By expanding this research to the residential sector, a novel incentive structure will be possible for multi-family buildings.

The multi-family research presented in this document identifies specific opportunities to explore and take advantage of the intersection of energy efficiency with health aspects to improve overall occupant satisfaction, comfort, and well-being. Given the special populations that tend to make up larger populations within federally operated or owned multi-family residential buildings, establishing specific use cases, resources, or tools within the Healthy Buildings Toolkit may expand opportunities for “win-win” solutions.

References

[1]Krieger, J. and D. Higgis. (2002). "Housing and Health: Time Again for Public Health." *American Journal of Public Health* (92:5); pp. 758-768. Accessed April 9, 2020 at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1447157/.

[2]U.S. Environmental Protection Agency. "Indoor Air Quality in Multifamily Housing." Accessed April 9, 2020 at: https://www.epa.gov/indoor-air-quality-iaq/indoor-air-quality-multifamily-housing.

[3]ACEEE. "The Multifamily Energy Savings Project." Accessed April 9, 2020 at: https://www.aceee.org/multifamily-project.

[4]U.S. Bureau of Labor Statistics. (June 2019). "American Time Use Survey – 2018 Results." Accessed May 18, 2020 at: https://www.bls.gov/news.release/atus.nr0.htm.

[5]FHA/HUD 223(f) Loans Guide. "Green Improvements Allow Borrowers to Save on MIP." Accessed October 8, 2020 at: https://www.hud223f.loans/hud-223f-faqs/green-mip-reduction.

[6]U.S. Environmental Protection Agency. (January 2016). "Energy Savings Plus Health: Indoor Air Quality Guidelines for Multifamily Building Upgrades." EPA 402/K-16-/01. Accessed April 23, 2020 at: https://www.epa.gov/sites/production/files/2016-02/documents/esh_multifamily_building_upgrades_508c_02_09_2016.pdf.

[7]U.S. Department of Defense, Office of the Assistant Secretary of Defense of Sustainment. "Privatized Housing Overview." Accessed May 18, 2020 at: https://www.acq.osd.mil/eie/fim/Housing/Housing_overview.html.

[8]Ibid.

[9]U.S. Government Accountability Office. (September 2014). *Overseas Real Property: State Department Needs to Improve Guidance and Records Management*. Report to the Committee on Foreign Affairs, House of Representatives. GAO-14-769. Accessed May 18, 2020 at: https://www.gao.gov/assets/670/666160.pdf.

[10]U.S. Department of Housing and Urban Development. (2019). "Achieving Utility Savings in HUD-Assisted Housing: Progress Report to Congress."

[11]Econometrica, Inc. (2016). "Interim Report: Evaluation of HUD's Rental Assistance Demonstration." Accessed October 8, 2020 at: https://www.huduser.gov/portal/sites/default/files/pdf/RAD-InterimRpt.pdf.

[12]Mills, E. and A. Rosenfeld. (1996). "Consumer non-energy benefits as a motivation for making energy-efficiency improvements." *Energy* (21); pp. 7-8. https://doi.org/10.1016/0360-5442(96)00005-9. Accessed April 28, 2020 at: https://www.sciencedirect.com/science/article/pii/0360544296000059.

[13]Fannie Mae. "Frequently Asked Questions (FAQs) Healthy Housing Rewards™ Healthy Design." Accessed October 8, 2020 at: https://multifamily.fanniemae.com/media/8486/display.

[14]Munzel, T., T. Gori, W. Babisch, and M. Basner. (2014). "Cardiovascular Effects of Environment Noise Exposure." *European Heart Journal* (35:13); pp. 829-836. doi: 10.1093/eurheartj/ehu030.

[15]Foraster, M., N. Künzli, I. Aguilera, M. Rivera, D. Agis, J. Vila, L. Bouso, A. Deltell, J. Marrugat, R. Ramos, J. Sunyer, R. Elosua, and X. Basagaña. (2014). "High Blood Pressure and Long-Term Exposure to Indoor Noise and Air Pollution from Road Traffic." *Environmental Health Perspectives* (112:11). Accessed April 22, 2020 at: https://www.ncbi.nlm.nih.gov/pubmed/25003348.

[16]World Health Organization Regional Office for Europe. (2011). "Burden of Disease from Environmental Noise." ISBN: 978 92 890 0229 5. Accessed May 6, 2020 at: http://www.euro.who.int/__data/assets/pdf_file/0008/136466/e94888.pdf?ua=1.

[17]The WHO Regional Office of Europe includes transportation, construction and industry community sources, and social and leisure sources in its definition of "environmental noise." It uses a harmonized noise metric for measurement, distinguishing between "day-evening-night" equivalent levels and "night" equivalent levels (Lden and Lnight).

[18]Mills, E. and A. Rosenfeld. (1996). "Consumer non-energy benefits as a motivation for making energy-efficiency improvements." *Energy* (21); pp. 7-8. https://doi.org/10.1016/0360-5442(96)00005-9. Accessed April 28, 2020 at: https://www.sciencedirect.com/science/article/pii/0360544296000059.

[19]Fitwel. "Fitwel Worksheet for the Multifamily Residential Building Scorecard." Access April 22, 2020 at: https://www.fitwel.org/standard/.

[20]WELL. "Well Certified v2 Appendix: Core and Multifamily Residential." Accessed April 22, 2020 at: https://v2.wellcertified.com/v/en/appendix/core-mfr.

[21]Enterprise Green Communities. "Criteria 7.10 Noise Reduction." Accessed October 8, 2020 at: https://www.greencommunitiesonline.org/healthy-living-environment.

[22]U.S. Department of Energy. "Lighting Choices to Save You Money." Accessed May 7, 2020 at: https://www.energy.gov/energysaver/save-electricity-and-fuel/lighting-choices-save-you-money.

[23]U.S. Department of Energy. (2019). *Energy Savings Forecast of Solid-State Lighting in General Illumination Applications*. DOE/EERE 2001. Accessed May 7, 2020 at: https://www.energy.gov/eere/ssl/downloads/2019-ssl-forecast-report.

[24]Peng, X., C.M. Mak, and H.D. Cheung. (November 2014). "The effects of daylighting and human behavior on luminous comfort in residential buildings: A questionnaire survey." *Building and Environment* 81: pp. 51-59. Accessed April 10, 2020 at: https://www.sciencedirect.com/science/article/pii/S0360132314001978.

[25]Mead, N.M. (2008). "Benefits of Sunlight: A Bright Spot for Human Health." *Environmental Health Perspective* (116:4); pg. A160-167. doi:10.1289/ehp.116-a160.

[26]Davis, R., A.M. Wilkerson, C. Samla, and D. Bisbee. (August 2016). *Tuning the light in senior care: Evaluating a trial LED lighting system at the ACC Care Center in Sacramento, CA*. PNNL-25680. Accessed May 26, 2020 at: https://www.energy.gov/sites/prod/files/2016/09/f33/2016_gateway-acc.pdf.

[27]U.S. Green Building Council. "Daylight and Quality Views." LEED O+M: Multifamily v4. Accessed May 7, 2020 at: https://www.usgbc.org/credits/multifamily-existing-buildings/v4/ eq122?view=language.

[28]WELL. "Well Certified v2 Appendix: Core and Multifamily Residential." Accessed April 22, 2020 at: https://v2.wellcertified.com/v/en/appendix/core-mfr.

[29]Enterprise Green Communities. "Criteria 5.8 Lighting." Accessed October 8, 2020 at: https://www.greencommunitiesonline.org/operating-energy.

[30]Trasande, L. and G. Thurston. (April 2005). "The role of air pollution in asthma and other pediatric morbidities." *American Academy of Allergy, Asthma and Immunology* (115:4); pp. 689-699. doi:10.1016/j.jaci.2005.01.056.

[31]Belanger, K., T.R. Holford, J.F. Gent, M.E. Hill, J.M. Kezik, and B.P. Leaderer. (March 2013). "Household Levels of Nitrogen Dioxide and Pediatric Asthma Severity." *Epidemiology* (24:2); pp. 320-330. doi:10.1097/EDE.0b013e318280e2ac.

[32]U.S. Environmental Protection Agency. "Improving Indoor Air Quality." Accessed May 18, 2020 at: https://www.epa.gov/indoor-air-quality-iaq/improving-indoor-air-quality.

[33]Institute of Medicine. (2011). "Chapter 8: Building Ventilation, Weatherization, and Energy Use." Climate Change, the Indoor Environment, and Health. Washington, DC: The National Academies Press. https://doi.org/10.17226/13115.

[34]U.S. Environmental Protection Agency. "Indoor Air Quality in Multifamily Housing." Accessed April 9, 2020 at: https://www.epa.gov/indoor-air-quality-iaq/indoor-air-quality-multifamily-housing.

[35]WELL. "Well Certified v2 Appendix: Core and Multifamily Residential." Accessed April 22, 2020 at: https://v2.wellcertified.com/v/en/appendix/core-mfr.

[36]Fitwel. "Fitwel Worksheet for the Multifamily Residential Building Scorecard." Accessed April 22, 2020 at: https://www.fitwel.org/standard/.

[37]Enterprise Green Communities. "Criteria 7.7 Ventilation." Accessed October 8, 2020 at: https://www.greencommunitiesonline.org/healthy-living-environment.

[38]Tonn, B., E. Rose, B. Hawkins, and B. Conlon. (September 2014). *Health and Household-Related Benefits Attributable to the Weatherization Assistance Program*. ORNL/TM-2014/345. Accessed April 10, 2020 at: https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRetroEvalFinalReports/ORNL_TM-2014_345.pdf.

[39]Ibid.

[40]Ibid.

[41]U.S. Housing and Urban Development. (November 2018). "Housing Opportunity through Modernization Act of 2016 (HOTMA) – Implementation of Minimum Heating Standards in Public Housing Properties." Notice PIH 2018-19. Accessed May 7, 2020 at: https://www.hud.gov/sites/dfiles/PIH/documents/PIH-2018-19HOTMA_HeatingStandardsNoticeFinal_rev.pdf.

[42]Lan, L., T. Tsuzuki, Y.F. Liu, and Z.W. Lian. (2017). "Thermal Environment and Sleep Quality: A Review." *Energy and Buildings* (149:15); pp. 101-113. https://doi.org/10.1016/j.enbuild.2017.05.043.

[43]Alattar, M., J.J. Harrington, C.M. Mitchell, and P. Sloane. (2007). "Sleep problems in primary care: a North Carolina Family Practice Research Network (NC-FP-RN) study." *J Am Board Fam Med.* 20; pp. 365-374. doi: 10.3122/jabfm.2007.04.060153.

[44]Drake, C.L., T. Roehrs, and T. Roth. (2003). "Insomnia causes, consequences, and therapeutics: an overview." *Depress Anxiety* 18; pp. 163-176. doi:10.1002/da.10151.

[45]Roberts, R.E., C.R. Roberts, and H.T. Duong. (2007). "Chronic insomnia and its negative consequences for health and functioning of adolescents: a 12-month prospective study." *J Adolesc. Health.* 42; pp. 294-302. doi: 10.1016/j.jadohealth.2007.09.016.

[46]Chen, M.Y., E.K. Wang, and Y.J. Jeng. (2006). "Adequate sleep among adolescents is positively associated with health status and health-related behaviors." *BMC Public Health.* 6; p. 59. doi:10.1186/1471-2458-6-59.

[47]Goodfriend, T.L. (2008). "Obesity, sleep apnea, aldosterone, and hypertension." *Curr Hypertens Rep* 10; pp. 222-226. https://doi.org/10.1161/01.HYP.0000116223.97436.e5.

[48]Lamberg, L. (2006). "Rx for obesity: eat less, exercise more, and—maybe—get more sleep." *JAMA*. 295; pp. 2341-2344. doi:10.1001/jama.295.20.2341.

[49]National Sleep Foundation. (2020). "Americans Feel Sleep 3 days a Week, With Impacts on Activities, Mood, and Acuity." Accessed May 7, 2020 at: https://www.sleepfoundation.org/sites/default/files/2020-03/SIA%202020%20Q1%20Report.pdf.

[50]Rosenkind, M.R., K.B. Gregory, M.M. Mallis, S.L. Brandt, B. Seal, and D. Lerner. (2010). "The Cost of Poor Sleep: Workplace Productivity Loss and Associated Costs." *Journal of Occupational and Environmental Medicine* (52:1); pp. 91-98. doi:10.1097/JOM.0b013e3181c78c30.

[51]HUD Office of Policy Development and Research. "BRIGHT Study Finds Improved Health at Boston Housing Authority's Old Colony Homes." Accessed October 8, 2020 at: https://www.huduser.gov/portal/casestudies/study-05042017.html.

[52]Ibid.

[53]Ibid.

[54]U.S. Department of Energy. "Update or Replace Windows." Accessed May 6, 2020 at: https://www.energy.gov/energysaver/design/windows-doors-and-skylights/update-or-replace-windows.

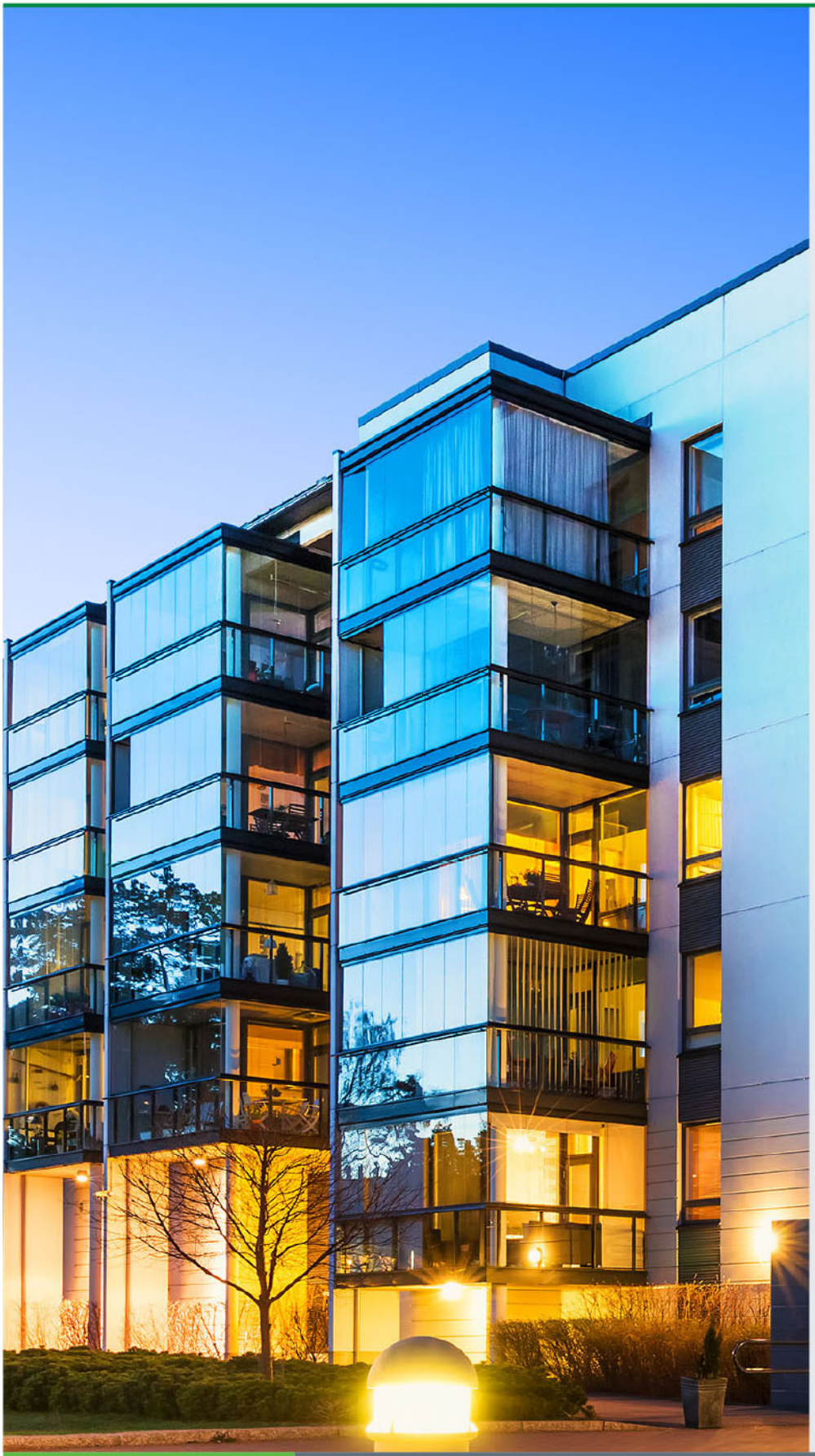
[55]Three3, Inc. and NMR Group, prepared for Massachusetts Program Administrators. (August 2016). "Massachusetts Special and Cross-Cutting Research Area: Low-Income Single-Family Health- and Safety-Related Non-Energy Impacts (NEIs) Study." Accessed April 9, 2020 at: http://ma-eeac.org/wordpress/wp-content/uploads/Low-Income-Single-Family-Health-and-Safety-Related-NonEnergy-Impacts-Study.pdf.

[56]Tonn, B., E.R., B. Hawkins, and B. Conlon. (September 2014). *Health and Household-Related Benefits Attributable to the Weatherization Assistance Program*. ORNL/TM-2014/345. Accessed April 10, 2020 at: https://weatherization.ornl.gov/wp-content/uploads/pdf/WAPRetroEvalFinalReports/ORNL_TM-2014_345.pdf.

[57]Fitwel. "Fitwel Worksheet for the Multifamily Residential Building Scorecard." Access April 22, 2020 at: https://www.fitwel.org/standard/.

[58]WELL. "Well Certified v2 Appendix: Core and Multifamily Residential." Accessed April 22, 2020 at: https://v2.wellcertified.com/v/en/appendix/core-mfr.

[59]Enterprise Green Communities. "Criteria 7.8 Dehumidification." Accessed October 8, 2020 at: https://www.greencommunitiesonline.org/healthy-living-environment.



FEMP
Federal Energy Management Program

U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

For more information, visit: energy.gov/eere/femp

PNNL-31432 · June 2021