Assessment of Industry Foundation Classes (IFC) in Supporting Building Energy Benchmarking

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Abstract

Building energy benchmarking provides great opportunities for building owners and operators to seek energy efficiency solutions by comparing the energy performance of their buildings with other buildings within their peer group. As more cities, states, and countries are enforcing mandatory building energy benchmarking programs, more building owners are adopting such approaches. However, due to the number and complexity of information items required by current benchmarking tools and the lack of accessibility of average building owners to such information, the benchmarking process can either provide inaccurate results or require the assistance of professional engineers. To solve these problems and streamline building energy benchmarking process, this paper assesses the potential of utilizing Industry Foundation Classes (IFC) for supporting information requirements during benchmarking process. This paper specifically identifies and categorizes information requirements of five benchmarking tools currently used in the U.S., and investigates information coverage of IFC for each tool. The assessment results show that IFC can fulfil the majority of benchmarking information requirements and as a result has the potential to improve the reliability of benchmarking results and streamline the benchmarking process.

Keywords: Building energy benchmarking, Industry Foundation Classes (IFC), Building Information Modeling (BIM), Information requirement

1 Introduction

Understanding current energy performance is an essential step for identifying energy efficiency problems and opportunities in existing buildings. Benchmarking is a process of comparing the energy performance of a building to that of other similar buildings and is often used as part of energy efficiency improvement processes (Hong et al. 2013). By providing energy performance evaluation through comparison, building energy benchmarking encourages building owners and operators to understand their building's relative energy efficiency and establish goals and plans for achieving energy efficiency improvements. According to a recent analysis conducted by the U.S. Environmental Protection Agency, buildings continuously benchmarking their energy use tend to reduce, on average, 2.4% of their annual energy consumption (Energy Star 2015). This evidently highlights the role of energy benchmarking in improving energy efficiency in buildings.

With the aim of achieving more energy savings in buildings, a number of regulatory activities in relation to benchmarking are being executed at the local, state, country, and international levels. Some cities and states in the U.S., such as New York City and Colorado, have passed policies and regulations that require benchmarking and transparency (Institute for Market Transformation 2015). UK and Australia are also example countries which have adopted benchmarking laws to address building energy performance issues (Buonicore 2010). With this world-wide interest and growing legislative efforts on improving building energy efficiency, building energy benchmarking is expected to be utilized heavily across the world.

All benchmarking tools require certain types of information about a building. Types and number of information requirements change amongst different tools, but in general, they include the building's operational features, energy consumption, and its envelop and systems. This information is typically collected and input by either building owners or licensed professional assessors hired by building owners. However, one of the problems in manual data collection and entry is that they can result in inaccurate information and hence unreliable results. Also, confusion and misinterpretation about definition of some information requirements (e.g., "*gross floor plan*") can also result in inaccurate benchmarking result. One research pointed out the high probability of an inaccurate input for 'gross floor area' caused by different interpretations by different users. For example, the Commercial Buildings Energy Consumption Survey (CBECS) by the Energy Information Administration (EIA) in the U.S. uses gross floor area including indoor parking areas, but many commercial real estate industries do not include those in the gross floor area calculation (Buonicore 2010). Even inaccuracies caused by rounding off the floor area are known to produce significant errors in the calculation of the building's energy use intensity (EUI): around 5-10% in general and 14-20% in smaller buildings (Sharp 1998).

In order to address the problems stated above, this paper explores the potential of Industry Foundation Classes (IFC) as an alternative information source for information requirements of building energy benchmarking tools. We first select five benchmarking tools currently used in the U.S., and identify information requirements of each benchmarking tool. Then, we categorize the identified information requirement items and map them with IFC schema. Finally, we analyze how much IFC's cover the benchmarking information requirements.

2 Information Requirements of Current Benchmarking Tools

2.1 Current benchmarking tools

In this paper, five building energy benchmarking tools currently used in the U.S. are selected for comparison of the types and number of information requirements of building benchmarking tools. The tools are selected based on their usage in the market, policy requirements, and developer's reputation. We also intentionally include benchmarking tools targeting both non-residential and residential buildings to evaluate the coverage IFC when supporting benchmarking of both building types.

Based on the purpose of benchmarking, we categorize benchmarking tools into two types: (1) rating-oriented benchmarking, and (2) suggestion-oriented benchmarking. The first type of benchmarking tools provides relative energy performance rating without conducting detailed level analysis of building systems. The second type involves analysis of building envelopes and systems for suggesting possible solutions for improving building energy efficiency. In this paper, we include both benchmarking types. The following paragraphs introduce each benchmarking tool used in this study and Table 1 provides an overview of them.

Energy Star Portfolio Manager, developed by the U.S. Environmental Protection Agency, is the most widely used benchmarking tool for commercial buildings (USEPA 2014). Several states and cities in the U.S. have mandated utilization of it for building energy performance tracking and disclosure (California State Assembly 2007, Council of the District of Columbia 2008, New York City Council 2009, Washington State Senate 2009). The main purpose of Energy Star is to provide relative energy performance score based on comparison with other similar buildings in Commercial Buildings Energy Consumption Survey (CBECS) database. Operational characteristics, such as hours of operation and number of occupants, are normalized for each building to provide fair comparisons.

Building Energy Quotient (BEQ) is a building energy rating program developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). BEQ is designed to provide both ratings and possible energy improvement solutions. BEQ rating program focuses on the building's metered energy use for the preceding 12-18 months, and compares it with normalized median EUIs for all building types in CBECS in order to derive the building's score. Together with the rating, BEQ's assessment also includes an ASHRAE Level 1 Energy Audit, which asks for detailed information about the current status of building such as problems in building system and environmental qualities, to be acquired by professional assessors (Jarnagin 2009).

EnergyIQ is an action-oriented energy benchmarking tool for non-residential buildings, developed by the Lawrence Berkeley National Laboratory (LBNL). It is called 'action-oriented' because it mainly aims at providing building owners possible actions to improve their buildings' energy efficiency. However, unlike BEQ, EnergyIQ does not require professional engineers to assess the building. Users input information about types and characteristics of the HVAC and lighting systems, as well as characteristics of the envelope of their buildings. A set of improvement solutions are suggested based on potential savings and return of investment. EnergyIQ contains whole building benchmarking as well as feature benchmarking, which looks at the equipment-level energy efficiency inside the buildings (Mathew et al. 2008). In addition to CBECS, it also include California Commercial End-Use Survey (CEUS) database for peer group comparison of buildings in California.

Home Energy Yardstick is another tool under EPA's Energy Star program, which is for residential buildings in the U.S. It aims at assessing relative energy performance of residential buildings by comparing them with similar buildings in Residential Energy Consumption Survey (RECS) database. Similar to Energy Star Portfolio Manager, Home Energy Yardstick requires input of information from 12 months of utility bills and to normalize building activities such as number of occupants and average operational hours.

Home Energy Scoring Tool (HEST) is an energy performance rating tool for residential buildings developed by LBNL with the support of U.S. Department of Energy (Bourassa et al 2012). It gives home owners relative score as Home Energy Yardstick does. However, building energy consumption in HEST does not come from utility bills. Instead, it comes from energy simulations based on detailed building features obtained by professionals. Moreover, HEST suggests possible energy efficiency solutions based on professional engineers. Like Home Energy Yardstick, energy performance rating in HEST is derived from comparison with peer group buildings in RECS database.

Table 1 provides an overview of the energy benchmarking tools described above.

Table 1 Benchmarking tools tested in this paper

Tool	**Energy Star**	**Building Energy Quotient**	**EnergyIQ**	**Home Energy Yardstick**	**Home Energy Scoring Tool**
Developer	EPA	ASHRAE	LBNL	EPA	LBNL, DOE
Target	Non-residential	Non-residential	Non-residential	Residential	Residential
Purpose	Rating	Rating & Suggestion	Rating & Suggestion	Rating	Rating & Suggestion
Database	CBECS	CBECS	CBECS, CEUS	RECS	RECS

2.2 Information Requirements of Current Benchmarking Tools

As mentioned in Section 1, building energy benchmarking intends to compare the energy performance of a target building to others. Generally, information about building operation conditions and occupancy activities are required to normalize the building use. Another information requirement of rating-oriented benchmarking is the energy use in the building. This is acquired either directly from metered energy consumption, or from simulation results of a model generated with building envelope and equipment level information. For suggestion-oriented benchmarking tools, detailed information about building envelope and equipment is needed for analyzing energy efficiency solutions.

We summarize the information requirements of building benchmarking tools tested in this paper into six categories. The summary is listed in Table 2.

Table 2 Categories of information requirements of benchmarking tools

Category	Intention	Typical input item examples	Tools requiring this information
General building information	Building identification, location (weather) normalization	Name, City, Zip Code	Energy Star Building Energy Quotient EnergyIQ Home Energy Yardstick Home Energy Scoring Tool
Building activities	Occupancy condition normalization	Gross floor area, weekly operating hours, number of employees	Energy Star Building Energy Quotient EnergyIQ Home Energy Yardstick Home Energy Scoring Tool
Weather	Weather normalization	Heating degree days, cooling degree days	Building Energy Quotient
Metered energy consumption	Energy use information	Monthly bills, annual energy use, meter start date	Energy Star Building Energy Quotient EnergyIQ Home Energy Yardstick
Building envelope	Create building model	Wall construction type, window area, glazing type	EnergyIQ Home Energy Scoring Tool
Building equipment	Create building model	Heating/cooling system type, Heating/cooling efficiency, Lighting system type	EnergyIQ Home Energy Scoring Tool

As shown in Table 2, all five tools require general building information and building activities. Also, all tools, except for Home Energy Scoring Tool, use metered energy consumption information for calculating EUI. Since Home Energy Scoring Tool uses simulated energy consumption instead of actual energy consumption, it requires detailed building envelope and equipment information for simulation purpose. In addition, Building Energy Quotient is the only tool that requires weather information such as heating degree days, cooling degree days, and DOE climate zone. It should be noted that although other tools do not require such information, they obtain weather information from building location information for weather normalization. Lastly, EnergyIQ and Home Energy Scoring Tool also have suggestion-oriented purpose, and as a result information related to building envelope and equipment is required by these two tools.

3 Utilizing BIM for Benchmarking Information Requirement

3.1 BIM and IFC Representation for Information Requirements

Industry Foundation Classes (IFC) are standardized (ISO 16739) Building Information Model (BIM) representation schema developed by buildingSMART. As one of the most comprehensive and prevalent BIM representation to date, IFC has been used to support many application areas within architecture, engineering and construction (AEC) industry. Specifically in relation to the building energy domain, IFC is known to support many information requirements of building energy performance simulation tools, such as EnergyPlus (Bazjanac 2008). In addition, several studies on HVAC system performance analysis and sustainable building rating systems have also shown IFC's potential to support information requirements of various application fields (Liu 2012, Biswas et al. 2008). In this section, we assess IFC's potential to support information requirements of building energy benchmarking by analyzing the coverage of IFC (release 4) in relation to the information requirements of five benchmarking tools described in the previous section.

3.2 Analysis of Benchmarking Information Requirements Coverage

3.2.1 Information requirement extraction

The Information requirements for each building benchmarking tool are extracted either from online tools (Energy Star, EnergyIQ and Home Energy Yardstick) or from information collection forms (Home Energy Scoring Tool and Building Energy Quotient). All online tools were accessed in May 2015 and information collection documents versions of HEST and BEQ are from August 2013 and March 2015, respectively.

Table 3 Summary of the information requirements of different building benchmarking tools

Category	**Number of information items**					
	required	**covered by 5 tools**	**covered by 4 tools**	**covered by 3 tools**	**covered by 2 tools**	**covered by 1 tool**
General building information	25	4	1	2	4	14
Building activities	16	0	0	0	4	12
Weather	5	0	0	0	0	5
Metered energy consumption	50	0	1	3	7	39
Building envelope	62	0	0	0	7	55
Building equipment	121	0	0	0	3	118
Total	279	4	2	5	25	243

The styles and purposes of the five benchmarking tools vary. In order to make the information extraction process consistent among different tools, several decisions were made as following:

- Since Energy Star and EnergyIQ require different information input for different types of non-residential buildings, we decided to consider only the office use.
- Selection of a peer group as required by EnergyIQ is not considered as information requirement for benchmarking given that it is designed for users to define their buildings' peer group without specific rules to be applied.

- Narrative descriptions on the building systems and environments as well as suggestions for energy efficiency improvement based on professional assessors' opinion in Building Energy Quotient are not considered as part of this study since they are not formally represented and reasoned about in the benchmarking tools.
- Similar information items in different tools are considered as different information items. For instance, 'Percent Exterior Glasses' in EnergyIQ is counted as a separate item from 'window area for each direction' in Home Energy Scoring Tool.

Based on these decisions, the information requirements of five building benchmarking tools is summarized in Table 3. From Table 3, it can be seen that information requirements for different benchmarking tools vary significantly. For example, most of the information items in the category of building envelope is required only by Home Energy Scoring Tool to create an energy simulation model. Another example is that most of the information items in the category of building equipment is required only by EnergyIQ to achieve action-oriented benchmarking purpose.

3.2.2 IFC Coverage of Building Benchmarking Information Requirements

After the information requirement of each tool is extracted, we mapped each information item to the IFC schema. We use the label 'Covered' for information items that can be directly mapped to a concept explicitly represented in IFC; 'Derivable' for information items that cannot be directly mapped to IFC, but can be derived from other information in IFC; and 'Not Covered' for information items that are currently not covered or derivable from within IFC.

For instance, 'Year built' is considered 'Covered' by IFC, because the single value property 'YearOfConstruction' in property set 'Pset_BuildingCommon' provides this information. On the other hand, 'Percent Exterior Glass' is considered 'Derivable', because it can be calculated from wall and window dimensions, which are covered by IFC. 'Water meter entry -> Cost' is considered 'Not Covered', because IFC does not contain water tariff information of the building.

Table 4 summarizes the mapping results between information requirements of five benchmarking tools and IFC schema.

Table 4 Building benchmarking information requirements and IFC schema mapping result summary

Category	Number of Information Items			Percentage	
	Covered by IFC	Derivable from IFC	Not Covered by IFC	Covered (include Derivable)	Not covered
General building information	20	1	4	84.0%	16.0%
Building activities	7	9	0	100%	0%
Weather	0	0	5	0%	100.0%
Metered energy consumption	12	3	35	30.0%	70%
Building envelope	37	11	14	77.4%	22.6%
Building equipment	92	5	24	80.2%	19.8%
Total	168	29	82	70.6%	29.4%

As a comprehensive representation of BIM, IFC is expected to cover detailed information about the physical characteristics of the building itself. Amongst the six categories of information requirement, general building information, building envelope and building equipment mostly require this type of information. Some of the information items in the category of building activities, for instance, number of computers, also requires information about physical objects within the building, which can be derived from IFC. IFC also contains general information about building occupancy conditions, which is able to support some information items within the building activities category, for instance, the number of occupants. Thus, it is not surprising to see that IFC covers, directly or indirectly large portion of information requirements in the categories of basic building information, building activities, building envelope and building equipment. However, it does not cover much about weather and metered energy consumption. With the purpose of calculating building energy use intensity, four out of five tools in this paper require detailed actual energy consumption information. Even though some objects and property sets in IFC schema, such as 'IfcFlowMeter', 'Pset_UtilityConsumptionPHistory' and 'IfcTimeSeries' can support some parts of information requirements of metered energy consumption, since updating metered energy usage in the BIM is not likely to happen in most cases, utility bills and meter for each energy source would still be a better information source for providing energy consumption than IFC.

3.2.3 IFC Coverage of Information Requirement of Each Benchmarking Tool

Table 5 shows IFC's coverage for information requirement of each tool. IFC's overall information requirement coverage for each tool is calculated at the bottom of this table. All of the information requirements of Home Energy Yardstick are covered by IFC, showing 100% coverage. EnergyIQ and Home Energy Scoring Tool have around 80% of information requirement coverage, followed by Energy Star and Building Energy Quotient, which has 57% and 56% respectively.

EnergyIQ and Home Energy Scoring Tool are two benchmarking tools that require detailed building envelope and building equipment information. As stated earlier, this information is well represented within IFC, thus, IFC's overall coverage of these two tools is above 80%. Although IFC covered all of the information requirement of Home Energy Yardstick, the dominant reason is this tool only requires 10 information items, and all these 10 items are related to general building information, occupancy conditions and energy usage, which can easily answered by building owners. Therefore, the actual impact of IFC on Home Energy Yardstick is less than EnergyIQ and Home Energy Scoring Tool. In addition, IFC's overall coverage of these Energy Start and Building Energy Quotient are not as good as the coverage of EnergyIQ and Home Energy Scoring Tool. This is mainly because the former two tools do not require envelope and equipment information, but require more detailed information about meter and energy usage.

By looking at the total number of information requirement items covered by IFC within each tool, we can see that EnergyIQ and Home Energy Scoring Tool get more benefit from utilizing of IFC. In other words, the major contribution of IFC in supporting information requirements of benchmarking tools comes from its ability to provide building envelop and building equipment information (the number of items covered by IFC for building envelop and building equipment category is 8 and 86 for EnergyIQ and 45 and 14 for Home Energy Scoring Tool.) One of the biggest challenges in utilizing building energy benchmarking tools is that information requirements of some tools are beyond knowledge level of average building owners. In this case, utilizing IFC to facilitate input of detailed building information, such as types and characteristics of HVAC system, windows and walls, can significantly support building owners who do not have special engineering knowledge or skills and reduce the efforts in gathering and providing this information to benchmarking.

The category that gets the least benefit from IFC is metered energy consumption. Even though some objects and property sets in IFC schema, such as 'IfcFlowMeter' and 'Pset_UtilityConsumptionPHistory' can support some parts of information requirements, most of the items that ask for dynamic information are not covered. Home Energy Yardstick has 100% of coverage in this category because it only requires type, start date, end date, and usage of meters, which can be answered by 'IfcFlowMeterType', 'IfcTimeSeries', and 'Pset_UtilityConsumptionPHistory'.

Table 5 IFC(rel4)'s coverage of amount of information requirements of each benchmarking tool.

Category	Energy Star		Building Energy Quotient		EnergyIQ		Home Energy Yardstick		Home Energy Scoring Tool	
	C	N/C	C	N/C	C	N/C	C	N/C	C	N/C
General building information	17(94%)	1(6%)	11(79%)	3(21%)	10(91%)	1(9%)	4(100%)	0	5(100%)	0
Building activities	5(100%)	0	8(100%)	0	2(100%)	0	2(100%)	0	3(100%)	0
Weather	0	0	0	5(100%)	0	0	0	0	0	0
Metered energy consumption	9(29%)	22(71%)	10(40%)	15(60%)	4(67%)	2(33%)	4(100%)	0	0	0
Building envelope	0	0	0	0	8(73%)	3(27%)	0	0	45(78%)	13(22%)
Building equipment	0	0	0	0	86(80%)	22(20%)	0	0	14(88%)	2(12%)
Total	31(57%)	23(43%)	29(56%)	23(44%)	110(80%)	28(20%)	10(100%)	0	67(82%)	15(18%)

C: covered by IFC, directly or indirectly.
N/C: Not covered by IFC.

4 Conclusion

In this paper, we investigated the potential of IFC to support information requirements of five building energy benchmarking tools. The benchmarking tools tested in this paper include both residential and non-residential building types with purposes of either performance rating or providing energy-efficiency suggestions. Information requirements of all five tools are identified within six categories. The result of mapping between identified information requirements and IFC schema shows that IFC can support information requirements of tested benchmarking tools with coverage from 57% to 100%. Specially, it is shown that benchmarking tools that require detailed information about building envelope and equipment, such as EnergyIQ and HEST, can get the most benefit from utilization of IFC. Although other categories such as general building information and building activities also have high coverage, we conclude IFC has less impact on those categories because the total number of items is relatively small and most of the items are easy to obtain by building owners, as compared to information requirement of building envelopes and pieces of equipment. Also, it should be noted that such tools which ask for information about building envelope and equipment usually are suggestion-oriented benchmarking. Therefore, we can conclude that suggestion-oriented benchmarking tools, such as EnergyIQ and HEST, can take more advantage of IFC than rating-oriented benchmarking such as Energy Star, Building Energy Quotient, and Home Energy Yardstick.

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