Building Energy Standards Can Fail to Deliver Expected Savings: The Importance of Code Compliance

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ABSTRACT

Building construction codes and performance standards addressing the minimum efficiency of new buildings and renovations are critical for any national energy efficiency strategy. However, the anticipated energy savings can be achieved only if buildings actually comply.

Also, performance standards are increasingly ambitious—e.g., as of 31 December 2020, new buildings in the European Union (EU) must consume "nearly zero" energy. Expected savings estimates must be adjusted based on evaluation findings.

Policymakers also call for standardized methodologies to better reflect savings and facilitate comparisons between countries. For example, the EU Energy Performance Buildings Directive (EPBD) Recast requires a common framework for a methodology for calculating the integrated energy performance of buildings and building units, and minimum requirements for the energy performance of new buildings and new building units.

The authors examine recent analyses showing significant uncertainty with measurement methods and/or actual compliance. Reasons for uncertainty include the following:

- Estimating techniques are inaccurate (incorrect modeling of physics)
- Estimating techniques are inaccurate (incorrect modeling of behavior)
- Code requirements are not understood
- Energy code compliance has low priority
- Unqualified site managers and poor workmanship.
- Substitution of products during construction

This paper summarizes recent building code and standards compliance evaluations in several countries, including the Netherlands, the UK, and the US, and provides recommendations relevant for other countries as well.

Background

An analysis based on a review of fifty studies of state energy code compliance and enforcement efforts in the United States (Misuriello *et al*. 2010) indicates a number of common issues: as-built conditions often differ from as-designed conditions, during construction substitution of non-compliant products is common, and there is a need to strengthen training and education for code compliance. Another conclusion was that most studies were one-time efforts with unique methods, making it a virtually impossible to compare the compliance studies. The authors indicate the need for the development of standard methods for collecting, analyzing, and reporting data. In Europe as well, examples exist of deviations between theoretical and actual energy performance of buildings. In this overview, results of studies conducted in the Netherlands, the United Kingdom, Denmark, and the US are discussed.

Energy Performance Gap in the Netherlands—The Residential Sector

In the Netherlands, the Energy Performance Standard (EPN) was introduced in 1995; the lower the EPN, the more stringent the standard. The Energy Performance Coefficient (EPC) of a dwelling is the ratio between a "theoretical amount of primary energy use" and the "reference use." The EPC should be equal or lower than the EPN to comply with the standard. The EPN threshold is becoming more stringent over time: The value was 1.4 in 1995, compared to 1.2 in 1988, 1.0 in 2000, 0.8 in 2006, and 0.6 in 2011.

Effectiveness of the EPC in the Early Days

In a study based on nine newly built neighborhoods representing a total of 200 dwellings, theoretical and actual energy use were compared to determine the effectiveness of the EPN. The measured energy consumption was adjusted for differences in lifestyle and household characteristics, and annual climate fluctuations. The ratio of theoretical energy use (used in the EPC calculation) to measured energy use for a reference family was determined. If the ratio is constant for various EPC values, it suggests that there are no measurable signs of a decreasing impact of the EPN standard, within that interval.

Figure 1 shows that for five out of nine construction projects, the actual energy consumption was lower than expected based on their theoretical energy consumption used in the EPC calculation (ratio < 1,0) (Jeeninga, Uyterlinde & Uitzinger 2001). This was especially the case for construction projects with higher EPC values. For three of the nine projects, the average actual use was higher than the theoretically expected energy use, but due to the small number of projects it cannot be concluded that more stringent norms do not lead to corresponding energy savings. Furthermore, there are considerable differences in family size at the different locations, which was not fully addressed in the analysis.

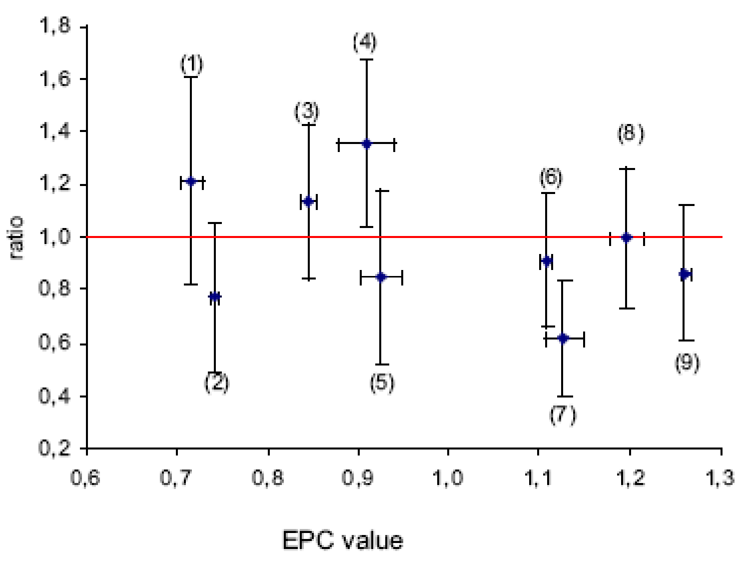

Figure 1. Ratio of actual and theoretical performance for various EPC values (Jeeninga, Uyterlinde & Uitzinger 2001)

The authors found that the variables causing an average energy use higher than the theoretical use (ratio over 1) are the connection to a heat distribution grid, the use of glass with lower U-values and the presence of a programmable thermostat. Variables that lead to a lower ratio are self-monitoring and the size of the dwelling (the bigger the dwelling, the easier it is to fit the norm). These findings suggest that estimating techniques of both physics and behavioral aspects can be improved.

Date of Issuing and Energy Performance

In a more recent study by Menkveld *et al*. (2010), actual and theoretical energy consumption were compared for dwellings constructed under a standard of EPN 1.0 and EPN 0.8. The more stringent standard of 0.8 came into force on January 1, 2006. Taking April 1 as a reference date, to account for the time needed to obtain a permit, one would expect that all dwellings with a permit issued before this date would have an EPC ≤ 1,0, and dwellings with a permit issued after this date would have an EPC ≤0,8. However, Figure 2 shows that the permit issue date turned out not a good indicator of the theoretical energy performance (EPC) of dwellings in the sample.

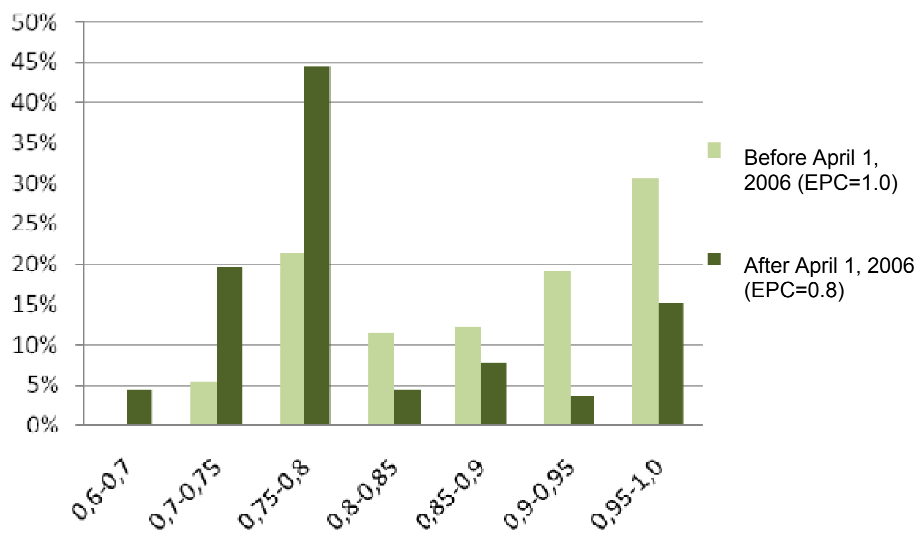

Figure 2. Distribution of EPC values for building permits issued before and after 1 April 2006 (Menkveld *et al*. 2010)

As-designed and As-built Performance

In this study, actual consumption was corrected for dwelling characteristics and consumer behavior. After correction a considerable variation still exists between energy consumption in the 248 dwellings in the sample (Menkveld *et al*. 2010). Savings in the dwellings with an EPC of 0.8 compared to an EPC of 1.0 were with 8% less than the expected savings of 20%. Based on a 95% confidence interval, the average savings in the sample ranged from 1% and 15%, with none reaching the theoretical 20%. The analysis shows that in this case the more stringent standard is not delivering the expected savings.

One of the findings in this study was that low-temperature heating in practice leads to higher average temperatures being set. If the study had not compensated for temperature setting (which was done), low-temperature heating systems would not contribute significantly to energy savings. This indicates that the modeling of behavior in the EPC can be improved.

Understanding the Performance Gap

Menkveld *et al*. (2010) interviewed stakeholders, who showed some doubts about the physics of the energy performance calculations. With the stricter standard, the use of quality statements and equivalence statements has strongly increased, according to the interviewees. A quality certificate is being used when a product has a higher performance than the default value in the EPC software according to the manufacturer. A certificate of equivalence is being used if a product is not included in the EPC software. Therefore, the decrease in energy use needs to be calculated in additional software provided by the manufacturer. The authors found that the construction companies being interviewed doubted whether the energy savings claimed in these two types of certificates are realized in practice, implying that estimation techniques are incorrect.

Construction companies indicated that they get little feedback from municipalities on their energy performance calculations and indicated that there are very few compliance checks by municipal officials at their construction sites. Municipal employees confirm that construction safety and fire safety have a higher priority in the compliance process. The intensity of compliance checks differs between municipalities.

Interviewees shared their concerns about behavior of residents reducing the potential energy savings by the various saving measures—e.g., keeping windows open when a balanced ventilation system is in place. While not a compliance issue, it is an example of "modeling behavior wrong" as it leads to underperformance on expected energy savings, and therefore reduced carbon savings and higher energy bills.

A last important finding is that it is not the EPC standard that seems to determine the total costs, but the applied installations. Depending on the installations chosen, a dwelling can be built to comply with the 0.8 standard at lower cost than some of the dwellings complying with the 1.0 standard. This means that a more stringent standard in this case doesn't necessarily lead to higher costs.

Energy Performance Gap in the Netherlands—The Tertiary Sector

Another study in the Netherlands was performed by the company Buildsight b.v. (2010), assessing the challenges and costs involved in improved compliance control, with a focus on checks on energy performance calculations and compliance checks at the construction site. In total, 30 non-residential buildings were visited during the construction phase with special attention being paid to quality of the construction work (e.g. junctions and thermal bridges) and materials used (e.g. insulation values for walls, roof and glass). Often, measures were not yet installed and could not be verified; in such cases Buildsight used default values as inputs when checking the energy performance calculations.

Several developers, for various reasons, were not willing to participate in the Buildsight study. Of the 30 buildings visited, authors managed to get hold of only 17 EPC calculations, five via developers and 12 from municipalities. However, none of the 17 calculations was available in the proper format, making it impossible to do a quick check on consistency with EPCheck software. After additional effort, one calculation has been received in the correct version and in the right software. When checking this single calculation, two mistakes were traced, one leading to noncompliance with the Building Code. The difficulties of getting access to calculations in the proper format and software, both from the project developer and the municipalities, therefore raises concerns.

Findings at the Construction Site

Compliance checks at the construction site revealed that, especially for walls, the installed insulation often was of a higher thermal resistance than assumed in the original calculations used for the building permit (see Figure 3). This was especially the case for buildings that only just met the required performance standard (EPN). An explanation for deviations, both in a positive and negative sense, is that the EPC calculations are made at an early stage, and that more detailed design follows later in the process. However, the sample is too small to draw conclusions. Another finding was that it is sometimes difficult to identify the characteristics of the materials used. This was especially the case for glazing.

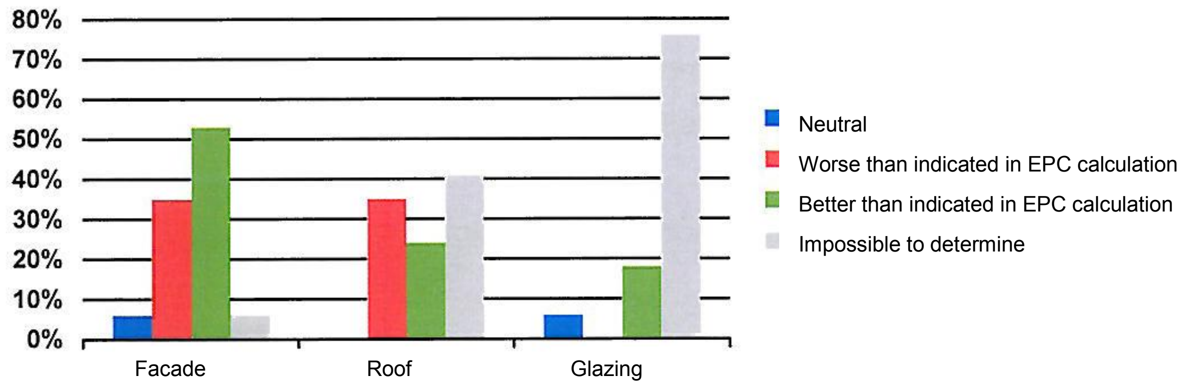

Figure 3. Energy performance of planned and used construction materials (Buildsight b.v. 2010)

Buildsight also recalculated the energy performance (EPC), based on deviations found at the construction site. This very likely leads to the energy performance standard (EPN) not being met any longer for one of the buildings. However, as only specific building systems were checked since not all systems and parts were yet in place, no conclusion can be drawn on the total energy performance in this phase. But it can be concluded that construction materials as assumed in the EPC are being substituted in the construction phase. Furthermore it can be concluded that it is sometimes difficult to do compliance checks (see Figure 3) and that an inspector has to visit a construction site several times, as construction materials are installed in various phases.

Energy Performance Gap in the United Kingdom

Although based on a smaller sample than in the Netherlands, evidence exists that actual energy performance in the UK lags behind the designed performance.

Noncompliance at the Building Site

Based on a survey of dwellings under construction in England and Wales, Baiche, Walliman and Ogden (2006) report a number of areas of noncompliance by construction companies in the UK. Typical practices include incorrect insulation of roofs and shortcomings in the construction of cavity walls (such as incorrect realization of the insulation layer). Occupants of new houses, interviewed as part of the study, said they had experienced drafty doors and windows, and malfunctioning heating systems, among other issues.

Building control inspectors, being part of the research, said they had observed that unqualified site managers, poor workmanship and a lack of knowledge of building regulations were the main reasons for noncompliance. Baiche, Walliman & Ogden (2006) call the increasing complexity of building regulations challenging, especially for small firms without special technical and design sections that the larger firms have. Small construction firms tend to rely on drawings provided to them by others.

Although the results of the research show that levels of compliance can be improved, there was no evidence of systematic and purposeful non-compliance with building regulations.

It is unclear to what extent building practice has improved since the above mentioned study. However, a more recent study by Bell *et al*. (2010) also shows deviations between as-designed and as-built performance. The study measured whole-house heat loss from 16 new dwellings. Average heat losses were 60% higher than determined in the design phase, leading to a performance gap of over 100% in some cases. In one field trial, the joint effect of high heat losses and an underperforming communal ground-source heat pump system was some 140% higher carbon emissions than calculated in the design phase.

The sample included a mix of house types and sizes: two-, three- or four-story houses, detached, semi-detached, and mid- and end-terrace houses. All dwellings used more energy than predicted. Only five out of 15 dwellings have a discrepancy of 15% or less.

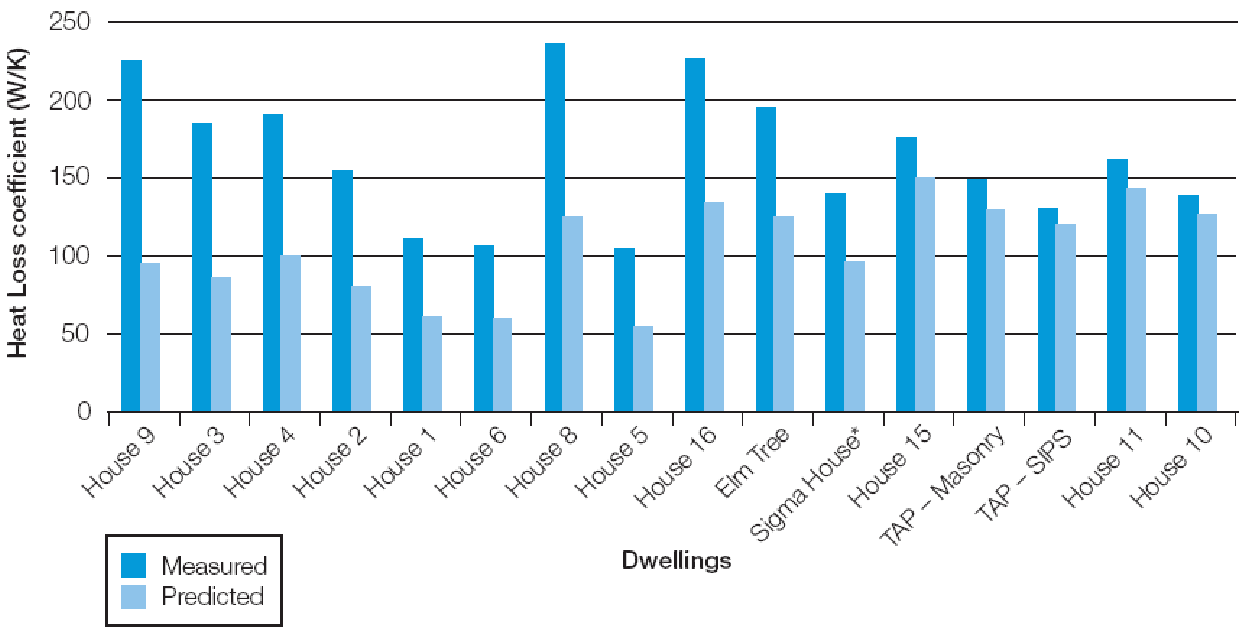

Figure 4. Measured versus predicted whole house heat loss (Bell *et al*. 2010)

The sample is not representative of the entire population, but discrepancies between designed and actual energy performance are large enough to take the results seriously. Despite the small sample, the Good Homes Alliance (2011) refers to this study when expressing the need for energy targets for "as-built" instead of "as-designed" performance. The Zero Carbon Hub task group (2010) stresses the importance of closing the gap between designed and built performance, also referring to the same study.

Professor Malcolm Bell, who led much of the LMU research, "highlights the crucial importance of improved procurement, design and construction processes and the need for the industry to measure actual performance so that the feedback provided by such measurements can be used to improve current practices." Measurement, feedback, and sharing best practices with the whole industry, including designers, the supply chain, and house builders, would make it easier for them to deliver buildings that comply with the code, and would probably also lead to more satisfied residents and the achievement of carbon reduction goals.

Energy Performance Gap: An Example from Denmark

Results from the Netherlands and the UK show examples of underperformance of buildings. The higher the required energy performance, the more challenging compliance will be become. Although there are also examples of well performing low energy dwellings, the following Denmark example shows how large the gap can become when insufficient attention is paid to design, construction, and behavior.

As shown in Figure 5, the energy performance of high-performance newly constructed dwellings (class 1) in Denmark fell short by up to a factor 3 compared to the allowed energy consumption for this building class for heating and electricity for building operation. Results are based on one year of monitoring (Weitzmann 2012). This underperformance can lead to energy consumption per square meter being higher than that of dwellings "just" complying with the standard, while class 1 buildings must have a performance that is 50% better than national standard requirements.

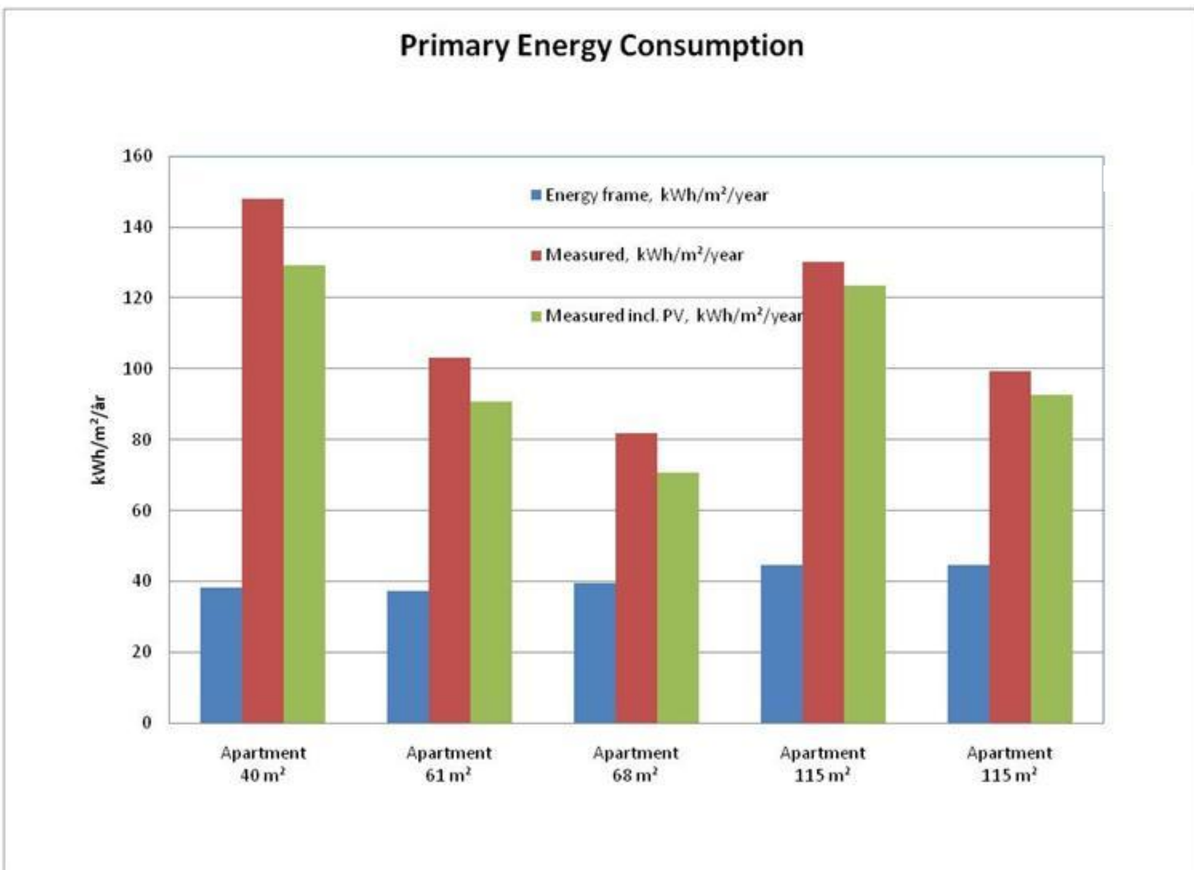

Figure 5. Energy consumption for class 1 buildings (Weitzmann 2012)

A survey showed that, of several home features asked about, residents were least happy about space heating, with 60% expressing dissatisfaction (see Figure 6). This implies that, in addition to higher energy bills, residents live in dwellings not delivering the comfort they expected (Weitzmann 2012).

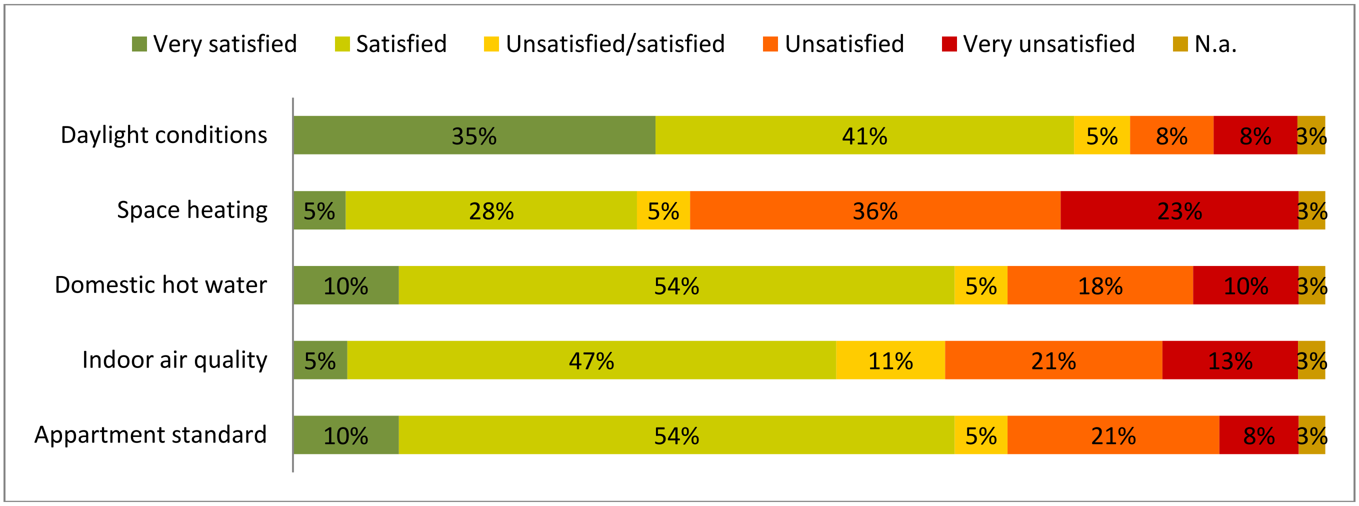

Figure 6. Satisfaction of residents in the apartments of figure 5 (Weitzmann 2012)

Energy Performance Gap: An Example from California

In the United States, California continues to be at the forefront of energy efficiency. Per capita energy consumption in California has remained essentially flat since the mid 1970s, while per capita energy consumption in the rest of the US has roughly doubled. A significant factor in that difference is that California developed some of the first energy efficiency standards, which came into effect in 1977.

Figure 7 (Kavalec 2009) provides a breakdown of the sources of California's gains in energy efficiency. Building and equipment energy efficiency standards provided over half of the total savings. The balance of the savings was achieved through a combination of naturally occurring advances in technology along with incentive programs offered by the utility industry in California.

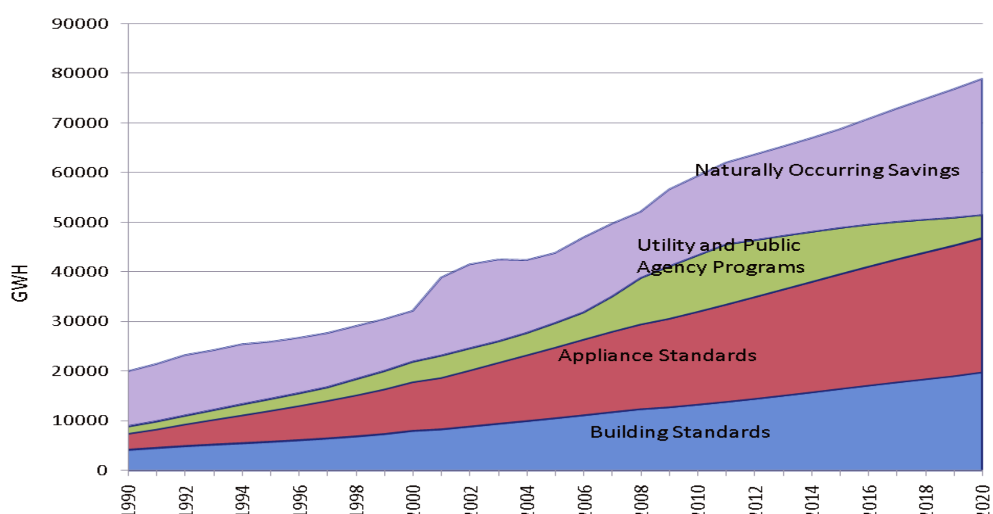

Figure 7. Energy saving scenario for California (Kavalec 2009)

Recent evaluations in the US attempting to confirm that code compliance is really achieving its potential have had mixed results. For example, Khawaja, Lee, and Levy (2007) show compliance ranging from 28% to 100% for specific building measures. Several current studies examining the compliance are underway; preliminary indications imply continued wide ranging and uncertain energy compliance rates.

Multiple factors are likely contributing to this problem. First, in the US, building codes are enforced by local building departments with limited resources and staff. Local building departments have many responsibilities, including some that life critical. Typically the same staff is responsible for structural, fire and electrical safety along with plumbing and miscellaneous zoning requirements. Energy efficiency is probably one of the lower priorities for any local building code office. A study for the Southern California Edison indicated that the lack of prioritization of the energy code is a major challenge in California (Heschong Mahone Group 2009). This problem is compounded by the lack of training and understanding of the energy code requirements and the fact that not only are current energy efficiency codes relatively new, they also constantly change. A recent study of code compliance in California uncovered this basic level of frustration by code officials. Independent evaluators found it almost impossible to find cooperative code official offices.

An Overview—Reasons for Lack of Code Compliance

Based on the studies discussed in this paper, a number of reasons and explanations were found for the lack of code compliance, including:

Estimating techniques are inaccurate – they model the physics wrong. Standards are typically developed using an engineering or computer simulation models of how the unit is expected to operate. Yet, even simple units are actually quite complex and difficult to model. Energy flows are three dimensional in space and occur over time. Also, interactive effects must be addressed—e.g. a more efficient lighting technology may require more heating and less cooling of the illuminated space.

Estimating techniques are inaccurate – they model behavior wrong. Models also need to capture the impact of human behavior, yet prediction is a difficult challenge and is often multi-dimensional. Generally, models assume some kind of "average" household, where the "average" may not be representative of any particular household due to the variance. Some types of behavior are difficult to predict (such as higher temperature setting in case of low-temperature heating systems). Furthermore, consumers are sometimes not well informed about how to operate their "efficient" buildings properly, leading to a poor energy performance of the "building."

Lack of knowledge of building regulations/ code requirements are not understood. The first energy efficiency codes have existed for decennia and have gone through several different iterations. Frequent updating makes it difficult for installers and compliance professionals to remain current. The codes are often complex, requiring simulation models to demonstrate theoretical compliance. Especially for small firms without special technical and design sections, the complexity of building regulations can cause major challenges.

Energy Code compliance has low priority. It is easy to imagine why code enforcement officials need to ensure the building is structurally sound, meets all fire, electrical and plumbing safety requirements, and is suitable for human occupancy. However, they may not regard energy efficiency as critical. Also, budget pressures mean staff is limited and often have more responsibilities. And as shown by the study in the Netherlands, energy performance calculations are not always available in a way that can be easily checked. Additionally, it is sometimes difficult to determine to determine at the construction side what materials are actually used.

Unqualified site managers and poor workmanship. Poor workmanship was specifically mentioned for the United Kingdom. But this barrier seems to exist in other countries as well, and is addressed by the Intelligent Energy Europe (IEE) programme 'BUILD UP Skills', the European Sustainable Building Workforce Initiative. Aim is to unite forces to increase the number of qualified workers in Europe's construction sector, with a focus on training of craftsman and on-site workers.

Substitution of products during construction. However, the Buildsight (2010) study in the Netherlands showed that this could both lead both to better and to worse performing construction materials than originally indicated in the energy performance calculation.

Conclusions and Recommendations

Predictions of consumption in buildings are almost always poorly related to actual consumption, indicating a fundamental weakness in the goal of actually achieving the predicted energy savings.

Based on the studies discussed for the Netherlands and the UK, it can be concluded that the reasons for noncompliance overlap with those found in the US. However, whereas in the US the American Recovery and Reinvestment Act of 2009 (ARRA) has led to an increase in building energy code compliance studies, the number of studies available in the Europe are still limited, both in number and in sample size.

Even though the studies discussed give a first impression of the size of and reasons for the energy performance gaps and noncompliance, sample sizes are too small to generalize findings and to make estimations of the national-level impact of noncompliance on achievement of carbon savings targets.

The two studies in the Netherlands with sample sizes of 200 or more showed that compliance was higher for dwellings with higher EPCs. This is logical, as less strict standards are easier to comply with. The studies in the Netherlands, UK and Denmark show that with more energy-efficient buildings or with more stringent standards, deviations between as-designed and as-built energy performance increase. Now that the target in Europe is Nearly Zero Energy Buildings (NZEBs) for 2020, compliance might become an even bigger challenge in coming years. The higher the energy performance aimed for, the higher the risk of a gap between theoretical and actual energy performance, and the more critical it will become for design and realization of the construction to be implemented with sufficient care for overall energy performance.

The overview of reasons for lack of code compliance in this paper, improving code compliance, and reducing the deviations between as-designed and as-built requires a shared effort from various stakeholder groups, such as the construction sector, code enforcement officials, the expert teams modeling physics, and behavior and training institutes.

Conducting evaluations on code compliance in several countries representing different code compliance environments, but using a uniform energy code compliance evaluation methodology, would help to achieve a better understanding of causes of noncompliance and potential ways to overcome them. When designing evaluations, it is important to use sufficiently large samples to be meaningful. Two of the studies discussed above worked with sample sizes of fewer than 20 buildings/dwellings, which is too low to draw robust conclusions. There should be considerable attention paid to the design of the evaluations in order to increase the probability of determining the root causes of the mismatches, which would enable the development of corrective actions. It is especially important to include both countries with mature building code activities as well as those with emerging building code activities.

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