# Assessment of Existing OpenStudio Measures: Reviews, Interviews, and Future Developments

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# EXECUTIVE SUMMARY

OpenStudio Measure development is continuously in progress and greatly propelled by the collaborative efforts within the building energy modeling community. To ensure the widespread adoption and benefit of OpenStudio Measures, developers must understand the current status of Measure development and the needs of OpenStudio Measure users. The first step involves a comprehensive review of existing content to prevent redundancy and gain insights into how OpenStudio Measures are used in the building energy modeling community. This knowledge can then be integrated into the Measure development process, and the expertise of practitioners and OpenStudio Measure users can be leveraged to shape future Measures.

Numerous OpenStudio Measures have been created and shared on the Building Component Library (BCL). The BCL is an open-source repository housing various OpenStudio-related resources, including building component blocks, descriptive metadata, and Measures describing modifications to building energy models. The OpenStudio Measures in BCL encompass a wide range of energy conservation Measures from basic lighting power reduction to complex HVAC model transformation. They also enable users to generate customized reports and facilitate the integration of energy simulation with other analytical processes.

This report presents review of 272 currently available OpenStudio Measures in BCL. The OpenStudio Measures were reviewed by category and subcategory. These Measures are summarized by their functionalities and keywords.

To gain insights into how OpenStudio Measures are used in building energy modeling community, interviews were conducted. A total of 12 interview responses were collected from 6 individuals in the industry and 6 individuals in academia.

The knowledge acquired from reviewing the existing Measures and interview results will be integrated into the Measure development process, and the expertise of practitioners and OpenStudio Measure users will be leveraged to shape future Measures.

# 1.  INTRODUCTION

OpenStudio is a versatile software tool kit available for Windows, Mac, and Linux systems designed to facilitate comprehensive whole-building energy modeling using EnergyPlus. OpenStudio is an open-source project that fosters community collaboration, expansion, and adoption within the private sector.

One of the key features within OpenStudio is OpenStudio Measure, which uses the Ruby scripting language to automate the model queries and transformation. In v.3.5.0, phase 1 support for Python was introduced. This scripting capability serves to automate tasks and allows for gradual expansion and customization of the OpenStudio platform [1].

OpenStudio Measures empower efficient and user-friendly manipulation of model structure and simulation results, seamlessly integrated into various project workflows by identifying key input parameters and outputs. This functionality enables creating new opportunities for more cost-effective analysis and granting convenient access to modeling outcomes enriched with expert knowledge and best practices [2,3].

OpenStudio Measure development is continuously in progress and greatly propelled by the collaborative efforts within the building energy modeling community [4]. To ensure the widespread adoption and benefit of OpenStudio Measures, developers must understand the current status of Measure development and the needs of OpenStudio Measure users. The first step involves a comprehensive review of existing content to prevent redundancy and gain insights into how OpenStudio Measures are used in the building energy modeling community. This knowledge can then be integrated into the Measure development process, and the expertise of practitioners and OpenStudio Measure users can be leveraged to shape future Measures.

## 2. OPENSTUDIO MEASURES

Numerous OpenStudio Measures have been created and shared on the Building Component Library (BCL) (https://bcl.nrel.gov/) [6]. The BCL is an open-source repository housing various OpenStudio-related resources, including building component blocks, descriptive metadata, and Measures describing modifications to building energy models. The OpenStudio Measures in BCL encompass a wide range of energy conservation Measures from basic lighting power reduction to complex HVAC model transformation. They also enable users to generate customized reports and facilitate the integration of energy simulation with other analytical processes.

### 2.1 OPENSTUDIO MEASURES IN THE BUILDING COMPONENT LIBRARY

In this section, currently available OpenStudio Measures in the BCL are reviewed. A total of 272 OpenStudio Measures exist, and they are categorized into 11 subcategories:

- Envelope
- Electric Lighting
- Equipment
- People
- HVAC
- Refrigeration
- Service Water Heating
- On-Site Power Generation
- Whole Building
- Economics
- Reporting

Figure 1 illustrates the distribution of OpenStudio Measures across these categories. Most of the available OpenStudio Measures can be classified under the Envelope (30%) or HVAC (24%) categories. No BCL OpenStudio Measures are available in the Refrigeration category.
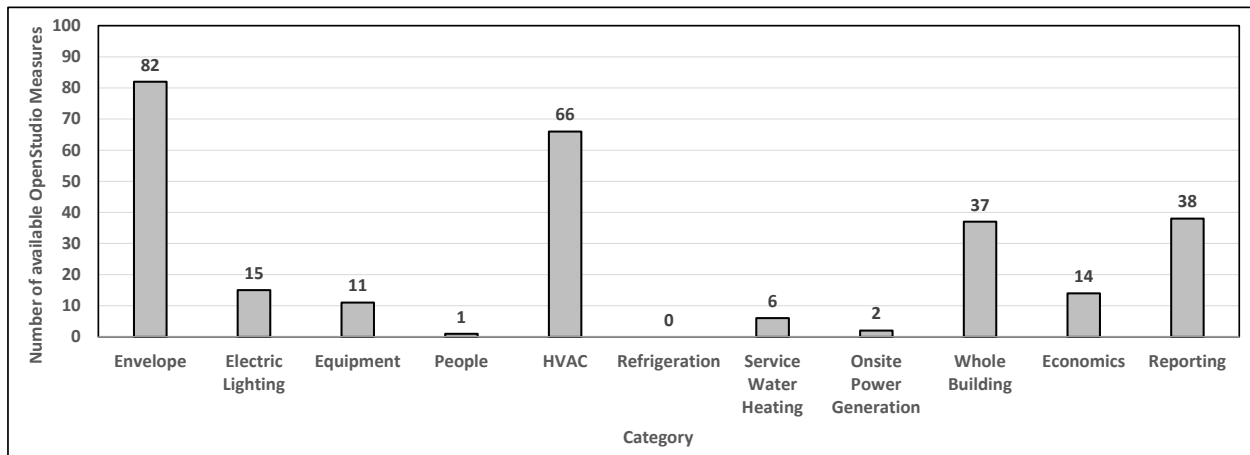


**Figure 1. Distribution of available OpenStudio Measures within each category.**

Each category contains subcategories. Figure 2 represents how these OpenStudio Measures are distributed among the subcategories. Figure 2 excludes the Refrigeration category because no OpenStudio Measures are available in the Refrigeration category.
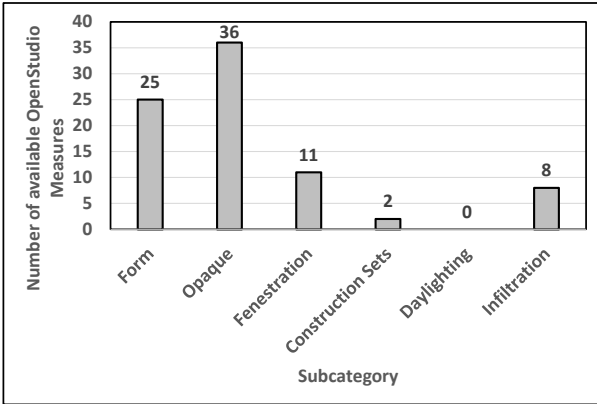
(a)   Envelope
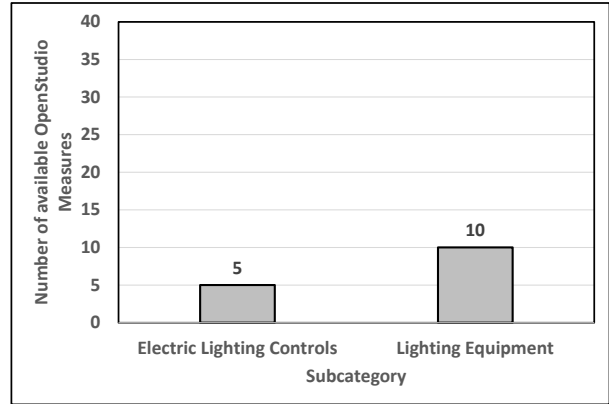
(b)   Electric Lighting
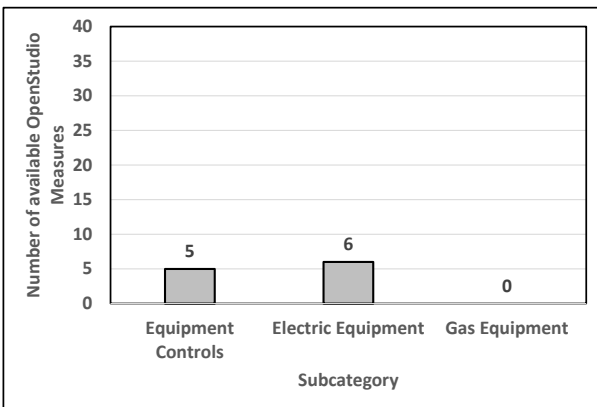
(c)   Equipment
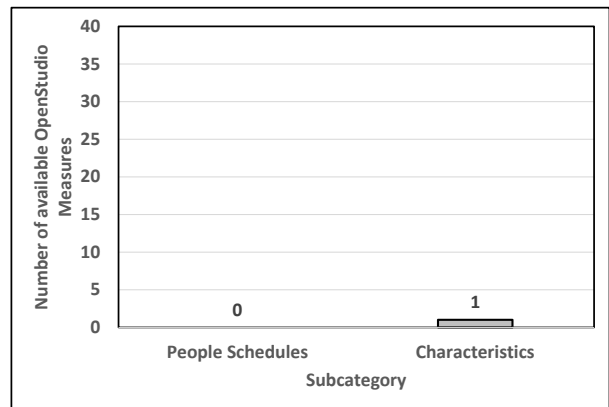
(d)   People
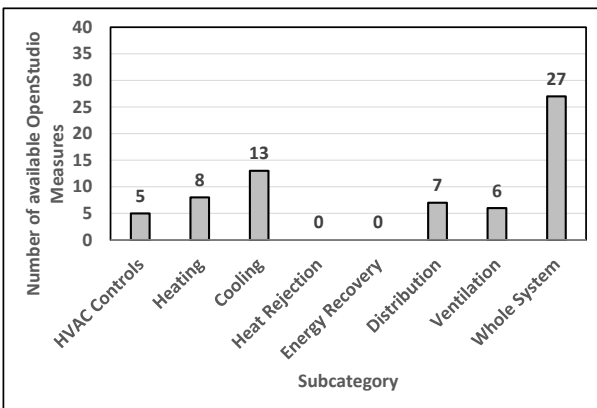
(e)   HVAC
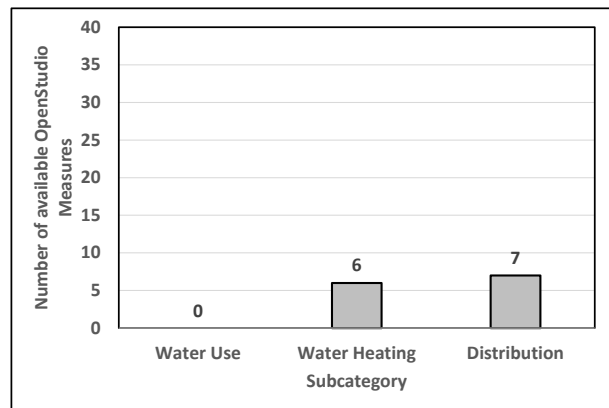
(f)   Service Water Heating
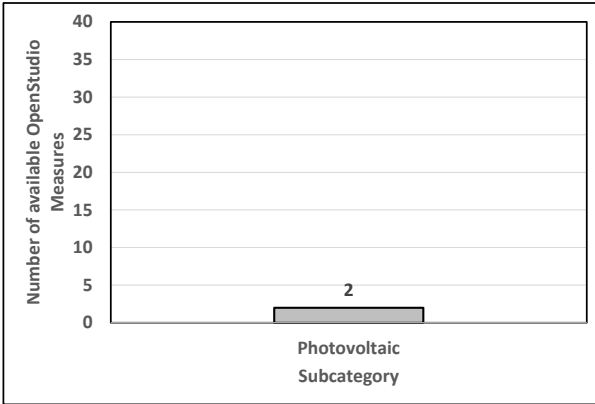
(g) On-Site Power Generation
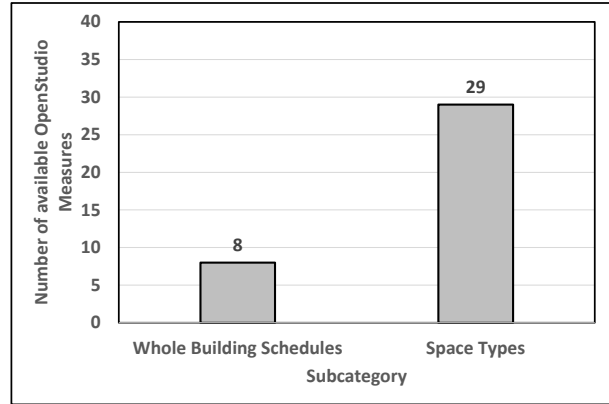
(h) Whole Building
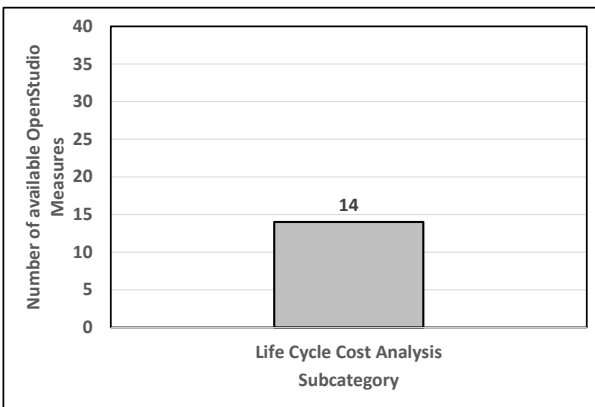
(i) Economics
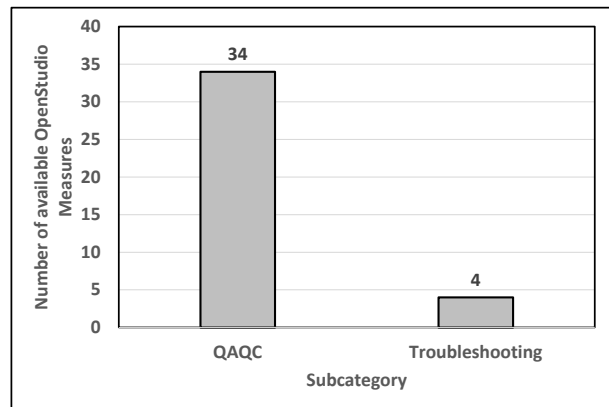
(j) Reporting

**Figure 2. Distributions of available OpenStudio Measures among subcategories for each category.**

The 11 main categories include a total of 35 subcategories. Among these, 11 subcategories do not have OpenStudio Measures. The following is a summary of OpenStudio Measures for each subcategory.

- Envelope
  - Form: OpenStudio Measures related to geometry, space, and orientation (e.g., creating shading surfaces, replacing geometry, rotating buildings, surface matching)
  - Opaque: OpenStudio Measures related to opaque construction (e.g., changing the R-values of walls and roofs; modifying or replacing walls, doors, and roof insulation)
  - Fenestration: OpenStudio Measures related to fenestration (e.g., replacing exterior windows, setting window-to-wall ratios)
  - Construction Sets: OpenStudio Measures related to construction sets (e.g., changing construction sets)
  - Daylighting: No OpenStudio Measures in this subcategory
  - Infiltration: OpenStudio Measures related to infiltration (e.g., replacing or setting infiltration values)

- Electric Lighting
  - Electric Lighting Controls: OpenStudio Measures related to electric lighting controls (e.g., adding daylighting controls, changing lighting schedules)

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- Lighting Equipment: OpenStudio Measures related to lighting equipment (e.g., adding exterior or interior lights, setting lighting power density, reducing lighting load)

- Equipment
  - Equipment Controls: OpenStudio Measures related to equipment controls (e.g., adding controls for electric vehicles or electric equipment, changing electric equipment schedules)
  - Electric Equipment: OpenStudio Measures related to electric equipment (e.g., setting equipment power density, reducing electric equipment load, adding electric vehicle load)
  - Gas Equipment: No OpenStudio Measures in this subcategory

- People
  - People Schedules: No OpenStudio Measures in this subcategory
  - Characteristics: OpenStudio Measures related to the thermal comfort model (e.g., adding thermal comfort models)

- HVAC
  - HVAC Controls: OpenStudio Measures related to HVAC control (e.g., adding rooftop unit controls, changing thermostat schedules, changing fan efficiency)
  - Heating: OpenStudio Measures related to heating (e.g., setting gas burner efficiency; calibrating gas, electric, or water heating coils)
  - Cooling: OpenStudio Measures related to cooling (e.g., adding ice storage, adding economizers, calibrating direct expansion cooling coils)
  - Heat Rejection: No OpenStudio Measures in this subcategory
  - Energy Recovery: No OpenStudio Measures in this subcategory
  - Distribution: OpenStudio Measures related to air distribution (e.g., improving fan and motor efficiency, assigning zones to systems, mixing zone air)
  - Ventilation: OpenStudio Measures related to ventilation (e.g., adding ventilation, reducing ventilation, setting minimum outdoor air flow rates)
  - Whole System: OpenStudio Measures related to the HVAC system (e.g., replacing or removing the HVAC system, changing heating and cooling efficiency, adding ideal air loads)

- Refrigeration
  - Refrigeration Controls: No OpenStudio Measures in this subcategory
  - Cases and Walk-ins: No OpenStudio Measures in this subcategory
  - Compressors: No OpenStudio Measures in this subcategory
  - Condensers: No OpenStudio Measures in this subcategory
  - Heat Reclaim: No OpenStudio Measures in this subcategory

- Service Water Heating
  - Water Use: No OpenStudio Measures in this subcategory
  - Water Heating: OpenStudio Measures related to the water heating system (e.g., adding or replacing the water heating system)
  - Distribution: The same OpenStudio Measures as those found in the Distribution subcategory under the HVAC category

- On-Site Power Generation
  - Photovoltaic: OpenStudio Measures related to PV systems (e.g., adding rooftop PV)

- Whole Building

- o Whole Building Schedules: OpenStudio Measures related to schedules (e.g., removing unused schedules, setting ground temperature, adding schedules, shifting operation hours)
  - o Space Types: OpenStudio Measures related to space types and the simulation model (e.g., assigning space types, changing building locations, creating prototype building models, replacing the simulation model)

- Economics
  - o Life Cycle Cost Analysis: OpenStudio Measures related to cost analysis (e.g., adding costs, setting life cycle cost parameters, adding utility data)

- Reporting
  - o Quality Assurance and Quality Control (QAQC): OpenStudio Measures related to simulation reports (e.g., adding simulation outputs, creating simulation reports, setting units)
  - o Troubleshooting: OpenStudio Measures related to troubleshooting (e.g., removing saved results)

In the Envelope category, 44% of Measures are related to Opaque, 30% are related to Form, and 13% are related to Fenestration. In the Electric Lighting category, 33% of Measures pertain to Electric Lighting Controls, whereas 66% are categorized under Lighting Equipment. Similarly, in the Equipment category, 45% of Measures are related to Equipment Controls, and the remaining 55% are categorized under Electric Equipment. The People category has one Measure, and it pertains to Characteristics.

The HVAC category has a total of 66 Measures with the following distribution: 41% are categorized under Whole System, 20% are related to Cooling, 12% are related to Heating, and 11% are related to Distribution.

The Service Water Heating subcategory has six Measures. Seven Measures are shown under Distribution in Figure 2(f), but these are the same OpenStudio Measures as those found in the Distribution subcategory under the HVAC category. Therefore, all the Measures in the Service Water Heating category are categorized as Water Heating.

The On-Site Power Generation category and Economics category each has one subcategory. Measures in the On-Site Power Generation category are related to Photovoltaic, and Measures in the Economics category pertain to Life Cycle Cost Analysis.

In the Whole Building category, 78% of Measures are associated with Space Types, and the remaining 22% are related to Whole Building Schedules. In the Reporting category, 89% of Measures are focused on QAQC, and the remaining 11% address Troubleshooting.

There are three types of OpenStudio Measures in OpenStudio:

1. Model Measures: These Measures are designed to be executed directly on the building model within the OpenStudio environment.

2. EnergyPlus Measures: Although many functions in EnergyPlus are also available in OpenStudio, some functions are exclusive to EnergyPlus. EnergyPlus Measures are a distinct type of Measure that focuses on leveraging EnergyPlus capabilities and utilize OpenStudio Software Development Kit (SDK) but only allow you to utilize functionality in Workspace, such as IdfObject.

3. Reporting Measures: These Measures are used for generating various types of reports based on simulation results.

Figure 3 illustrates the distribution of available OpenStudio Measures among the different types. Specifically, 82% of the available OpenStudio Measures are Model Measures, 10% are EnergyPlus Measures, and 8% are Reporting Measures.
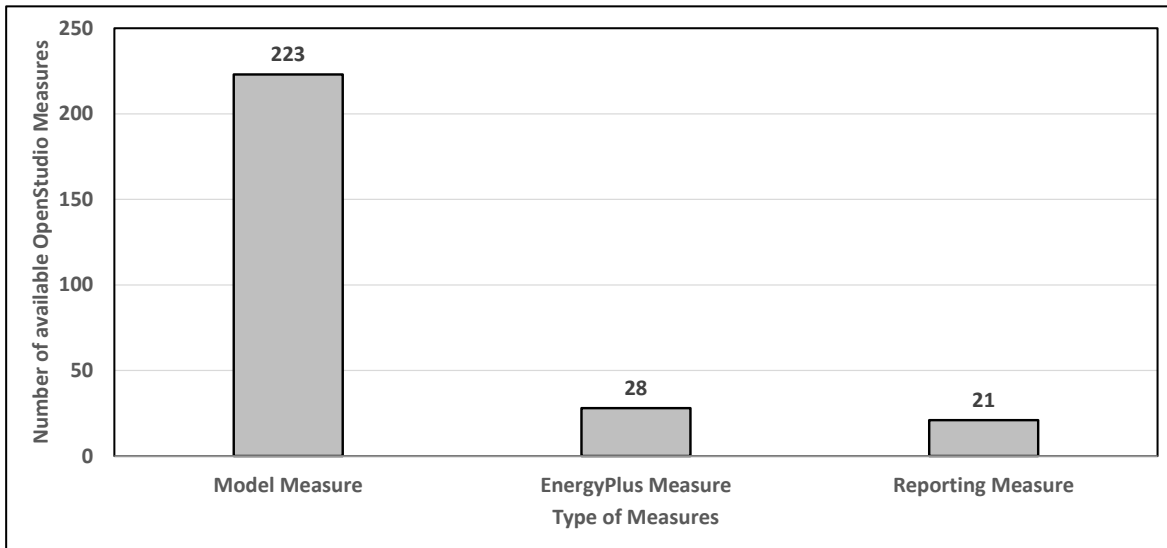


**Figure 3. Distribution of available OpenStudio Measures among types of Measures.**

## 2.2 FUNCTIONALITY ANALYSIS OF BCL OPENSTUDIO MEASURES

The ORNL team conducted a comprehensive review of 272 BCL OpenStudio Measures with the following objectives:

- To provide a concise summary of the definitions and functionalities of OpenStudio Measures
- To improve understanding of the functions and characteristics of existing OpenStudio Measures

As detailed in Section 2.1, the OpenStudio platform initially organized these 272 Measures into 11 categories, further subdivided into 35 subcategories. In this section, the ORNL team systematically grouped OpenStudio Measures into groupings based on their unique functionalities and intended uses. Additionally, the team analyzed keywords extracted from Measure names, definitions, functions, and input parameters to gain deeper insights into the Measures' functions and characteristics.

### 2.2.1 Summary of Functionalities of OpenStudio Measures

This subsection presents a concise summary of OpenStudio Measures based on functionalities. 12 distinct groupings were chosen (Figure 4):

- HVAC System
- Construction/Construction Set
- Simulation Reports
- Building Load
- Space/Space Type
- Simulation Model
- Schedule
- Infiltration/Ventilation
- File (referring to import/export simulation files or other program files)

- Utility
- Control
- Others
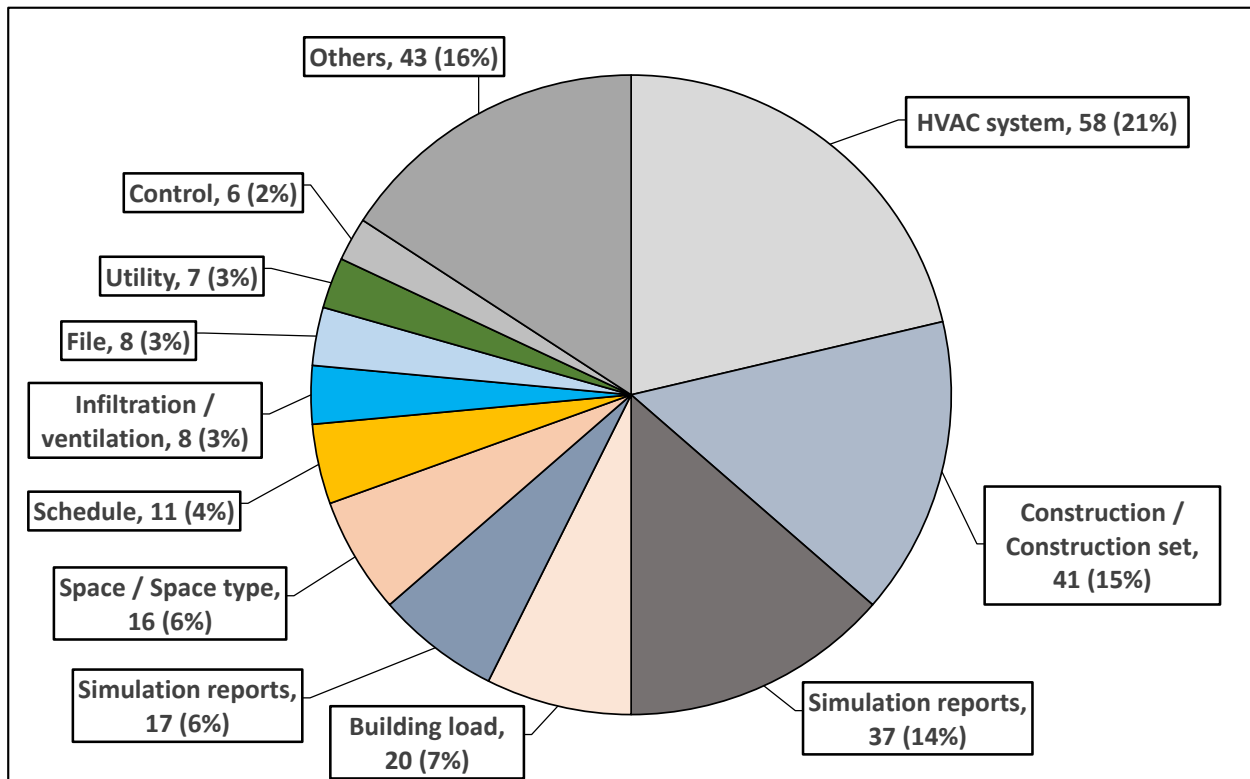


**Figure 4. OpenStudio Measures Functionality Breakdown.**

Table 1 summarizes the functionalities of OpenStudio Measures within each grouping generated by the ORNL team. Across all groups, the common functions of OpenStudio Measures include adding, changing, removing, setting, and replacing the model objects, construction, schedules, and systems. The most common functions are *change construction*, *replace system*, and *add object*. The 'Object' in Others grouping refers to simulation input parameters that are not covered in other groups (e.g., overhang, installation cost, etc.).

**Table 1. Summary of the functionalities of OpenStudio Measures within each group**

| Group | Functionalities | Number of existing OpenStudio Measures |
|---|---|---|
| **HVAC system** | Add system | 5 |
| | Calibrate system | 18 |

| | | |
|---|---|---|
| | Change efficiency | 4 |
| | Change setpoint | 1 |
| | Remove system | 1 |
| | Rename node | 1 |
| | Rename system | 1 |
| | Replace system | 22 |
| | Set a rated COP | 2 |
| | Set air flow rate | 2 |
| | Sizing system | 1 |
| **Construction/Construction set** | Assign construction set | 1 |
| | Change construction | 28 |
| | Detect thermal bridge | 1 |
| | Rename construction | 1 |
| | Replace construction | 6 |
| | Set construction/construction set | 4 |
| **Simulation reports** | Export simulation reports | 2 |
| | Generate outputs | 13 |
| | Generate plot | 3 |
| | Generate report | 15 |
| | Remove results | 1 |
| | Set unit | 3 |
| **Building load** | Add load | 2 |
| | Change load | 15 |
| | Set load | 3 |
| **Space / Space type** | Assign space type | 3 |
| | Calibrate space/space type | 2 |
| | Change space type | 1 |
| | Create space type | 2 |
| | Create thermal zone | 1 |
| | Merge space | 1 |
| | Move space origin | 1 |
| | Replace name | 1 |
| | Set space type | 2 |
| | Set window to wall ratio | 1 |
| | Set zone height | 1 |
| **Simulation model** | Change building location | 1 |
| | Create model | 13 |
| | Replace model | 2 |
| | Rotate building | 1 |
| **Schedule** | Add schedule | 3 |
| | Change schedule | 8 |
| | Set schedule | 1 |

**Table 2. Summary of the functionalities of OpenStudio Measures within each group (continued).**

| Group | Functionalities | Number of existing OpenStudio Measures |
|---|---|---|
| **Infiltration/ Ventilation** | Change infiltration | 3 |

| | Change ventilation | 1 |
| --- | --- | --- |
| | Set infiltration | 4 |
| **File** | Export file | 4 |
| | Import file | 4 |
| **Utility** | Add utility data | 2 |
| | Set parameter | 1 |
| | Set utility rate | 4 |
| **Control** | Add control | 6 |
| **Others** | Add object | 20 |
| | Change object | 3 |
| | Import object | 5 |
| | Remove object | 4 |
| | Rename object | 1 |
| | Scale geometry | 1 |
| | Set ground temperature | 2 |
| | Set run period | 3 |
| | Surface matching | 2 |
| | Test measure | 2 |

### 2.2.2    Keyword Analysis of OpenStudio Measures

The objective of the keyword analysis was to associate OpenStudio Measures with keywords that succinctly characterize each Measure, facilitating a clearer understanding of its function and intended use. To identify and extract keywords from existing OpenStudio Measures, the ORNL team reviewed Measure names, definitions, modeler definitions (referring to definitions for OpenStudio users), functions, and input parameters.

For the 272 OpenStudio Measures, the ORNL team extracted 951 keywords. Figure 5 illustrates a word cloud generated using keywords extracted from the existing OpenStudio Measures. Among these keywords, certain recurrent terms stand out: *cost* appears 75 times, and *AEDG* (Advanced Energy Design Guides) appears 38 times because of Measures related to AEDG for K–12 or office buildings. Additionally, *K–12* is observed 30 times, *schedule* 28 times, and *HVAC* 23 times. Cost is associated with OpenStudio Measures categorized under HVAC Systems, Construction/Construction Sets, Utility, and Building Load.

**Figure 5. Word cloud analysis of keywords extracted from existing OpenStudio Measures.**

# 3. INTERVIEWS

To gain insights into how OpenStudio Measures are used in the building energy modeling community, interviews of users were conducted. The objectives of the interviews were as follows.

- Identify the current use of OpenStudio Measures within the building energy modeling community.
- Gain an in-depth understanding of OpenStudio Measures utilization by industry experts, practitioners, and researchers.
- Incorporate insights from experts and prioritize the OpenStudio Measure development cases.

To facilitate this interview process, a concise questionnaire was made available through an online survey form.

## 3.1 INTERVIEW QUESTIONS

The interview questionnaires were designed for experts and OpenStudio Measure users in academia and industry. The interview questionnaires were structured into four distinct sections:

- Area of expertise: This section aimed to gather information about the interviewee's background and expertise.
- Current OpenStudio Measures uses: This section was designed to understand the interviewee's familiarity with and preferences in using OpenStudio Measures.
- Improvements of current OpenStudio Measures: This section sought feedback regarding suggested improvements of the existing OpenStudio Measure library.
- Development/enhancement of OpenStudio Measures: This section aims to gather insights regarding areas in which OpenStudio Measures may require development or enhancement.

The detailed interview questions are given in Appendix A.

## 3.2 INTERVIEW RESULTS

### 3.2.1 Area of Expertise

A total of 12 interview responses were collected from 6 individuals in industry and 6 individuals in academia. Interviewees could select their areas of expertise from multiple choices, as shown in Figure 6. Specifically, 8 of the 12 interviewees had expertise in HVAC systems and building, and 6 interviewees specialized in policy. There were two responses in the *others* category, which included expertise in software development and utility company energy efficiency Measure design.
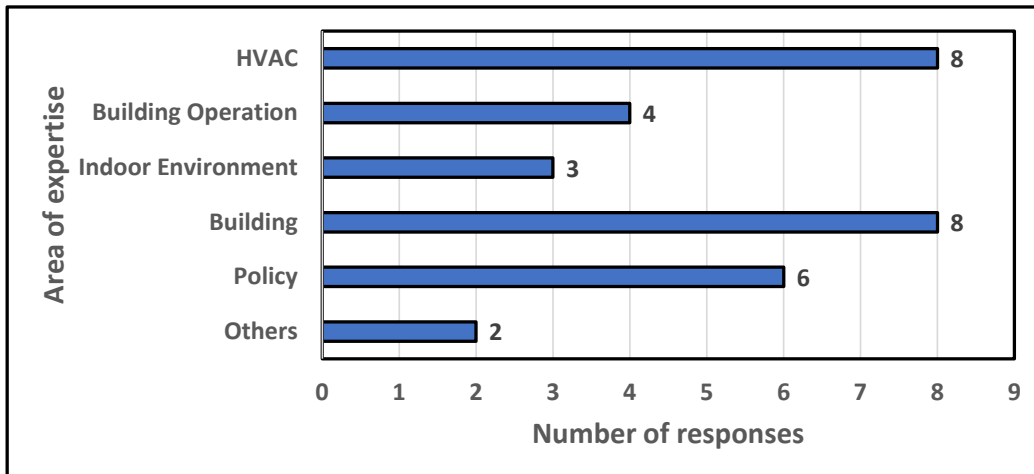
**Figure 6. Interviewees' areas of expertise.**

### 3.2.2 Current OpenStudio Measures Uses

Next, the ORNL team asked about the interviewees' prior experiences with OpenStudio Measures from the BCL. This was done to gauge the interviewees' familiarity with OpenStudio Measures. Of the 12 responses received, 7 interviewees reported frequent usage of the OpenStudio Measures, 4 interviewees used the OpenStudio Measures 1–2 times, and 1 interviewee indicated having no prior experience with the OpenStudio Measures, as shown in Figure 7.
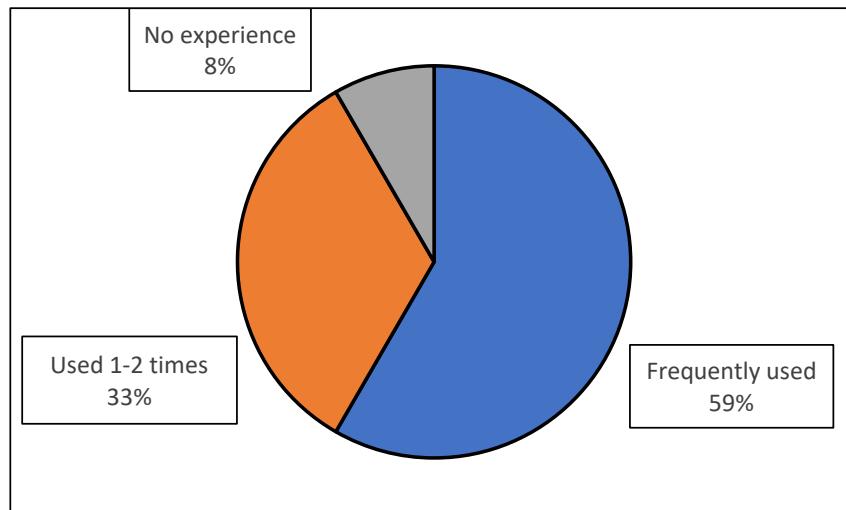


**Figure 7. Experience with OpenStudio Measures from the BCL among interviewees.**

The ORNL team discovered that more than 90% of the interviewees had experience with OpenStudio Measures from the BCL, and 59% of the interviewees reported frequent usage. Given the various methods available for implementing OpenStudio Measures in OpenStudio simulation models, the ORNL team inquired about the sources of OpenStudio Measures that interviewees had used.

Figure 8 shows the sources of OpenStudio Measures used by interviewees. Of the 12 interviewees, 10 used the BCL to incorporate OpenStudio Measures into their OpenStudio simulation models, and 7 interviewees created user-defined Measures that were not available in the BCL. Additionally, 4

interviewees used customized model-alteration code instead of using OpenStudio Measures. Interestingly, 4 interviewees reported using all 3 provided sources of OpenStudio Measures.
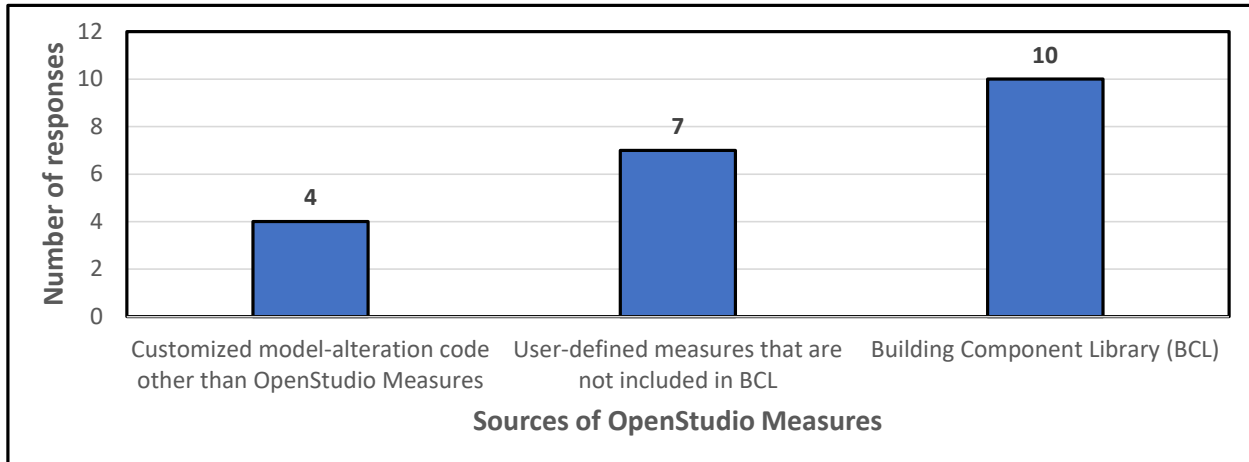


**Figure 8. Sources of OpenStudio Measures used by interviewees.**

### 3.2.3    Improvement of Existing OpenStudio Measures

The ORNL team provided five suggestions to enhance the current OpenStudio Measures library. Interviewees were asked to rate these suggestions on a scale from 1 to 5, with 1 indicating the least-needed and 5 indicating the most-needed improvements. Figures 9 to 13 present the interviewee ratings for each of these suggestions. To determine which suggestions received the highest ratings from interviewees, the ORNL team calculated the average rating for each suggestion:

- More diverse OpenStudio Measure types are needed: 3.5
- More accessible and easy-to-use OpenStudio Measures are needed: 3.9
- More detailed guidelines and documentation for OpenStudio Measures are needed: 4.3
- Incorporating recent technologies/features is needed: 4.3
- Updates to existing OpenStudio Measures with the latest information/data are needed: 4.2
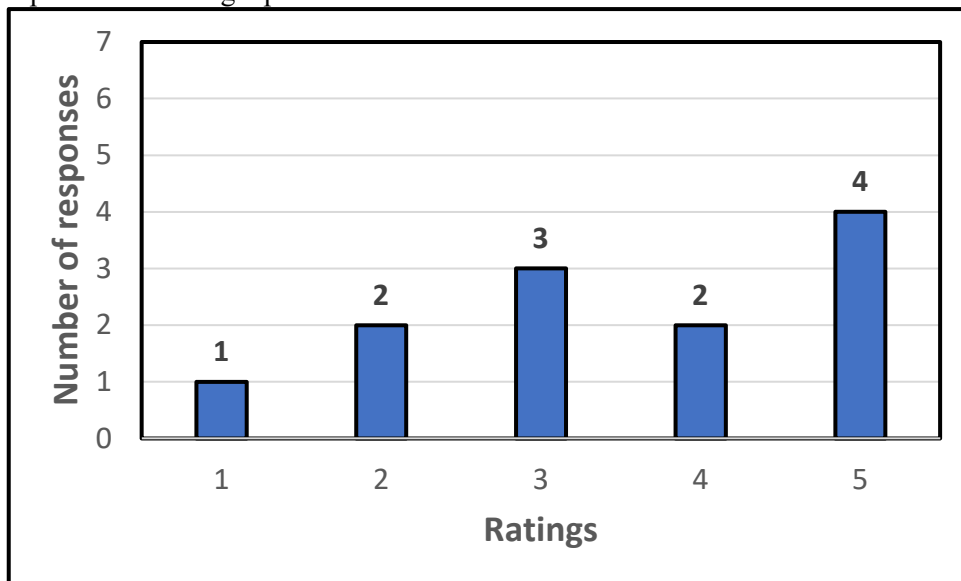
**Figure 9. Ratings for "More diverse OpenStudio Measure types are needed."**
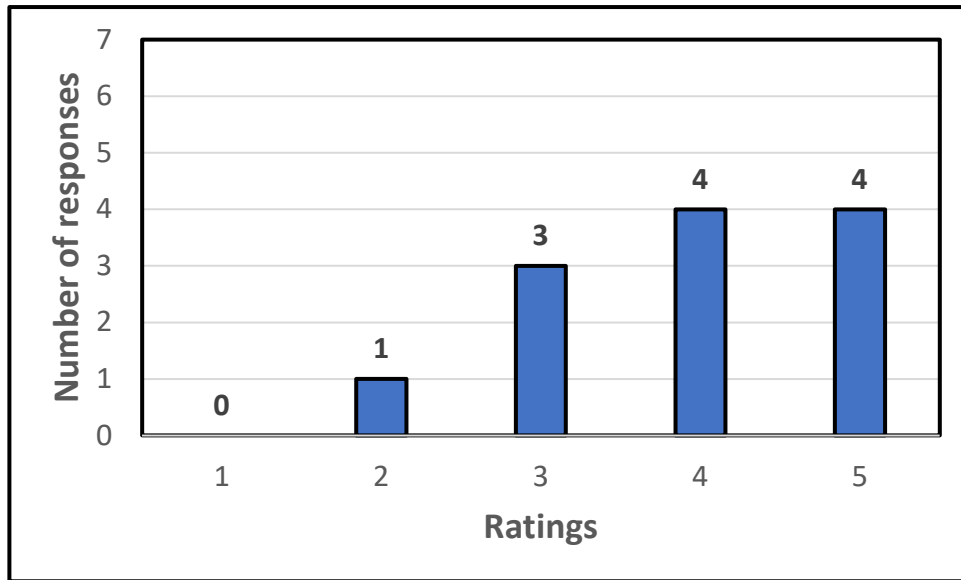


**Figure 10. Ratings for "More accessible and easy-to-use OpenStudio Measures are needed."**
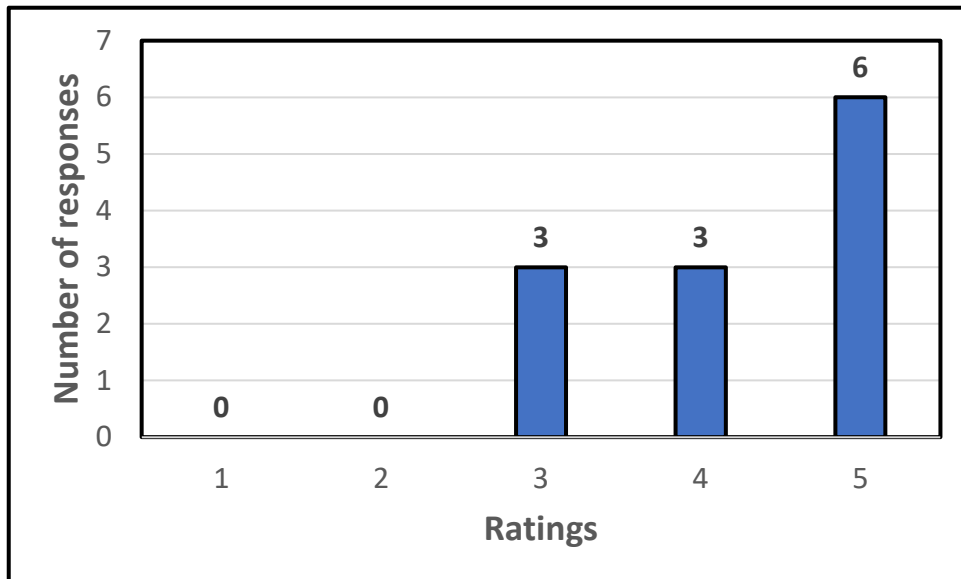


**Figure 11. Ratings for "More detailed guidelines and documentation for OpenStudio Measures are needed."**
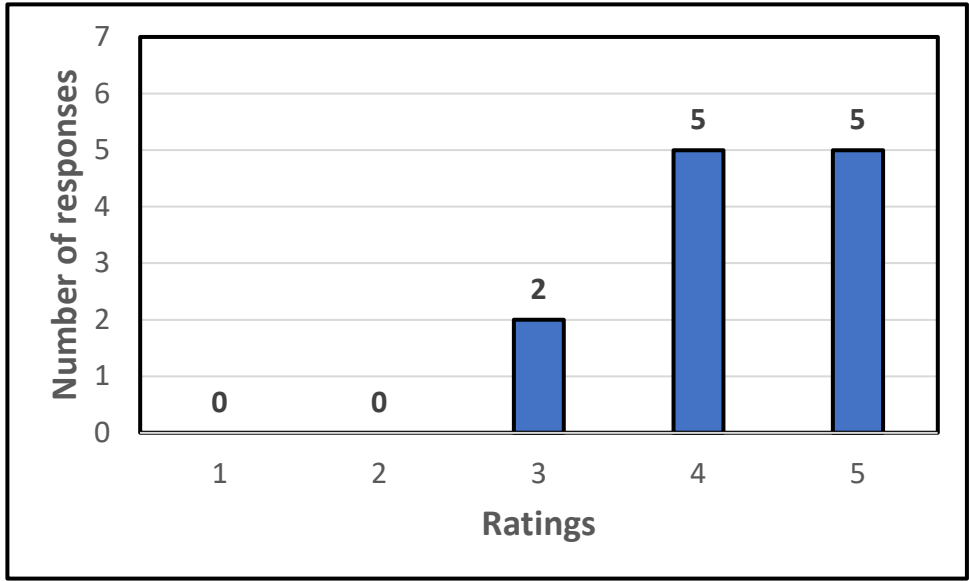
**Figure 12. Ratings for "Incorporating recent technologies/features is needed."**
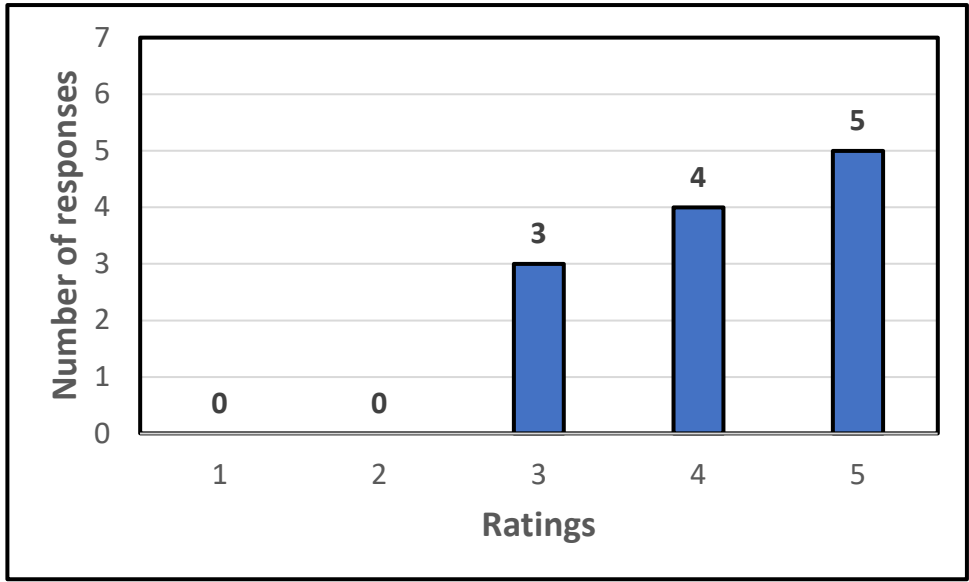


**Figure 13. Ratings for "Updates to existing OpenStudio Measures with the latest information/data are needed."**

In addition, the interviewees provided additional comments to suggest improvements for the current OpenStudio Measures. Many interviewees responded that a best practices guide for authoring OpenStudio Measures is needed. Some users who write custom Measures but do not have GitHub experience have difficulties sharing their customized code on Github. Also, more getting-started documentation, videos, or short online courses on Measure development would be very helpful to new Measure users and new Measure writers. The other interviewees also pointed out that a dedicated collection of well-written Measures that use Energy Management System (EMS) functions would be a great resource for OpenStudio users to understand how EMS can and should be used to extend OS capabilities. One reviewer commented that with respect to OpenStudio Python Measures, a small set of Measures written in both languages would greatly help beginning OS Measure writers to make transitions between the two languages.

### 3.2.4    Development/Enhancement of OpenStudio Measures

### 3.2.4.1    Technology Measures

As stated in Section 3.1, the ORNL team asked about the development and enhancement of OpenStudio Measures. To gain a better and clearer understanding, the ORNL team formulated questions based on the types of OpenStudio Measures. Specifically, concerning technology Measures, the ORNL team generated three potential Measure development scenarios. The interviewees were asked to rate the potential Measure development scenarios using the same scale as in Subsection 3.2.3. Figures 14 to 16 present the ratings provided by interviewees for each scenario.

To identify which potential Measure development scenarios received the highest ratings from interviewees, the ORNL team calculated the average rating for each scenario. The following are the averaged ratings for each potential Measure development scenario:

- Provide accessible OpenStudio Measures that do not require detailed input/information or an understanding of the detailed algorithms: 3.7
- Include recent new-technology-related OpenStudio Measures: 4.3
- Include EnergyPlus objects or newly added features that are not currently supported by OpenStudio: 3.4

To elicit the unique insights and perspectives of the interviewees, the ORNL team also requested interviewees to provide explanations for the scales they assigned. To aid in comprehension, the ORNL team correlated the explanations provided by interviewees with the corresponding scale ratings. Under the following subheadings, the details of how interviewees rated the three scenarios are elaborated, and suggestions made by interviewees for each scenario are provided.

***"Provide accessible OpenStudio Measures that do not require detailed input/information or understanding of the detailed algorithms"***
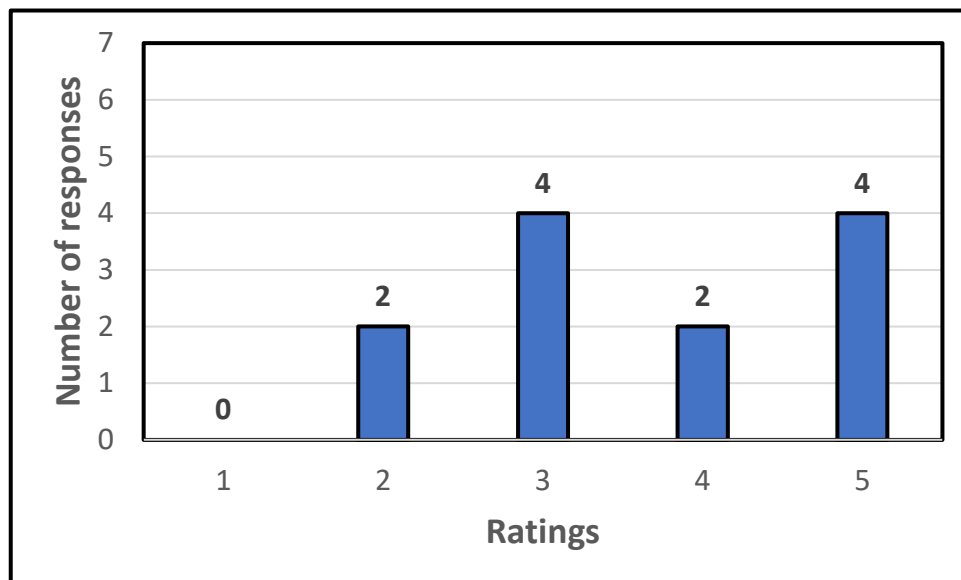


**Figure 14. Ratings for "Provide accessible OpenStudio Measures that do not require detailed input/information or understanding of the detailed algorithms."**

Interviewees who responded with higher ratings commented that the biggest use for Measures is to wrap expert knowledge and judgement into a programmable form that a novice can use. It is also very helpful in the early-stage simulation phase to not require too many detailed inputs when details are uncertain. On the other hand, some interviewees responded that they more focused on thorough justifications of the algorithms behind the Measures to better interpret and validate the results and that detailed input features, detailed references, and/or details sources are needed.

The following are examples of suggestions the interviewees provided for this scenario:

- The Measures should have much better descriptions. For example, the descriptions should include all input fields that are modified or objects that are added, deleted, or modified.
- The Measure should reference a journal article that describes its use in practice, and other publications (e.g., ASHRAE Guideline 36 [6]) that describe its use in theory so that users can learn more about it.
- A simplified approach for a complicated feature (e.g., heat pump and double skin façade) needs to be provided.
- create_typical_building_from_model is a great example. With just a few inputs, it can help a novice create a typical building.

***"Include recent new technology-related OpenStudio Measures"***
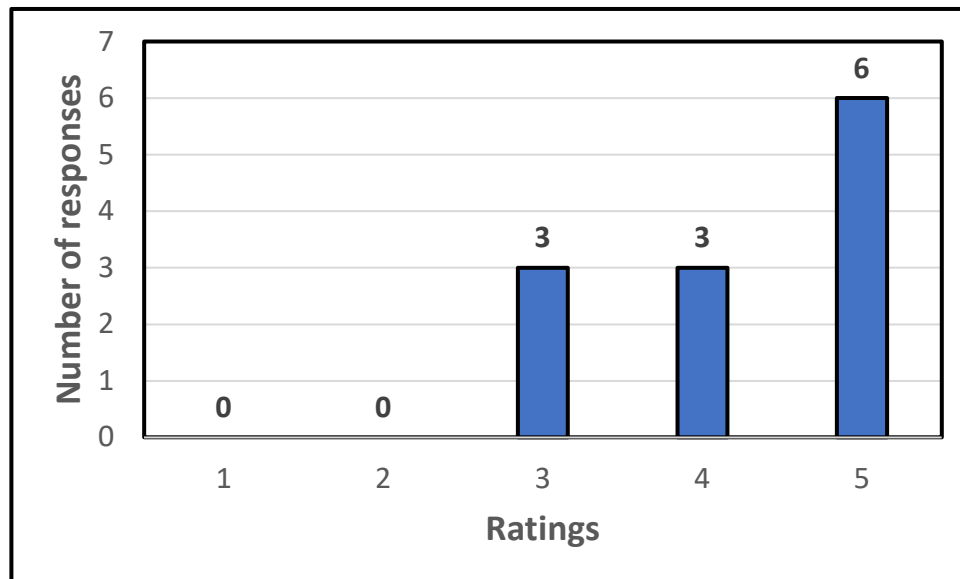


**Figure 15. Ratings for "Include recent new technology-related OpenStudio Measures."**

In general, interviewees gave higher ratings for "Include recent new technology-related OpenStudio Measures." One interviewee responded that efforts to promote investments in decarbonization are shifting the focus of performance analysis toward heat-pump and heat-pump water-heating technologies. New combined heating and hot water equipment is available on the market but not easily modeled. Other interviewees also pointed out that some of the cutting-edge technology-related Measures are not included in the BCL, such as different types of PV panels, green-roof systems, thermal storage (heating, not cooling), chiller heat recovery, and low-temperature heat pumps. One interviewee suggested that an embodied and operational carbon calculation Measure would be good examples to consider.

*"Include EnergyPlus objects or newly added features that are not currently supported by OpenStudio"*
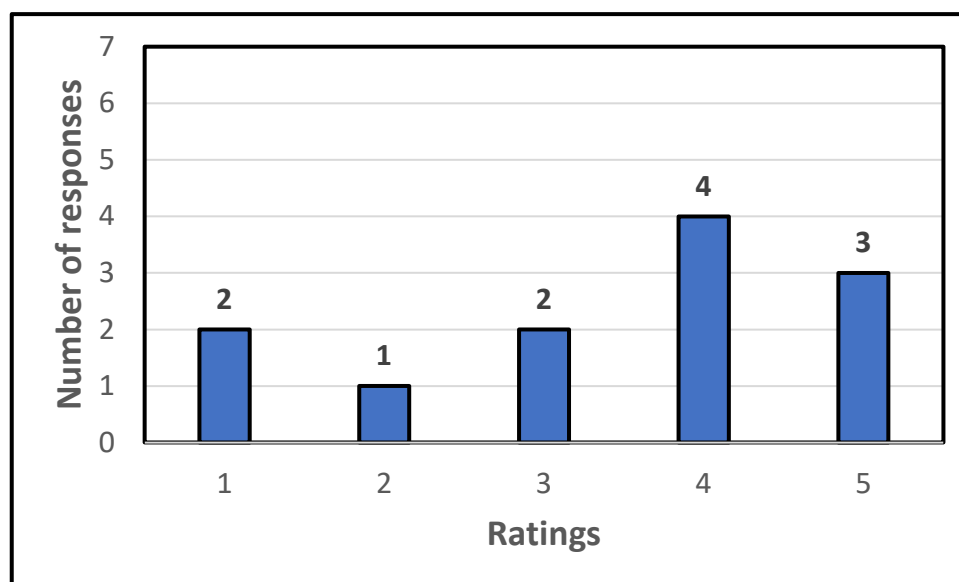


**Figure 16. Ratings for "Include EnergyPlus objects or newly added features that are not currently supported by OpenStudio."**

Some interviewees rated this scenario highly because EnergyPlus and OpenStudio are usually used side by side because some EnergyPlus objects are not available in OpenStudio. Because new EnergyPlus objects have been introduced recently, dedicated resources to wrap the objects and provide OpenStudio Application Programming interface (API) access would be helpful. On the other hand, some interviewees gave a lower ranking because some objects do not work well together, and the benefit of OpenStudio is that it provides a more polished API that manages the detailed pieces of EnergyPlus for the users. The other interviewees pointed out that this feature is applicable to advanced users only.

### 3.2.4.2  Analysis/Reporting Measures

This section discusses the development and enhancement of OpenStudio Measures, focusing specifically on analysis and reporting Measures. The ORNL team formulated three potential Measure development scenarios pertaining to analysis and reporting Measures. Figures 17 to 19 represent the ratings provided by interviewees for each potential Measure development scenario related to analysis and reporting Measures.

As mentioned in Section 3.2.4.1, to identify which potential Measure development scenarios received the highest ratings from interviewees, the ORNL team calculated the average scale for each scenario. The following are the averaged scales for each potential Measure development scenario:

- Produce more comprehensive simulation reports: 3.0
- Provide more visual analysis of simulation results: 3.3
- Introduce supplementary analysis features (e.g., life cycle cost, carbon emission, utility rate, construction cost): 4.3

As in the previous section, the ORNL team also associated the explanations provided by interviewees with the corresponding scale ratings. Under the following subheadings, the details of how interviewees rated the potential Measure development scenarios are described, and suggestions made by interviewees for each scenario are also provided.

*"Produce more comprehensive simulation reports"*
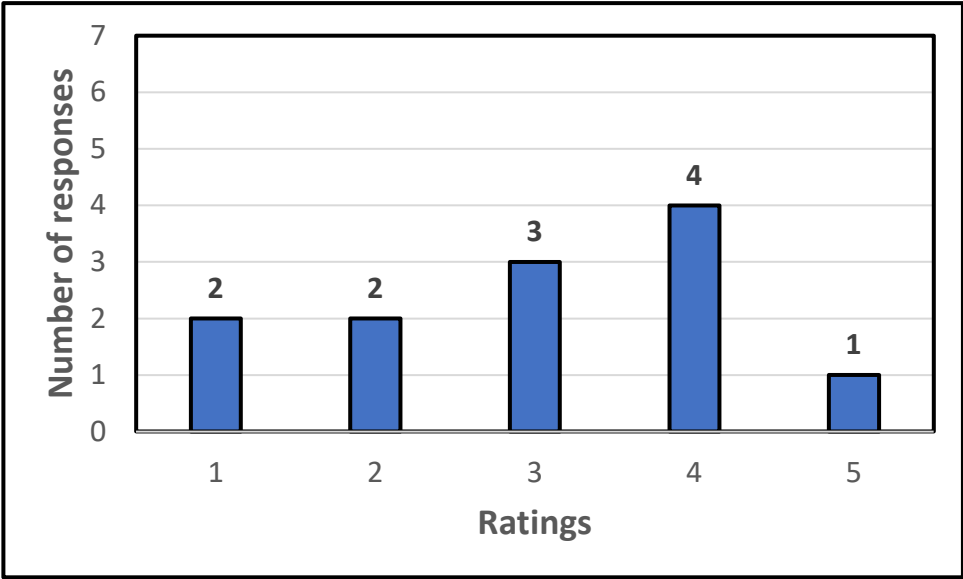


**Figure 17. Ratings for "Produce more comprehensive simulation reports."**

For this scenario, some interviewees gave higher ratings because more comprehensive simulation reports would help users by providing a holistic perspective and interpretations of results rather than simply showing the raw data. On the other hand, some interviewees gave lower ratings because the existing simulation reports provide sufficient detail.

The following are examples of suggestions the interviewees provided for this scenario:

- Reports that leverage common graphical libraries supported by Python should be produced. With the new ability to write Python Measures, presumably many new graphical libraries (PyChart, etc.) are now accessible.
- Reports that leverage EnergyPlus reports should be produced.

*"Provide more visual analysis of simulation results"*
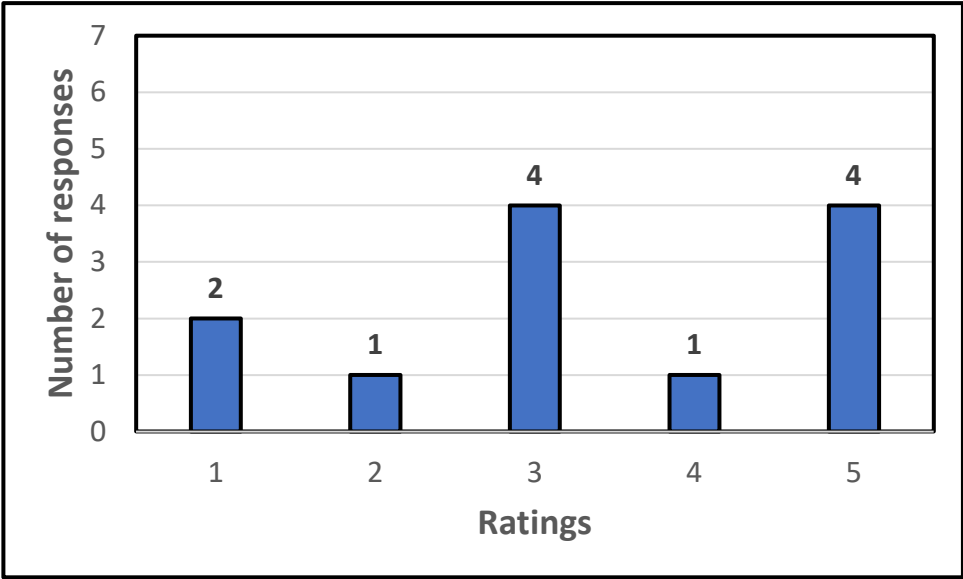


**Figure 18. Ratings for "Provide more visual analysis of simulation results."**

For this scenario, the stated rationale of interviewees who gave higher ratings was that visual analysis is a more practical way to observe and interpret results than tabular report and enables better understanding of the results. On the other hand, some interviewees gave lower ratings because the primary purpose of a reporting Measure is to visualize the output of one data point, and reporting Measures are not as useful when visualization of many data points is needed. The other interviewees also pointed out that visual analysis can be postprocessed by other tools such as Python.

The following are examples of suggestions the interviewees provided for this scenario:

- Reporting Measures need a refresh to use more modern graphics libraries.
- OpenStudio reports should be merged with EnergyPlus reports.
- Generated 2D/3D-based results should be fetched and overlapped over the 3D rendering of the model.
- There should be better flexibility in comparing one or more parameters in Dview, and users should be able to customize the labels and font sizes.

*"Introduce supplementary analysis features (e.g., life cycle cost, carbon emission, utility rate, construction cost"*
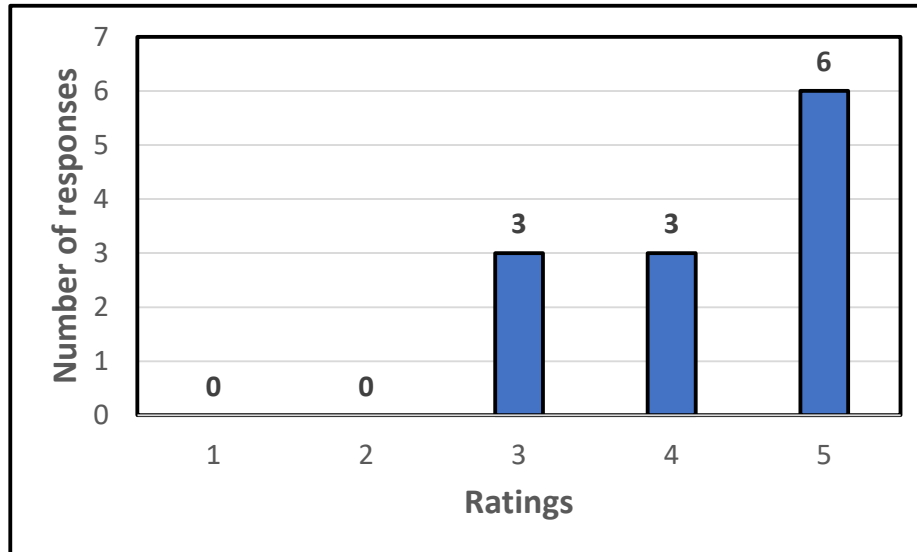


**Figure 19. Ratings for "Introduce supplementary analysis features (e.g., life cycle cost, carbon emission, utility rate, construction cost)."**

Most interviewees gave higher ratings for this scenario. The interviewees commented that the addition of these supplementary analysis features would be beneficial because they are very important Measures in the present context, and all these features (e.g., life cycle cost, carbon emission, utility rate, construction cost) are used in many projects. The rationale for interviewees who gave a rating of 3 was that introducing supplementary analysis features would be beneficial, but that doing so would expand OpenStudio beyond its core purpose (i.e., energy modeling), or the interviewees commented that they have their own rate-analysis tools already.

The following are examples of suggestions the interviewees provided for this scenario:

- Provide a Measure that connects to the Cambium data files for emissions determination.
- Provide a Measure that connects to the Utility Rate Database for utility tariff computations.
- Introducing supplementary analysis features will attract more new users if OpenStudio makes them user friendly. (When this interviewee worked in the industry, they wanted these functions to extend the useability—for example, LCC [LCA] and carbon emission. They stated that utility cost and construction cost are too varied by county, state, and city.)

## 4. DISCUSSION

After a thorough review of existing OpenStudio Measures, the ORNL team identified several areas for further development and improvement.

- Limited types of Measures: Multiple types of OpenStudio Measures currently exist; however, additional types of Measures could be included to expand the current functionality of OpenStudio Measures.
- Limited applicability: Some Measures (e.g., AEDG, Zero Energy Design Guides) are applicable only for certain building types; they can be extended to other building types and space types.
- Need to update Measures: Some Measures require updates to incorporate the most current information available or correct input parameters for their originally designed functions.
- Need for detailed information: Some definitions and modeler definitions lack sufficient detail and require comprehensive explanations for users to grasp the OpenStudio Measures.
- Duplicated Measures: Seven OpenStudio Measures under the Distribution subcategory in the Service Water Heating category are identical to Measures found in the Distribution subcategory under the HVAC category. Consequently, when users download OpenStudio Measures from the Distribution subcategory in the Service Water Heating category, these Measures are automatically placed in the HVAC system category rather than the intended Service Water Heating category. As a result, users cannot use these Measures as intended.

The interview results showed that additional Measures need to be developed or current features need to be improved. Based on the interview results, the ORNL team has prioritized the following tasks:

- Improve existing OpenStudio Measures
  - Provide more detailed guidelines and documentation for OpenStudio Measures
  - Incorporate recent technologies/features
  - Update existing OpenStudio Measures with the latest information/data
- Develop or enhance OpenStudio Measures
  - Include recent new technology-related OpenStudio Measures
  - Provide accessible OpenStudio Measures that do not require detailed input/information or an understanding of the detailed algorithms
  - Introduce supplementary analysis features (e.g., life cycle cost, carbon emission, utility rate, construction cost)

In addition, interviewees said that a more user-friendly interface for OpenStudio is needed and recommended publishing complete workflows made of OpenStudio Measures in addition to the Measures individually. Having a set of OpenStudio Measures that work well together to implement a complete simulation workflow gives users a strong starting point for creating their own parametric studies.

## 5. CONCLUSIONS

OpenStudio Measure development is continuously in progress and greatly propelled by the collaborative efforts within the building energy modeling community. To ensure the widespread adoption and benefit of OpenStudio Measures, developers must understand the current status of Measure development and the needs of OpenStudio Measure users. The ORNL team conducted a comprehensive review of existing content (a total of 272 OpenStudio Measures in BCL) to prevent redundancy and gain insights into how OpenStudio Measures are used in the building energy modeling community. OpenStudio Components, OpenStudio Standards, or other OpenStudio Measure resources are not part of the scope of work.

The team grouped in 12 distinct groupings and analyzed keywords extracted from Measure names, definitions, functions, and input parameters to gain deeper insights into the Measures' functions and characteristics. Of the 272 OpenStudio Measures, the ORNL team extracted 951 keywords; the most dominant keywords were cost, AEDG, K–12, schedule, and HVAC.

To gain insights into how OpenStudio Measures are used in the building energy modeling community, interviews were conducted. The interview results showed a need for developing additional Measures or improving current features. Based on the interview results, the ORNL team has prioritized the following tasks:

- Improve existing OpenStudio Measures
  - Provide more detailed guidelines and documentation for OpenStudio Measures
  - Incorporate recent technologies/features
  - Update existing OpenStudio Measures with the latest information/data
- Develop or enhance OpenStudio Measures
  - Include recent new technology-related OpenStudio Measures
  - Provide accessible OpenStudio Measures that do not require detailed input/information or an understanding of the detailed algorithms
  - Introduce supplementary analysis features (e.g., life cycle cost, carbon emission, utility rate, construction cost)

This knowledge acquired from reviewing the existing Measures and interview results will be integrated into the Measure development process, and the expertise of practitioners and OpenStudio Measure users will be leveraged to shape future Measures.

## 6. REFERENCES

[1] Brackney, L., Parker, A., Macumber, D., and Benne, K. (2018). *Building Energy Modeling with OpenStudio*. New York: Springer International Publishing.

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# APPENDIX A. DETAILED INTERVIEW QUESTIONS

The following are the questions that were included in the interview questionnaire given to experts and OpenStudio Measure users in academia and industry.

1. Area of expertise
    1.1. What is your area of expertise? You can choose multiple categories.
        a. HVAC [ ]
            (e.g., Equipment, design/sizing, control/operation, maintenance, etc.)
        b. Building operation [ ]
            (e.g., Building-to-grid, building control, building data acquisition, energy metering, etc.)
        c. Indoor environment [ ]
            (e.g., Thermal comfort, indoor air quality, occupant-related, etc.)
        d. Building [ ]
            (e.g., building envelope, architectural design, retrofit, building system integration, lighting, construction, etc.)
        e. Policy [ ]
            (e.g., building energy policymakers, building codes, decision making)
        f. Others: _____

2. Current OpenStudio Measure uses.
    2.1. What is your previous experience with OpenStudio Measures from the BCL?
        a. No experience  [ ]
        b. Used 1-2 times  [ ]
        c. Frequently used  [ ]

    2.2. What are your sources of OpenStudio Measures? You can choose multiple categories.
        a. Building Component Library (BCL) (https://bcl.nrel.gov/). [ ]
        b. User defined measures that are not included in BCL [ ]
        c. Customized model alteration code other than OpenStudio Measures [ ]
        d. Others: _____

3. Improvement of the current OpenStudio Measures.
    3.1. What enhancement would you suggest for the existing OpenStudio Measure library to better align with your requirements? Please select from multiple categories and rate your needs on a scale of 1 (least needed) to 5 (most needed).
        a. More diverse OpenStudio Measure types are needed [ ]
        b. More accessible and easy-to-use OpenStudio Measures are needed [ ]
        c. More detailed guidelines and documentation for OpenStudio Measures are needed [ ]
        d. Incorporating recent technologies/features is needed [ ]
        e. Updates to existing OpenStudio Measures with the latest information/data are needed [ ]
        f. Others: _____

4. Development/Enhancement of OpenStudio Measures.
    4.1. Please evaluate potential Measure development scenarios below using a scale from 1 to 5.
        4.1.1. Technology Measures
            a. Provide accessible OpenStudio Measures that do not require detailed input/information or understanding of the detailed algorithms
                i.   Scale: [ ]
                ii.  Please provide a rationale for your scale. _____
                iii. Please provide example(s) of suggestions. _____
            b. Include recent new-technology-related OpenStudio Measures
                i.   Scale: [ ]

      ii.   Please provide a rationale for your scale. _____

     iii.   Please provide example(s) of suggestions. _____

  c.   Include EnergyPlus objects or newly added features that are not currently supported by OpenStudio.

      i.   Scale: [ ]

      ii.   Please provide a rationale for your scale. _____

     iii.   Please provide example(s) of suggestions. _____

### 4.1.2. Analysis/Reporting Measures

  a.   Produce more comprehensive simulation reports

      i.   Scale: [ ]

      ii.   Please provide a rationale for your scale. _____

     iii.   Please provide example(s) of suggestions. _____

  b.   Provide more visual analysis of simulation results

      i.   Scale: [ ]

      ii.   Please provide a rationale for your scale. _____

     iii.   Please provide example(s) of suggestions. _____

  c.   Introduce supplementary analysis features (e.g., Life cycle cost, carbon emission, utility rate, construction cost)

      i.   Scale: [ ]

      ii.   Please provide a rationale for your scale. _____

     iii.   Please provide example(s) of suggestions. _____

If you have any further comments or suggestions regarding OpenStudio Measures, please feel free to share them in the space provide below.