Measurements and Verification (M&V) Guidelines for Weatherization Plus Health Program

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ABSTRACT

Weatherization Plus Health (Wx+H), a pilot program introduced by the Washington State Department of Commerce, has proposed a new scope to improve the indoor environment quality (IEQ) for low-income housing residents—one that extends beyond energy benefits. Typical interventions include the distribution of green cleaning kits, walk-off mats, ventilation system upgrades, and resident education, among other elements. Wx+H experts are working to capture the long-term impact of these combined measures to assess the program's potential. Although guidelines and best practices exist to measure and verify the impacts and influences of energy conservation, these indicators do not holistically incorporate occupant satisfaction and perceptions regarding health benefits in the context of low-income housing. This paper presents a preliminary literature review that summarizes measurements and verifications (M&V) schemes applicable to the residential sector from two major standards: ASHRAE Guideline 14 and the international performance measurement and verification protocol. Additionally, reports from the Washington State Commerce Department were analyzed to identify procedures and factors that might influence M&V schemes as applied by Washington State who are leading health and energy programs. Barriers, opportunities, and innovative M&V are discussed.

INTRODUCTION

Low-income households usually deal with high energy costs and poor thermal comfort due to energy inefficiencies in their homes, while additionally experiencing physical deficiencies and health issues (Hernandez & Phillips, 2015). Evidence suggests that unhealthy housing comprises a major cause of respiratory health issues that can disproportionately impact vulnerable populations (De Souza, Evans-Agnew, & Espina, 2018; Kuholski, Tohn, & Morley, 2010). Living in a home with poor indoor environmental conditions is associated with several negative health outcomes, notably the development of asthma, affecting over 10 million U.S. children aged 17 and under (Bloom, Cohen, & Freeman, 2010), and aggravation of chronic obstructive pulmonary disease (COPD) (Fong, Mui, Chan, & Wong, 2010). In order to improve health outcomes for people at risk of and suffering from these diseases, we must understand what housing environmental conditions play a role, as well as how occupant behavior can impact the home environment.

The federal Weatherization Program (WAP) was created in 1973 to address the energy shortage at a time when unemployment and energy prices both spiked as a consequence of a major world oil crisis, affecting low-income families in particular (Kaiser, 2004). WAP's original goal was to reduce fossil fuel consumption; however, the program lacked any provision for trigger-reducing home improvements for families with asthma and other respiratory diseases (Souza et al., 2018). In 2015, in an effort to improve health outcomes for low-income families, Washington State created a program called Weatherization plus Health (Wx+H). Forging a partnership between Pierce County Human Services' WAP program and the Tacoma-Pierce County Health Department's asthma education program, this initiative not only provides home-based structural intervention but also introduces health strategies to meet the goals of the Healthy People 2020 program with the goal of enhancing quality of life for those families suffering from asthma and or COPD (Washington State Department of Health, 2013). Table 1 summarizes the most frequent weatherization and health interventions provided by Washington State, according to a comprehensive analysis that helped to personalize interventions in order to address each of the low-income-families' needs.

Table 1. Wx+H Interventions for Low-Income Housing in Washington State

Measurements installed	**Total Enhanced 254 units**	**Comprehensive * 159units**	**HH Only** 63units**	**Low cost HH*** 32units**
Green cleaning kit	94%	94%	92%	94%
Bedding (dust mite)	70%	71%	71%	66%
Mechanical ventilation	65%	89%	37%	3%
HEPA vacuum	65%	67%	59%	66%
Walk-off mats	64%	61%	68%	72%
CO detector	57%	74%	44%	3%
Low VOC flooring	33%	32%	52%	0%
Smoke detector	24%	33%	13%	3%
Advanced ventilation	17%	19%	22%	0%
HEPA/MEPA filter	17%	19%	17%	3%
Air sealing	69%	92%	43%	9%
Attic insulation	48%	75%	0%	3%
WH low cost	46%	72%	5%	0%
Passive venting	41%	60%	10%	3%
Floor insulation	39%	62%	0%	3%
HVAC-replace	30%	46%	3%	0%
Lighting	30%	46%	3%	0%
Duct sealing	28%	43%	6%	0%
Furnace tune and clean	20%	32%	0%	0%

(Source: Schueler & Janowitz, 2017)
***Comprehensive services**: Households approved to receive weatherization and health interventions ****Household Health (HH) only**: Homes that had previously received or did not need weatherization
*****Low-cost HH**: Recipients who received initial assessments, home visits, and those low-cost measures that were distributed at that time, but were screened out or dropped out soon after

With these new trends in health and energy intervention, the low-income residential stock is likely to experience substantial upgrades in weatherization procedures, including envelope modifications such as installation of extra insulation, updated ventilation systems, more efficient heating systems, and increased airtightness to improve the overall housing performance (Shresta et al., 2019). However, little research has been performed post occupancy to measure the actual performance of these modifications to optimize energy efficiency without undermining comfort and indoor environmental quality for residents. Additionally, research is needed to examine

M&V procedures that can be applied to low-income housing to assess residents' health outcomes.

Table 2. M&V Protocols for Parameters Coupled with Health Implications

Parameter	Health Implications	References	M&V Protocols
Carbon dioxide (CO_2)	Higher CO_2 concentrations in tissues can raise chances of heart rate variations and increase of peripheral blood circulation, which can cause headaches, sleepiness, and changes in body temperature.	(MacNaughton et al., 2017; Vehvilainen et al., 2016)	Optimum values less than 500 ppm[1]. Take samples in multiple rooms, especially in those without windows.
Carbon monoxide (CO)	CO toxicity can cause extreme reduction in oxygen available to organs, which can provoke intoxications and even premature death. The most common symptoms are headache, nausea/vomiting, dizziness, lethargy, and a feeling of weakness.	(Blumenthal, 2001; Francisco et al., 2018)	Check potential sources including vented and unvented combustion appliances, such as kitchen boilers, water heaters, stoves. Installation of continuous monitoring through detector devices.
Formaldehyde	Can be rapidly absorbed after inhalation or oral exposure and is well known to produce cancer. It is also related with respiratory problems.	(Derbez et al., 2018; NTP, 2016)	Values below 7 ppb[2] are acceptable for daily exposures. Check materials, building components, cleaning products, and /or other potential indoor sources.
Humidity	Levels below 30% RH are associated with increased coughing, wheezing, and fine particle resuspension. Prolonged periods of humidity over 75% are likely to result in condensation and mold or bacteria growth.	(Cedeno-Laurent et al., 2018; Pigg, Cautley, & Francisco, 2018)	Optimum levels of relative humidity are between 40% and 60%.

[1]ppm: parts per million
[2]ppb: parts per billion

Table 2. M&V Protocols for Parameters Coupled with Health Implications (Continued)

Parameter	Health Implications	References	M&V Protocols
Nitrogen Dioxide and Nitrogen Oxide (NO2 and NOx)	Irritate airways and aggravate respiratory diseases. They also contribute to the development of and asthma.	(EPA, 2019a, 2019b)	Principal sources are combustion and decomposition. Check combustion areas, fireplaces, garbage locations, and management of compostable or organic waste.
Particulate matter (PM)	Can contribute to heart and cerebrovascular problems, lung cancer, respiratory infections, and COPD	(Cohen et al., 2017)	Improve envelope airtightness levels. Assessment and control of indoor sources of PM. No smoking can be allowed indoors.
Radon	Poses a risk factor for lung cancer	(Derbez et al., 2018)	Indoor and outdoor measurement over different seasons. Radon levels can change with temperature.
Temperature	Rapid changes and spikes are triggers for health problems, reduction in performance and learning.	(Cedeno-Laurent et al., 2018)	Comfort range is 68°F to 75°F in winter and 72°F and 82°F in summer.
Total Volatile Organic Compound (TVOC)	Causes odor annoyance, eye/airway irritation, allergies, headaches, nose and throat discomfort, dyspnea, nausea, fatigue, loss of productivity.	(EPA, 2019c)	Values below 500ug/m3 are considered acceptable. Check materials and components for retrofit, with low TVOC emissions.
Ventilation	Low rates trigger a range of respiratory health effects in adults and children, such as mucosa and allergy symptoms, and are associated with reduced of cognitive performance.	(Fisk, 2017; Sundell et al., 2011)	Installation of systems in bathroom and kitchen as minimum. Check functionality and ventilation rates according to current ASHRAE standard, last version available.

Generally, M&V protocol refers to the methods that can be used to evaluate changes in occupancy patterns, operations, and control settings, relative to a building and its context. A relevant component of M&V is to define the monitoring points required to establish baselines and quantify post-retrofit performance along with defining the respective measurement methods (Burman & Mumovic, 2017). Furthermore, these protocols can be used on the residential stock to evaluate changes beyond energy optimizations that may affect both low-income families' health and their residences' energy performance, such as hygrothermal performance (Tariku, Kumaran, & Fazio, 2015) and levels of environmental pollutants (P. Fabian, Adamkiewicz, & Levy, 2012).

This paper presents a preliminary literature review to summarize existing M&V schemes that can be applied to this particular residential sector for the Wx+H program. Furthermore, research, industry, and policy gaps in these areas are explored and compared with the industry standard on M&V for residential buildings.

METHODOLOGY

A systematic literature review was performed to collect and analyze the state of the practice for M&V. This process included a three-step screening protocol:

Phase 1: Collect books, articles and reports
Phase 2: Filter and categorize studies and results
Phase 3: Analyze results

In phase 1, a keyword search was performed for publications that included books, scientific articles, and reports in three main scientific collections: EBSCO, Web of Science, and ScienceDirect. For this search, a combination of keywords was used: "measurement and verification," "indoor environmental quality," "healthy buildings," "retrofit," "weatherization," "residential," and "low-income." This search brought up in 368 publications, all of which were analyzed through their titles, reducing the number to 14. Additionally, 18 reports from the Washington State Commerce Department were added to this pool.

In phase 2, the authors performed an abstract review, based on which 14 articles and reports were selected for in-depth analysis. The chosen publications had to either present findings or strategies about measurements and verifications in residential buildings and/or to include metrics of evaluation for the IEQ.

In phase 3, the selected articles were analyzed by qualitative coding performed though Atlas.ti software package. The articles were divided into three groups: energy demands, healthy interventions, and IEQ metrics.

RESULTS

The following results offer a concise critical overview of the major existing protocols, which include the ASHRAE Guideline 14, the International Performance Measurement and Verification Protocol (IPMVP), and the guidelines provided by Washington State for its program Wx+H that cover retrofit interventions applied to low-income housing.

Wx+H program provides guidelines to incorporate various energy savings with a focus on the maintenance, repair, and/or replacement of structural and non-structural components of housing. A more quantitative approach focusses on elements to address health needs and priorities beyond energy efficiency yet, according to scientific evidence, highly related (Hernández & Bird, 2010; Pigg, Cautley, & Francisco, 2017). Such elements include cleaning kits, high performance vacuums, CO detectors, VOC low flooring, and other provisions and equipment to improve the IAQ and IEQ, which are highly related to health impacts (Manuel, 2011). The detailed effects of the Wx+H are not well understood in terms of indoor environmental behavior and the impact such behavior can have for occupants. The interventions implemented have not been tested in terms of occupant satisfaction or perceived health outcomes. Procedures for systematic follow-up and education will be needed to realize the full potential of the program.

Available protocols for measuring actual performance are highly oriented toward commercial and industrial buildings. While the IPMVP is recognized around the world, this protocol is especially suited to commercial and industrial buildings; its main objective is prioritizing energy savings through optimizations, with an emphasis on electrical demands (EVO, 2002). A second volume of this protocol provides concepts and practices for improved IEQ; however, concerns about unintended consequences of improving energy efficiency are rising (Shrubsole, Macmillan, Davies, & May, 2014).

Another established protocol is ASHRAE Guideline 14-2014, Measurement of Energy, Demand, and Water Savings (ASHRAE, 2014). Though its scope includes all type of facilities – residential, commercial, institutional, and industrial – aspects such as IAQ and IEQ are lacking in the main document that provides detailed explanations for electricity, renewable systems, gas, oil, water and wastewater. Notably, such guidelines have been extensively applied to the industrial and commercial sector, but protocols to assess energy and environmental performance for residential buildings remain scarce. M&V protocols can comprise a valuable tool to assess uncontrolled behavior, thus helping researchers better understand the changes an indoor environment can undergo due to energy efficiency retrofit that in turn affect the quality of life for residents. The parameters shown in Table 2 identify some of metrics that can modify IEQ and as consequence impact health outcomes. The table also incorporates health implications found in the literature review.

DISCUSSION

Protocols for buildings to assess changes in the indoor environment and health measurements are limited, especially for the residential and low-income sectors. The literature indicates a need to include a more comprehensive assessment to understand aspects that go beyond energy consumption and reduction of carbon emissions (Colton et al., 2014; Shresta et al., 2019; Shrubsole et al., 2014), such as ramifications for health and safety that can result in a more successful overall efficient retrofit intervention (Manuel, 2011). Other aspects such as ventilation rates (Sundell et al., 2011), building components or materials emission quality (Derbez et al., 2018; Kubba, 2012), and other pollutants such as radon and carbon monoxide (Francisco et al., 2018; Pigg et al., 2018) among other concerns to maintain a healthy IEQ.

The guidelines and protocols found on ASHRAE and IPMVP can initially help to shape the M&V plan for low-income housing; however, a recognizable gap persists, especially for residential buildings in the low-income sector. The complexity of these calculations and assessments requires the input of experts who might not be available to consult on low-income weatherization programs, creating a barrier for agencies and stakeholders. Therefore, simplified guidelines and protocols to address health, safety, and energy are needed to provide a holistic understanding of retrofit interventions, and outline a careful but straight forward evaluation protocol. Additionally, M&V needs to be addressed as an integral component of a project, one which can facilitate improvements of the built environment and benchmark IEQ and low-income housing.

In this effort to provide a more comprehensive assessment through protocols for healthy buildings, it is also important to generate cross-collaboration among different stakeholders. We support creation of a shared network database which contains actual performance information of the buildings being assessed, allowing project delivery and planning to increase feasibility, illuminating uncertainties from retrofitting projects, and sharing evaluations and other pertinent information (Walter, Price, & Sohn, 2014). Such a network can make available to stakeholders a special analysis quantifying the consequences of retrofit interventions on the indoor environment. Uncertainties in this context can represent a major challenge because of the human factor, indoor environment (Taylor et al., 2018), and the health implications in low-income housing (De Souza et al., 2018). However, evidence suggests that the benefits of including combined healthy and energy interventions can exert a positive influence, especially for vulnerable populations. (M. P. Fabian, Adamkiewicz, Stout, Sandel, & Levy, 2014)

CONCLUSION

This paper summarizes M&V protocols for the Washington State Wx+H program. The literature review suggests that protocols for residential buildings, and specifically low-income housing, are needed in order to provide assessment towards healthy interventions, as well as influence on the IEQ. M&V can help program leaders and other planners to understand the relationship between energy efficiency interventions and indoor health factors for a more comprehensive assessment, especially for vulnerable populations.

Future research should focus on understanding analysis protocols and guidelines for weatherization interventions across the United States. It is assumed that geographic localization, weather, infrastructure, technical support and resources may impact the way such protocols are implemented, necessitating a detailed analysis of procedures to be implemented in low-income housing. By developing M&V protocols for low-income housing in multiple contexts, it is possible to compare different scenarios, understand the influence of a building's construction type, and determine the impact of regulation and local policies.

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