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# Danish Sector Guide for Calculation of the Actual Energy Consumption

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**Abstract**
*Energy calculations have for a long time been a controversial topic as building owners do not necessarily achieve the promised energy savings after a building upgrade, but is this due to incorrect calculations or rather the evidence of misunderstandings in the communication?*

*In Denmark, the innovation network for sustainable construction, InnoBYG started work on a Danish sector guide for the calculation of actual energy consumption in relation to upgrading of buildings. The focus was to make a common guide for energy calculations that can be used by consultants performing calculations. The guide should help to ensure more uniformity in calculations. Furthermore, the aim was to highlight the influence of uncertainties related to the calculation. This should ensure a transparent and comparable communication of the calculation assumptions, the result and the associated uncertainty of the energy calculation for building owners and developers.*

*This paper describes the process that leads to the sector guide and briefly explains the content in both the technical guide and the communication paper. Finally the paper discusses some of the known dilemmas related to the measured energy consumption compared with the estimated energy demand by calculation. The paper concludes that the result of an energy calculation should not be given as a single figure but rather as a spread between the best and worst case for the assumed conditions. Finally, a brief update on current actions is given related to the sector guide for calculation of actual energy consumption.*

***Keywords – Energy calculations, actual energy consumption, energy perfomance***

## 1. Introduction

The first Danish Building Regulations from 1961 were mainly based on practical experience and building tradition combined with the first nationwide energy requirements. Since then, a strong focus on energy requirements has kept up with the development of the regulations. Since 2006, the energy requirements have also included requirements for existing buildings undergoing a building upgrade if it is cost-effective and long-term objectives for new buildings, and this enables developers to implement planned subsequent energy requirements. The latter option works in practice, as stricter requirements concerning energy consumption are often imposed in new buildings.

Compliance with the Danish Building Regulations requirements must be documented using a calculation tool based on EN ISO 13790 [1], like the Danish building energy calculation program, Be10 [2]. The calculated energy demand for a building is based on default/standardised values for energy supply, heating, ventilation, cooling and domestic hot water, and hence the tool is used for benchmarking of buildings, but the calculation is not suitable for predicting the expected actual energy consumption of a new building. The strong focus on energy efficiency is also transmitted to existing buildings, and results in an increased demand for accurate energy calculations, which can be used for estimating the actual energy consumption and savings associated with building upgrades.

Denmark has advanced far in reducing energy consumption in new buildings but there is also a great potential in the existing buildings. In the autumn of 2012, a wide range of stakeholders from the building sector was invited to participate in a political initiative named “network of energy retrofitting”. The invited stakeholders were all involved in energy retrofitting of buildings, including representatives of owners, tenants, consultants, contractors, financial institutions, NGOs, knowledge institutions and others.

As background material, an analysis by Wittchen & Kragh [3] showed a potential for energy savings until 2050 of around 30% for space heating and domestic hot water in the Danish building stock based on energy retroffitting according to the requirements stipulated in the Danish Building Regulations 2010 [4]. Later in May 2014 initiatives to promote and improve energy retrofitting were launched and this also pinpoints the discrepancy between calculated and achieved energy savings as a focus area.

Experience demonstrates that estimates of the energy consumption and energy savings after a building upgrade have been associated with uncertainties so great that they constitute a barrier to a greater extent of effective and credible implementation of in-depth energy retrofits and building upgrades.

As an example, the Danish Property Agency started a building upgrade in an office building in 2011. The discrepancies between the calculated and measured results led to an extensive investigation in search of explanations and possibly methods for reducing the energy consumption [5]. Part of the discrepancy was caused by the heating supply that included extra buildings and a complex building installation that was not commissioned and therefore malfunctioned, but also the measured data before the upgrade showed discrepancies of up to 10% indicating that the “before” situation might not have been well defined.

This illustrates that the Danish building sector needs common guidelines for the calculation of the actual energy consumption in relation to the upgrading of buildings.

The Danish innovation network for sustainable construction, InnoBYG with a wide representation from the construction industry, including clients, consultants, developers and knowledge institutions, saw the need for a sector guide that can ensure the confidence in the energy calculations with greater transparency in the communication between the client and the consultant and an agreed uniform use of methods of performing energy calculations across the building sector.

The Danish Association of Consulting Engineers (FRI) was the instigator of the development of the sector guide and thus an InnoBYG project was launched widely supported by the building sector with a project team consisting of InnoBYG members including consultants, building owners, building operators and knowledge institutions in the autumn of 2013.

This paper presents the process that led to the sector guide and the contents, which are intended partly to give an introduction to communication between client and consultants in relation to building upgrade and getting a guide for performing accurate energy calculations. The Danish sector guide for calculation of actual energy consumption are intended for consultants that perform the energy calculations related to building upgrade for developers or building owners with both small and large building portfolios, but it is also available for other interested parties.

## 2. Methods

The inspiration for the development of a Danish sector guide was the result of an InnoBYG workshop in December 2012 that should gather input from a wide representation of the Danish building sector on subjects that needed research, knowledge or development in relation to sustainable energy retrofitting of buildings. Especially engineers were very interested in ensuring confidence in energy calculations and during the summer of 2013 FRI therefore pushed for the start of an InnoBYG project on the development of a sector guide for calculation of actual energy consumption. This was followed by a start-up workshop in October, where all InnoBYG members were invited to participate.

At this workshop the overall goals and the target group were discussed for the sector guide. The overall results of the start-up workshop were that the focus of the sector guide should be a guiding text for best practice for calculating actual energy consumption. The guide must contain a description of the different calculation methods that should also contain information on where the different methods are appropriate for use and guidance on how to ensure that passive robust solutions are implemented in the building. It will not be a requirement that the sector guide for calculation of actual energy consumption is followed, but it can be a valuable tool for both new and experienced engineers and consultants. It is also important to focus on needed capabilities and where it is necessary to rely on specialist knowledge. For example, it is a complex task to make the behavioural assumptions and estimating U-values and thermal insulation of building elements. Therefore, the sector guide will also focus on common assumptions of input parameters that will ensure a uniform calculation basis. This was suggested to be supported by a list of typical operational errors, and reflected in scenarios that analyze the overall impact, and suggestions for sensitivity analysis, which can illustrate the effect of changes in input parameters on calculation results.

Furthermore, it was an important outcome that the purpose of the sector guide should be communicated in a way that is comprehensible even to non-experts of energy calculations and at the same time the sector guide must not mislead the public into thinking that energy retrofits and related building upgrades on their own can lead to the transformation of the building stock. However, it is anticipated that enhanced focus on building performance related to both indoor climate and energy can be a driver.

At the workshop, all of the 25 participants agreed to join either the active group that agreed to develop the actual sector guide for actual energy consumption or the passive group that agreed to comment on the work from the active group.

In the process of developing the sector guide, the active working group was divided into two groups with one focusing on the technical part and the other on communication with special focus on matching expectations between the building owner and the consultant. During the development process the working groups both conducted working meetings where the participants did the actual writing of the sector guide, which clearly indicate the deep sector involvement behind the guide. During the process the technical group also found inspiration in similar work for new buildings [6] as experience from new buildings also show discrepancies between calculated and realized energy consumption. In March 2013, a draft version of the sector guide was ready for comments and consequently sent to the passive group of participants for commenting. This was followed by a workshop discussing the content which caused some rewriting of the communication part, but at the end of June 2014 the Danish sector guide for calculation of actual energy consumption was finally published [7].

## 3. Results

This section presents the contents of the sector guide for calculation of actual energy consumption. The results are compiled in a technical guide that is designed to calculate a realistic estimate of the energy consumption in a building - not as a single figure, but as a range of how much energy is expected to be consumed. At the end of the technical guide, a communication paper is added and this is entitled “Uncertainty in energy calculations”. The communication paper is intended as a starting point for discussing assumptions and expectations for calculations of energy savings between the building owner and the consultant who performs the energy calculations.

The sector guide is built on a process where the building owner or developer and the consultant have the opportunity to reach a common understanding of the energy demand in a specific building, like what are the significant assumptions and what are the uncertainties associated with energy calculations underlying the estimates of energy consumption and savings.

The method in the sector guide is based on the qualification of already known calculation methods and tools. The level of detail is adjusted relative to the current level of knowledge, which can be increased by, for example, registrations that enhance the level of information of the building, which also reduces uncertainties, see Figure 1.

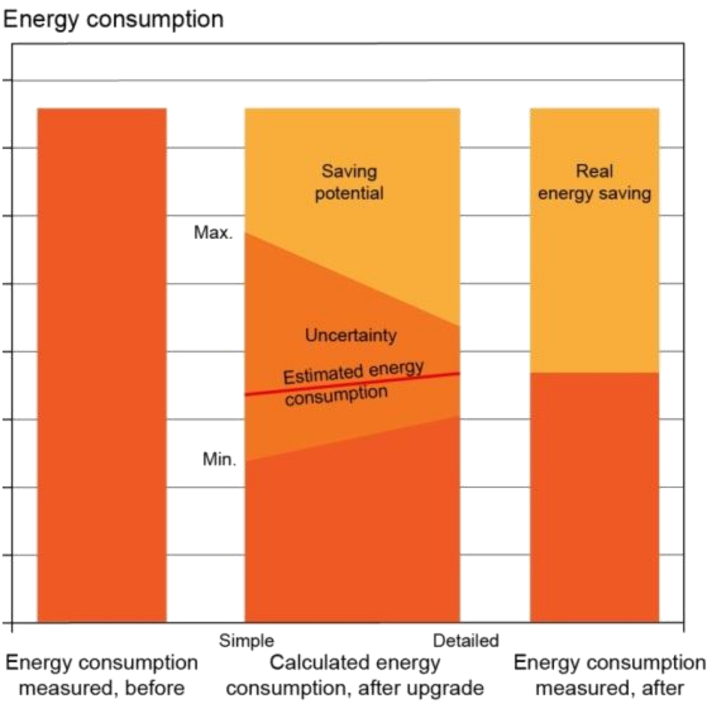


Fig. 1 Calculation of a future energy consumption is subject to some uncertainty in relation to a future energy consumption measured after the building upgrade.

The tools range from simple corrected degree-day models and the program Be10, which is used for documentation of compliance with the requirements in the Danish Building Regulations. Based on the dynamic analysis of the indoor climate or from measurements the level of detail can be qualified for control and regulation of the technical installations.

The estimates represent averages of the expected energy consumption or equivalent energy saving, which is always indicated by a corresponding spread for the uncertainty. Mean and spread can be further reduced by qualification of input data and adjusted to reduce the uncertainty by e.g. more detailed inspection, registration, measurement or qualification of real operating conditions.

For complex building upgrade projects, where a higher degree of precision is required in relation to assumptions as well as results, the preliminary work for an energy calculation starts with a physical inspection of the building to determine key parameters of constructions, installations and building use. The inspection is not an isolated activity but should be seen as a supplement to other activities related to the technical calculations.

The calculated expected energy savings is made based on the choice of calculation method, and the necessary level of detail depends on the scope and knowledge of the actual energy retrofitting.

Energy retrofitting of buildings can be made to varying degrees. In some buildings, only energy improvements of a single building element are implemented, while in other buildings energy retrofitting in several building elements are included. Finally there can also be major in-depth building renovation, where a large part of the building envelope and / or technical installations is renovated.

The extent of a retrofitting can be divided into energy improvements that include isolated single actions or combined actions. The choice of calculation tool depends among other things on whether the energy retrofit consists of a single action (independent) or combined actions (measures that affect each other). The sector guide includes lists of actions that should be treated as single or combined actions depending on the building typology such as housing or other buildings like offices and schools. Next step in the calculation procedure is to decide the level of detail based on simple calculation by hand or in spreadsheets and advanced calculations that are based on calculation models using more detailed calculation tools.

The sector guide for calculation of the actual energy consumption also has a chapter on standard assumptions related to energy retrofitting of buildings. This includes numbers for the expected hours in use, internal heat load and domestic hot water use. This is followed by guidelines for qualifying input parameters for the energy calculation, which includes

- geometry
- building structures
- hours in use

- ventilation
- internal heat load
- lighting
- other electrical equipment
- cooling
- heat distribution
- pumps
- domestic hot water
- heat installation
- renewable energy
- building control systems

The sector guide also gives recommendation for the reporting of energy calculations in order to ensure comparability and how to report uncertainty in the result combined with guidelines for sensitivity analysis.

## 4. Discussion

The uncertainty between the calculated and the future measured actual energy consumption is due to many factors, such as user behaviour, use of the building, the building structure and varying weather conditions in different years. But the uncertainty of the estimated energy consumption can be reduced for example by extended inspections and further investigations of the actual use of the building or by extra computer simulations. It will cost extra if the consultant needs to obtain further knowledge of a building in order to reduce the uncertainty of the energy calculation. A building owner must therefore decide how great the need is for reducing the uncertainty in prediction of the future energy consumption compared with the cost of the building upgrade. In the following, some examples of parameters influencing an energy calculation are presented.

The user behaviour is very important for the energy calculation and it will be reflected in the energy calculation. In Denmark, the standard value for indoor temperature in the design situation is 20 °C, but the indoor temperature will often be around 22 °C, so the sector guide gives recommendations for changing standard values to more realistic actual values. Along with a building upgrade, the use of the building may also be changed so that the number of persons per area is increased which will affect the need for electricity and water consumption. The uncertainty of user behaviour can be reduced by active control systems for technical installations like motion sensors and timers for different ventilation strategies.

The building structure can also induce uncertainty. As an example, it is often assumed that the building envelope is insulated following a typical period or style for the original construction period combined with an assumption of the actual condition of the insulation. Another example is the technical installation which is normally assumed to function normally, which may not actually be the case, but it will require specific knowledge to verify this.

The impact of weather conditions impose another uncertainty on energy calculations as all calculations are normally performed using a reference year. In reality, a given year can be either colder or warmer than the reference year and this is illustrated in Figure 2. The figure shows an example of an office building that is energy retrofitted and it can be seen that a warm year before an energy retrofitting of a building followed by a colder year after the energy retrofit may impact, the result of the energy consumption so much that the consumption after the building upgrade may be higher than before the energy retrofit. This is a very relevant point because the weather has a very strong impact on the energy calculation and there is no way to control it except to be aware of the yearly changes.

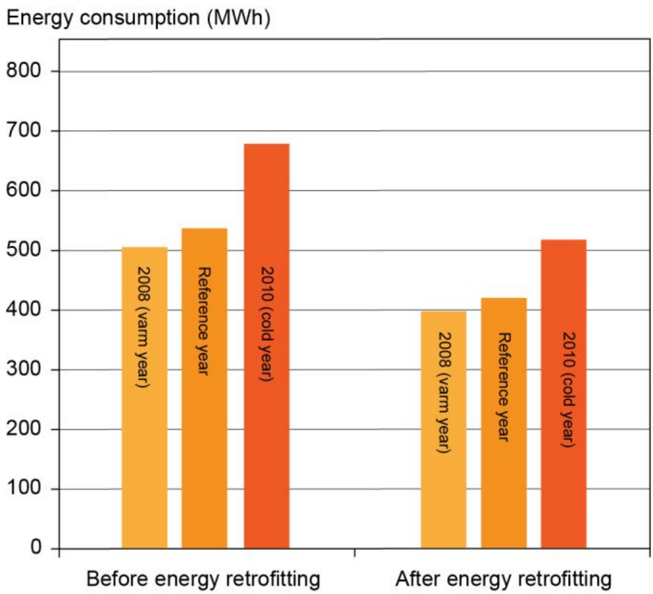


Fig. 2 Yearly weather variations affect the energy consumption. Therefore, the energy consumption after a building energy upgrade in a cold year may be higher than in a warm year before upgrading.

When energy calculations are performed, it is also important to notice that different energy-retrofitting initiatives may affect each other. For example, an old lighting system may, for example, be replaced by a new LED-based system that consumes less electricity. This will save energy, but as the new lighting system has a lower internal heat load, the heating demand in the building will be expected to increase.

As mentioned earlier, the ‘before’ situation may not be very well defined as the measured data before an energy upgrade in an example case [5] showed discrepancies of up to 10%. This is an important result that should be included in the communication as the calculations of energy savings is very dependent on the definition of the before situation.

## 5. Conclusions

Energy calculations are complex and therefore it is concluded that it is necessary that the building owner and the consultant performing energy calculations have a common understanding of the assumptions and uncertainties in the calculations. They must have a mutual understanding of the level of details that is necessary in the actual calculation in order to achieve the wanted accuracy. Therefore, it is concluded that the result of an energy calculation should not be given as a single figure, but rather as a spread between the best and worst case for the assumed conditions.

Furthermore, there is a need for specific knowledge about the building and its installations as well as the user behaviour in order to obtain an accurate calculation result. The calculated energy savings will be very dependent on the assumed ‘before’ situation, but even in this case there are yearly variations.

### *A. Future work*

In June 2014, the Danish sector guide for calculation of actual energy consumption 1.0 was published. Subsequently, the InnoBYG network got funding for continuation of another four-year period. At the end of 2015, a new project was formed that should gather the first example cases and experience of using the sector guide. In the autumn of 2016, this will lead to an update version 2.0 of the sector guide for calculation of actual energy consumption.

## Acknowledgment

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