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SUMMARY: In order to succeed in developing a more sustainable society, buildings will need to be continuously improved. This paper discusses how to rate the energy performance of buildings.

A brief review of recent approaches to energy rating is presented. It illustrates that there is no single correct or wrong concept, but one needs to be aware of the relative impact of the strategies. Different strategies of setting energy efficiency standards are discussed and the advantages of the minimum life cycle cost are shown. Indicators for building energy rating based on simulations, aggregated statistics and expert knowledge are discussed and illustrated in order to demonstrate strengths and weaknesses of each approach. In addition, the importance of considering the level of amenities offered is presented.

Attributes of a rating procedure based on three elements, flexible enough for recognizing different strategies to achieve energy conservation, is proposed.

1. Introduction

Rating a building's energy performance is becoming an increasingly important aspect of building operation. A highly rated building may be eligible for special recognition through a range of voluntary or compulsory programs, which increases its resale value and rental income. Rating can also help identify poorly operated buildings and opportunities for energy and cost savings. This use of rating procedures —which also include benchmarking—is a worldwide phenomenon, of which a brief overview will be introduced below.

Most rating programs have been rather small, penetrating less than one percent of the building stock. Recently, however, much larger programs have been launched. The U.S. Environmental Protection Agency (USEPA) has residential and commercial buildings programs already involving more than a thousand buildings (www.energystar.gov). The European Union (EU) proposed measures to promote energy efficiency of buildings (Council of the EU 2001 and 2002) which includes finding methods for estimating the building energy consumption, limits of maximum energy use in new and retrofitted buildings, energy rating and regular inspections of boilers and HVAC-systems.

Different approaches for rating the energy use in buildings have been developed over the last twenty years. At least in the beginning, these approaches could be categorized according to primary reliance on:

- ☐ Design data
- ☐ Actual performance approaches (such as utility bills)
- ☐ Extrapolations from short-term, in-situ measurements.

Recent approaches to rating can sometimes be still assigned to one category; for example, labeling schemes based on in-situ measurements like Home Energy Labeling Procedure (HELP) (Richalet et al. 2001). However, most new labeling procedures are hybrids including combinations of the above approaches. Model based benchmarking is one example of a hybrid. It is a method for estimating the minimum amount of energy required to meet a set of basic functional requirements of the building. The scoring is obtained relative to a set of buildings of the same type by comparing computed and actual energy use as well as the effectiveness of the building, (Federspiel et al. 2002). The USEPA has developed a labeling method for the USA based on energy bill data and easily obtained information of the building. The labeling is voluntary and accessible on the web (http://poet.lbl.gov/arch/) and the rated buildings earning a sufficiently high rating are eligible for the Energy Star® Label (Hicks and Clough 1998 and Hicks and von Neida 1999). The Australian Building Greenhouse Rating (www.abgr.com.au) has also provided a star-rating scheme. The scheme is intended to be an Australian national approach to benchmark the "greenhouse" performance of buildings and tenancies to other buildings within the same state. The rating is derived from actual amount of annual consumption of energy. An energy-rating tool (e-Energy) using statistics of collected energy use, building performance and occupancy data has been develop by BCA-NUS Building Energy and Research Information Center at the National University of Singapore (www.bdg.nus.edu.sg). The scoring accounts for five levels and includes different energy audit results.

In Montreal, Canada, an energy rating system for existing houses was proposed, combining the information from utility bills with on-site measurements and computer simulations and was tested on a sample of 45 houses (Zmeureanu et al. 1999). The method is used to assign an index of performance in terms of the annual heating energy consumption or cost, but also to recommend a goal for a lower, technically feasible, heating bill. The philosophy was to increase the awareness of the owner by a presentation of the actual energy performance compared to that of reference houses, but also of potential savings through renovation or changed habits of users. Another example where awareness of the owners' influence is accounted is a Danish energy labeling system (Laustsen 2001). The scoring is based on data of water consumption and energy use and CO_2-emissions, which is compared to other similar buildings. For labeling, the house-owner also needs to present an energy-plan, including proposals for cost-effective saving possibilities.

In this paper, we propose a new framework for rating the energy performance of buildings. We begin with a description of some problems encountered in rating energy performance, followed by our proposal. This is not a new rating system with tools, simulation prototypes, and scoring procedures; instead, we describe the attributes of a performance rating system.

The rating methodology discussed in this paper is based on the assumption that an efficient building shall be both low energy and energy efficient. Low energy means low energy annual use. Energy efficient accounts how efficient the system uses supplied energy in terms of the physical properties of the building, installations, appliances, users, etc. When rating its energy efficiency, both the relative and absolute aspects of the subject must be included. The methodology also accounts that the conserving of supplied energy should not interfere on the level of amenities appropriate for the activities in the building.

It is important to recognize that, from a rating perspective, there is no guarantee that a building with low energy use is necessarily energy efficient. The energy use can be low just because the building is empty most of the time; the building's amenities are minimal, etc. The same contradictions can be found for efficient buildings, not being low energy. Equipment with high energy-efficiency potential may not be appropriately installed to reduce the energy loads. High-energy buildings, i.e. buildings using much energy, can do so with good efficiency. These buildings may be well provided with appliances that would be very energy consuming without their energy-efficient features.

A distinction can be made between how to obtain a 'Low energy building 'and how to obtain an 'Energy efficient building'. Low-energy building concepts are often accomplished through minimization of external purchased energy, with high influences of users. Energy efficient building solutions, on the other hand, are often accomplished by selecting the lowest possible energy requirements with reasonable utilization of resources (Abel 1994). A strategy for identifying and rating low energy and energy efficient buildings is to define what shall be conserved and the purpose of what shall be accomplished.

Rating schemes are generally associated with either certification or labeling. Certification in this context means evaluating the building in the design stage and labeling means comparing the in-use performance of a building with other similar buildings. In this paper, we discuss rating in terms of labeling of occupied buildings, unless otherwise indicated.

In section 2, different concepts of energy efficiency are introduced and discussed. There are no right or wrong concepts, but one has to be aware of their impact. In section 3 it is discussed how to decide if a building is energy efficient and if one building is more energy efficient than another building. In section 4, the need for evaluating the amenities before deciding if a building is energy efficient is presented. Finally, in section 5, a rating procedure, based on three elements, is introduced.

2. Setting energy efficiency standards

When regulations call for minimum energy efficiencies in building design and appliance manufacture, they are expected to translate into lower operating costs for the occupants, reduced energy demand for the utilities, and lower carbon emissions. Prescriptive recommendations, that require minimum levels for insulation or efficiency for equipment, have existed for a long time, especially in cold regions such as Scandinavia (Kreuger and Eriksson 1922 and 1924). However, the State of California, USA, (International Energy Agency 2000) was the first US-government to establish a construction standard based on the building's total energy consumption rather than a combination of specific measures. The foundation of this approach was a maximum energy "budget" for each major building category and in each climate zone. This approach–which was developed over twenty years ago–has been imitated (and improved upon) in dozens of other building codes around the world, including ASHRAE 90.1, and the US Energy Policy Act of 1992 (EPACT) (Government of the United States of America, 1992).

But what is the correct energy budget for an "efficient" building? The answer depends on the approach. There are three general approaches to selecting a maximum budget:

- ☐ Negotiated
- ☐ Statistical
- ☐ Minimum life cycle cost.

A negotiated approach means simply selecting a budget with no formula or clear procedure. This approach may be taken when, for example, a standard is developed through negotiations between the government and the building industry. In practice, nearly all standards contain an element of negotiation.

The statistical approach seeks to determine the present range of performance. Then a standard is chosen such that only the lowest 50% (or some other number) would meet a new standard. The Europeans used this approach in the initial efficiency regulations for residential refrigerators (International Energy Agency 2000). The US ENERGY STAR Buildings Program aims to certify only the buildings with a rating above 75% (roughly corresponding to 25% of the buildings) (www.energystar.gov). In Japan, the "TopRunner" appliance efficiency program identifies the best performance presently available and sets the standard so that all new units must surpass that in five years (http://www.eccj.or.jp/toprunner/).

The life cycle cost approach seeks the efficiency levels that yield the lowest lifetime costs (taking into account both investment and energy operating costs). These calculations begin with a conventionally constructed building or appliance as a baseline, and then examine the trade-offs in initial investments in energy-saving technologies to energy costs. This approach has been adopted in for example North America, Australia, Southeast Asia and Europe (Cole and Kernan 1996, Treloar et al. 2000, Aye et al. 2000, Wong et al. 2003, Nielsen and Svendsen 2002, Adalberth 2000 and Thormark 2002).

The impact of these different strategies to regulate energy use can be very successful. Unfortunately, it is difficult to demonstrate because buildings are complex entities with hundreds of trade-offs. Instead, we show the impact of three different energy budget strategies applied to a single appliance: refrigerators. Fig. 1 shows actual energy use data for “top-freezer” refrigerators sold in the United States in 1989. The approximate levels of the three strategies are shown as lines. These lines slope upwards with increasing volume because this is the primary determinant of energy consumption (at least for refrigerators with the same features).

The “Best 25%” reflects the strategy of selecting a standard that allows 25% of the current models to meet a future regulation. This approach would appear to be an effective means of eliminating many inefficient models and greatly increasing energy efficiency.

The “TopRunner” approach identifies the most efficient units in each category and then requires all units to have lower energy use than that model after five years. This is equivalent to drawing a line connecting the units with the lowest consumption. This strategy will save more energy than the best 25% strategy, possibly a lot more if one manufacturer offers exceptionally efficient units.

The “Lowest life cycle cost” line is calculated from engineering economic analysis of prototype units. The slope was determined by connecting the energy use for the lowest life cycle costs. Substantial energy savings will result if manufacturers have been selling particularly inefficient models, where inexpensive improvements will yield large savings.

Fig. 1 also shows data for refrigerators manufactured in 1998. This demonstrates that, when pressed by a standard, the manufacturers were able to achieve the savings anticipated in the engineering-economic analysis. All of the 1998 refrigerators were able to either meet or surpass the standard. (Interestingly, manufacturers often used lower-cost technologies not anticipated by the analysts.). Note that these levels would not have been considered technically feasible if existing models were used as a guide.

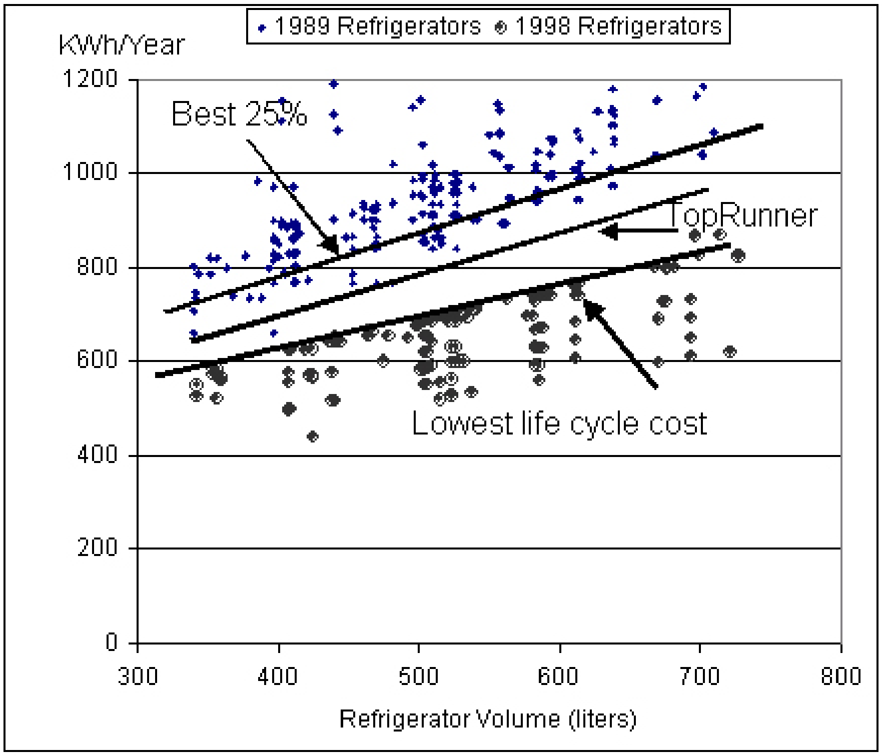


Figure 1. Electricity use of refrigerators manufactured in 1989 and 1998 with lines showing different standards-setting strategies.

This example illustrates how different concepts of efficiency can have enormous impacts on regulations and potential energy savings. There is no single "correct" concept and none of these approaches is "wrong", but one needs to be aware of the relative impacts of the strategies. It can also be suggested that if a standard is set, based on simulation of all variables involved in the performance, a link with a rating system is simpler to be introduced.

3. Indicators for building energy rating

Evaluations of whether one building is more 'low-energy' than another building can be complex if the activities in the building or the climate is not the same, or if different fuels are used. For similar buildings operated under similar conditions, the decision is less difficult. Nevertheless, assessing the building's energy efficiency usually has additional difficulties. In the design-stage, simple criteria of energy efficiency can be assessed. For example:

> Does the building meet the design goals?
> Is one design superior to another?

For occupied buildings, classifications of buildings based on energy efficiency are even more difficult. Here, we will focus on two aspects touched by the concept of energy efficiency:

- ☐ Comparing (or ranking) the energy efficiency of buildings
- ☐ Calculating an absolute assessment of a building's energy efficiency.

In practical terms these procedures translate into two questions. First, how can a person decide if one building is more energy efficient than another building? Second, how can a person decide if a building is "energy efficient"? Thus, the first requirement is a means of establishing relative efficiency and the second is a means of establishing absolute efficiency. We do not propose to answer these questions, but instead offer insights from actual data and common indicators of energy performance. We apply these data to the following three approaches to evaluating building performance:

1. Simulation
2. Aggregated statistics
3. Expert knowledge.

Again, our goal is not to identify the best approach but to use actual measurements to demonstrate the strengths and weaknesses of each approach.

3.1. Simulated data approach (SDA)

ASHRAE Standard 90.1 is a well-used standard for measuring the energy efficiency of buildings in the design stage. From an energy rating perspective the method includes comparing a target value, a prototype, or a reference building to the performance of the proposed building, where energy simulation software is used for that purpose. The simulation approach has some value in that it reveals the ideal behavior of a building or its behavior with standardized weather and operating conditions.

On the other hand, the simulation approach ignores the wealth of information about actual conditions, such as the utility bills, data from Energy Management Systems (EMS), and known occupancy patterns. More important, for an occupied building a simulation approach alone cannot even begin to address important aspects of construction, operation, and maintenance. For example, is the building performing as designed? Is something broken? Can the building be improved?

The assumptions within the prototype building are also important because subtle differences can have large impacts on energy use. One example is the building's shape or aspect ratio. Using the regression equation proposed by (Signor et al. 2001) we can calculate that a commercial building in equatorial climate (Salvador, northeast Brazil) with 12 x 60 m^2 on plan and 1 floor would have an annual energy consumption of 242 kWh/m^2,year , but the same floor plan with 10 floors the energy consumption would be 188 kWh/m^2,year. Another building with 150 x 30 m^2 on plan and 1 floor would have an annual energy consumption of 184 kWh/m^2,year and with 10 floors the energy consumption would be 129 kWh/m^2,year. A study in a cold climate region of Turkey (Oral 2003) illustrates the significant influence of building form on the heating energy use. Thus the energy budget approach of comparing a building only to itself is important.

Energy rating of an occupied building means that the influence of the occupants has to be measured in one way or another. Different attempts have been investigated to include that information in simulation models. One methodology is to incorporate information from energy end use measurement, walk-through and audits in simulations from building design documentation. Accurate evaluations of the energy use were obtained when that concept was applied to case studies of commercial buildings in warm climate conditions (Pedrini et al. 2002).

An alternative performance evaluation approach is to treat the building as a "black box" and derive performance parameters from time series of energy, weather, and other data. This technique is often called "inverse modeling". Some of these parameters can be associated with the building's energy efficiency, even if they do not have direct physical interpretations.
A study of inverse modeling has been made on monitored data of inhabited dwellings using neural networks to model the overall heat loss coefficient and heat gained from the supplied energy from appliances (Olofsson and Andersson 2002). It was found that the modeled performance was close to the simulated as well as the estimated, based on methods that are more traditional. It was also found that the inverse modeling method could be used to

estimate the exchanged air volume based on natural ventilation to an accuracy of 10%. Disadvantages with this method are that continuous monitored series of data is needed and indications of potential savings can be difficult to evaluate. For obtaining such evaluations simulations are needed.

Rating of buildings is difficult when buildings have different fuels, different building forms and different user consciousness. For that purpose, an excellent way of rating buildings is simulations, since you can control variables (schedules, set points, etc.). These simulations have proved to be useful for evaluations limited to the envelope system, equipments, climate and schedules of use. They can also be calibrated to influences from users. This gives a possibility to evaluate the absolute limit for building energy efficiency for an investigated building. However, if the rating is supposed to reflect the energy efficiency of the occupied building the actual influence of the user must also be taken into account. Such evaluation can be based on aggregated building energy statistics.

3.2. Aggregated statistics approach (ASA)

The level of energy use of categories of buildings in terms of statistical metrics can be evaluated based on aggregated statistics. A widely used metric is the Energy Unit Index (EUI). It is defined as the total energy use normalized to the floor area. The metric can be studied based on statistical averages, medians, percentiles etc. Analyses with median metrics prove to be successful, because of less sensitivity to individual buildings (Sharp 1996). For obtaining an illustration of the statistical distribution of the efficiency histograms can be an aid.

In this paper, we introduce a companion method to histograms, a frequency function. The statistical frequency distributions has been fitted to the LogNormal function

$$f(x)=\frac{A}{\sqrt{2\pi}wx}e^{\frac{-\left[\ln\frac{x}{x_c}\right]^2}{2w^2}}$$

where the frequency [*f(x)*] is based on the amplitude [A], the standard deviation [w] and the center [x_c], i.e. where *f(x)* has its maximum.

In this section, we will illustrate how frequency functions can be used for investigating:

1. Energy conservation evaluated on a single efficiency measure on appliances
2. Total electricity use for residential buildings based on climate region
3. Total electricity use for residential buildings based on year of construction.

These sub-sets of buildings were chosen for illustrating how energy efficiency can be related to general criteria. The same categories were not identified as the strongest determinants of energy use. An example to find such arguments is linear regression modeling. In a study of commercial buildings the strongest determinants of energy use were floor area, number of workers and PCs, owner-occupancy, operating hours and presence of economizer or chiller (Sharp 1996).

Data used in our study were collected in the 1997 Residential Energy Consumption Survey (RECS) (United States Department of Energy (DOE) 1997a). RECS was first conducted in 1978; the tenth survey was conducted in 1997. In the 1997 RECS, the data were collected from a sample of 5,900 housing units statistically selected to represent the 101.5 million units in the United States. The Energy Information Administration of the U.S. Department of Energy has conducted the survey through personal interviews with owners and managers. The nature of all data included in RECS is that any non-professional engineer could collect it. The information includes the physical characteristics of the housing units, the appliances utilized including space heating and cooling equipment, demographic characteristics of the household, the types of fuels used, and other information that relates to energy use. RECS also provide energy consumption and expenditure data. However, the survey includes no evaluation of amenities.

3.2.1. Energy conservation evaluated on a single efficiency measure of appliances

The total use of electrical energy for houses with and without an Energy Star label on the refrigerator was evaluated. The EUI-distributions fitted to the statistical frequency are illustrated in Fig. 2.

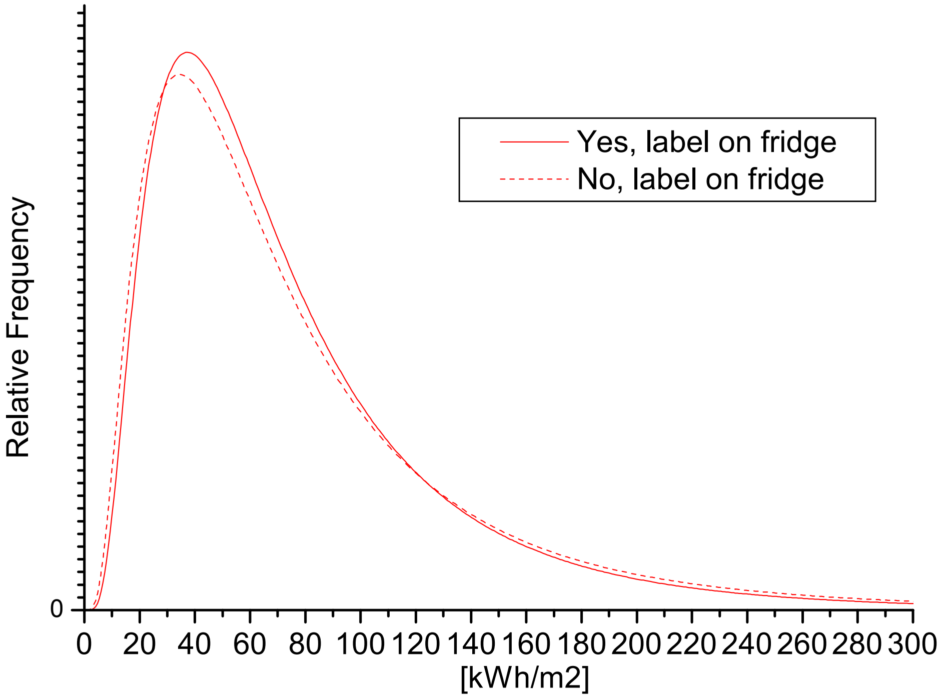


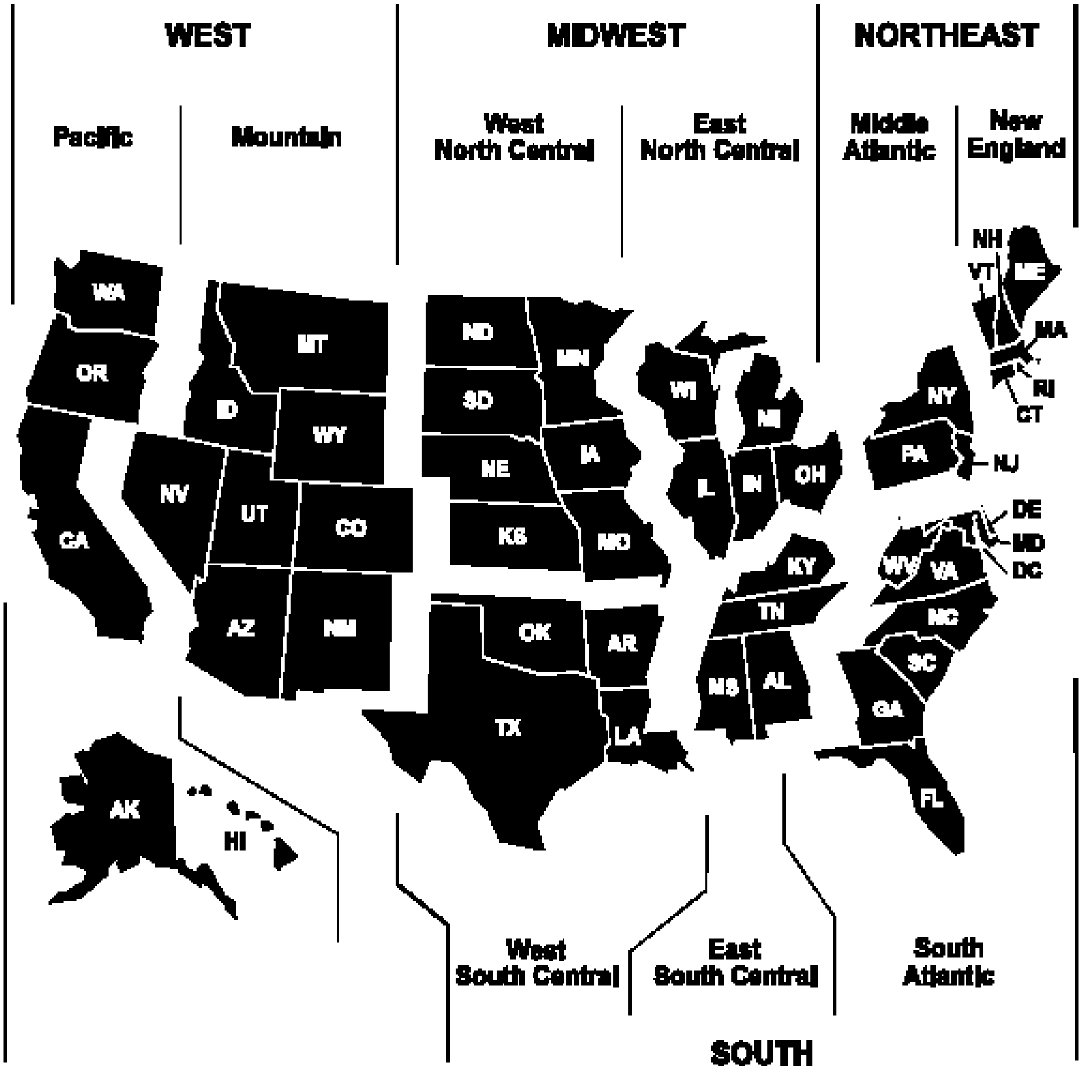
Figure 2. EUI-distributions of normalized total electricity use for residential buildings categorized based on if the households have an Energy Star label on the refrigerator.

The shapes of the curves were very close to each other. According to the distributions, the centers were also very close. Both houses with and without labels on the refrigerators had the centers of the EUI-distribution at 61 kWh/m^{2}year. The corresponding medians were also investigated. The EUI-median for houses with labeled refrigerators was 60 kWh/m^{2}year and for those not labeled 56 kWh/m^{2}year. This can be compared to the results of all buildings in RECS, which had the center at 59 kWh/m^{2}year and the median at 60 kWh/m^{2}year.

The results for the two groups are indistinguishable. One weakness of this study was the small representation of buildings with labeled refrigerators. In this particular case, there were 395 observations with labels and 5324 without. It should also be noticed that the buildings in RECS are selected based on different general statistical arguments and not minor characteristics, such as the one discussed above. Thus, the 395 buildings with labeled refrigerators are not statistical representative. The study illustrates problems with methods such as distributions and medians on sets with unrepresentative buildings. No statistical method can dodge that problem.

3.2.2. Total electricity use for residential buildings categorized by climate regions

A study has been made on EUI-distributions, calculated from total electricity use on houses allocated to four census regions with differences in climate. These regions were the four US census regions according to the map in Fig. 3. The results are illustrated in Fig. 4.



Source: U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States,1996* (Washington, DC, October 1996), Figure 1.

Figure 3. The four US census regions as defined in the RECS.

The EUI-distributions of houses in the Northeast had its center at 62 kWh/m^2,year, Midwest and West at 59 kWh/m^2,year and South at 58 kWh/m^2,year. Houses in the Northeast had its median at 63 kWh/m^2,year, Midwest at 61 kWh/m^2,year, West at 58 kWh/m^2,year and South at 58 kWh/m^2,year. Here it can be noticed that the difference between centers and medians are rather small.

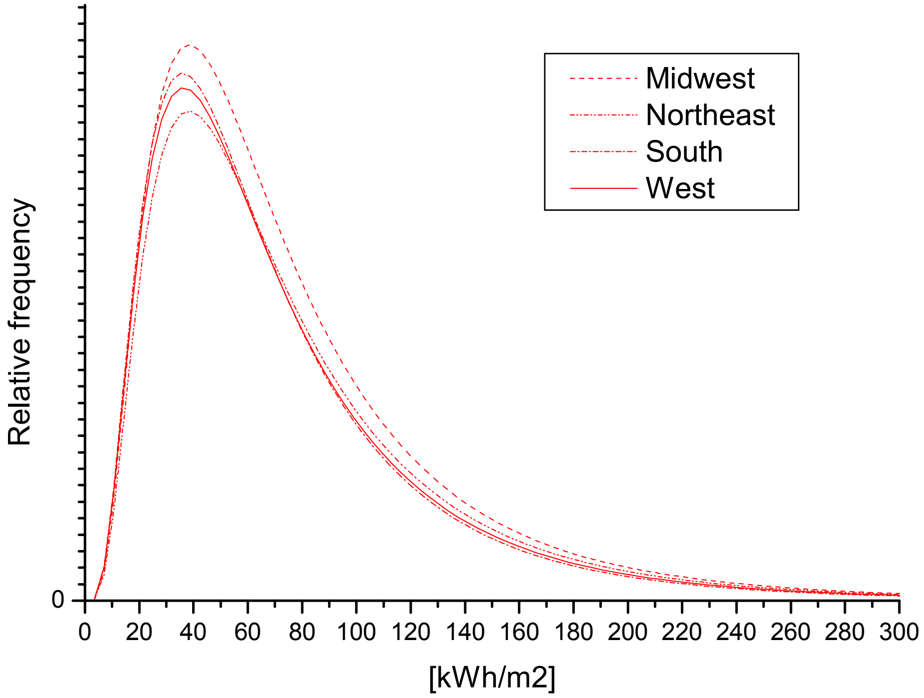


Figure 4. EUI-distributions of normalized total electricity use for residential buildings categorized based on Census Region.

The houses in RECS have been selected to capture the national variation and approximately one fourth of the buildings in RECS are allocated to each census region. Thus, in this study, the statistical representation of each census region can be assumed to be acceptable.

This study illustrates an insignificant difference in total electrical energy use between regions, which could have been expected. The similarities in total electrical energy use can for example be based on more energy conservation in buildings in colder regions, more AC (using electricity) in buildings in warmer regions. It should be noticed that some buildings have auxiliary-fuels, such as natural gas, fuel oil, liquefied petroleum gas (LPG), and kerosene for heating and/or cooling. Thus, another explanation of the unexpectedly small differences can be that more auxiliary-fuels are used in colder regions, which reduces the relative difference in use of electrical energy.

3.2.3. Total electricity use for residential buildings based on year of construction

Based on categorization in vintage, a study was made on the houses in RECS. The categories and number of observations were according to:

☐ Built before 1940s, 1171 houses
☐ 1940s-50s, 1322 houses
☐ 1960-70s, 2022 houses
☐ 1980-90s, 1381 houses.

The number of houses in each category indicates that the survey is statistically representative.

The distributions are illustrated in Fig. 5. The center of the distribution were 43 kWh/m^2,year for houses in vintage before 40s, 54 kWh/m^2,year for houses in vintage 1940s-50s, 69 kWh/m^2,year for houses in vintage 1960s-70s and 78 kWh/m^2,year for houses in vintage 1980s-90s. The statistical median was 43 kWh/m^2,year for houses in vintage before 1940s, 53 kWh/m^2,year for houses in vintage 1940s-50s, 69 kWh/m^2,year for houses in vintage 1960s-70s and 75 kWh/m^2,year for houses in vintage 1980s-90s. The correspondence between centers and medians are rather close.

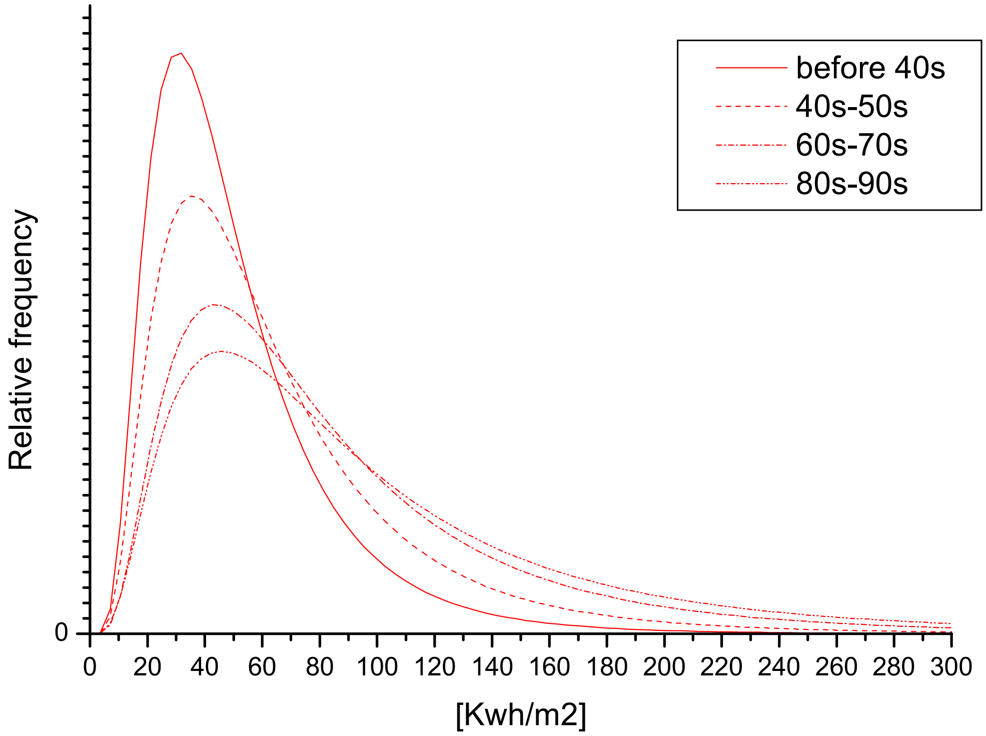


Figure 5. EUI-distributions of normalized total electricity use for residential buildings categorized based on year of construction.

One might assume that newer buildings use less electricity than older buildings. This study indicates the opposite; the level of energy use in older buildings was lower. However, one should not conclude that older houses are more efficient. Older buildings may use less energy because fewer appliances are used inside them. Newer buildings are better equipped. Additionally, the use of the auxiliary fuels natural gas and fuel oil have decreased in the building stock every decennium since the 1950s (United States Department of Energy (DOE) 1997a). Thus, this study indicates that there is no guarantee that newer occupied buildings, that are more probable to be provided with more efficient equipment, has lower total electrical energy use than newer buildings.

3.2.4. Conclusions from the study on EUI-distributions

The study of EUI indicators was made on total electrical energy use. However we expect similar results from studies of building with other fuels, as well as total energy use. According to the results it would appear as if the climate does not influence the electrical energy use. One might infer that building standards are not achieving their intended savings (because new buildings were using more energy than old ones). We believe that this is actually illustrating one aspect of using total energy alone as a measure of energy efficiency. In addition, the services (air-conditioning/ ventilation), lighting and hot water provided in new buildings may be significantly better than old buildings. Conclusions regarding energy efficiency based on statistical investigations can be done, but they are vulnerable to easy misinterpretation. On the other hand, aggregate statistics are appropriate—and sometimes necessary—when determining relative energy efficiency of buildings.

Similar studies using EUI distributions have been made on commercial buildings using the Commercial Building Energy Consumption Survey (CBECS) (United States Department of Energy (DOE) 1997b). The investigations of CBECS gave the same indications (http://eetd.lbl.gov/EA/Buildings/Projects/Billing). However, it should also be pointed out that there is a basic difference between residential and commercial buildings when discussing low energy buildings and energy efficient buildings. There are differences in sources of energy as well as loads.

3.3. Expert knowledge approach (EKA)

We explored the behavior of indicators when used for ranking the performance of buildings. We drew on detailed data from eleven well-documented dwellings in seven countries. Characteristics on the investigated dwellings are illustrated in Tab. 1. The data were used to calculate twenty energy performance indicators (www.lbl.gov/~akmeier).

Table 1. Summary of the houses' characteristics

House ID	Country	Floor Area (m^2)	Year Built	Space-Heating	Fire-place	Heat Pump	Water Heating
A	Finland	164	1991	Elec.			Elec.
B	Japan	165	1987	Oil			Oil
C	Germany	168	1987	Oil			Oil
D	USA	325	1989	Elec.		yes	Elec.
E	USA	112	1993	Gas	yes		Gas
F	USA	223	1994	Elec.		yes	Elec.
G	USA	162	1994	Elec.		yes	Elec.
H	USA	163	1994	Elec.		yes	Elec.
I	Sweden	109	1982	Elec.			Elec.
J	Canada	215	1990	Gas			Gas
K	Poland	107	1980	Dist. heat			Gas

The impact of different indicators was evaluated by observing how the rating of the houses changed. For example in Tab. 2 the eleven houses are ranked in terms of primary energy. House D has been marked to show the changes in rating based on different indicators. This shows that the position of House "D" changes dramatically depending on the choice of indicator.

Table 2. Rating of 11 houses with identities A to K in terms of primary energy use.

House ID	Space Heat per m2	Space heat per person	Space Heat per HDD18	Space Heat per HDD18 per m2	Total Energy	Total Energy per m2	Total Energy per person	DHW Energy	Lighting and Appliances
B	B	B	I	B	I	B	K	C	K
I	I	I	B	I	B	C	B	D	I
C	C	C	C	F	C	D	I	B	B
E	F	K	F	C	K	I	C	K	H
F	D	F	E	D	H	K	H	J	C
K	E	G	K	J	E	J	A	I	E
G	J	A	H	H	D	F	F	H	D
D	G	E	J	G	J	H	D	F	A
H	K	H	G	E	F	A	G	E	J
J	H	D	A	A	A	E	E	A	F
A	A	J	D	K	G	G	J	G	G

Major conclusions from the study on the indicators of the eleven houses were:

- The rating of houses by different indicators is critically dependent on the treatment of electrical energy. Houses that appear very efficient in terms of site energy may fall in apparent efficiency when this consumption is converted to primary energy at 1 kWh of site energy = 10 MJ of primary energy. That demonstrates the importance of which definitions that is used for the indicators.
- Space heating energy is declining in importance, and is less than one third of energy use, even for homes located in very cold climates. At the same time, energy use of appliances is increasing (especially when treated in terms of primary energy). Indicators need to reflect total energy use of buildings rather than focus on space heating.
- Homes with similar physical characteristics and equipment are likely to maintain their relative rating across a broad range of indicators. Occupants and appliances certainly will affect the absolute values, but the ratings remain the same.
- The quality of the indoor environment, such as temperature, air quality, and other amenities, are not adequately reflected in any of the indicators. Environmental quality rises in importance because some amenities are energy-intensive.

This study was limited to homes in very cold regions; so unique problems associated with comparing cooling performance did not even arise. Assessing cooling energy performance is particularly complex because cooling energy use is a combination of loads caused by differences in temperature and humidity, solar gain, and internal heat sources. The relative contributions also fluctuate through the day and are extremely sensitive to the environment around the building. In addition, the sizes of these loads are difficult to measure and normalize.

In the course of this compilation, it was also found that international comparisons are complicated by inconsistent definitions of many key terms, some of which are fundamental to all indicators. Significant errors in this study were introduced by definitions of:

1. Floor area
2. Calculation of heating degree-days
3. Energy content in fuels
4. Conversions from site to primary energy.

Although only eleven houses were investigated, there were major practical and physical complexities of attempting and developing standard measures. This is an important problem when more buildings are to be included in the evaluation, but also when more complex indicators are to be used.

These conclusions, while based on examination of only a few houses, also apply to national studies and comparisons. The difficulties in evaluating performance of individual houses have implications for measuring the success of national or regional policies to improve energy efficiency and to reduce CO_2 emissions (www.lbl.gov/~akmeier). If the desired efficiency information is not revealed in a small group of well-documented buildings, then it will surely not be revealed in the same indicator based on cruder national statistics.

Schipper (Schipper 1997) found similar situations with commercial buildings. For example, commercial buildings with large data processing centers appear to be very inefficient if one fails to make an allowance for this near-industrial activity occurring within them. Similarly, buildings operated 24 hours/day may appear to be inefficient because they have high-energy use. When their energy use is adjusted to reflect these extended schedules, they may rank among the best.

From this study, two reflections can be noticed. First, it is most probable that the representation in the available data set in surveys based on expert knowledge is too small for compilations of level of energy use as well as for relative energy efficiency. Secondly, these sorts of surveys can be useful for studies of absolute efficiency for different concepts of energy efficiency, of similar buildings operated under similar conditions.

3.4. Concluding remarks on the investigated approaches

Assessing the building's energy use is difficult because efficiency encompasses many factors. The foregoing study of building energy efficiency indicators has illustrated some possibilities and limitations to account the level of energy use as well as the relative and absolute assessment of the energy efficiency.

We suggest that simulations are useful to assess how efficiently the energy is used. Simulations may also be suitable for finding out improvements in terms of an absolute level of energy efficiency for the actual building investigated. However, for finding the relative level of energy efficiency, access to actual impact of users as well as aggregated statistics of occupied buildings will be needed. Simulations can include an evaluation in terms of climate, equipment, envelope and schedule of use. By using a simulation, potential measures to save energy can be compared to standards and can take account of investment as well as energy costs. The simulation can also be based on different system boundaries to compare the use of primary energy to site energy, etc.

Each simulation model has its own strengths and weaknesses (not to mention errors) (Judkoff and Neymark 1995). In addition, there remain many subjective aspects involved in the translation of a building design into an input file suitable for the simulation program (Pettersen 1994). For rating, the simulations of building energy efficiency alone can be useful in many senses. However, an exception is to take account of actual conditions in occupied buildings. For that measurements will be needed.

Assessing the absolute energy efficiency of buildings can also be evaluated from expert surveys of well-documented buildings. These sorts of surveys generally include small sets of building and will thus be less useful for rating.

From the investigation of indicators, it has been found that based on aggregated statistics statistical frequency distributions can be an applicable method for rating the external purchased energy. This will indicate if the building is a low-energy or high-energy building.

If it is operating 24 hours per day or contains unusual, energy-intensive activities, a building with a high-energy consumption is not necessarily an inefficient building. That is not necessarily considered in the suggested investigation of either absolute or relative level of energy efficiency or low energy, but could be evaluated separately. That aspect has also to be evaluated when rating the energy efficiency of buildings.

4. Amenities

A low energy building is not efficient if the low energy use is achieved by shorter occupancy schedules or by not providing the services that should make the place pleasant, i.e. inappropriate amenities.

The amenities that should be investigated can for example be: ventilation rates, air velocities, inside air and surface temperatures, reduced emissions from unhealthy insulation materials, lighting, and noise from HVAC-equipment. A distinction should be made for what should be provided in order to meet the service demanded and what should be regarded as unnecessary or wasteful use. Here, the appropriate level of amenities is what is required for using the building as intended. For example, if there is a sauna in a building the use of that facility should be considered when evaluating the energy use. Further, when rating amenities it is also important to understand national and local differences of the level of services.

Thus, before deciding if the building is energy efficient, the building amenities have to be investigated and evaluated. For an occupied building, a survey can include ensuring that the level of services meets the designed levels or other standards, depending on the activities. For new buildings, this evaluation can be based on a simulation.

5. Elements of a rating procedure

Existing rating systems have the drawback that a single criterion of energy efficiency often conflicts with other design issues (Soebarto and Williamson 2001). As enlighten earlier low energy, energy efficiency and sufficient amenities can conflict. Hence we propose a rating method must contain elements from these three categories (Meier et al. 2002):

Element 1. The building must be energy efficient. That means that the building must contain energy-efficient technologies that, when operating as designed, will effectively reduce energy use or heat gain and internal load density for hot climates. Put another way, it is impossible for an energy efficient building to be poorly insulated in a cold climate or have a low COP chiller in a hot climate.

Element 2. The building must supply the amenities and features appropriate for that kind of building. Thus, an office must provide around 60 hours/week of suitably conditioned air, lighting, and equipment.

Element 3. The building must be a low energy building. That means that the building must be operated in such a manner as to be efficient. The evidence of this is low supplied energy for heating and cooling benchmarked to other similar operated buildings.

We suggest that the scoring of *Element* 1 will include three parts:

I) The first part can be to evaluate the efficiency of the building in terms of the calculated heat loss or heat gain from energy passing the envelope. The heat loss will be simulated, using design conditions, based on a function of: the overall heat loss coefficient, exchanged air volume, the temperature difference and free heat from solar irradiation, occupants, etc.

II) The second part can be to evaluate the effectiveness of HVAC-installations. A score of the efficiency can be simulated for the equipment. That can be in either primary or site energy.

III) For occupied buildings the third and last part can be to define the total system effectiveness. The simulation is based on the information in this paragraph from I) and II), but also for appliances, hot water preparation, etc.

For occupied buildings, evaluating the suggested performance in *Element 2* will include an on-site visit to ensure the level of amenities. For new buildings, this can be based on a simulation.

Evaluating the suggested performance in *Element 3* will include an evaluation of the level of energy use according to the energy bills. This evaluation will be based on benchmarking of simple energy use metrics, using data from similar buildings as well as simulated data.

With this kind of definition, it can be possible to establish a kind of "score" or rating. The score would be based on the scores for the three separate aspects. A low energy and energy efficient building may not excel in all three of these aspects, but the building must offset an "average" value in one aspect with "excellent" values in the others. A very clever and attentive operator, for example, might be able to extract low energy use from only moderately efficient physical plant.

In principle, this approach would be flexible enough to recognize different strategies to achieve energy conservation. The first requirement, that is, the building must contain equipment and materials that permit it to be efficient. For obtaining that rating, the energy-efficiency must be assessed to a level of what can be judged as efficient for that particular building. That information can be retrieved from a simulation or inverse modeling (Olofsson and Andersson 2002). The second requirement, that is, the building must have appropriate amenities, could be assessed by rating to design or other demands. The third requirement, that is, the building must be efficient operated. That requirement includes an evaluation of users and can be judged by rating the energy use to aggregated statistics of similar buildings.

From practical continuation perspective energy rating procedures for European buildings can be required to meet the proposed certification by the European Union (EU) (Council of the EU 2001 and 2002), by the Energy Star in The US, etc. A rating procedure can also be useful for users to operate their buildings energy efficient. To be easy to use the rating of the three elements should be computed with modern existing simulation technology and using access to aggregated statistics of similar buildings.

The energy associated with the construction and demolition of a building plays an increasingly important role as the operating energy declines. Thus, an energy efficient building may need a fourth element: low energy consumption for construction and demolition. This is already important in Japan because buildings are traditionally replaced after only twenty years (Gao et al. 2001).

Economic considerations can often conflict with other criteria of e.g. energy efficiency. Most rating schemes exclude cost (Soebarto and Williamson 2001). In this paper, there has not been any discussion of how to identify the most cost-efficient buildings. That is definitely an important issue for making all real world design decisions. Assessment of the most cost efficient building includes assumptions of expected changes in interest rates, energy costs, etc. A rating system of low energy and energy efficient buildings can be based on arguments analogous to setting energy efficient standards, which is more analogous to minimizing the environmental impact.

6. Concluding remarks

In the perspective of rating energy performance of buildings this study has illustrated that the strategy for defining energy efficiency is important for successful rating. A strategy should include how to select the energy budget for an energy efficient building as well as how to evaluate the level of low energy and the relative and absolute energy efficiency. The level of amenities must also be considered.

Different aspects of low energy and energy efficient buildings have been reviewed. Conflicts between these aspects have been highlighted and based on that a list of three elements including - energy efficiency, amenities and energy use - has been outlined.

Data that are easy to access would be a requirement for a useful rating of energy performance of buildings. Modern existing simulation technology should be used for the evaluation. Access to aggregated statistics of similar buildings could be useful for including a model of the user influence. A next step is to evaluate the outlined procedure in practice.

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