Comparing Building Energy Performance Measurement

A framework for international energy efficiency assessment systems

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Executive Summary

Buildings use large amounts of energy, with significant short-term economic and long-term environmental costs. Building energy efficiency, therefore, is a valuable comparative indicator. Yet there is little transparency of energy performance in the real estate marketplace. Attempts to compel building owners to evaluate their energy efficiency have spawned numerous rating tools and assessment programs. But efficiency can be measured in many ways, and methodologies are not standardized.

This paper proposes a classification framework for energy efficiency evaluation tools by comparing seventeen building energy performance assessment systems from ten countries: the National Australian Built Environment Rating System (NABERS), the National House Energy Rating Scheme (NatHERS) and the Australian Capital Territory house energy rating scheme in Australia; EnerGuide, the Canadian Residential Energy Services Network (CRESNET) E-Scale and Real Estate Property Association of Canada (REALpac) Energy Benchmarking in Canada; *Energimærkning* in Denmark; *Diagnostic de Performance énergétique* (DPE) in France; *Energieausweis* in Germany; Building Energy Rating (BER) and Display Energy Certificates (DEC) in Ireland; the Ministry of Housing and Urban and Rural Development (MOHURD) rating in China; *Sistema Nacional de Certificação Energética e da Qualidade do Ar* (SCE) in Portugal; Energy Performance Certificates and Display Energy Certificates in the UK; and the Home Energy Rating System and ENERGY STAR in the U.S.

The unique assumptions and definitions underpinning these systems make it difficult to compare results; direct translation is nearly impossible. But breaking apart the methodological characteristics of each approach enables the systems to be compared and studied. Each system is evaluated by the approach to six basic underlying characteristics: energy consumption, energy type, building floor area, building type, performance scale, and energy uses. This framework reveals that the systems are diverse, and none of those studied uses the same methodology. Upon further analysis it can be concluded that:

- Meanings behind common terms and concepts are poorly defined.
- Performance assessment systems are extremely flexible to local priorities.
- There is consistency in how to define energy quantification methods and energy types, but little consensus on how to define floor area or what energy loads to be included and excluded from assessment.

- It is still unclear how rating methodology and assessment structure affect the success of building energy performance.

Above all, there is a need for closer consideration of what energy efficiency connotes and its evaluation process. Increased understanding and transparency of precisely what is assessed and how it can help real estate investors, multinational corporations, policymakers, and researchers make more informed decisions based on what building energy performance scores truly mean.

Glossary of Acronyms

ACThers	Australian Capital Territory House Energy Rating Scheme
ASHRAE	American Society of Heating, Refrigeration, and Air-conditioning Engineers
BER	Building Energy Rating [Ireland]
BRE	Building Research Establishment [UK]
BREEAM	BRE Environmental Assessment Method [UK]
CEN	European Committee for Standardization
CBECS	Commercial Building Energy Consumption Survey [U.S.]
DEC	Display Energy Certificate [UK and Ireland]
DPE	*Diagnostic de Performance Energétique* [France]
EPC	Energy Performance Certificate [UK]
ESPM	Energy Star Portfolio Manager [U.S]
EPBD	Energy Performance of Buildings Directive
EU	European Union
HERS	Home Energy Rating System [U.S.]
iSBEM	Interface for the Simplified Building Energy Model [UK]
ISO	International Organization for Standards
LEED	Leadership in Energy and Environmental Design [U.S.]
MOHURD	Ministry of Housing and Urban Development [China]
NABERS	National Australian Built Environment Rating Scheme
NatHERS	National House Energy Rating Scheme [Australia]
PCA	Property Council of Australia
RICS	Royal Institute of Chartered Surveyors [UK]
REALpac	Real Property Association of Canada
RECS	Residential Energy Consumption Survey [U.S.]

SCE	National Energy Performance Certification System & Indoor Air Quality in Buildings [Portugal]
UK	United Kingdom
US	United States

1. Introduction

Building energy performance is a measure of efficiency. A more efficient building, making use of fewer energy resource inputs per productive output, minimizes detrimental environmental impacts and maximizes financial return. Considerable research supports the increased value of green and energy efficient buildings (IMT 2012). Energy performance assessment establishes a baseline from which efficiency improvements can be made. As a policy instrument, requiring the disclosure of buildings' energy use can facilitate compliance with energy efficiency standards, inform the planning process for public programs and resources, and stimulate a market response to relative efficiency in buildings.

Methods of assessing energy performance in buildings are diverse and largely local in application. There are only a few energy rating methodologies or systems that can be used in multiple countries. Many are specialized to particular regions or even to particular cities. Overall, there is a lack of understanding of how building energy efficiency compares across markets. In the international real estate market this kind of comparison is increasingly useful for regions to match up building performance and exchange best practices.

This paper proposes a classification for energy performance systems, analyzes 17 systems in ten countries, and clarifies the different meanings and implications behind common terms. The goal is not standardization of systems (although that would certainly be convenient), but rather a standard framework of comparison; a common set of terms and characteristics that can explain any system. The purpose of this paper is to provide a framework for comparison of performance assessment that will be relevant to researchers, real estate companies, and institutional investors.

The classification structure mostly addresses technical and methodological characteristics; however, building definitions are included. Comprehensive "green" ratings, which may include energy as one of many elements of assessment, are explicitly excluded.

First, through an introduction of the history and development of energy assessment systems, we provide context for this analysis. To follow, we outline the methods for classification and then explain the fundamental components of any assessment system and how they differentiate from the systems studied. Finally, with a comparison of how all the subject systems are classified, we provide a conclusion of the findings and applications of this analysis.

1.1 History of Energy Performance Assessment

Monitoring energy systems in buildings has its roots in the 1920s, when mechanical engineers used air flow modeling algorithms to study early HVAC systems (RMI 2010). The practice evolved to tracking heat flows throughout the 1950s and eventually to predicting cooling loads and peak demand (ibid). Following the oil shocks of the early 1970s, energy efficiency and conservation became a clear priority and, aided by the arrival of advanced computer technology, measuring energy performance in buildings gained serious momentum. The Swedish government launched a project in 1977 to estimate energy savings in homes based on utility bills and building characteristics (Santamouris 2005). In 1979, the state of Montana used its own Building Energy Consumption Reporting software to monitor energy performance in public buildings (Computerworld 1979). Energy evaluation methods continued to develop according to cost-containment and energy security imperatives exposed by oil crises.

Thereafter, energy assessments seeded comparative ratings of efficiency. The first home energy ratings in the U.S. were conducted in 1981 by the National Shelter Industry Energy Advisory Council (which became RESNET in 1995). Throughout the 1980s and 1990s the Building Research Establishment (BRE) conducted scores of energy audits across the UK, which served to produce the Domestic Energy Model, a predecessor of current energy rating tools.[1] The U.S. EPA created its ENERGY STAR rating tool for buildings in 1995.

The concept of requiring energy assessments was conceived in Denmark and, although progress was slow at first, it has now spread around the world. Denmark launched its mandatory energy rating systems for commercial and residential buildings in 1992 and 1993, respectively. Momentum increased following the European Union’s Energy Performance of Buildings Directive (EPBD) in 2002, which caused national-level energy rating policies to emerge in 31 European countries. Over the next decade, Brazil, China, Australia, and 24 U.S. states and cities also passed legislation requiring building energy rating.

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[1] In 1990 the BRE also launched its BREEAM standard, progenitor of the LEED and Green Globes systems. These standards offered a more holistic sustainability measure, which mixed with the burgeoning environmental movement to originate the “green building” epithet. Their role in deepening confusion of terms like “rating” in the market place is addressed in Section 2.1.

1.2 Current Policy Landscapes

As a result of all this policy activity around the world, we are left with a diversity of energy rating tools, systems, and policies. This paper studies only systems for assessing energy performance in buildings. However, systems which assess the full environmental impact of buildings, like the well-known LEED program, complicate the terminological landscape. In addition, many words have unique meanings in certain geographic and sectoral circumstances: “rating” could have a disputed meaning between a Canadian and an American or between a developer and an engineer. There is a need both to standardize definitions of terms which are used too broadly and to parse out the different words that exist for the same concept.

There have been efforts to do this for energy performance assessment terminology within Europe, with both the European Committee for Standardization (CEN) Standards and Europrosper glossaries. These tools provide good local standardization, but fall short of defining broader terms which are taken for granted within the European Union. Moreover, standardization is only part of the issue.

Although having a common lexicon is important to communicating between regions, it is equally important to have terms of comparison for actual assessment processes and the resulting ratings or labels. It is not possible to convert an Energy Star rating from the U.S. to an equivalent MOHURD rating from China, but knowing how each was constructed allows for a framework of comparison. By analyzing the fundamental components that all energy assessment techniques address—such as how energy use or floor area is measured—it is possible to create a structure by which to classify them. Understanding this underlying structure allows for a more detailed discussion of the purpose, meaning, and effectiveness of energy performance ratings around the world.

There have been a few notable past attempts and partial precedents for this classification effort. The government of Massachusetts, for example, provided an overview of the select components it deemed relevant to designing an energy performance assessment system in a recent white paper (DOER 2012). The International Organization for Standards (ISO) and CEN have published technical standards for how energy rating methodologies should be designed and notated. But these standards are prescriptions, not tools for comparison or analysis. In methodology, though not content, this paper mirrors more closely the approach from a study by the Building Performance Institute Europe (BPIE 2011), which provided a framework for understanding the varying definitions of “nearly zero energy” by deconstructing the basic components underpinning national standards.

2. Process

2.1 Systems Analyzed

This paper examines systems in place across select and diverse geographies. This diversity makes comparison complicated, but it ensures that the classification is thorough and representative. Understanding that different countries have unique metrics, conventions, priorities, and resources, we chose to analyze those with substantial building stocks and non-voluntary systems in place which are applicable nationwide. The following countries and assessment systems are analyzed:

- **Australia**
    - NABERS, NatHERS, ACThers
- **Canada**
    - EnerGuide, CRESNET E-Scale, REALpac Energy Benchmarking
- **Denmark**
    - *Energimærkning*
- **France**
    - DPE
- **Germany**
    - *Energieausweis*
- **Ireland**
    - BER, DEC
- **People's Republic of China**
    - MOHURD
- **Portugal**
    - SCE
- **United Kingdom**
    - EPC, DEC
- **United States**
    - Portfolio Manager, Target Finder, HERS

There are many potential candidates from the EU (31 have followed the EPBD)[2] but we have chosen the three largest EU economies – Germany, France, UK – and the three systems regarded by many to be the most successful – Portugal, Denmark and Ireland.[3] Systems in the U.S.,

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[2] All 27 Member States are required to certify buildings as a result of the EPBD, and four non-members have also done so.

[3] A variety of analyses have portrayed these three countries (Portugal, Ireland and Denmark) as being the most "successful" in Europe. Generally, success refers to

Australia, and Canada are required at varying levels of government (including municipal, state/territory, and national) and are nationally applicable. The final subject, China, has a nationwide rating requirement and a large, rapidly growing building stock.

2.2 Terminology and Word Choice

Since energy performance assessment is an international phenomenon—spanning languages and cultures—there is a panoply of terms and meanings. Even within the same country, each term may have multiple meanings. The language in this paper has been neutrally standardized, in order to be inclusive and clear. Part of the intent of this analysis is to clarify terms with confusing definitions and the array of international synonyms.

The most important terminology relates to the systems and practice of assessing energy performance. In the U.S. and Australia, "rating" refers indiscriminately to an energy performance assessment structure (rating system), the associated evaluation methodology (rating tool), its use (the actual act or process of rating), and the final result (rating score) (Perez-Lombard). The term "benchmarking" is also used to describe the over-arching assessment system.[4] European standards (CEN) confine "energy rating" exclusively to an efficiency evaluation process; the assessment structure is the "certification" system and the resulting score is the energy "class". Unfortunately, these more precise terms are inapplicable anywhere else (Table 1). The most common definition acknowledged in all the jurisdictions studied in this paper is "rating" as an evaluation of energy performance.

In this paper, as a means to avoid confusion or conflation of terms, the overarching frameworks which govern the evaluation, comparison, and labeling of a building's energy efficiency are called "performance assessment systems". "Performance," usually expressed as relative efficiency, refers to the responsible use of energy. "Rating" refers to the methodology or tool used for the efficiency evaluation; the result of such an evaluation is a "score". The physical product relating this score is a building "label". These terms will be used in such ways for the rest of this paper.

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widespread compliance with certification and consumer trust in the system. For more on these metrics, see BPIE's Energy Performance Certificates Across Europe, IEA's 2012 Policy Pathways report, and ECEEE's Successful EPC schemes in two Member States.

[4] The term "benchmarking" is used as a verb in the U.S. and Australia. In Europe, however, the noun "benchmark" is synonymous with "reference building"—a peer building or its energy performance level which is used as a point of comparison.

Table 1: Energy performance assessment terminology worldwide

	Australia	Canada	China	E.U.	U.S.
Assessment system	Rating	Labeling	Rating	Certification	Benchmarking; Rating
Evaluation methodology	Rating	Rating	Rating	Rating	Rating
Result of evaluation	Rating; Score	Rating; Score	Rating	Class; Rating	Rating; Score
Physical product of assessment	Label	Label	Label	Label; Certificate	Label; Rating; Statement

Note: Analysis based on IMT analysis of terminological reference in research papers, official documents, and actual energy labels.

2.3 System Components

Determining the energy performance of a building is in many ways a subjective process. Semantic distinctions of what critical terms like "energy" refer to end up dramatically affecting the evaluation process and therefore how efficient a building is deemed to be. When performance evaluation becomes an official policy, however, these kinds of definitions are codified, either explicitly or implicitly. The definition and calculation methodology of these variables are paramount for understanding differences and categorizing systems.

By analyzing the policies and methodologies for energy performance assessment in the countries included in this paper, we have created a means of classification for such systems (see Appendix). The classification is based on six fundamental components which impact assessment and are chosen or not chosen when systems are created. The components proposed here are:

- Quantifying Consumption
- Energy Measurement
- Floor Area
- Building Type
- Comparability Metric
- End Uses

3. Classification Criteria

3.1 Quantifying Consumption

The most fundamental and commonly acknowledged distinction among performance assessment systems is how energy use is quantified. Energy consumption figures are generated in one of two ways: They are calculated through modeling software or recorded from actual utility bills. The former approach is carried out with a standard set of building energy use characteristics or a tailored set particular to the building in question; the latter approach can be normalized for use characteristics, like weather and occupancy patterns, that would otherwise skew building performance (Figure 1). This process of producing energy data for performance assessment distinguishes different rating types.

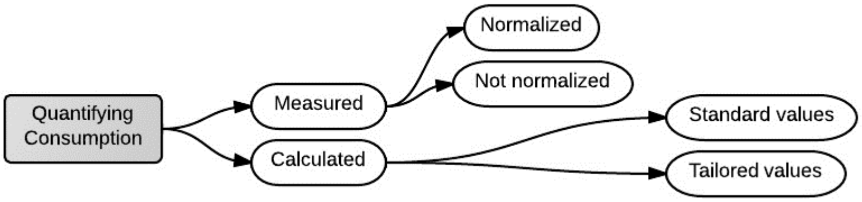

Figure 1: Options for Quantifying Consumption

Methodologies that simulate energy use are referred to as calculated ratings or asset ratings.[5] The word "asset" is intended to highlight the rating as reflective of the inherent energy-performance properties of the physical object of the building itself, as opposed to the dynamic and variable processes of building operation. This measure of building energy consumption is based on approved building modeling algorithms or software (also known as predictive design tools) to simulate energy consumption using inputs for physical and operational characteristics of the buildings (e.g., floor area and occupancy, respectively). When these inputs are standard values,[6] the assessment represents the energy performance of a building under standardized conditions and is often called a *standard energy rating* [7] (IEE-CENSE). With inputs tailored to a specific building, a so-called *tailored energy rating* is valuable in cases where a building is designed for non-standard use or has a unique mix of space types with variable use patterns (Cohen 2004).

A methodology based on actual energy consumption is commonly called a *measured rating* due to the fact that energy use is not estimated but counted by utility meters. Since this approach indicates the efficiency of a building while in operation, it is also referred to as an *operational*

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[5] Other synonyms include predictive rating, demand rating, or theoretical rating.

[6] These standard values are unique to each system, so add another layer of complexity to comparing different calculated ratings.

[7] A standard rating applied to an unbuilt building, performed in the design phase pre-occupancy, is called a "design energy rating".

rating.[8] These ratings are more common in existing buildings, unsurprisingly, and in residential ones which are regarded as more sensitive to occupant behavior. In the same way that a calculated figure can use standardized inputs to estimate consumption, a measured rating can use default inputs to effectively normalize for various operating conditions. Systems are most commonly normalized for weather based on climate zone. Still, normalized characteristics vary by system. For the measured rating in the German certification system, *Energieausweis*, only weather-normalizes energy expended by heating (Concerted Action 2011) while the US's ENERGY STAR rating normalizes all energy uses.

Normalization is usually applied to the actual property being evaluated, but that is not always the case. In the UK's EPC system, weather adjustments are made to reference buildings (also known as "benchmarks" in the EU), normalizing them to the building being evaluated. As a result, benchmarks in the UK are geographically and annually changeable, but building consumption is never altered for normalization purposes (Cohen 2007).

Energy performance assessment policies customarily use a measured or calculated rating to serve unique policy objectives. Knowing how efficiently a building is used in practice, as opposed to a virtual simulation, is simpler, costs less, and allows for better tracking of progress over time. Policies requiring measured ratings tend to affect commercial (and particularly office) buildings and focus on smaller geographic areas. However, as measured ratings reflect particular operational practices, they are difficult to use to compare buildings under very different management.

Using the two types in tandem is a preferable solution, and likely the direction performance assessment will head in the future. It creates better accountability for performance (since operators can compare performance to forecasts) and strengthens the financial justification for energy efficiency (i.e., enables property appraisal to be more complete). If it were easy, it would already have been attempted. But only China's MOHURD system requires both calculated and measured ratings, and the two are not yet successfully integrated (Mo et al). In order for a calculated and measured rating to be relatable, they must be calibrated to shared metrics, assumptions, and methodologies. At present, several projects (like the State of Massachusetts' Building Energy Asset Labeling Program) are pursuing this goal of integrated rating types.

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[8] Other synonyms include metered, performance-based, or consumption-based rating.

3.2 Energy Measurement

Inherent in evaluating building energy use is a definition for what constitutes consumption—determining from where along the utility supply chain energy use is measured. Most rating tools measure total energy: the amount expended at the building site as well as losses in the generation and transmission processes. Which individual loads (e.g., heating, appliances) are typically included is discussed later (Section 2.8). Others, especially when evaluating actual usage data, measure delivered energy: the amount consumed by the building at the meter level. Most rating systems will take into account the net energy consumed by subtracting any on-site production. Some account for final energy, which is a measure of the actual consumption value from a building's end uses, and site-generated energy (Figure 2).

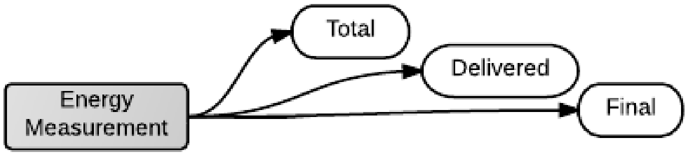

Figure 2: Energy Measurement options

Both IEA (International Energy Agency) and ASTM (formerly American Society for Testing and Materials) define total energy as the amount of fuel that is required to operate a building and incorporates energy consumed by the production of electricity as well as losses due to transmission and delivery. To connote the inclusion of the energy losses between the point of origin and point of use, total energy is also referred to as source energy in the U.S. In the EU, energy is described as either primary (fuel energy) or secondary (converted from fuel energy). Measuring building energy use in primary energy is fundamentally the same as using total (or source) energy, because both count the fuel resources consumed in energizing a building. Measuring consumption with secondary energy is rare since it accounts only for units of converted fuel rather than all resources consumed at the building site.

Delivered energy refers to the energy supplied to a building system to satisfy its end uses. It is also called demand energy since, for performance assessment purposes, it measures the energy consumed at the building level or past the point it crosses the system boundary. Delivered energy is not to be confused with final energy, which is used, largely in the EU, to describe the ultimate amount of energy consumed at a building's individual end uses. It is therefore also commonly called useful energy.[9]

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[9] Certain publications have used the terms bought energy or consumed energy as well, although delivered energy itself is commonly measured by the energy "bought" through a building's utility bills.

Some assessments also measure the energy contribution of on-site generation in these calculations. Non-renewable energy sources converted on-site will be taken into account, affecting the delivered but not total energy figure. On-site renewables are generally included, although the EU's official standards let individual countries make that decision. A further breakdown of energy use distinguishes net energy from delivered by subtracting the energy produced on site and supplied back to the grid.

The chosen energy type that is evaluated in an assessment system depends ultimately on local policy objectives. A system which uses delivered or final energy is more likely to appeal to the economic sensibilities of end users who can control what they use. One which uses total energy is more likely to send a broader environmental message on the impact of building energy use. Still, it is common for an assessment system to use different energy types in combination. In China's MOHURD system, all energy labels include scores based on both delivered and total energy; Energy Star in the U.S. and NABERS in Australia use a measured rating to evaluate delivered energy but the tools extrapolate from that a total energy figure which is used to calculate a building's score.

3.3 Floor Area Measurement

Buildings are almost universally quantified in floor area, but assessment systems, and corresponding national industry standards, measure this differently. For any particular rating, building area can be defined exclusively as conditioned floor space or as a combined figure including both conditioned and unconditioned space. Thereafter, the space can be measured in gross, net, or rentable square feet. Different jurisdictions have their own requirements for what is counted in each of these measurement types.

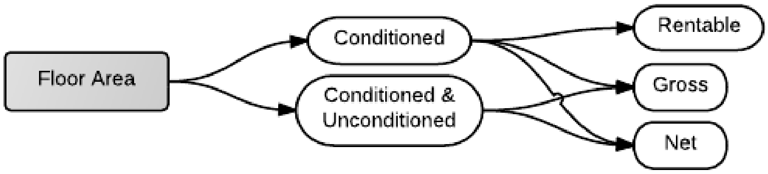

Figure 3: Floor Area options

Unfortunately, there are often manifold definitions of these floor area measures—even within single countries or for particular assessment systems.[10] Specific space inclusions are spelled out in detail by national building codes, standardizing bodies (e.g. ASTM, CEN) or building

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[10] There are also definitions codified by tools and systems. The BASIX system in New South Wales, for example, excludes bathrooms, garages, and other spaces from its measure of conditioned area (www.basix.nsw.gov.au).

industry standards (e.g. PCA, RICS). But there are fundamental distinctions among definitions used in performance assessment which reflect particular environments and policy objectives.

Generally, conditioned space is that which is subject to mechanical heating or cooling; the rest is unconditioned. Part of the trouble with knowing where to draw the line for the sake of energy performance comes with pseudo-interior spaces, like porches and garages, where energy is still often consumed. Unconditioned space is usually included to ensure the entire physical structure is accounted for and to reduce confusion. This is the standard in most jurisdictions. Exceptions include the DPE system in France and HERS in the U.S., which define residential buildings by only their conditioned space. This policy choice reflects the large proportion of residential energy consumption devoted to conditioned space—52 percent of total energy use, compared to 30 percent in commercial buildings.[11] Other exceptions include countries like Denmark and Australia, where all buildings are measured with conditioned space, which promotes consistency.

Beyond conditioned or unconditioned space, gross floor area is the crudest measure of building size. It usually accounts for the full footprint of a building, measuring from the outside face of external walls. Gross area is used where registering the whole building is important and used in systems with both asset and operational ratings. It is far easier for enforcement and tracking, since public records rarely use the alternatives.

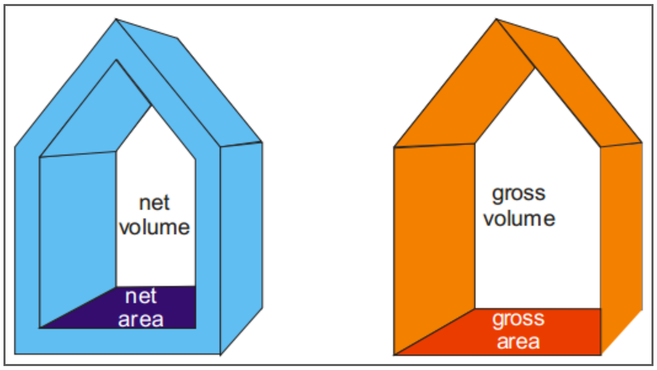

Figure 4: Net & Gross Space (source: ASHRAE Building EQ-Symposium)

Net floor area is a smaller measurement, used as an approximation of occupied area. It can include deductions for internal walls as well as some internal spaces—each calculation process has its own specific exclusions—but, overall removes the thickness of buildings' walls from the area calculation (Figure 4). Net is less popular than gross in the studied performance assessment systems, but where used it is universally applied. For all building and rating types, the German

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[11] EIA Annual Energy Outlook 2011: CBECS and RECS data from 2009.

Energieausweis system uses so-called "net gross" floor area: the sum of all areas treated thermally within a building minus the interior and exterior walls (Cohen et al 2007).

Rentable floor area, also called "lettable" or "leasable" area, represents the revenue-generating space within a building. There are variations in types of rentable floor area calculations, particularly in the treatment of common spaces and service areas. Rentable area is particularly relevant for rating tools covering large multi-tenant, non-residential, and large multifamily buildings; and has the pro-business benefit of aligning with common terminology in the commercial real estate sector. Australia's NABERS program is designed for rentable floor area, but measures differ by building type. Hotels are sized by number of guests; homes by number of occupants. NABERS offers unique space type-related labels, too. This promotes accountability and removes market barriers to disclosing efficiency scores.

Whatever the measure of building size, or its approximation, alignment with industry standards is of critical importance. Part of the difficulty lies in the incorporation of floor area into other aspects of performance assessment. For example, if a database of surveyed buildings' consumption is used as the metric of comparison (see Sec. 2.7), the size of those buildings should be measured in the same way.

3.4 Building Type

The methodologies behind efficiency evaluation are tailored to particular building types. Building age, ownership, and use pose unique challenges which affect assessment design. For example, on a practical level, it is impossible to measure energy consumption in a building that has yet to be constructed. On a mechanical level, energy consumption patterns in non-residential buildings are vastly different from those in residential ones. From a political perspective, the nature of what energy uses are publicized in an efficiency score can be a sensitive privacy issue for private homes or public facilities. Given these considerations, it is important to note what types of buildings are evaluated by a particular system. This classification covers three main distinctions for a building type: new or existing; private or public; and non-residential, residential single-family or multifamily (Figure 5).

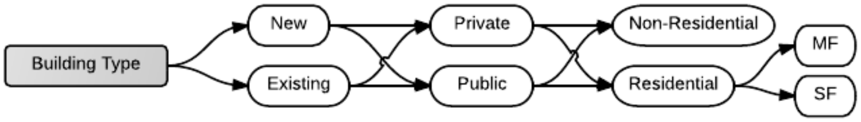

Figure 5: Building Type Options
("MF" is Multifamily;[12] SF is single-family)

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[12] There are many definitions of "multifamily" in the jurisdictions studied. But, in any case, there is always a distinction between single- and multifamily stock.

The age of a building is an important building type distinction for an assessment policy. Most obviously, a new building has no utility bills before operation. But assessing performance in new buildings can help reinforce other regulations: many EU countries are tailoring certification to efficiency standards for new construction. Additionally, certain ages of building stock are better suited to particular assessment procedures and should be evaluated differently for the sake of saving on cost, time, or accuracy. In France, for example, buildings built before and after 1948 are evaluated with different rating methodologies.

The difference between "new" and "existing" is largely self-evident. The more challenging question, however, is when does a "new" building become an "existing" one? The definition is explicit in Australia, where the national Commercial Building Disclosure law defines an "existing" building as one that has held a certificate of occupancy for two years. In general, though, a new building label can only be issued once since efficiency labels have a limited shelf life.

Table 2: Validity period of ratings in selected national assessment systems.

Country	AUS	DEN	FRA	GER	IRL	PRC	POR	UK	U.S.
System	NABERS	Energimærkning	DPE	Energieausweis	BER	MOHURD	SCE	EPC/ DEC	ENERGY STAR
Calculated Rating	-	5	10	10	10; 2*	1*	10; 6[†]	10	1*
Measured Rating	1	-	10	10	1	5	-	1	1

* For new buildings. [†] For "public" buildings (see Table 3 for complete definition).
Sources: Concerted Action EPBD Report, 2010; Mo et al 2010.

The renewal periods of efficiency labels vary by country and by rating type (Table 2). In Europe, certificates must be renewed at least every 10 years, according to the EPBD. In Denmark and Portugal they are renewed often. Generally speaking, systems using operational ratings are renewed more often, since producing a score is relatively easy and these assessments are meant to reflect day-to-day operation.

The second important building type distinction is the difference between "public" and "private". This delineation is not standardized among different countries. Yet, public buildings are frequently subject to markedly different requirements for energy performance assessment, making comparison difficult. In countries with specific requirements for public buildings, a formal definition must be established (see Table 3). Some differences are dramatic. In China, for example, public buildings include all non-residential buildings—a unique concept compared to the French definition which is restricted to government agency buildings.

Table 3: National definitions of "public building" for the purposes of energy performance assessment.*

China	All non-residential buildings, such as government-owned office, private-sector office, hotels, schools, hospitals, airports and shopping centers, etc.
Denmark	"A building used for public administration; institutions, companies and associations with expenses covered by public means; and publicly-owned companies."
France	"Building occupied by any government body."
Germany	"If public authorities or other organizations deliver public services for a large number of persons and the building has an area which is larger than 1000m."
Ireland	Any public body, authority, or institution set up by government enactment, including local governments and institutions of public health and education.
Portugal	"Every non-residential building over 1000 sq meters owned by private or government bodies."
UK	"Occupied by public authority and by institutions providing public services."

Sources: Concerted Action EPBD Report, 2010; Mo et al 2010; Ireland Statutory Instrument No. 243 of 2012. Quoted passages come directly from official documents.
**The U.S., Canada, and Australia are not present in the table because, while there may be standards for buildings owned by the federal governments in these countries, there are no laws requiring performance assessment of the entire public sector.*

Although the notions of land ownership and the roles of government differ across political landscapes and cultures, the international definitions of "public", with regard to energy performance assessment, is not a pure translation issue. In Europe, the EPBD law requires that "public buildings"—but not private ones—prominently display their performance labels. The term "public", however, can be locally defined. Portugal took the opportunity to define all non-residential buildings as "public"; in France a building must be occupied explicitly by a government body to be public; in other places, schools, public housing, and other civic buildings qualify.

Finally, this classification reduces building use types to two options—non-residential and residential. While there are obviously many more sub-types, this singular distinction is sufficient to understand the majority of ratings used in international assessment systems without overly-complicating the analysis. There are varying definitions of what constitutes “commercial” space—in certain business environments, multifamily residential buildings would qualify—so here we have opted for “non-residential”, a term which covers a broad set of uses. Although specific rating methodologies vary based on the fundamental differences in space uses, the systems analyzed here subject all non-residential building types to the same type of assessment (ie. using the same standard for floor area, energy type, comparability, etc.).

3.5 Comparability Metric

Any assessment system needs a metric of comparison in order for efficiency scores to be relevant. There are two types of standards of comparison. An absolute reference point is based on a single objective number; a relative reference point is based on the performance of peer buildings. This benchmark can be constructed in two different ways: derived from either statistical data analysis (a statistical standard) or from a hypothetical building with a particular energy profile (a simulated standard). A simulated building, in turn, can be created according to the characteristics of a typical building in the market, a building built to minimum codes, or some other customized condition (Figure 6).

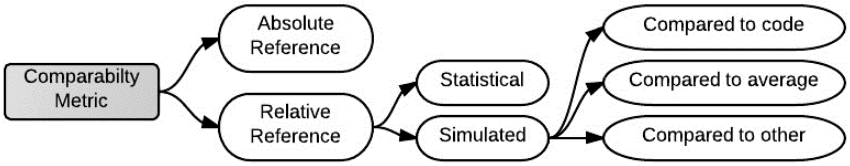

Figure 6: Comparability Metric options

Building performance systems using an absolute[13] standard are defined in reference to a single value, providing a common metric for diverse buildings. Systems in Germany, France, Ireland[14] and Denmark use an absolute reference point of zero kWh per square meter. An absolute standard is better suited to a policy stance highlighting an end goal (like Net Zero Energy). It is useful in jurisdictions where there is an energy performance requirement or thermal regulation (the latter term is common in Europe, where such schemes usually govern only heating/cooling systems). For example, in Denmark the energy performance assessment system is pegged to consumption rates defined in the Danish Building Regulation.

Conversely, a relative standard uses reference buildings as the metric of comparison, expressing performance in relation to a comparator building. Ideally, reference buildings share the same basic

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[13] Also called a “technical” standard.

[14] This only applies to non-residential buildings under Ireland’s BER system.

characteristics as the building being evaluated, with basic parameters like climate zone and building type considered the minimum required constants (Perez Lombard et al). A relative standard enables buildings to be compared more effectively to the market at large.

Reference buildings for a relative standard can be generated in two ways. Most commonly, they are the result of a statistical average from a complex set of building energy use data.[15] Databases of surveyed buildings form the backbone of many performance metrics: CBECS[16] in the U.S. and TM46[17] in the UK underpin the relative standards behind the ENERGY STAR and DEC systems, respectively. Such statistical comparisons are limited to the performance of buildings in the population, however, and require a complete database from which a statistically-significant figure can be drawn. Not all jurisdictions have the luxury of a large dataset of building energy performance and construction characteristics.

Reference buildings can also be generated through simulation, using default values for certain key inputs. Such a simulated standard can create a scale of comparison based on particular code or market standards. In the UK's EPC system, for example, the National Calculation Methodology allows buildings to be rated using the Simplified Building Energy Model (iSBEM) tool, which uses two unique simulated benchmarks. Both benchmarks have the same size, shape, orientation, and use patterns as the evaluated building, but one is a notional benchmark, which is simulated to meet minimum standards (ie. code), and the other is a typical benchmark, which is simulated to reflect an average existing building with an emissions rate of 233 percent over 2010 code (Aggerholm et al).

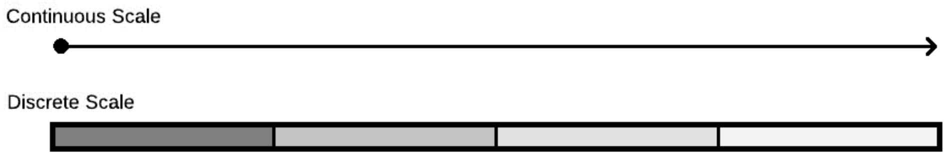

Figure 7: Continuous and discrete scale visualizations.

All metrics of comparison are expressed on a scale when scores are attributed and labels produced. Scales must be calibrated to the relevant building stock and be either continuous or discreet in structure. With a continuous scale, values can fall anywhere on a number line; with a discrete scale, there is a limited number of categories into which

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[15] For this reason, many sources—including publications from ASHRAE and the Massachusetts Department of Energy Resources—use the term "statistical standard" in the place of "relative standard".

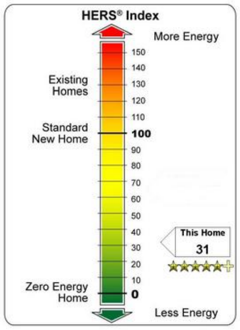
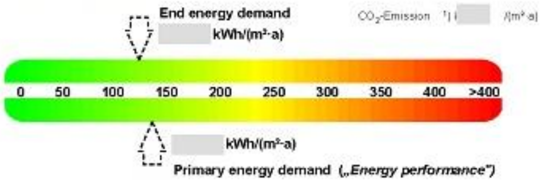
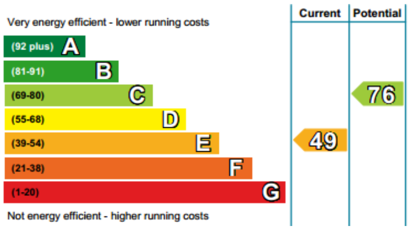
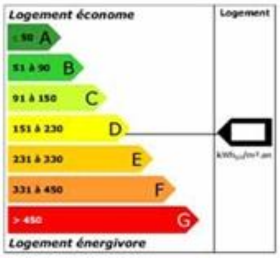
[16] The Commercial Building Energy Consumption Survey, published by the Energy Information Administration in the U.S.

[17] A publication of the UK's Chartered Institution of Building Services Engineers.

all values are grouped (this is illustrated in Figure 7). Energy performance on a continuous scale could be any number (usually a consumption figure) in a given range, while on a discrete scale performance falls into only a few categories (often from A to G) of relative performance. These two scale types are simply design choices, but the difference can affect the success of entire policies. Research from the European Union, for example, suggests a continuous scale proves to be more confusing to homeowners in Europe (IDEAL 2012).

Relative and absolute standards can appear with either a continuous or discrete scale (see Table 4). The American HERS rating scale is a continuous scale using a relative standard—homes are placed on a number line which represents a percentile of relative performance. Germany's *Energieausweis* and France's DPE are based on absolute consumption numbers, but the former uses a continuous scale and the latter a discrete one. And the EPC scale from the UK is split into lettered categories which represent performance relative to a benchmark emissions rates.

Table 4: Examples of metrics using combinations of different standards and scales.

	Relative Standard	**Absolute Standard**
Continuous Scale	 HERS (U.S.)*	 Energieausweis (Germany)
Discrete Scale	 EPC (UK)	 DPE (France)

Source: CA-EBPD Country Reports 2010.

Continuous scales allow for better differentiation of the best and worst energy performers since these buildings' scores are not lumped together in broadly inclusive categories of relative performance (ASHRAE 2009). Yet it is more difficult to illustrate comparative performance. Discrete scales are a challenge for performance assessors and raters. If a property's performance lies near the border between categories, for example, it is possible for different evaluators to assign a dramatically different performance with only slightly different results.

3.6 End Uses

Energy performance assessment systems do not always evaluate every activity which consumes energy in a building. An end use in this sense refers to a type of activity or process which ultimately consumes energy in a building. It can also be described as energy need or energy load. Broadly speaking, the major building end use types are cooling, hot water heating, heating, lighting, mechanical ventilation, and plug and process loads (Figure 8). The end uses evaluated in an assessment system can be a major distinguishing factor.

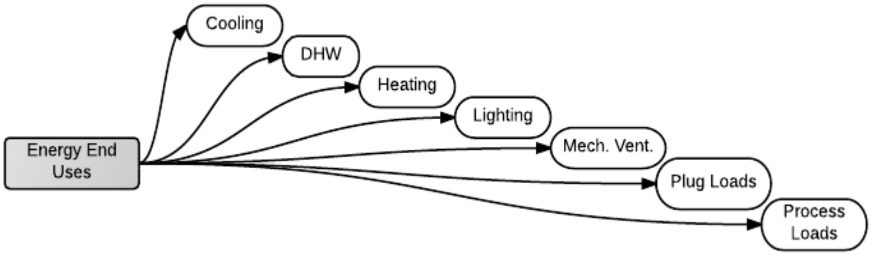


Figure 8: Energy End Use options
(DHW is Domestic Hot Water)

End uses are defined in numerous standards, largely with international consensus. The definitions with least consistency are *plug loads* and *process loads*. Often the two are lumped together to include anything not accounted for in the other five categories, covering uses as diverse as cooking appliances, computers, elevators, and refrigeration equipment.[18] The distinction is less relevant in this study, as the systems analyzed included or ignored the pair together.

The conventional delineation distinguishes between end uses which are essential to building operations and those which are more subject to occupant behavior. In the US, the distinction is drawn by which end uses are regulated in most energy codes and standards: thus, the terms *regulated* and *unregulated energy* are common. In Europe and elsewhere, the distinction is between energy used for heating and cooling a space--*thermal energy*—and everything else (*electrical* or *mechanical energy*). Both terminologies describe the same principle, but

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[18] According to U.S. Department of Energy, ASHRAE, and the Center for the Built Environment at UC-Berkeley, plug loads are a subset of process loads. Process loads constitute any energy uses which are not essential to building function, such as appliances, elevators, or industrial equipment. plug loads are uniquely powered by traditional AC outlets—generally encompassing appliances and personal electronic devices (CBECS 2010).

can actually include some different uses in different places. In the US, *regulated energy* generally excludes only plug and process loads. But in some cases, *thermal energy* may exclude lighting loads (mainly for commercial buildings) or domestic hot water loads (generally for residential ones).

Assessment systems differ in the inclusions and exclusions of particular end uses to be measured in a building. This can dramatically affect perceived performance. Most measured ratings will include all energy consumption because utility bills rarely parse out end uses. Calculated ratings select which components of energy use will be figured into a consumption model, and commonly exclude uses like plug loads and lighting which are considered largely occupant-dependent. Calculated ratings will model end uses that are regulated—this almost always includes heating, cooling, mechanical ventilation, and hot water heating. Some calculated ratings make exceptions: in China's MOHURD system, hot water heating is excluded; France's DPE system overlooks mechanical ventilation.

Conventions can vary with respect to different building types. While most commercial building energy modeling software ignores plug and process loads, HERS in the US includes projected energy use for both. Another calculated rating system, SCE in Portugal, evaluates only heating, cooling, and hot water heating for residential buildings but includes mechanical ventilation, lighting, plug and process loads for commercial ones. Ultimately, the nature of end uses considered reflects the conventions and priorities of the policymakers and energy professionals who designed the assessment systems in their region.

4. Conclusion

Comparing international building performance assessment systems is an ongoing challenge. This classification is meant to deepen the understanding of how performance assessment methodologies are constructed. Breaking apart the methodological characteristics of numerous systems enables them to be compared and studied, although not directly translated or equated.

Building performance assessment systems in different countries are unique. Comparing building labels or scores is rarely feasible, but it is possible to compare their underlying systems based on the treatment of certain fundamental components. An analysis by these characteristics (a visual comparison of the seventeen systems treated in this paper can be found in the Appendix) proves that none of the studied assessment systems are the same. Some obvious trends emerge: calculated ratings typically measure total energy; almost all systems assessed heating, cooling, and hot water heating; measured ratings rarely evaluate residential buildings. More surprisingly, however, this classification decouples rating components often thought to be synonymous and shows the diversity of the systems studied. For example, some calculated ratings include plug and process loads and some do not; many measured ratings assess primary energy; absolute performance scales are used for many calculated and measured ratings; and no consensus on how floor area is measured, even among similar rating types, is apparent.

Parsing out the individual characteristics of each system increases transparency in energy performance assessment. For the real estate industry, the value of a greener, more energy-efficient asset is easier to ascertain with an understanding of how these characteristics are quantified. While this classification does not allow building-to-building comparisons, it enables the real estate community to peek behind the curtain of energy performance and make determinations about what is important to them. For policymakers and researchers, the relative success of building energy efficiency policies depends partly on how assessment systems are designed. This framework facilitates evaluation and analysis by making clear what assumptions and objectives underlie existing systems.

It is still unclear how rating methodology and assessment structure affect the success of building energy performance. There is no consensus on what success looks like, either. Widespread, accurate, and publicly-accepted energy labels are independent indicators. But a first step towards policy comparison is speaking the same language, comparing assessment programs by universal criteria, and fostering an understanding about underlying assumptions and priorities.

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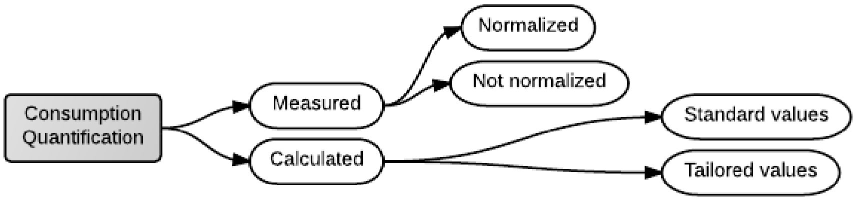
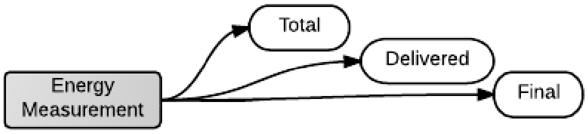
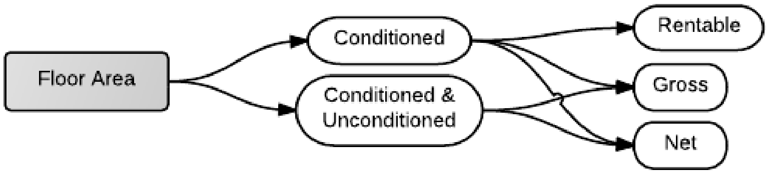
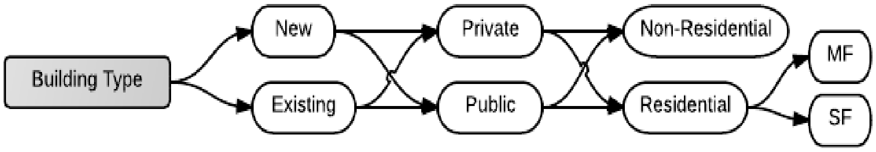
Appendix

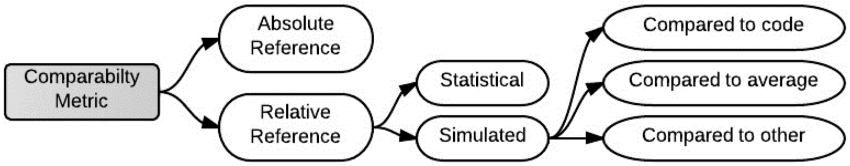
A.1 Classification Criteria

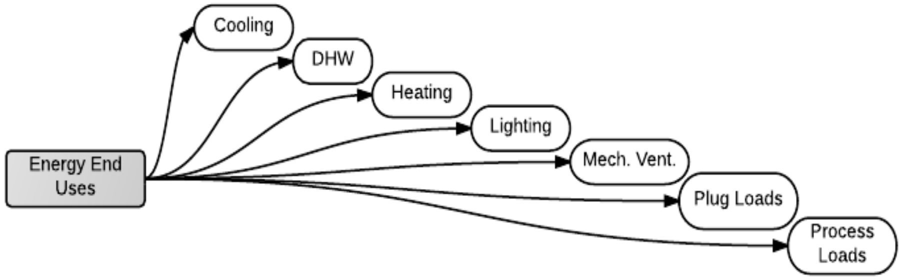












A.2 Classification Matrices by Country

Country			USA		
Program/System			ENERGY STAR		HERS
Tool/Methodology			Portfolio Manager	Target Finder	HERS
Building Type	New			o	o
	Existing		o		o
	Public		o	o	
	Non-Res		o	o	
	Res SF				o
	Res MF		o		
Assessment Type	Calculated			o	o
	Measured		o		
Energy Type	Total		o ❶	o	o
	Delivered		o		
	Final				
Floor Area	Gross		o	o	o
	Rentable				
	Conditioned		o	o	o
	Unconditioned		o	o	
End Uses	Lighting		o	o	o
	Mech. Vent.		o	o	o
	DHW		o	o	o
	Heating		o	o	o
	Cooling		o	o	o
	Plug/Process Loads		o	o	o
Baseline	Absolute Standard				
	Relative Standard	Statistical	o	o	
		Simulated (to Avg.)			
		Simulated (to Code)			o
		Other			

❶ Extrapolated from Delivered Energy.

Country			IRELAND		
Program/System			BER		DEC
Tool/Methodology			DEAP	NEAP or SBEM	ORCalc
Building Type	New		o	o	
	Existing		o	o	o
	Public				o
	Non-Res			o	
	Res SF		o		
	Res MF		o		
Assessment Type	Calculated		o	o	
	Measured				o
Energy Type	Total		o	o	o ❶
	Delivered				
	Final				
Floor Area	Gross		o	o	o
	Rentable				
	Conditioned		o	o	o
	Unconditioned			o	o
End Uses	Lighting		o	o	o
	Mech. Vent.		o	o	o
	DHW		o	o	o
	Heating		o	o	o
	Cooling		o	o	o
	Plug/Process Loads				
Baseline	Absolute Standard		o		
	Relative Standard	Statistical			o
		Simulated (to Avg.)		o	
		Simulated (to Code)		o	
		Other			

❶ Extrapolated from Delivered Energy.

Country			AUSTRALIA		
Program/System			NABERS	NatHERS	ACThers
Tool/Methodology			NABERS Energy	Various ❷	First Rate
Building Type	New			o	o
	Existing		o	o	o
	Public				
	Non-Res		o		
	Res SF		o	o	o
	Res MF		o		
Assessment Type	Calculated			o	o
	Measured		o		
Energy Type	Total		o ❶		
	Delivered			o	o
	Final				
Floor Area	Gross		o ❸	o	o
	Rentable		o ❸		
	Conditioned			o	o
	Unconditioned				
End Uses	Lighting		o ❹		
	Mech. Vent.		o ❹	o	o
	DHW		o ❹		
	Heating		o ❹	o	o
	Cooling		o ❹	o	o
	Plug/Process Loads		o ❹		
Baseline	Absolute Standard		o ❺		
	Relative Standard	Statistical	o		
		Simulated (to Avg.)		o	o
		Simulated (to Code)			
		Other			

❶ Extrapolated from Delivered Energy.

❷ Including AccuRate, First Rate, BASIX, BERS.

❸ To determine area, offices use Net Lettable Area (NLA), hotels use number of guests and rooms, homes use residents, shopping centers use Gross Lettable Area Retail (GLAR) and several space use measures (eg. cafeteria seats).

❹ Common area lighting, external lighting, HVAC, car parks, services and lifts for base buildings; plug loads, tenancy lighting and supplementary air-con for tenants; ratings cover central air-con, common area light and power, and car park energy for shopping centers; and all energy use in homes or hotels.

❺ NABERS's sixth star is calibrated to zero net energy.

Country			**UNITED KINGDOM**		
Program/System			**EPC**		**DEC**
Tool/Methodology			**SBEM**	**SAP**	**ORCalc**
Building Type	**New**		o	o	
	Existing		o	o	o
	Public				o
	Non-Res		o		
	Res SF			o	
	Res MF			o	
Assessment Type	**Calculated**		o	o	
	Measured				o
Energy Type	**Total**		o	o	
	Delivered			o	o
	Final				
Floor Area	**Gross**		o	o	
	Rentable				
	Conditioned		o	o	o
	Unconditioned		o	o	o
End Uses	**Lighting**		o	o	o
	Mech. Vent.		o	o	o
	DHW		o	o	o
	Heating		o	o	o
	Cooling		o	o	o
	Plug/Process Loads				o
Baseline	**Absolute Standard**				
	Relative Standard	**Statistical**			o
		Simulated (to Avg.)	o	o	
		Simulated (to Code)	o		
		Other			

Country			FRANCE					
Program/System			DPE					
Tool/Methodology			3CL, Comfie, or DEL6					
Building Type	New		o			o		o
	Existing			o ❼	o ❽		o	o
	Public							o
	Non-Res					o	o	
	Res SF		o	o	o			
	Res MF		o	o	o	o ❾	o ❾	
Assessment Type	Calculated		o	o		o		
	Measured				o		o	o
Energy Type	Total		o	o	o ❶	o	o ❶	o ❶
	Delivered							
	Final		o	o	o	o	o	o
Floor Area	Gross							
	Rentable							
	Conditioned		o	o	o	o	o	o
	Unconditioned		o	o	o			
End Uses	Lighting				o		o	o
	Mech. Vent.				o		o	o
	DHW		o	o	o	o	o	o
	Heating		o	o	o	o	o	o
	Cooling		o	o	o	o	o	o
	Plug/Process Loads				o		o	o
Baseline	Absolute Standard		o	o	o	o	o	o
	Relative Standard	Statistical						
		Simulated (to Avg.)						
		Simulated (to Code)						
		Other						

❶ Extrapolated from Delivered Energy.

❼ Only buildings built post-1948. Exception: residential buildings built pre-1948 that are being sold (and not leased).

❽ Only buildings built pre-1948.

❾ Only apartment buildings with a common heating source.

Country			GERMANY				
Program/System			Energieausweis				
Tool/Methodology			Various ⑩				
Building Type	New		o			o	o
	Existing		o	o	o	o	o
	Public					o	o
	Non-Res		o	o	o		
	Res SF		o	o	o		
	Res MF		o	o	o		
Assessment Type	Calculated		o	o ⑪			o ⑫
	Measured				o ⑪	o ⑫	
Energy Type	Total		o	o			o
	Delivered				o	o	o
	Final						
Floor Area	Gross						
	Rentable						
	Conditioned		o	o	o	o	o
	Unconditioned		o	o	o	o	o
End Uses	Lighting		o	o	o	o	o
	Mech. Vent.		o	o	o	o	o
	DHW		o	o	o	o	o
	Heating		o	o	o	o	o
	Cooling		o	o	o	o	o
	Plug/Process Loads				o	o	
Baseline	Absolute Standard		o	o	o	o	o
	Relative Standard	Statistical					
		Simulated (to Avg.)					
		Simulated (to Code)					
		Other					

⑩ Any tool must meet the designated standard, called DIN V 18599.

⑪ Existing non-residential, existing multi-family (5+ units), and existing residential planned or refurbished after 1977 have the option of using a measured rating.

⑫ Public buildings are able to use either a calculated or measured rating.

Country			**DENMARK**	
Program/System			**Energimærkning**	
Tool/Methodology			**EK-Pro, Energy08**	
Building Type	**New**		o	o
	Existing		o	o
	Public			o
	Non-Res			o
	Res SF		o	
	Res MF		o	
Assessment Type	**Calculated**		o	o
	Measured			
Energy Type	**Total**		o	o
	Delivered			
	Final			
Floor Area	**Gross**		o	o
	Rentable			
	Conditioned		o	o
	Unconditioned			
End Uses	**Lighting**			o
	Mech. Vent.		o	o
	DHW		o	o
	Heating		o	o
	Cooling		o	o
	Plug/Process Loads			
Baseline	**Absolute Standard**		o	o
	Relative Standard	**Statistical**		
		Simulated (to Avg.)		
		Simulated (to Code)		
		Other		

Country			**PORTUGAL**	
Program/System			**SCE**	
Tool/Methodology			**Various ⑬**	
Building Type	**New**		o	o
	Existing		o	o
	Public			o
	Non-Res			o
	Res SF		o	
	Res MF		o	
Assessment Type	**Calculated**		o	o
	Measured			
Energy Type	**Total**		o	o
	Delivered			
	Final			
Floor Area	**Gross**			
	Rentable			
	Conditioned		o	o
	Unconditioned		o	o
End Uses	**Lighting**			o
	Mech. Vent.			o
	DHW		o	o
	Heating		o	o
	Cooling		o	o
	Plug/Process Loads			o
Baseline	**Absolute Standard**			
	Relative Standard	**Statistical**		
		Simulated (to Avg.)		o
		Simulated (to Code)	o	
		Other		

⑬ Portugal's Energy Ministry, ADENE, has published calculation methodologies based on EN 13709 (for residential buildings) or indexed to a ASHRAE 140.2004 (for non-residential). Private companies can develop tools for certification which are verified in the quality assessment process.

Country			**CHINA**	
Program/System			**MOHURD**	
Tool/Methodology			**MOHURD**	
Building Type	**New**		o	o
	Existing		o	o
	Public		o	
	Non-Res		o	
	Res SF			
	Res MF			o
Assessment Type	**Calculated**		o	o
	Measured			
Energy Type	**Total**		o	o
	Delivered		o	o
	Final			
Floor Area	**Gross**		o	o
	Rentable			
	Conditioned		o	o
	Unconditioned			
End Uses	**Lighting**			o
	Mech. Vent.			o
	DHW			
	Heating		o	o
	Cooling		o	o
	Plug/Process Loads			
Baseline	**Absolute Standard**			
	Relative Standard	**Statistical**		
		Simulated (to Avg.)	o	o
		Simulated (to Code)		
		Other		

Country			CANADA		
Program/System			EnerGuide	CRESNET	REALpac EB
Tool/Methodology			Hot2000	E-Scale	⓮
Building Type	New		o	o	
	Existing		o	o	o
	Public				o
	Non-Res				o
	Res SF		o	o	
	Res MF				
Assessment Type	Calculated		o	o	
	Measured				o
Energy Type	Total		o	o	
	Delivered				o
	Final				
Floor Area	Gross		o	o	o
	Rentable				
	Conditioned		o	o	o
	Unconditioned		o	o	o
End Uses	Lighting		o	o	o
	Mech. Vent.		o	o	o
	DHW		o	o	o
	Heating		o	o	o
	Cooling		o	o	o
	Plug/Process Loads			o	o
Baseline	Absolute Standard				
	Relative Standard	Statistical			o
		Simulated (to Avg.)			
		Simulated (to Code)	o	o	
		Other			

⓮ REALpac Energy Normalization Methodology.

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About the Institute for Market Transformation (IMT)

The Institute for Market Transformation (IMT) is a Washington, DC-based nonprofit organization promoting energy efficiency, green building, and environmental protection in the United States and abroad. IMT's work addresses market failures that inhibit investment in energy efficiency and sustainability in the building sector. For more information, visit imt.org.

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