# A Multicriteria Framework for Low-Income Household Energy Audit Tools in the U.S.

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# Introduction – Energy and Buildings

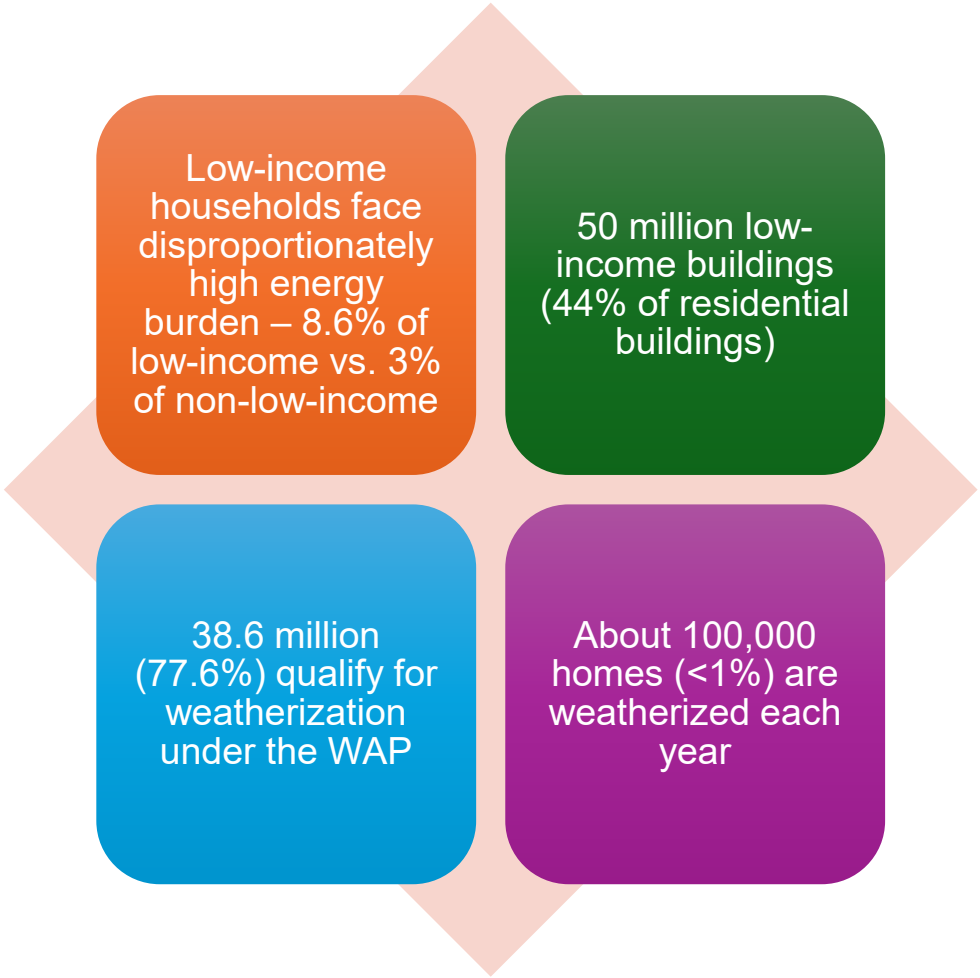
Buildings account for 40% of energy consumption and 39% of GHG emissions

$422 billion in electricity bills ($1,300 per person) in 2021

1.3% annual increase between 2018-2050 (U.S. EIA, 2019)

2050 NZE target means 4% efficiency improvement by 2030 (IEA, 2019)

# Low-income household energy consumption



# The Problem

Lots of energy efficiency initiatives/programs - Better Building Initiative, Better Climate Challenge, Energy Saver, WAP (low-income specific)

The Problem: Lack of framework to meet evolving needs of low-income (residential) households

Residential buildings variability require a more nuanced approach that captures the complexities of different building types or occupants

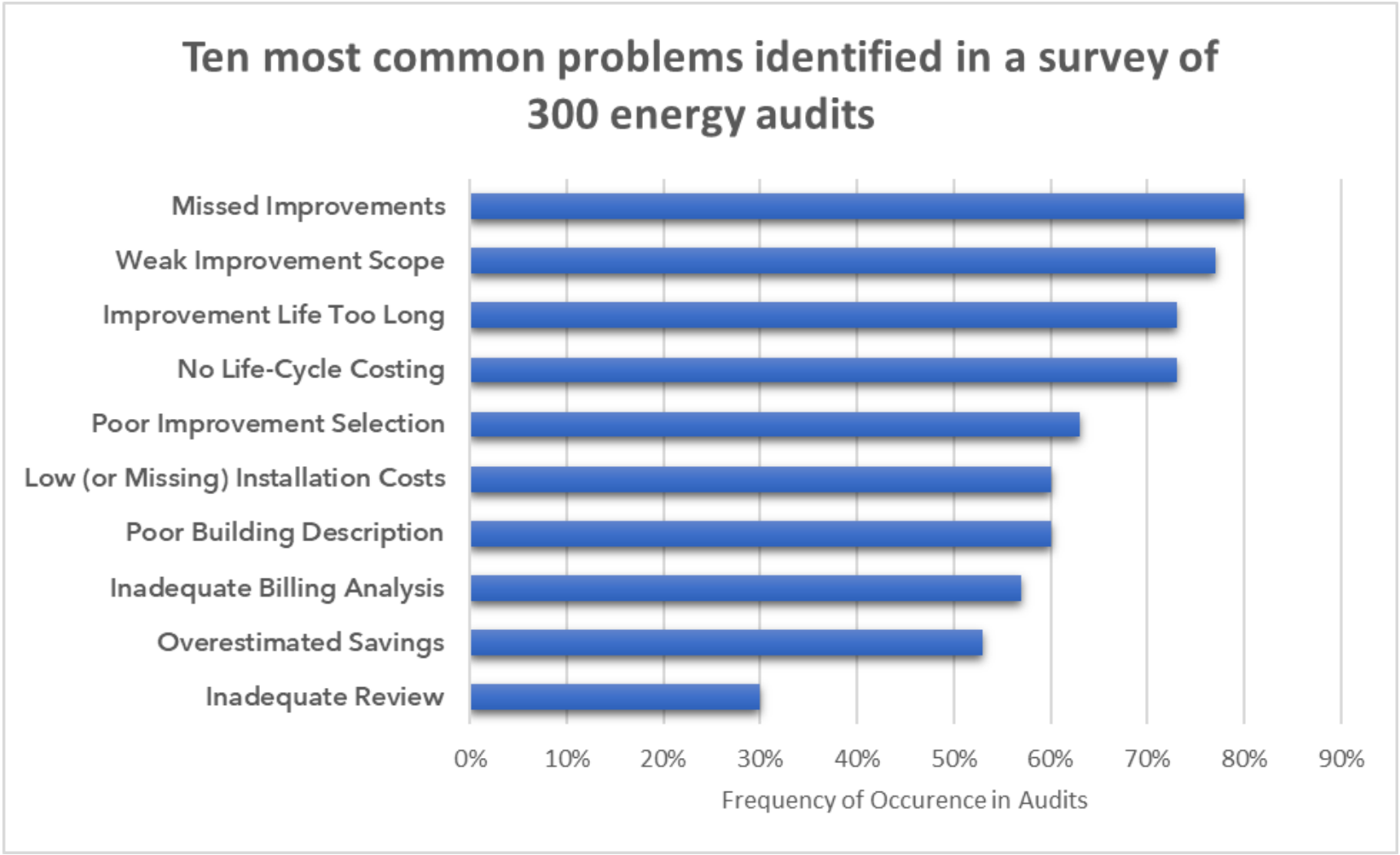
NEI not sufficiently captured and addressed within the framework of traditional energy audits.

# Research Significance

- Mitigating Energy Poverty
- Novel Tool
- Whole-Impact Approach
- Guiding Government Initiatives

# The Challenges of Energy Audits

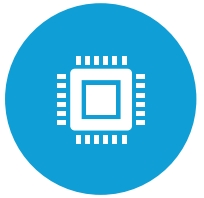
Source: Shapiro, 2011; ASHRAE Journal



# The Role of Energy Audit Software

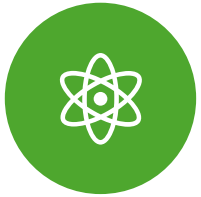
Perform high depth of analysis and rapid delivery of result

Provide accurate, comprehensive, and cost-effective energy efficiency solutions



Efficient data collection, entry and processing

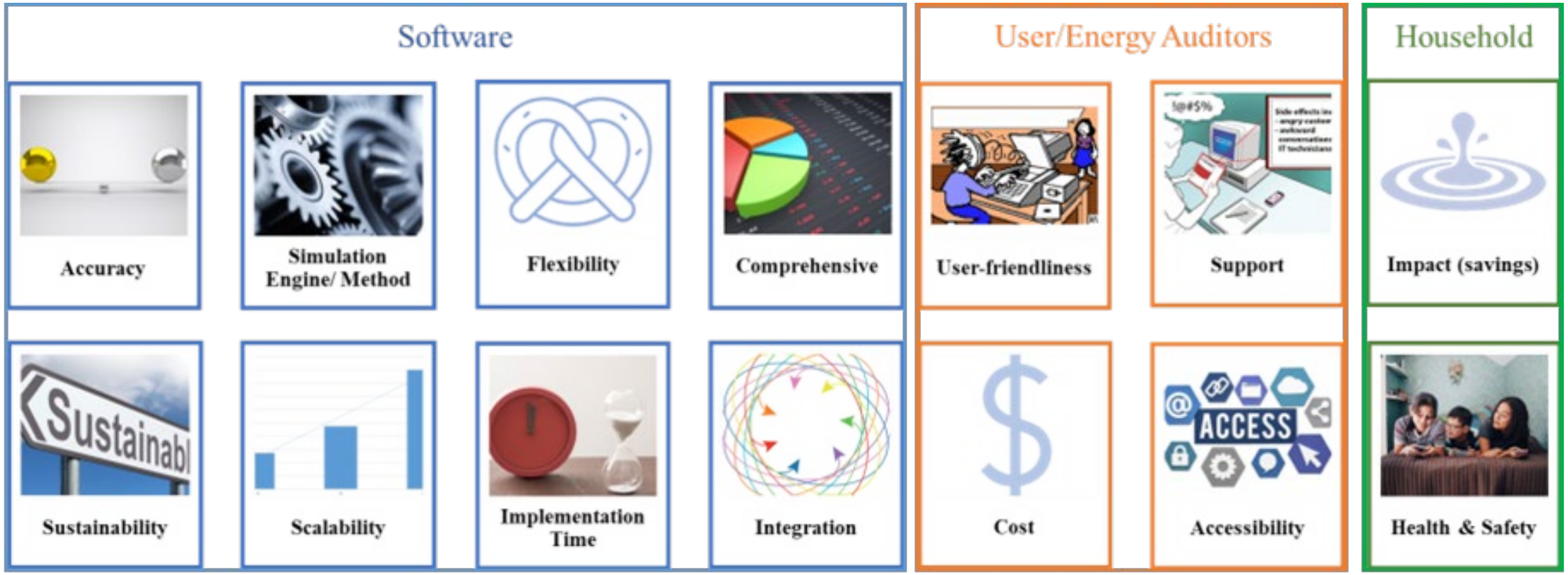
Allows variety of input methods and data types



Combines building physics, local weather data & economic parameters to simulate sophisticated building energy consumption

Captures distinct aspects of buildings' energy systems

# Defining the Framework



# Preliminary Results: Qualitative Metrics

| Software-focused Criteria (Part A) | | | |
|---|---|---|---|
| **Accuracy (ACY)** | **Simulation Method/ Engine (SME)** | **Flexibility (FLEX)** | **Comprehensiveness (COM)** |
| 1. Meets ANSI/ASHRAE Standard 140<br>2. Meets BESTEST-EX reference simulation results and acceptance criteria | Simulation Method<br>A. Physics-based<br>B. Hybrid method<br>C. Data-driven<br>Engine<br>A. Known open-source state-of-the-art engine.<br>B. Proprietary | A. Allows customization of data input and assumptions | 1. Accounts for different fuel types<br>2. Accounts for renewable energy resources<br>3. Provides end-use energy distribution |

| Software-focused Criteria (Part B) | | | |
|---|---|---|---|
| **Integration (INT)** | **Scalability (SCAL)** | **Sustainability (SUS)** | **Implementation Time (TIME)** |
| 1. Integrates with home automation systems.<br>2. Integrates with utility rebates.<br>3. Integrates with renewable energy technologies | 1. Can support many buildings.<br>2. Usable in various locations<br>3. Can be run on different software/ hardware | 1. Can explore renewable energy technologies.<br>2. Quantifies energy usage in terms of GHG emissions/savings.<br>3. GHS emission/savings metrics are relatable.<br>4. Provides net-zero energy/emission measures<br>5. Estimates the social cost of carbon. | 1. Provides an audit checklist to facilitate data gathering.<br>2. Clear and concise labeling to help users understand required data input fields.<br>3. In-built data validation to ensure the right data type and format is entered.<br>4. Inline error message to identify and correct errors<br>5. Intuitive user interface<br>6. How long does it take to run a two-story, 3-bedroom, single family home?<br>*A.* $\leq$ 10 core-seconds<br>*B.* $>$ 10 core-seconds<br>1. What is the RRT for running a two-story, 3-bedroom, single family home?<br>A. $\leq$ 100 milliseconds<br>B. > 100 milliseconds |

# Preliminary Results: Qualitative Metrics

| User-focused Criteria | | | |
|---|---|---|---|
| **User-friendliness (USE)** | **Support (SUP)** | **Accessibility (ASB)** | **Cost (COST)** |
| 1. Installing and uninstalling was fast and easy.<br>A. Yes<br>B. No<br>C. N/A (for web or cloud-based applications)<br><br>2. Application provides keyboard shortcuts.<br>3. Navigating pages and input fields is possible using the tab key<br>4. The choice of design colors is appealing and poses no problem to the eye<br>5. Font type and size are readable.<br>6. Icons and shapes are understandable.<br>7. No issues with viewing the tool on different devices (laptop, tablet, desktop)<br>8. Running the application does not affect using other activities.<br>9. It is easier to select items from menus.<br>10. It is easier to search for information.<br>11. Could use the application without having to refer to user guide often.<br>12. The application works well with [external] mouse and keyboard<br>13. Software does not crash during use.<br>14. Software comes with regular updates and bug fixes | 1. The software comes with a user manual.<br>2. Training materials (videos and webinars) are provided/available for use of the software.<br>3. There are emails or online chats or FAQs and answers to help resolve problems<br>4. There is a phone number to call for support<br>5. There is a means to provide feedback to developers | 1. Software Availability<br>A. Online mode only<br>B. Offline mode only<br>C. Offline and online modes<br>2. All software features are available from a keyboard.<br>3. Features and reports are accessible to color-blind persons | 1. Software is free to user with full features in a non-B2B transaction<br>2. Paid software<br>A. Has a limited free-trial version with full features.<br>B. Has free version with limited features with no time restrictions<br>C. Has a limited free-trial version with limited features.<br>D. Has no free trial version |

# Preliminary Results: Qualitative Metrics

| Household-focused Criteria | |
|---|---|
| **Impact (savings) (IMP)** | **Health and Safety (HS)** |
| 1. ECMs generated by software lead to energy and cost savings that is<br>A. Significantly lower than predicted (more than 25% less<br>B. Around what was predicted (within 25% margin of error)<br>C. Significantly above what was predicted (more than 25% higher) | 1. Software has checklists to inspect general *health hazards* such as mold, moisture, lead, radon, etc.<br>2. Software helps to inspect safety concerns related to *injury prevention.*<br>3. Software checks safety of the *elderly, disabled and children.*<br>4. Software checks safety related to *structural integrity of building.*<br>5. Software checks safety related to *fire and electrical safety* |

# Preliminary Results: Quantitative Metrics

| Software-focused Criteria (Part A) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Accuracy (ACY)** | | **Simulation Method/Engine (SME)** | | **Flexibility (FLEX)** | | **Comprehensiveness (COM)** | |
| ACY-1 | 10 | SME-1-A | 10 | FLEX | 5 | COM-1 | 5 |
| ACY-2 | 5 | SME-1-B | 6 | | | COM-2 | 5 |
| | | SME-1-C | 4 | | | COM-3 | 5 |
| | | SME-2-A | 3 | | | | |
| | | SME-2-B | 2 | | | | |
| **Software-focused Criteria (Part B)** | | | | | | | |
| **Integration (INT)** | | **Scalability (SCAL)** | | **Sustainability (SUS)** | | **Implementation Time (TIME)** | |
| INT-1 | 3 | SCAL-1 | 5 | SUS-1 | 5 | TIME-1 | 2 |
| INT-2 | 3 | SCAL-2 | 5 | SUS-2 | 4 | TIME-2 | 3 |
| INT-3 | 3 | SCAL-3 | 3 | SUS-3 | 3 | TIME-3 | 4 |
| | | | | SUS-4 | 2 | TIME-4 | 4 |
| | | | | SUS-5 | 2 | TIME-5 | 3 |
| | | | | | | TIME-6-A | 5 |
| | | | | | | TIME-6-B | 3 |
| | | | | | | TIME-7-A | 5 |
| | | | | | | TIME-7-B | 3 |

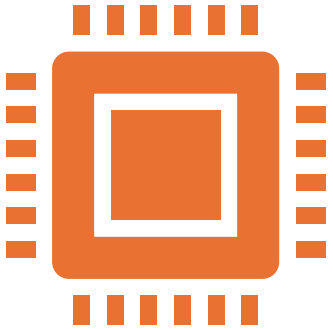
# Preliminary Results: Quantitative Metrics

| User- or Energy-Auditor-focused Criteria | | | | | | | |
|---|---|---|---|---|---|---|---|
| **User-friendliness (USE)** | | **Support (SUP)** | | **Accessibility (ASB)** | | **Cost (COST)** | |
| USE-1-A | 3 | SUP-1 | 5 | ASB-1-A | 3 | COST-1 | 5 |
| USE-1-B | 1 | SUP-2 | 3 | ASB-1-B | 2 | COST-2-A | 4 |
| USE-1-C | - | SUP-3 | 4 | ASB-1-C | 5 | COST-2-B | 3 |
| USE-2 | 1 | SUP-4 | 2 | ASB-2 | 2 | COST-2-C | 2 |
| USE-3 | 1 | | | ASB-3 | 2 | COST-2-D | 1 |
| USE-4 | 2 | | | | | | |
| USE-5 | 2 | | | | | | |
| USE-6 | 1 | | | | | | |
| USE-7 | 3 | | | | | | |
| USE-8 | 2 | | | | | | |
| USE-9 | 1 | | | | | | |
| USE-10 | 1 | | | | | | |
| USE-11 | 2 | | | | | | |
| USE-12 | 1 | | | | | | |
| USE-13 | 2 | | | | | | |
| USE-14 | 3 | | | | | | |

# Preliminary Results: Quantitative Metrics

| Household-focused Criteria | | | |
|---|---|---|---|
| **Impact (savings) (IMP)** | | **Health and Safety (HS)** | |
| IMP-1-A | 5 | HS-1 | 2 |
| IMP-1-B | 10 | HS-2 | 2 |
| IMP-1-C | 7 | HS-3 | 2 |
| | | HS-4 | 2 |
| | | HS-5 | 2 |

# Possible Use Cases



Software developers could apply it to develop new BEM or energy audit software as well as improve existing software

Energy efficiency agencies/organizations, program managers and certifying bodies could use this framework to determine and approve energy audit software for use in their energy efficiency programs

# Proposal of Remaining Work

Use a weighted multicriteria decision analysis (MCDA) for scoring different software where the aggregate scores of each criterion in the framework are used as weights

Testing the model with different energy audit software

# Software Selection Criteria for Framework Testing

March 29, 2024

| | |
|---|---|
| Available | Home Energy Saver (HES) Pro by Lawrence Berkeley National Laboratory (LBNL)<br>Home Energy Yardstick by Energy Star®<br>eQuest®, by DOE<br>OptiMiser® by DOE<br>TREAT® by PSD Consulting<br>EnergyGuage® by the University of Florida's Florida Solar Energy Center (FSEC)<br>REM/Rate™ Desktop by NORESCO LLC<br>Weatherization Assistant suite of software (NEAT, MHEA and MULTEA) by Oak Ridge National Laboratory (ORNL) |
| Suitable | REM/RATE™<br>TREAT<br>Weatherization Assistant |

# Template for Software Testing

| Criteria | Software A | Software B | Software C |
|---|---|---|---|
| **General Information** | | | |
| Vendor | | | |
| Targeted User | | | |
| Primary Use | | | |
| Availability | | | |
| **Accuracy** | | | |
| ANSI/ASHRAE 140 standard | | | |
| BESTEST-EX | | | |
| **Simulation Method/Engine** | | | |
| Simulation Method | | | |
| Simulation Engine | | | |
| **Flexibility** | | | |
| Customization | | | |
| Assumption | | | |
| **Comprehensiveness** | | | |
| Variety of fuel types | | | |
| Renewable energy resources | | | |
| End-use energy distribution | | | |
| **Integration** | | | |
| Home automation systems | | | |
| Utility rebates | | | |
| Renewable energy technologies | | | |
| **Scalability** | | | |
| Supports many buildings | | | |
| Multi-location usage | | | |
| Runs on different systems | | | |

# Highlights

A framework of more than 50 factors that should be considered in energy audit software that is approved for use in energy efficiency programs, particularly for low-income households.

The proposed framework can contribute to the development of more effective energy audit software for low-income households.

The proposed framework can help to address some of the most pertinent energy- and non-energy-related challenges of energy efficiency retrofits and energy audit software development.

The framework can be used to score different energy audit software based on their suitability for specific energy efficiency programs.

The proposed framework can contribute to the global NZE target by 2050 by accelerating the deployment of clean energy technologies and improving the energy efficiency of low-income homes.

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# Thank You