From Energy to Equity: Measuring What Weatherization Really Delivers

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Abstract

For many underserved households, energy upgrades mean more than lower bills; they can mean safer, healthier, and more resilient homes. Delaware's department of natural resources and environmental control (DNREC) is advancing this broader view of energy equity by evaluating the non-energy benefits (NEBs) of its weatherization assistance program. In partnership with DNREC, our team is calculating Delaware-specific residential non-energy benefits for thermal comfort, noise, health, indoor air quality, changes in home humidity, and changes in mold presence.

The study combines literature review with participant feedback to build evidence on outcomes that traditional evaluations often overlook. By pairing quantitative data with lived experience, the analysis links insulation, air sealing, and ventilation upgrades to measurable gains in comfort, safety, and building durability. This mixed-methods approach offers a practical framework for valuing the full spectrum of benefits that accompany reduced energy use.

Weatherization measures are relatively low-cost but deliver lasting value, particularly in Delaware's older, weather-exposed housing stock. This study marks DNREC's first comprehensive effort to quantify how broader benefits translate to residents' well-being and program performance.

By recognizing both energy and non-energy outcomes, this work offers practical lessons for evaluators, program administrators, and policymakers seeking to better capture the full value of efficiency. It demonstrates how comprehensive valuation can strengthen the case for weatherization, guide investment decisions, and build programs that deliver measurable benefits beyond energy savings. Delaware's approach highlights how integrating NEBs into evaluation and planning can make future initiatives more inclusive, resilient, and cost-effective across all communities.

Introduction

This paper presents the results of a non-energy benefits (NEBs) study conducted for the Delaware Department of Natural Resources and Environmental Control's (DNREC's) Weatherization Assistance Program (WAP). Building on prior DNREC WAP evaluation work that quantified participant-valued benefits related to comfort, noise, and health, the study expands the valuation framework to include indoor air quality, humidity, and mold. By pairing participant survey responses with estimated annual energy savings, the analysis develops updated Delaware-specific NEBs values that can inform future program planning, cost-effectiveness screening, and benefit-cost analysis.

Weatherization programs are traditionally evaluated through the lens of energy savings, bill reductions, and cost-effectiveness. However, for many low-income households, the benefits of weatherization extend well beyond reduced energy use. Improvements to insulation, air sealing, ventilation, and other building envelope measures can influence how a home feels and functions on a day-to-day basis by improving thermal comfort, reducing outside noise, enhancing indoor air quality, controlling moisture, and supporting healthier living conditions. These

outcomes represent important aspects of household well-being that are often experienced directly by participants but are not fully reflected in conventional energy-based evaluation metrics.

The study presents participant-reported outcomes across six non-energy benefit categories, develops updated participant-valued monetary estimates for each benefit, and recommends Delaware-specific NEBs values for future Weatherization Assistance Program evaluations. In doing so, the study expands Delaware's existing NEBs framework and demonstrates how participant experience can be incorporated into program evaluation alongside traditional measures of energy performance.

Background

DNREC's Weatherization Assistance Program serves income-eligible households by providing home energy improvements that reduce energy burden while improving housing quality and resilience. Typical weatherization measures include insulation, air sealing, duct sealing and insulation, ventilation improvements, hot water pipe and equipment insulation, and other cost-effective energy efficiency upgrades. Although these measures are implemented primarily to reduce household energy consumption, they also influence a wide range of indoor environmental conditions that affect participants' daily lives.

By reducing air leakage, improving thermal performance, and addressing moisture-related issues, weatherization measures can increase comfort, stabilize indoor temperatures, reduce unwanted outdoor noise, improve indoor air quality, and mitigate conditions associated with excess humidity and mold. These outcomes may contribute to improved health, greater housing durability, and an enhanced quality of life while complementing the direct energy savings achieved through the program.

Previous DNREC WAP evaluations established Delaware-specific participant-valued estimates for thermal comfort, noise, and health, demonstrating that non-energy benefits represent a meaningful component of the overall value delivered by weatherization. The present study extends that work by incorporating indoor air quality, humidity or dampness, and mold into the valuation framework. Expanding the scope of evaluated benefits provides a more comprehensive assessment of participant experience and allows Delaware to better capture the full range of outcomes associated with residential weatherization.

Literature Review

Non-energy benefits (NEBs) represent the additional value created by energy efficiency programs beyond direct reductions in energy consumption. For residential weatherization programs, these benefits commonly include improved thermal comfort, reduced outside noise, better indoor environmental quality, improved occupant health, and increased housing durability. Because these outcomes are often among the most meaningful benefits experienced by participating households, numerous evaluations have sought to quantify them alongside traditional energy savings.

Previous weatherization research has employed three primary methodological approaches to estimate participant-level NEBs. The first is contingent valuation, in which participants assign a monetary value to improvements such as comfort or health, often relative to expected energy bill savings. The second relies on direct measurement or participant-reported outcomes, including changes in indoor temperatures, medical utilization, asthma triggers, sleep quality, or

thermal stress. The third uses secondary data and established economic values to monetize observed health, safety, or societal outcomes. Many recent studies combine multiple approaches to develop comprehensive estimates of participant benefits.

Table 1 summarizes several representative weatherization NEBs studies completed over the past fifteen years. Although methodologies differ across jurisdictions, nearly all studies conclude that weatherization produces meaningful benefits beyond energy savings. Reported benefits consistently include improvements in thermal comfort and health, while more recent studies have expanded to evaluate indoor environmental quality, humidity, mold, and broader societal outcomes.

Table 1: Summary of Representative Weatherization NEBs Studies

Study	Primary Methodology	Key NEBs Evaluated
Massachusetts Low-Income NEIs (2011)	Contingent valuation	Comfort, noise, health
U.S. DOE National WAP (2014)	Direct measurement and secondary data	Health, thermal stress, missed work
Massachusetts Health & Safety NEIs (2016)	Direct measurement and secondary data	Comfort, thermal stress, health
DNREC WAP Evaluation (2020)	Contingent valuation	Comfort, noise, health
TVA Home Uplift (2022)	Surveys and direct measurement	Comfort, health, safety
Connecticut HES-IE NEIs (2023)	Mixed methods	Comfort, noise, health, air quality, humidity, mold
Tennessee Home Uplift IEQ (2023)	Direct measurement	Indoor environmental quality and comfort
TVA Medicaid Outcomes (2025)	Administrative health data	Healthcare utilization and costs

Among these studies, the 2020 DNREC Weatherization Assistance Program evaluation is particularly relevant because it established Delaware-specific participant values for thermal comfort, noise, and health using a contingent valuation approach. Participants reported the monetary value of these benefits relative to expected annual energy savings, and the resulting estimates became the basis for Delaware's existing participant-level NEBs values.

The present study builds directly upon that work while expanding the valuation framework. In addition to comfort, noise, and household health, the current study evaluates indoor air quality, humidity or dampness, and mold. By broadening the range of participant-reported outcomes, this research seeks to provide a more comprehensive assessment of the benefits experienced by Delaware Weatherization Assistance Program participants and to develop updated Delaware-specific NEBs values for future program evaluation and cost-effectiveness analysis.

Methodology

This section describes the survey design used to collect participant-reported NEBs, the framework used to estimate NEBs values, and the characteristics of the survey sample.

Study Design

To estimate participant-level NEBs associated with Delaware's WAP, the study team developed a participant survey that combines process-oriented questions, measure verification, and a dedicated NEBs valuation module. The survey instrument captures both the direction of participant-reported change and participants' valuation of those changes relative to annual energy savings.

The survey covers the following topics:

- Participation Motivations and Barriers
- Measure Verification
- Thermostat Behavior
- Quantification of NEBs
- Health, Comfort, and Noise Impacts
- Home Characteristics
- Demographic Characteristics

The study focuses on six NEBs categories:

- Comfort or Home Draftiness
- Noise
- Household Health
- Indoor Air Quality
- Humidity or Dampness
- Mold

These categories were selected based on two considerations: the types of improvements commonly produced by weatherization measures and the aspects of the home environment that participants can readily observe and report. Insulation, air sealing, and ventilation improvements directly influence thermal comfort, drafts, and indoor environmental conditions, while changes to airflow and moisture control can affect humidity levels, mold conditions, and perceived indoor air quality. Together, these categories reflect outcomes that are closely tied to residents' day-to-day experience in their homes.

These outcomes are particularly relevant for Delaware households because many weatherization participants live in older housing stock where issues such as drafts, inconsistent temperatures, moisture, and indoor air quality are common. Improvements in these areas can meaningfully affect comfort, health, and overall housing conditions. By focusing on outcomes that residents can directly perceive within their homes, the study captures benefits that are

meaningful to participants and that may represent an important component of the overall value delivered by the Weatherization Assistance Program.

For each category, respondents are first asked whether the energy efficiency improvements resulted in a positive change, negative change, or no change. This question establishes the direction of participant-reported impacts across the six NEBs categories.

Respondents reporting positive or negative changes are then asked to estimate the value of that impact in dollar terms relative to expected annual energy savings. When respondents are unable to provide an open-ended dollar value, the survey offers a follow-up categorical valuation framed as a share of annual energy savings. These response options include values equivalent to 25%, 50%, or 75% of annual savings, the same value as annual savings, or more than annual savings.

Sample

The study sample consisted of 568 participant households that received weatherization services through DNREC's Weatherization Assistance Program during the study period. The sample was selected to support participant survey fielding and achieve approximately 70 completed surveys for the NEBs valuation analysis. A total of 116 completed surveys were ultimately obtained, corresponding to a response rate of 21%. The sample spans both manufactured homes and single-family homes and includes a range of ownership, occupancy, and primary heating fuel types. Table 2 summarizes the distribution of sampled households by building type and primary heating source.

Most sampled households are single-family homes, which account for 384 of the 568 sampled participants. Within that group, owner-occupied single-family site-built homes represent the largest share of the sample. Manufactured homes account for the remaining 184 sampled households, the majority of which are owner-occupied mobile homes. The sample also includes smaller numbers of renter-occupied mobile homes, single-family rental site-built homes, and one owner-occupied property containing two to four units.

The sample also reflects substantial variation in primary heating fuel. Natural gas is the most common heating source, followed by electric heat, propane, and oil, with a smaller number of kerosene-heated homes. The largest subgroup consists of owner-occupied single-family site-built homes heated by natural gas, followed by owner-occupied mobile homes heated by propane. This diversity provides a broad representation of housing types and heating systems served through Delaware's Weatherization Assistance Program.

Table 2: NEBs Survey Sample by Building Type and Primary Heating Fuel

Building Type	Electric	Kerosene	Natural Gas	Oil	Propane	Grand Total
Owner-occupied mobile home	35	6	2	32	93	168
Renter-occupied mobile home	4	0	0	3	9	16
Owner-occupied 2–4 units per site	0	0	1	0	0	1

Owner-occupied single-family site built	106	2	159	77	21	365
Single-family rental site built	7	0	7	3	1	18
Total	**152**	**8**	**169**	**115**	**124**	**568**

NEBs Valuation Framework

Survey responses were analyzed to estimate participant-reported non-energy benefits associated with weatherization improvements. The analysis translated survey responses into participant-valued monetary estimates for each NEBs category while accounting for potential overlap across multiple benefits.

First, responses were summarized to estimate the share of participants reporting positive, negative, or no change across each of the six NEBs categories. These descriptive statistics provide an overview of how frequently participants experienced changes in comfort, noise, household health, indoor air quality, humidity or dampness, and mold following weatherization improvements.

Second, responses to the valuation questions were converted into monetary estimates for each NEBs category. Open-ended dollar responses were reviewed, standardized, and summarized to estimate average participant valuations. For respondents selecting categorical responses, the reported percentages of expected annual energy savings were converted to dollar values using each participant's estimated annual energy savings.

Because weatherization improvements often affect multiple aspects of the indoor environment simultaneously, the survey included a combined-value question for respondents reporting more than one non-energy benefit. Individual benefit values were proportionally scaled to each respondent's combined valuation to reduce potential double counting across categories, consistent with the methodology used in previous Delaware WAP evaluations and other survey-based NEBs studies.

Finally, participant-valued estimates were aggregated across the sample to develop updated Delaware-specific NEBs values for each category. These estimates were compared with values developed in previous Delaware evaluations and with findings reported in the broader weatherization literature.

Results

The sections below present the findings from the expanded non-energy benefits (NEBs) evaluation for Delaware's Weatherization Assistance Program (WAP). The results include participant-reported changes in six non-energy benefit categories, participant valuations of those benefits, updated Delaware-specific NEBs estimates, and comparisons with previous Delaware WAP evaluations. Where appropriate, the results are compared with the earlier CY2016-2019 evaluation to assess how participant experiences and estimated values have changed over time.

Participant-Reported Non-Energy Benefits

Survey respondents were first asked whether participation in the Weatherization Assistance Program resulted in a positive change, negative change, or no change across six non-energy benefit (NEB) categories: thermal comfort, noise, household health, indoor air quality, humidity or dampness, and mold. Table 3 summarizes participant responses for the current evaluation.

Table 3: Participant Observations of Non-Energy Impacts

Type of impact	Thermal comfort	Noise	Health	Air quality	Humidity	Mold
Positive	58%	38%	42%	49%	46%	37%
Negative	9%	8%	7%	5%	6%	9%
No impact	32%	52%	43%	37%	34%	27%
Don't know / No Answer	1%	1%	9%	9%	14%	28%

Thermal comfort was the most frequently reported benefit, with 58% of respondents indicating that weatherization improved the comfort of their home. Nearly one-half of respondents also reported improvements in indoor air quality (49%) and humidity or dampness (46%), while 42% reported improvements in household health. Improvements in noise were reported by 38% of participants, and 37% reported reductions in mold following weatherization. Across all six categories, relatively few respondents reported negative impacts, ranging from 5% for indoor air quality to 9% for thermal comfort and mold. Between 27% and 52% of respondents reported no noticeable change across the six categories, while "Don't know" responses were more common for mold (28%) and humidity (14%) than for the other NEBs evaluated.

Table 4 compares participant-reported outcomes for thermal comfort, noise, and health with results from the previous Delaware WAP NEBs evaluation (CY2016-2019). The share of respondents reporting improved thermal comfort declined from 83% in the previous evaluation to 58% in the current study, while the percentage reporting no change increased from 15% to 32%. Correspondingly, reported negative comfort impacts increased from 1% to 9%. These differences were statistically significant at the 90% confidence level.

Table 4: Participant Observation Comparison CY2016-2019 vs. CY2024

Type of impact	Thermal comfort		Noise		Health	
	CY2016-2019	CY2024	CY2016-2019	CY2024	CY2016-2019	CY2024
Positive	83%	58%*	47%	38%	37%	42%
Negative	1%	9%*	1%	8%	3%	7%
No impact	15%	32%*	51%	52%	57%	43%*
Don't know / No Answer	1%	1%	1%	1%	3%	9%*

Participant-reported improvements in noise also declined, although the differences were smaller than those observed for thermal comfort. The percentage reporting positive changes decreased from 47% to 38%, while reports of negative impacts increased from 1% to 8%. However, the proportion of respondents reporting no change remained nearly identical across the two evaluation periods.

Health-related responses were generally more consistent across evaluations. Positive health impacts increased modestly from 37% to 42%, while the share reporting no change decreased from 57% to 43%. Although the percentage of respondents reporting negative health impacts increased from 3% to 7%, negative responses remained relatively uncommon overall. Together, these findings indicate that participant-reported improvements continue to be most pronounced for thermal comfort, while the expanded survey demonstrates that substantial shares of participants also perceive benefits related to indoor air quality, humidity, and mold that were not evaluated in previous Delaware WAP studies.

Participant-Valued Non-Energy Benefits

Respondents reporting positive or negative impacts were asked to estimate the annual value of those changes relative to their expected annual energy bill savings. Table 5 summarizes the progression from participants' initial responses through the normalization, outlier removal, and billing-adjustment process used to develop the final NEBs values.

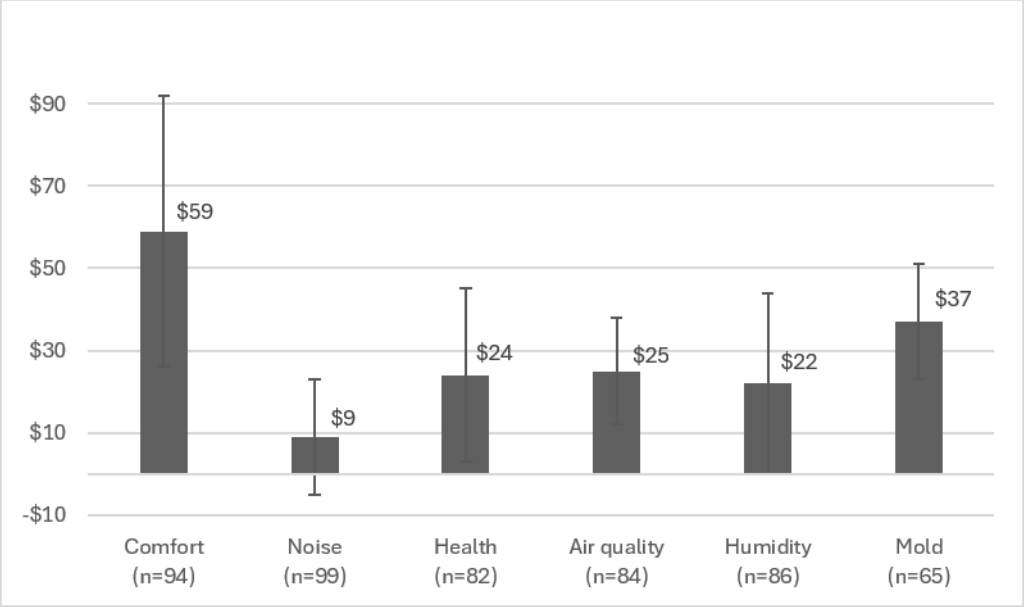
Table 5: Participant-Valued Non-Energy Benefits

NEB	(n)	Responses, including outliers		Scaled, outliers removed		Adjusted estimates, post billing analysis	
		Dollar (per household) per year	**% of bill savings**	**Dollar (per household) per year**	**% of bill savings**	**Dollar (per household) per year**	**% of bill savings**
Comfort	94	$136	35%	$63	16%	$59	16%
Noise	99	$85	21%	$13	3%	$9	2%
Health	82	$118	30%	$25	6%	$24	7%
Air Quality	84	$117	30%	$24	6%	$25	7%
Humidity	86	$106	27%	$25	6%	$22	6%
Mold	65	-$1,364	-330%	$46	11%	$37	11%

Prior to normalization, respondents assigned the greatest value to thermal comfort ($136 per household annually), followed by health ($118), indoor air quality ($117), and humidity ($106). Noise was valued at $85 per household, while the initial mold responses produced a negative average because a small number of extreme responses substantially influenced the mean. After removing outliers and accounting for overlap among multiple reported benefits, the participant-valued estimates became considerably more consistent across categories.

Following normalization and application of the billing realization rate, the total participant-valued non-energy benefits equaled $176 per participating household per year. Thermal comfort represented the largest individual benefit at $59 per household annually, followed by mold ($37), indoor air quality ($25), health ($24), humidity ($22), and noise ($9). Figure 1 illustrates the final adjusted participant-valued NEBs together with their 90% confidence intervals.

Figure 1: Post Billing Analysis Values with Confidence Intervals, CY2024

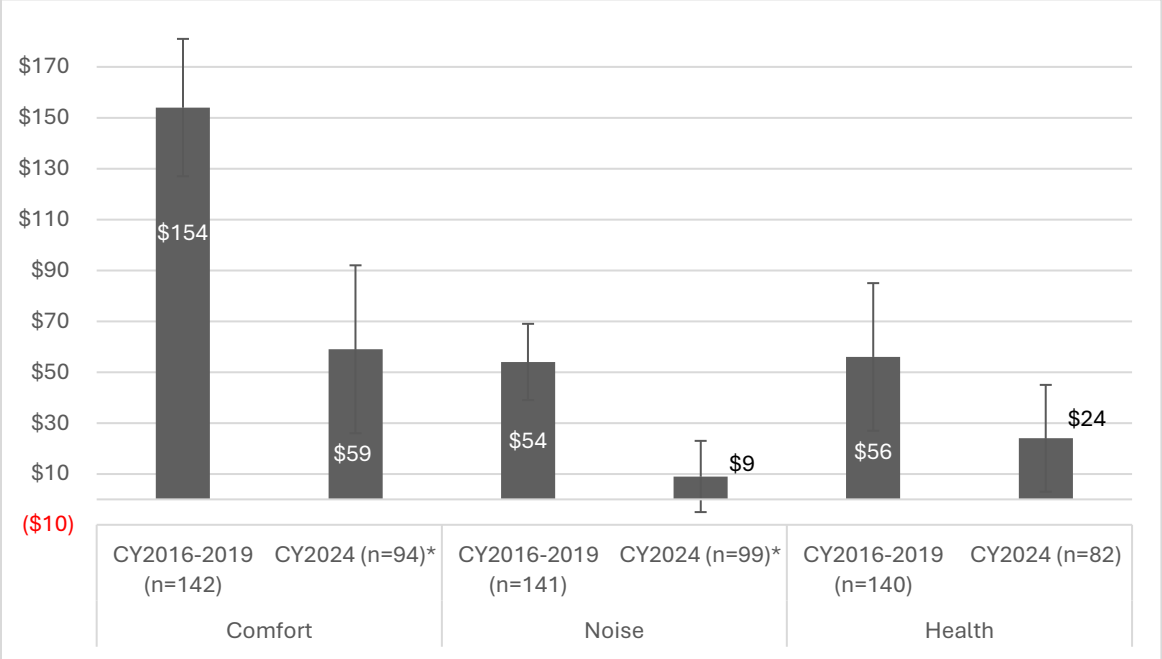


Thermal comfort exhibited both the highest participant-valued benefit and the greatest variability across respondents. Confidence intervals for the remaining benefit categories were comparatively narrower, although overlap among several estimates suggests that participants valued improvements to health, indoor air quality, humidity, and mold at broadly similar levels. Collectively, the adjusted estimates indicate that participants place meaningful value on a range of weatherization outcomes beyond direct energy bill savings.

Comparison with Previous Delaware Findings

The current evaluation provides the first opportunity to compare participant-valued non-energy benefits from the expanded CY2024 survey with the values developed during the previous Delaware WAP NEBs evaluation. Figure 2 compares the adjusted annual participant-valued estimates for the three benefit categories common to both studies: thermal comfort, noise, and health.

Figure 2: Comparison of Participant-Valued NEBs, CY2016-2019 and CY2024



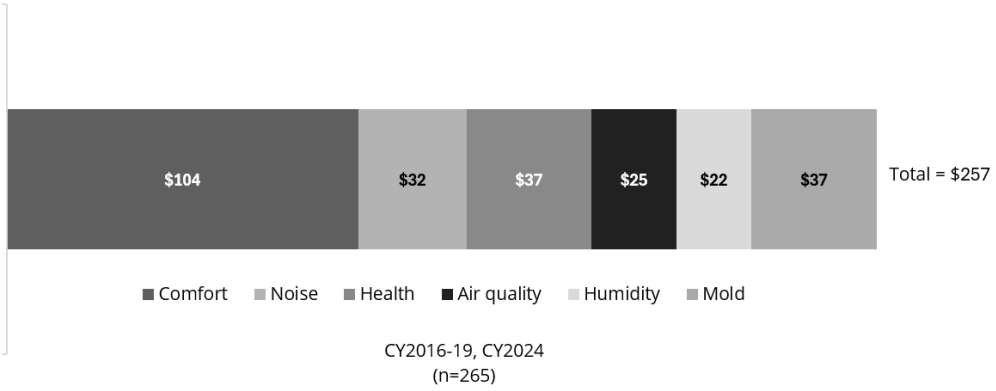
Across all three categories, participant-valued estimates were lower in the current evaluation than in the previous study. Thermal comfort decreased from $154 to $59 per participating household annually, while noise declined from $54 to $9 and health decreased from $56 to $24. The reductions in thermal comfort and noise were statistically significant at the 90% confidence level, while the difference in health was not statistically significant.

Although the participant-valued estimates for the original three NEBs categories declined, the current study also quantified three additional participant-reported benefits that were not included in previous Delaware evaluations: indoor air quality, humidity or dampness, and mold. Together, these newly quantified categories contributed an additional $84 per participating household annually, partially offsetting the reductions observed for comfort, noise, and health. As a result, the expanded framework provides a more comprehensive assessment of participant-valued benefits associated with weatherization and forms the basis for the updated Delaware NEBs recommendations presented in the following section.

Recommended Delaware NEBs Values

A primary objective of this study was to develop updated Delaware-specific non-energy benefit values for use in future Weatherization Assistance Program evaluations and cost-effectiveness analyses. To maximize the available evidence while incorporating the expanded scope of the current survey, recommended values were developed by combining participant responses from the previous Delaware WAP NEBs evaluation (CY2016-2019) with those collected during the current study. The combined dataset includes 265 participant observations and reflects both the original benefit categories and the three additional indoor environmental outcomes evaluated in the current survey.

Figure 3: Total WAP NEBs values, CY2016-2019 and CY2024 combined



The combined analysis produced a recommended total participant-valued non-energy benefit of $257 per participating household annually. Thermal comfort remains the largest individual benefit, accounting for $104 of the total recommendation. Health and mold each contribute $37 per household annually, followed by noise ($32), indoor air quality ($25), and humidity or dampness ($22).

These recommended values preserve the larger historical evidence base developed through previous Delaware evaluations while expanding the framework to recognize additional participant-valued outcomes associated with weatherization. Collectively, the results indicate that although thermal comfort continues to represent the largest single non-energy benefit, improvements to indoor environmental quality account for a substantial share of the total value experienced by participating households.

Discussion

The results demonstrate that weatherization delivers benefits extending well beyond reduced energy consumption. While thermal comfort remains the most highly valued participant-reported outcome, the expanded survey illustrates that improvements in indoor air quality, humidity, and mold also represent meaningful components of participants' overall experience. Together, these findings reinforce the premise that weatherization programs influence multiple aspects of household well-being that are not captured through energy savings alone.

Compared with the previous Delaware evaluation, participant-valued estimates for thermal comfort, noise, and health were lower across all three categories. Several factors may have contributed to these differences. First, the current study surveyed a different cohort of Weatherization Assistance Program participants several years after the previous evaluation, during a period characterized by changing housing conditions, inflation, and evolving participant expectations. Second, the expanded survey explicitly asked respondents to consider indoor air quality, humidity, and mold as separate benefit categories. Benefits that participants may have previously attributed broadly to comfort or health may therefore have been distributed across a wider range of outcomes in the current valuation exercise. Finally, the study period coincided with an unusually cold winter in Delaware. Weather conditions influence how participants

experience their homes and may affect perceptions of thermal comfort and the value assigned to weatherization improvements. Although the current study was not designed to isolate the effect of weather conditions, seasonal differences may have influenced participant responses and should be considered when comparing results across evaluation periods.

Perhaps the most important finding is that expanding the NEBs framework produced a more comprehensive estimate of participant-valued benefits without substantially changing the overall magnitude of total non-energy benefits. Although values for thermal comfort, noise, and health declined relative to previous Delaware estimates, the newly quantified benefits associated with indoor air quality, humidity, and mold contributed an additional $84 per participating household annually. This indicates that previous evaluations may not have fully captured the range of household benefits experienced by weatherization participants.

The study also demonstrates the value of combining participant-reported experiences with a structured valuation framework. Asking respondents to value individual benefits relative to expected energy savings, while accounting for overlap across categories through the combined-value question, provides a transparent and repeatable approach for estimating participant-valued NEBs. This methodology offers a practical framework that can be replicated in future low-income energy efficiency evaluations and adapted as additional benefit categories become relevant.

Recommendations and Conclusion

This study expands Delaware's Weatherization Assistance Program non-energy benefits framework from three participant-valued benefit categories to six by incorporating indoor air quality, humidity or dampness, and mold alongside thermal comfort, noise, and health. Using participant survey responses and a structured valuation methodology, the study developed updated Delaware-specific NEBs estimates that better reflect the broader range of household benefits associated with weatherization.

Based on the combined evidence from the CY2016-2019 and CY2024 evaluations, the study recommends adopting a participant-valued NEBs estimate of $257 per participating household annually for future Delaware WAP evaluations and cost-effectiveness analyses. This recommendation preserves the historical evidence developed through previous evaluations while incorporating the expanded understanding of indoor environmental benefits identified in the current study.

More broadly, the findings suggest that participant-valued benefits extend beyond traditional measures of comfort and health. Improvements in indoor environmental quality represent meaningful outcomes for low-income households and should be considered alongside energy savings when evaluating weatherization programs. As utilities and program administrators continue to assess the full value of energy efficiency investments, incorporating participant-valued non-energy benefits provides a more complete understanding of program impacts and supports more informed planning, resource allocation, and benefit-cost analysis.