Success factors of energy efficiency measures in buildings in Norway

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Abstract

The aim of the study was to identify factors and parameters, which could contribute to the successful implementation of energy efficiency measures in buildings, and to find which parameters introduce uncertainties in achieving the planned energy savings. A database of 41 buildings was developed for the analysis. The database contained information related to buildings, energy efficiency measures, and energy use over several years. A presentation method for the persistence of the energy efficiency measures was introduced. Through the energy performance contract, energy savings of 30 % of the total energy use were suggested on average. The results showed that the success factors of the energy efficiency measures were: previous energy use, project cost, consultant experience and engagement, and implementation of a good operation plan. The persistence of the energy efficiency measures was influenced by the achieved savings in the first year, the guaranty period, and the implementation of the operation measures. Uncertainties in the presented results were induced by the following factors: temperature correction method, difference in reported building area, correctness of the information regarding the implemented measures, and calculation method. The uncertainty due to lack of information or not delivering the operation measures was about 20 % of the total energy use.

Keywords: energy use, energy savings, measure persistence, real energy savings, uncertainty in energy savings

1. Introduction

Energy efficiency in buildings has been an important topic since 1970 and has been widely recognized as an option to decrease energy use. For that purpose, different tools, methods, standards, and business models have been developed. In the European Union, the directive on end-use energy efficiency [1] has been introduced as a complement to the directive on the promotion of the use of energy from renewable sources [2], so that both directives can contribute to the reduction of primary energy consumption in society. Finally, energy efficiency is introduced as a business model via energy performance contracting to deliver energy efficiency projects [3]. Recently, the topic of energy efficiency and building retrofitting has been widely discussed, as shown in [4]. However, there are different barriers to the implementation of energy efficiency measures. For example, the barrier to the implementation of carbon reduction strategies in large commercial buildings in China is: limited scope for energy management to be effectively incorporated into projects [5]. On the other hand, a huge emphasis on renewable energy sources could induce an under-investment in energy efficiency and an over-emphasis of renewable systems, as pointed out in [6, 7]. Therefore, investment in energy efficiency measures should be a prerequisite to the installation of solar water heating and solar electricity in zero energy homes [6]. Different opinions and barriers in the implementation of energy efficiency measures might be due to a lack of measurements and documentation of real case studies. The 2012 World Energy Outlook emphasizes that monitoring, verification, and enforcement activities are essential to realize expected energy savings [8]. Therefore, the aim of this study was to analyze factors, which could contribute to achieve planned energy savings. The analysis was performed by evaluation, verification, and monitoring of the energy savings induced by implementing energy efficiency measures. This study included technical as well as economic and expertise factors obtained from real energy use and energy efficiency projects.

Since energy efficiency in buildings became an important topic, many studies with different aims have been reported. For example, the technical performance of residential retrofit measures and their relative cost are evaluated in [9], while, in the work of Goldman, factors that account for variation in energy savings among households installing similar measures were analyzed [10]. In the work of Rysanek and Choudhary, a very good decision tool to search for optimal building energy retrofits was developed. This is a calculation tool, based on non-probabilistic optimization, which takes into consideration technical and economic uncertainty [11]. On the other hand, after so many years, there are still no available methods to identify the most cost-effective retrofit measures for particular projects [4]. The main challenge is that there are many uncertainties, such as climate and changes in services, human behavior, and government policy [4]. For example, in the work of Wall et al. [9], the trend of increased savings for larger investment is observed. Further, in the same work, the relationship between contractor cost and present savings is found [9]. All these provided motivation for this study to analyze project investment and engineer expertise to find success factors for energy efficiency measures. In the work of Xu et al., the six clusters of success factors in the energy efficiency project were identified: 1) project organization process, 2) energy performance contracting (EPC), 3) knowledge and innovation of sustainable development, and measurement and verification, 4) implementation of a sustainable development strategy, 5) contractual arrangement, and 6) external economic environment [3]. In the work of Xu et al., interviews and surveys were used to obtain project data [3]. In our study, the reports from the EPC, data from energy monitoring, and communication with a company that performed the EPC were used to obtain input data for the analysis in this study.

Different methods have been used to assess and analyze energy efficiency measures and their results, starting from the International Performance Measurement and Verification Protocol (IPMVP) that gives standard terms and procedures for quantifying the results of energy efficiency investments [12]. Further, researchers suggest statistical and innovative methods to estimate energy efficiency measures. To assess the renovation packages for increased energy efficiency for multi-family houses, economic parameters, indoor environmental quality, and, specifically, environmental aspects associated with energy demand are analyzed in [13]. In the work of Xu et al., the cluster method has been used. Life-Cycle Cost analysis combined with a Mixed Integer Linear Programming is used to estimate and optimize retrofit measures in [14]. In general, all these methods give good results. In our study, regression analysis and stock diagrams were used to analyze calculated and measured energy use over several years.

One of the conclusions in the work of Ma et al. [4] is that most previous studies were carried out using numerical simulations, while actual energy savings due to the implementation of retrofit measures in real buildings may be different from those estimated. Therefore, more research with practical case studies is needed to increase the level of confidence in potential energy savings [4]. It can be difficult to prove real energy savings for a variety of reasons, such as insufficient data, issues in the prediction methods, uncertainty in measure implementation, etc. All these can lead to difficulty in proving the persistence of energy efficiency measures over the years. For example, the BECA project addresses the lack of monitored building performance data in the documentation of the energy savings and cost-effectiveness of conservation measures and practices [10]. The work of Wall et al. shows that, typically, predicted energy use is very different from the real energy use for an individual house [9]. The measured performance of LEED buildings had little correlation with the certification level of the building or the number of credits achieved by the building at design time, as shown in [15]. Uncertainty in the energy efficiency measures can be induced by a few factors such as: low implementation rate of the suggested measures, lack of information from the design-phase, occupant behavior, physical differences among buildings prior to retrofit, variations in product and installation quality, and measurement error [10, 16]. The persistence of energy efficiency measures refers to an estimation of how long the consequences of an implemented measure can be noticed on energy use. This factor can be used to promote an energy efficiency measure. However, in the work of Piette et al., it is found that energy increases during the first four years of operation by 36 % compared to the design predictions in 28 commercial buildings [16]. Therefore, in the same work, a need for commissioning and simple evaluation techniques to ensure persistence of savings is indicated [16]. Considering the above-mentioned issues such as lack of documentation and uncertainty, it can be difficult to prove the persistence of energy efficiency measures. On the other hand, a great need for commissioning, information collection, and documentation is clearly emphasized, if energy efficiency measures have to be proven and promoted.

Energy labels on buildings have been mandatory in the European Union since 2006 with the application of European Directive 2002/91/CE [17] on the energy performance of buildings. The objective of this directive is to promote the improvement of the energy performance of buildings within the community, taking into account outdoor climatic and local conditions, as well as indoor climate requirements and cost-effectiveness [17]. However, during the years since the application of Energy Performance of Buildings Directive (EPBD), some issues have been found. Some of the issues relate to the understanding of the energy label and the use of the information provided on the energy label [18]. For example, in the work of Szalay, one of the problems mentioned is that energy performance is expressed in a complex way, including many components that are not directly related to the building [19]. A study on how the labels work in Belgium shows that only 11 % of all proposed energy-efficiency measures have been implemented one year after the energy assessment. On the other hand, information about the investment cost and possible savings can encourage building users to implement measures [20]. Finally, lifetime commissioning is suggested as a tool to organize information and to perform quality control of the implemented energy efficiency measures in [18]. Therefore, as a part of this study, building information was organized based on a method for proving measure persistence suggested in Annex 47 [21].

In this study, data from 41 buildings were organized to identify which factors contributed to achieving planned energy efficiency results. Several years' worth of energy monitoring data were used in the analysis. In the next section, the following estimation methods are introduced: a method for comparing planned and achieved energy use and a method to estimate energy efficiency persistence. The analyzed buildings are introduced briefly in the third section. The fourth section starts with an illustration of the energy statistics of the analyzed buildings, continues with an identification of the success factors for energy efficiency, and concludes by identifying uncertainty in the implementation of the energy efficiency measures.

2. Method

To estimate the results of energy efficiency measures and what contributes mostly to energy savings, a method, presented in this section, was developed. The method included data collection and data analysis. The idea behind the data collection was to organize data in a generic way, to enable a simple comparison of the energy efficiency projects. Data analysis included an estimation of the parameter influence on the energy efficiency measures and also on the persistence of the measures. A difference was made between the two last-mentioned estimations, because the energy saving caused by an energy efficiency measure could change over time. The aim of an energy efficiency project is to maintain energy savings. Therefore, it was necessary to estimate those parameters which make the greatest contribution to maintaining the planned energy savings.

2.1. Data collection and data structure

The data necessary for this study included building type and characteristics, project cost, retrofit and energy efficiency measure descriptions, and annual energy use before and after the measures. To easily analyze all these data, the building information was organized based on a method for data collection suggested in Annex 47. This method was developed not only to prove the cost-benefit and persistence of the lifetime commissioning measure [21], but also to enable the quantifying of the results of energy efficiency investments suggested in IPMVP [12]. Finally, the building data were organized in a database. The necessary data were obtained from various sources, such as: the EPC reports, data from energy monitoring, and communication with a company that performed the EPC. All the analyzed buildings purchased EPC from a company that was a consultant and property development company. Due to the company's requirement and in order to maintain the anonymity of the analyzed buildings, the company name is not mentioned in this article.

In order to easily provide energy-use data for a few years, one of the criteria to analyze a building was it had an available energy monitoring system. Further, it was important to collect data about both the suggested energy efficiency measures and the actual implemented measures. It was noticed that not all the suggested measures were necessarily implemented. In addition, many changes could occur within the building, such as change in the area, working time, operation time of the equipment, number of users, etc. All these induced many difficulties in finding the real data. Uncertainty in energy savings due to uncertainty in the building information is presented in Section 4.3.

In Section 3, a summary of the obtained data for 41 buildings is presented.

2.2. Estimation of parameter influence

To estimate the influence of a parameter on the energy savings and hence reach a conclusion on the success of energy efficiency measure, a parameter is introduced, as shown in Equation (1). The parameter in Equation (1) compares the calculated energy use with the actually achieved energy use after the energy efficiency implementation. Since the parameter in Equation (1) measures the difference between the calculated and the achieved energy use, it is named the bias. Therefore, in the further text and analysis, this parameter is called the bias.

$$p = \left(\frac{E_{assumed} - E_{achieved}}{E_{assumed}}\right) \cdot 100 \tag{1}$$

where $E_{assumed}$ (kWh) is the calculated energy use and $E_{achieved}$ (kWh) is the achieved or measured energy use after the energy efficiency measure's implementation. The calculated or assumed energy use was calculated based on practical assumptions and previous energy use, as given in the following equation:

$$E_{assumed} = E_{before} - E_{savings}. \tag{2}$$

$E_{savings}$ (kWh) was estimated based on the previous projects, experience, and practical assumptions about possible energy saving when certain measures were implemented. The method to estimate the assumed energy use is a knowledge-based method that has been widely used in energy savings companies in Norway. The possible consequences of the use of this estimation method are discussed later in the text. E_{before} (kWh) is the total energy use in the basis year. In this study, the basis year was assumed to be the year before the measurement's implementation.

The idea of introducing the bias as a comparison factor, Equation (1), arose from the simplicity of the results' presentation and of understanding which factors have a positive influence on the success of the energy efficiency measures. In this case, to simply understand the results, the following expression can help:

- if $E_{achieved} = E_{assumed}$, $p = 0$, the achieved energy saving is the same as the assumed energy saving;
- if $E_{achieved} > E_{assumed}$, $p < 0$, the achieved energy saving is lower than the assumed energy saving;
- if $E_{achieved} < E_{assumed}$, $p > 0$, the achieved energy saving is higher than the assumed energy saving.

Based on the introduced expression above, a parameter was treated as having a positive influence on the success of the energy efficiency measures if $p > 0$. An example of how observed parameters were treated in this study is shown in Figure 1.

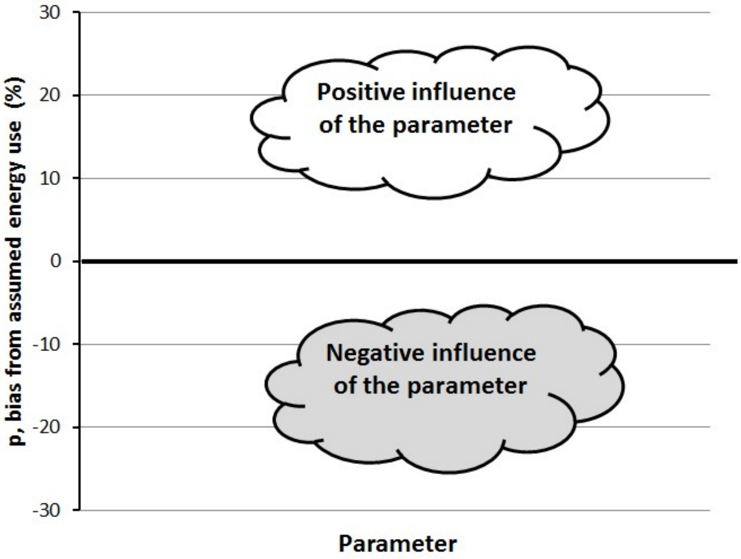

Figure 1. Bias from the assumed energy use as a means to estimate the success of the energy efficiency measures

Figure 1 shows how the parameters, such as building year, project cost, consultant, and building type, were treated in relation to their influence on the energy efficiency measures. For example, if an increase in a parameter gave $p > 0$, above zero in Figure 1, the parameter was considered to have a positive influence on the energy efficiency measures. Therefore, in this study, the aim was to find which parameters produced $p \geq 0$.

One can argue that in economic analysis, a positive bias would mean a higher achieved energy use compared to the assumed energy use. In this study, the idea was to obtain a positive number for the bias when a higher energy saving than the assumed energy saving was achieved. This means that a lower achieved energy use than the assumed would give a positive bias in this study.

In Equation (1), data for the assumed and achieved energy use present the total energy use. The reasons for this were the following: most of the analyzed buildings used electricity for both appliances and heating, and assumed energy savings were expressed as a percentage of the total energy use in the available documents. One can argue that this was not sufficiently good for the analysis, but these data on the total energy use were only available in the reports and the EPC documentation provided by the previously mentioned company. Unfortunately, this is a typical practice for most of the energy savings companies in Norway; the energy use is expressed only as the total energy use. Even for the building energy certificate in Norway, both electricity and district heating energy use are summed with an equal weight, without considering their energy quality [22]. This could partially explain the reason why companies present only the total energy use without considering different energy carriers. A similar problem regarding insufficient information about building energy use is pointed out in [23].

2.3. Estimation of measure persistence

To achieve planned energy savings, it is important to verify and monitor the results, as previously mentioned in [8]. The persistence of energy efficiency measures is a mean to estimate how long the consequences of an implemented measure can be noticed on the energy use. Currently, there is no available method for how to present the persistence of energy efficiency measures. Building energy certification takes into consideration neither changes in energy use over several years, nor persistence of energy efficiency [24]. Therefore, a method using stock diagrams was suggested in this study. The presentation of and the analysis method for the persistence of energy efficiency measures are shown in Figure 2.

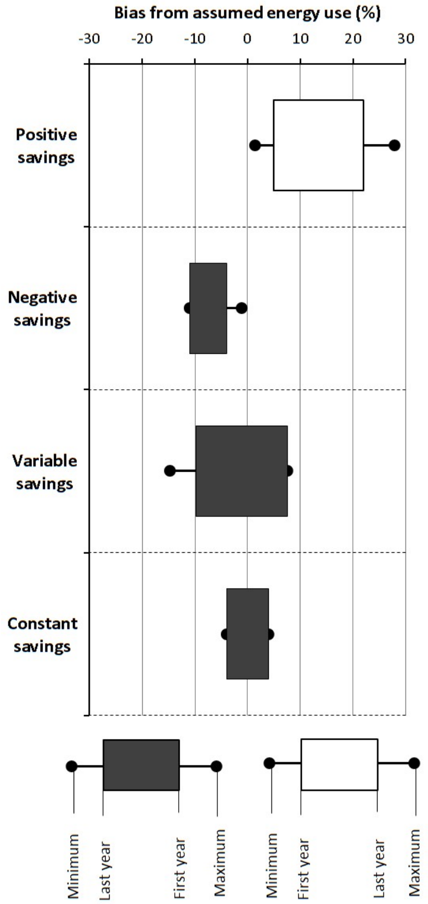

Figure 2. Presentation of the persistence of energy saving measures

In Figure 2, four different possibilities for energy savings' development over the years are shown: positive, negative, variable, and constant savings. Positive savings means that an observed building saved more energy than assumed and increased savings over the years, i.e. the achieved bias was positive and increased. As presented in Figure 2, the positive savings would give a white bar. Conversely, if an observed building used more energy than assumed over the years, the bias, p, would move to the negative values. Therefore, an increase in energy use, compared to the assumed, would give a black bar. Practically, a black bar means that the implemented energy efficiency measured had not persisted over the years. In addition, in this stock diagram, the minimum and maximum values of the bias over a few years were included. Observation of the change between the minimum and the maximum value of the bias gave an indication of how the persistence changed over time.

The aim of this study was to find the building energy use data for as many years as possible. Unfortunately, it was not possible to find the energy use over a few years for all the buildings. One of the reasons was that some of the measures were performed recently and energy use data were not available. Therefore, only buildings with three to four years' available energy use were included in the analysis of the persistence of the energy efficiency measures.

3. Building database

This analysis included 41 buildings. The building data were organized in a database as explained in Section 2.1. It was not easy to collect all the desired data as explained in IPMVP and Annex 47. The idea to analyze energy efficiency measures by using this database was initiated during Annex 47, but it was not possible to provide all the necessary data five years ago in Norway. Currently obtained data on the energy efficiency measures and data on a few years of energy use are great possibility obtained for this study.

Buildings were divided into six categories: hotels (H), schools (S), office buildings (O), shopping malls (SM), health centers (HC), and sport centers (SC). Data about these buildings are briefly summarized in the Appendix in Tables A1 to A6. The following building data are presented in these tables: heated area, building year, investment cost, energy use in the basis year, assumed energy savings, and the number of suggested energy efficiency measures. Energy use in the basis year and the assumed energy savings are given per heated area in kWh/m^{2}a. The investment cost in these tables is the total project cost including consultant time, equipment, and implementation of the suggested measures. The investment cost is given in NOK; 1 EUR = 8.18 Norwegian krone (NOK) at date of writing.

The idea with the data collection was to find as much data as possible in order to understand the intention of the suggested measures. In the analyzed buildings, many different measures were implemented, while detailed monitoring for each of them was not implemented. Therefore, it could be difficult to analyze and isolate energy efficiency measures and their consequent effects. However, to understand and differentiate between the measures, they were organized into four groups:

- *Operation measures* – included the following: control, monitoring, new settings for the temperatures and air flow rates, operation instructions, implementation of the building energy management system (BEMS), energy monitoring system, etc.
- *Equipment improvement* – included the following: improvement or change of equipment, purchasing a new boiler, purchasing a new air handling unit, energy saving light bulbs, heat recovery unit, installation of the water saving equipment, etc.

- *Insolation measures* – included the following: tightening of windows, insulation of pipes and components, etc.
- *Not energy savings measures* – included measures that primarily were not energy savings measures, but their final consequence could give energy savings. These measures could be: instructions for the cleaning staff, regular check of the equipment, improved organization of the equipment, etc.

The above organization of the energy efficiency measures was suggested to enable an easy distinction to be made among the measures that were to a greater or lesser extent dependent on the operation and maintenance personnel, users, and consultants. The measures defined in the group *operation measures* required that they were operated, installed, and monitored in a proper way. These measures could be simple, but they could give considerable energy savings. However, the benefit of the *operation measures* could be changed when operation personnel changed or when building users changed operation parameters by themselves. Implementation of the *operation measures* could require the installation of some additional equipment, which could belong to some other group of measures. For example, the introduction of a BEMS requires the installation of additional equipment, sensors, and computers. The main point of the BEMS is to control, manage, and report on building energy performance by means of the computers that control energy use and the HVAC equipment. Essential to the BEMS is a proper control and monitoring that can lead to energy savings. Therefore, in this study, a measure such as installing the BEMS system was treated as an *operation measure*.

A detailed description of the implemented measures in each building case is not provided in this article, because a list of all the measures in each building could take many pages. Therefore, only the number of implemented measures is given in the Appendix in Tables A1 to A6.

4. Results

The results obtained by analyzing the energy efficiency measures in 41 buildings are summarized in this section. Firstly, a descriptive analysis of the buildings, the building information, and the energy use in the first year are presented. In the next section, factors contributing to the energy efficiency measures and their persistence are discussed. Finally, uncertainties in the energy savings are discussed. The energy use presented in the next section was temperature corrected by using the degree day method [25] and assumptions related to the building type. Further, the energy use was corrected based on the obtained data related to the changes in the buildings.

4.1. Descriptive analysis of the building data

The aim of this section is to give a brief overview of the buildings and the possibilities for energy savings in them. All the energy-use data presented in this section related to the energy use in the first year after the energy efficiency measures were implemented. A brief introduction to all the building categories, building years, and planned energy savings is provided in Figure 3.

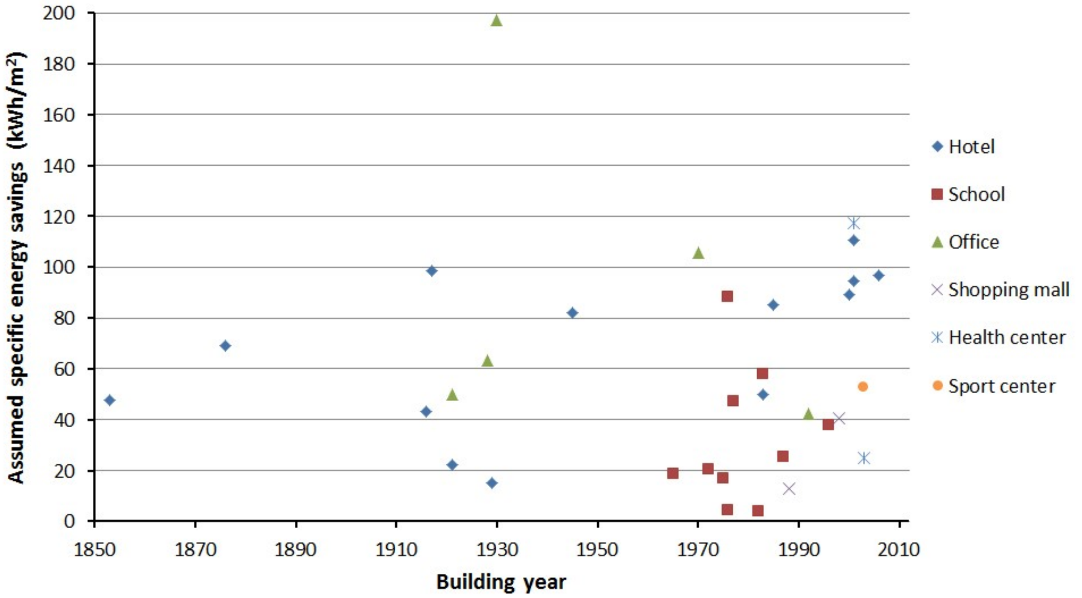

Figure 3. Influence of the building year on the assumed energy savings

From Figure 3 it is clear that most of the analyzed buildings were built in the period from 1970 to 1990. This could influence the fact that some of the conclusions related to these building years. The assumed annual energy savings varied from a few to 200 kWh/m^2 in Figure 3. Excluding the office building, O2, built in 1930, and the sport center, SC2, that was not plotted in Figure 3, it was possible to notice a trend: recently constructed buildings had higher assumed energy savings. This could not be a final conclusion, however, because it could also be seen that the assumed energy savings were lower for schools, even those built recently. The reason for these savings in schools could be due to the available budget for performing the energy efficiency measures. The influence of the project cost is discussed in the next section.

The relationship between the total specific energy use and the specific energy savings is given in Figure 4. A linear trend-line between these data can also be seen in Figure 4.

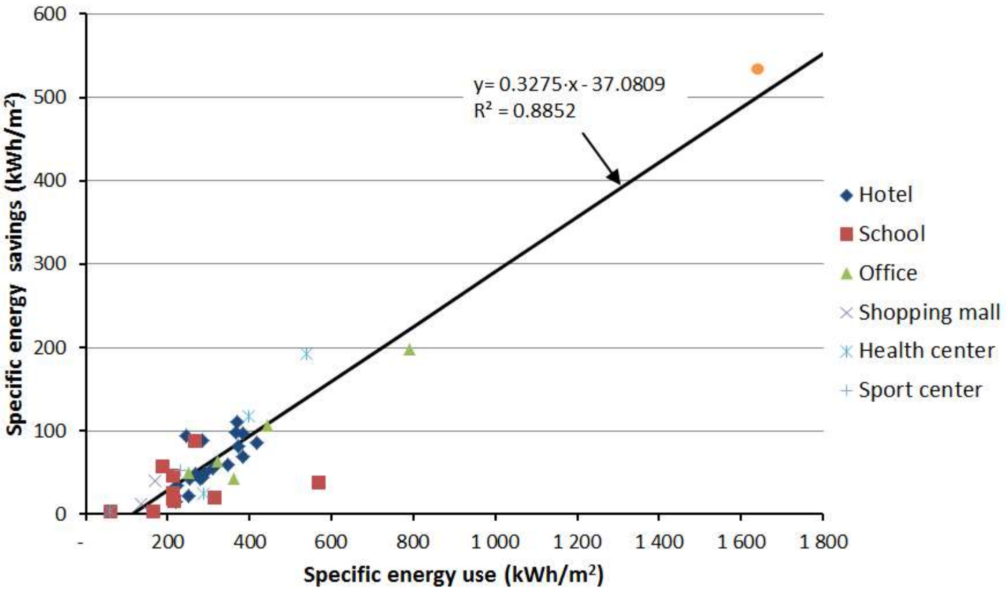

Figure 4. Relationship between the specific energy use and the specific energy savings

The results in Figure 4 indicated that the suggested energy efficiency measures should give 30 % of energy savings. Since the data provided in this study came from the EPC, this meant that energy savings of 30 % of the total energy use were suggested on average throughout the EPC. In the current study, most of the buildings had a specific energy use lower than 600 kWh/m^2. Since the trend-line in Figure 4 had a high value for goodness of fit, R^2, it could be reasonable to accept the obtained relationship in Figure 4.

Finally, the total measured and the total calculated energy uses are shown in Figure 5. The measured energy use was energy use after the first year of the measurements' implementation. Different building types are marked in Figure 5. For comparison, a perfect fit line between the measured and the calculated energy use is given in Figure 5.

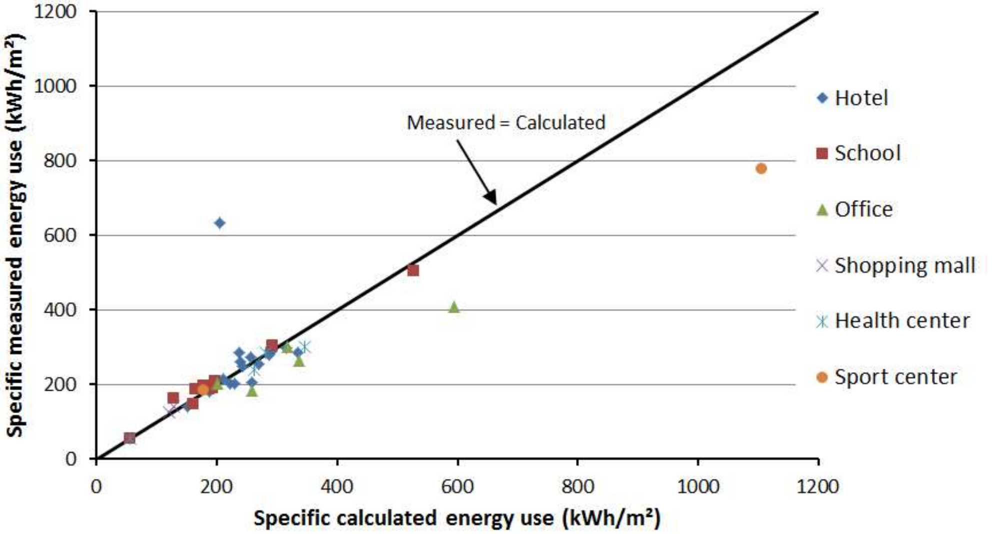

Figure 5. Calculated versus measured total energy use in the first year

In Figure 5, there were many variations between the assumed and the calculated energy use. In total, 18 of 41 buildings achieved a lower energy use than the assumed. The difference between the calculated and the measured energy use varied from 29 % lower energy use to 20.5 % higher energy use than the calculated energy use. Energy use that was ±5 % of the calculated energy use in the first year was achieved by 14 buildings. The results in Figure 5 showed that buildings with a total assumed energy use lower than 310 kWh/m^2 achieved in reality a higher energy use than the assumed. In contrast, buildings with a total assumed energy use higher than 310 kWh/m^2 achieved in reality a lower energy use than the assumed. The reason for this could be that the buildings with low energy use were overestimated, because of difficulties in finding profitable measures. These buildings already use a low amount of energy, and higher energy effectiveness might require investment in expensive technologies. On the other hand, the buildings with a high energy use in the basis year were underestimated, because the consultants, the EPC providers, did not need to guarantee such big energy savings before reasonable profitability would be reached. These diversities between the calculated and the measured energy use, especially for buildings with higher energy use, could be induced by the calculation methods. As mentioned in Section 2.2, the consultants used the knowledge-based method developed from their experience. When analyzing the buildings such as sport centers and complex office buildings, it could be inappropriate to use only the knowledge-based method. Similar results were found in the work of Kohler and Hassler, in which the measured results are shown to be 35 % lower than the calculated results in older buildings with higher energy use (built before 1977) and 10 % higher for newer buildings with lower energy use (built after 1977) [26]. Further, related to the buildings with high energy use, it may be that large savers installed more retrofit measures, with large estimated savings and higher cost than did the small savers, as pointed out in [27]. The sport center, SC2, the orange circle with the biggest difference between the calculated and the measured energy use, implemented eight energy efficiency measures such as: new lighting system, new doors, new energy source technology, new air handling units with heat recovering, improvement in the humidity control, and some other measures.

After a brief introduction to the buildings, further analyses are presented in the following sections.

4.2. Success factors and persistence of energy efficiency measures

As mentioned in the introduction, factors such as project cost, expertise, project organization, economic environment, and maintenance could influence the success of the energy efficiency measures. Therefore, in this section some of the factors, specifically the influence of the building type, the project cost, and expertise, have been analyzed. In addition, an analysis of the measure persistence is presented.

One of the first factors analyzed was the building type. In Figure 6, an average bias from the assumed energy use is shown for different building types. The values for the bias from the assumed energy use were calculated by using Equation (1). The average bias meant that the values in Figure 6 represent an average value for all the buildings within an observed building type.

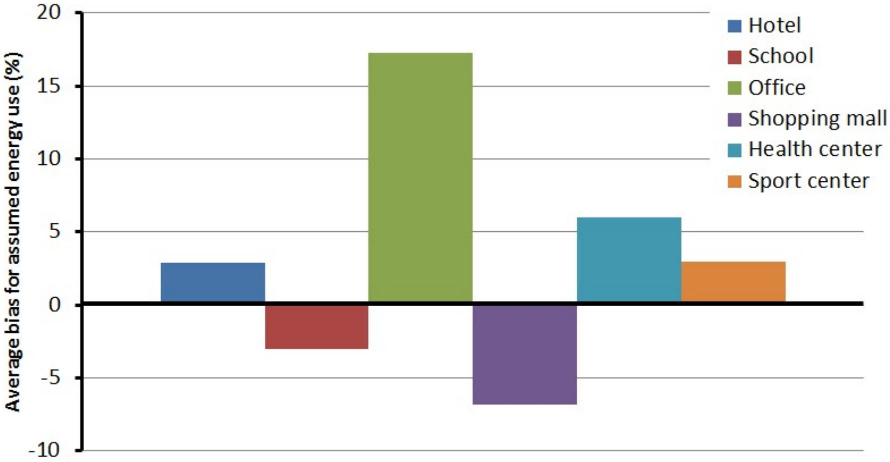

Figure 6. Influence of the building type on the achieved energy savings in the first year

The results in Figure 6, which were interpreted in the same way as that explained in Figure 1, showed that office buildings, hotels, health and sport centers had a lower energy use than the assumed energy use. In contrast, schools and shopping malls had a higher energy use than the assumed energy use. Based on Figure 6, it could be concluded that the building type might influence the success of the energy efficiency measures. The office building seemed to be the most suitable for the implementation of the measures. To recap, the results in Figure 6 were based on the energy use in the first year. Analysis of the persistence, illustrating what happened to energy savings after the first year, is presented later in this section. In addition, the reason for the large bias in the achieved energy savings for the office buildings could be the calculation method, as discussed in relation to Figure 5. It might be that the energy efficiency measures for the office buildings were underestimated, since the two office buildings, O1 and O2, were built in 1928 and 1930 respectively; see Appendix, Table A. 3. A similar issue was discussed in relation to Figure 5 and mentioned in [26].

The next factor analyzed was the project cost, with the results being displayed in Figure 7. Here the values for the bias were also calculated using Equation (1). Figure 7's results were interpreted in the same way as that explained in Figure 1.

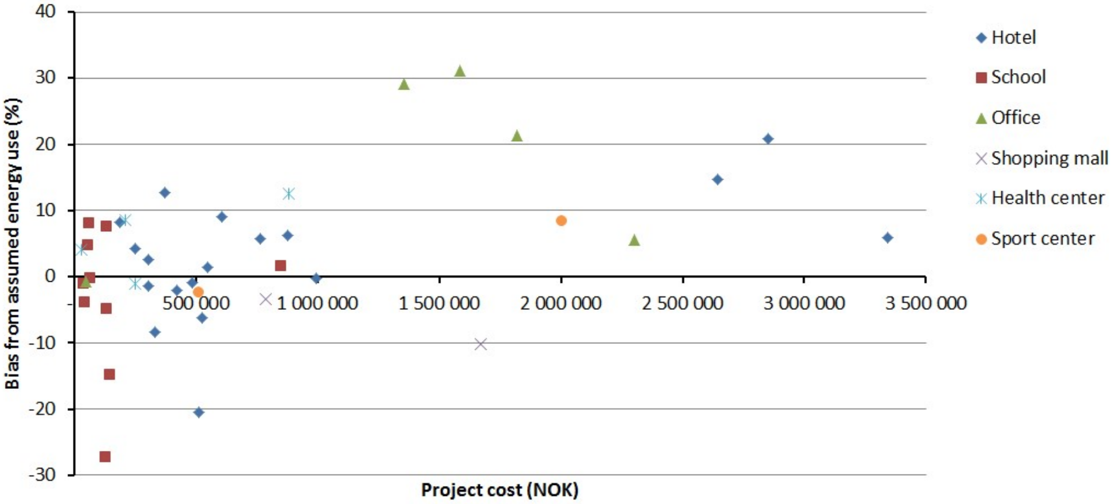

Figure 7. Influence of the building type and the investment cost on the achieved energy savings in the first year

In Figure 7 it is possible to observe that all the buildings, except shopping malls, with a project cost higher than 524 000 NOK[1] achieved a total energy use lower than or equal to that assumed, and consequently energy savings equal to or higher than assumed. This especially concerned the office buildings and hotels. For comparison, similar conclusions arose from Figure 6. For example, four of the office buildings implemented the energy efficiency measures with a high investment (see the green triangles in Figure 7), and they achieved higher energy savings than assumed. Further, the office building, O5, making a low investment, of 44 532 NOK, achieved almost the planned energy use in the first year. In

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[1] 1 EUR = 8.18 Norwegian krone (NOK) at date of writing

general, the results in Figure 7 indicated a trend: small projects with low cost gave an overestimation of the suggested measures and consequently the assumed energy savings were not achieved. In contrast, large projects with high cost gave an underestimation of the suggested measures and consequently the achieved energy savings were higher than the assumed. Through communication with the company that performed the EPC, information about the resources and expertise employed on a project were related to the project cost. This gave an idea for the analysis presented in Figure 8, in which the bias from the assumed energy use versus the project cost is shown. In addition, the consultants or the EPC providers were used as a parameter in Figure 8. The consultants were not listed by name to preserve the anonymity of the companies, being identified only by a letter.

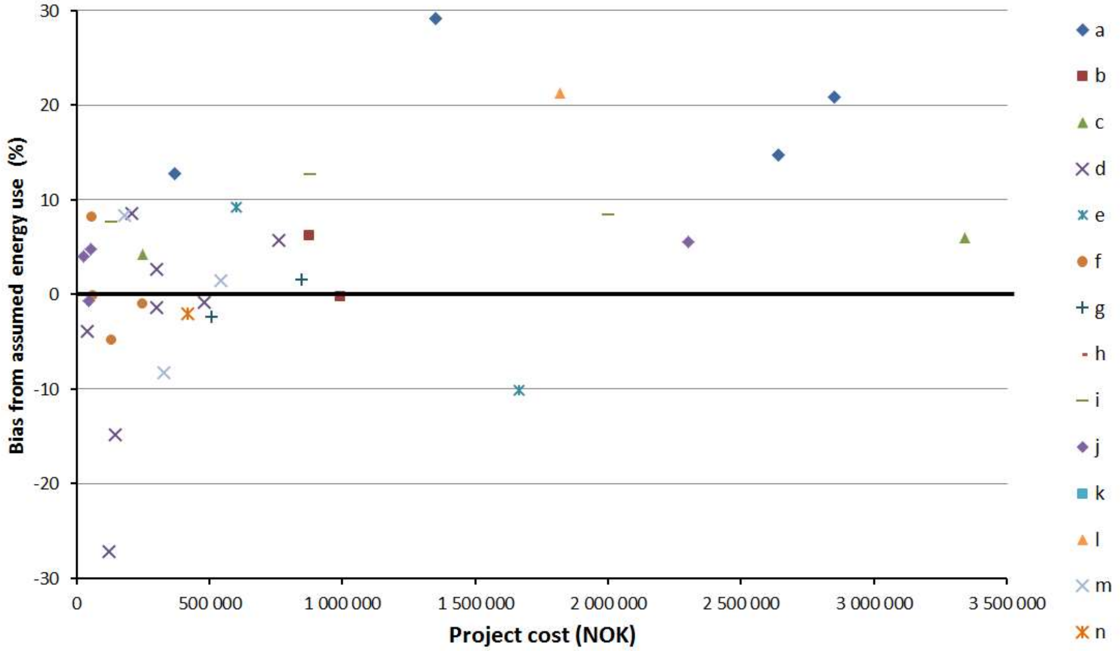
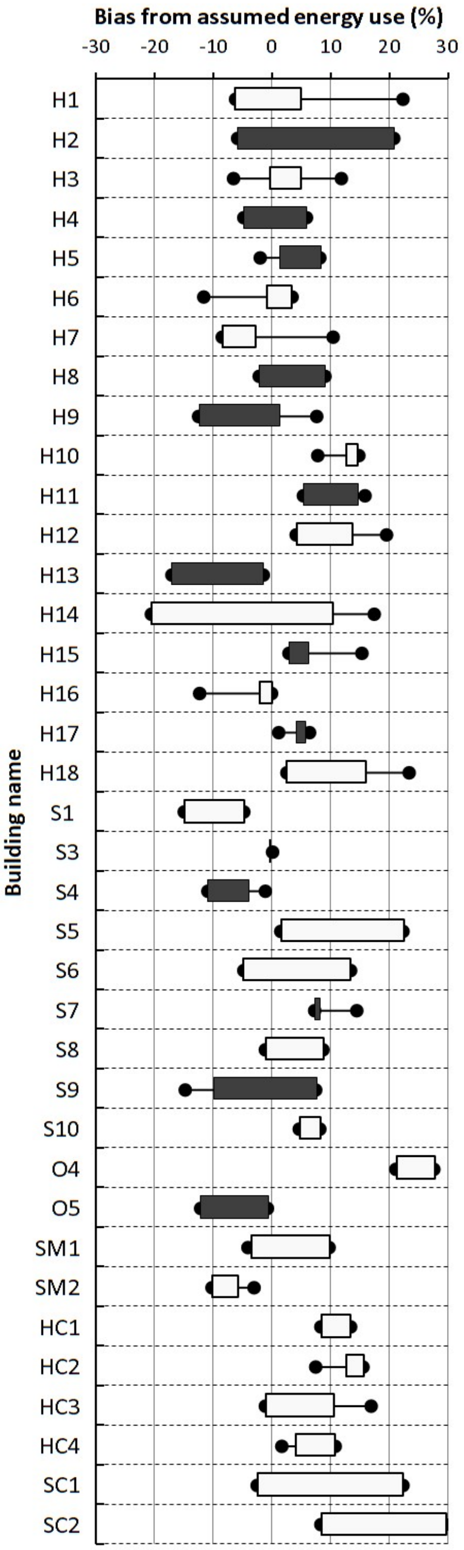


Figure 8. Influence of the expertise and the investment cost on the achieved energy savings in the first year

Similarly to Figure 7, it can be seen in Figure 8 that most of the buildings with a high project cost achieved a total energy use lower than or equal to that assumed. In addition, in Figure 8, the consultants were introduced as a parameter. Results indicated that consultants, a, c, i and l, usually delivered projects with high energy savings. Moreover, it might be noted that the same consultants were engaged for projects with a higher project cost. Communication with the company that performed the EPC, and discussion about Figure 8, revealed that for high-investment projects usually the best and the most experienced consultants were engaged. In addition, if necessary, internal resources and additional analysis were used to deliver good results. These factors could have led to the implementation of the suggested measures and the achievement of assumed energy savings. Further, in high-investment projects, there is a high focus on following up the projects and training the maintenance staff in case buildings. The experienced consultants knew well how to transfer knowledge to the maintenance and operation personnel, and what was needed for the *operation measures* to actually be achieved. Therefore, based on Figure 7 and Figure 8, it might be concluded that the investment cost and the employed expertise contributed to achieving planned energy use or even lower energy use.

The other parameters, such as building year, energy use in the basis year, heated area, and percentage of the operation measures, were also analyzed. The results showed that building year, energy use in the basis year, and heated area did not give any indication of contributing to the achievement of the energy efficiency measures. The buildings where energy savings were dependent on the proper operation showed a large variation and negative savings in the achieved energy savings in the first year. This meant that a high number of the suggested *operation measures* could lead to a higher energy use than the assumed, due to the fact that the *operation measures* were implemented improperly or were dependent on operation staff expertise. Further analysis of the *operation measures* and their influence on the measure persistence is presented in relation to Figure 9 and Figure 10.

The company that delivered the EPC guarantied the energy savings in the observed building within one year of the measurement implementation. This meant that, if after the first year the energy saving was not achieved, the company needed to perform additional analysis and deal with the problem in order to achieve the assumed savings. If the guarantied energy savings were achieved, no complainant would appear and the company would not be asked to carry out any additional analysis. The company usually suggested continuing with a contract for building operation. However, if the guarantied energy savings were achieved, the customers were usually not interested in additional support. The explanation of the results in Figure 9 and Figure 10 is based on the explanation related to Figure 2.



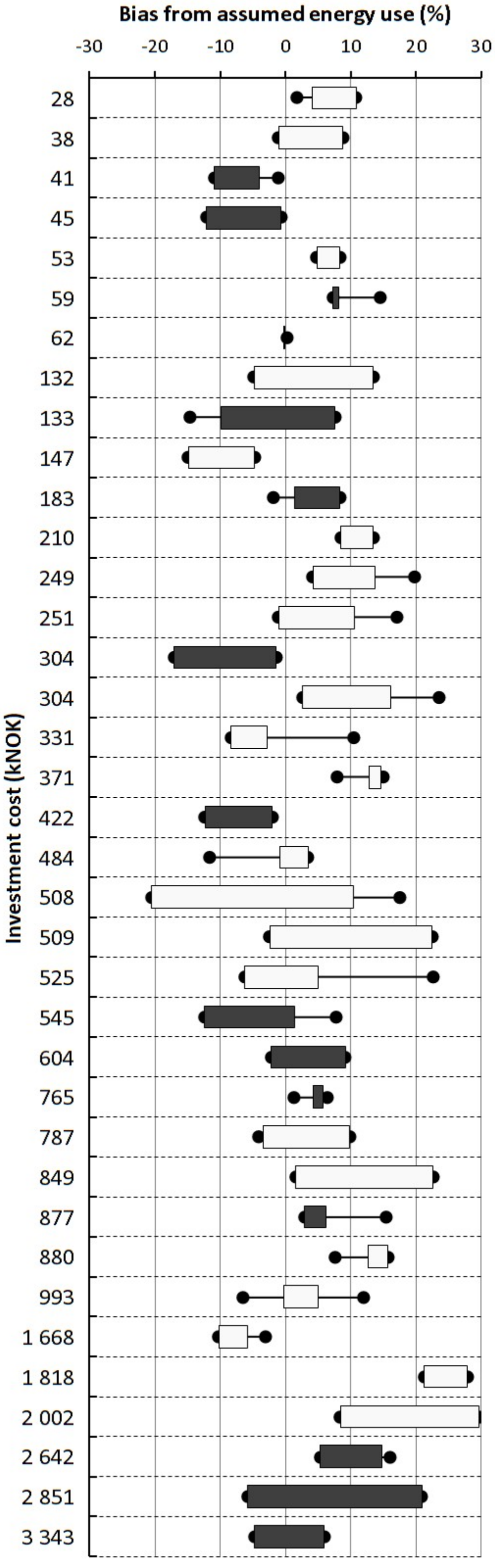


Figure 9. Influence of the building type on the measure persistence

Figure 10. Influence of the investment cost on the measure persistence

From Figure 9 and Figure 10 it was not possible to identify clearly whether the building type and the investment influenced the persistence of the energy savings measures. Further, the persistence analysis of the influence of the building year and the consultant did not show any clear influence on the measure of persistence. However, in analyzing Figure 9 and Figure 10, it is possible to note that the buildings that achieved a negative bias in the first year, higher energy use than the assumed, decreased their energy use after the first year. In Figure 9 and Figure 10, it can be noted that many buildings that had started with the bias $p<0$ increased their energy savings and obtained a white bar after a few years, indicating positive savings. In contrast, the buildings that achieved a positive bias in the first year, lower energy use than the assumed, increased their energy use after a few years. A trend was noticed for the buildings with the higher energy use in the first year: these buildings had a high number of the *operation measures*, which might be implemented improperly or were dependent on operation staff expertise. It can be concluded that the buildings that achieved a lower energy use in the first year increased energy use after a few years, whereas the buildings that achieved a higher energy use in the first year decreased their energy use after the first year. Finally, it can be concluded that the persistence of the energy efficiency measures was influenced by the achieved savings in the first year, the guaranty period, and the implementation of the *operation measures*.

4.3. Uncertainty in energy efficiency measures

In this study, reports from the EPC, data from energy monitoring, and communication with a company that performed the EPC were used to obtain input data for the analysis. In collecting all the data for the 41 buildings, many uncertainties were met and it was difficult to collect all the data. This could influence the quality of the conclusions. Therefore, a brief uncertainty analysis is provided in this section. Uncertainties due to temperature corrections and the lack of information about the implemented measures are presented here.

The energy use data consisted of temperature corrected by using the degree day method, as mentioned at the beginning of Section 4. The degree day method is a robust, rough, and simple tool that can be used to analyze building energy demand. Usually, the degree day method is the best when dealing with a large group of buildings [25]. However, this method is usually used for the temperature correction of the individual buildings [28]. The uncertainty in the energy use data due to temperature corrections is presented in Figure 11.

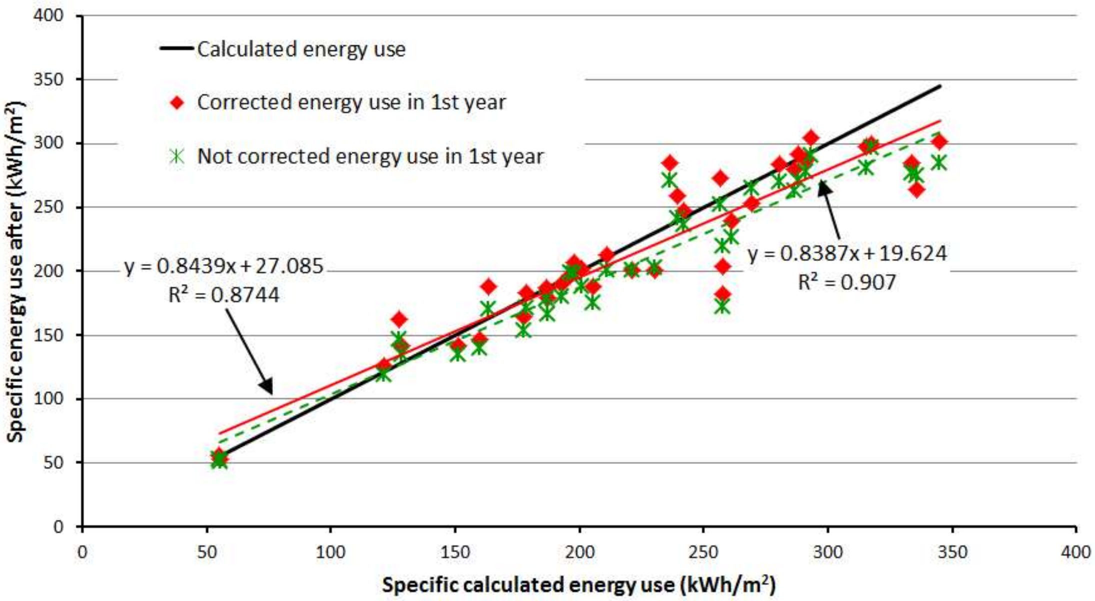


Figure 11. Uncertainty in energy use due to correction method

Figure 11 is similar to Figure 5, in which the relation between the assumed and the measured energy use is displayed. In Figure 11, the red line shows the temperature corrected energy use, while the green dashed line shows not corrected energy use. From Figure 11 it is immediately evident that the differences between the temperature corrected and not corrected energy use were small. Furthermore, it can be seen that the measured energy use was lower than the calculated, as discussed after Figure 5. Based on the equation for the trend-lines and the values for the goodness of fit, R^2, two conclusions can be drawn from Figure 11. The goodness of fit had a higher value for the not corrected energy use. This meant that the not corrected energy use better explained the relationship between the calculated and the measured energy use. To recap, the degree day correction method is not preferable for individual buildings. This could also be the reason that the goodness of fit for the corrected energy use was lower than for the not corrected. Also, in this study, the different buildings with their specific occupant behavior and variety in the installed equipment were analyzed, while the temperature correction had not taken that into consideration. The second conclusion came from observation of the trend-line coefficients. The coefficient of the trend-line was higher for the corrected energy use. In the observed case, the corrected energy use gave a slightly higher energy use than the not corrected energy use. When the target is to present as low as possible energy use, the use of the not corrected energy use would be better in this case, because it showed that less energy was used; see Figure 11.

Changes could also be made to the building area after the energy efficiency measurement implementations. Usually, it was difficult to identify such changes; some, but not all, of the changes in the building area were reported. A test was made to decrease the building area after the measurement implementation for 10 %. In the test results, the coefficient of the trend-line was higher for about 10 % compared to the trend-line coefficient of the not corrected energy use in Figure 11. This meant that a 10 % uncertainty in the information about the building area could introduce a 10 % uncertainty in the obtained results.

As mentioned in the introduction and Section 2.1, it was difficult to collect all the information about the energy efficiency measures and their implementation in reality. Some additional information was obtained afterward through interviews and e-mail communications. It was important to assess the uncertainty in energy use due to the lack of information, because a suggested measure in an EPC document did not mean that the measure was actually implemented. As mentioned in Section 4.2 regarding the measurement persistence, it was noted that the *operation measures* might be implemented improperly. Therefore, in Figure 12, an analysis on the uncertainty in energy use due to the lack of implementation of the *operation measures* is presented. To produce the results in Figure 12, the calculated energy use was changed by removing all the energy savings related to the *operation measures*. This meant that in Equation (2) for $E_{savings}$, the energy savings related to the *operation measures* were not counted.

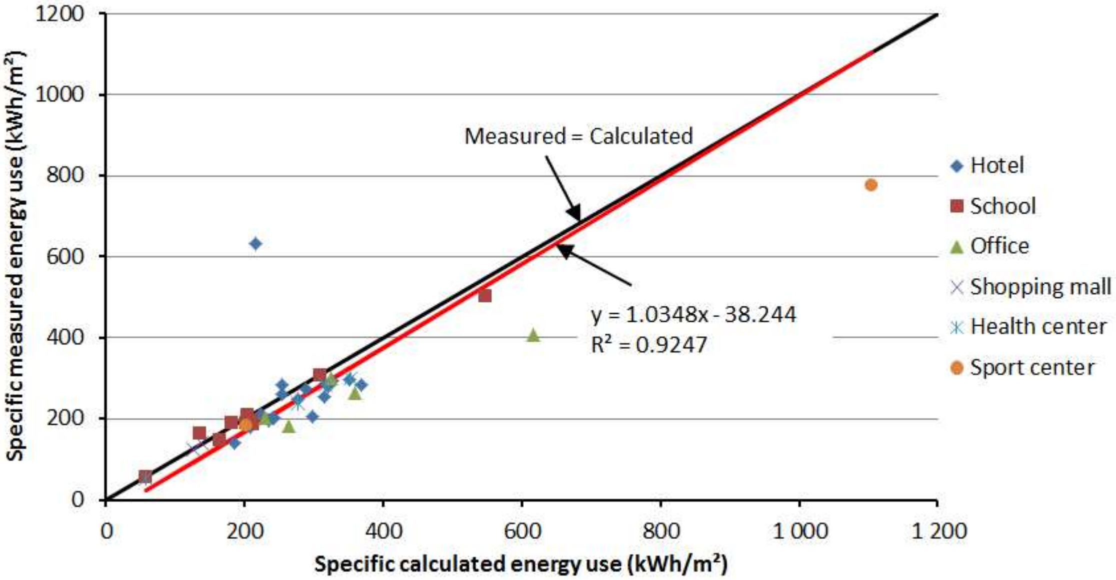


Figure 12. Uncertainty in energy use due to lack of the implementation of the *operation measures*

When the assumed energy use was calculated without considering the energy savings due to the *operation measures*, the assumed and the measured energy use were almost the same. This conclusion could be drawn because the trend-line coefficient was close to 1, and the goodness of fit was close to 1; see Figure 12. Comparing Figure 11 and Figure 12, it can be observed that the difference between the trend-line coefficients was about 20 %. This could induce the conclusion that the uncertainty due to lack of information or not delivering the *operation measures* was about 20 %.

5. Conclusions

In this study the success factors and the motivation for the energy efficiency measures in buildings were analyzed, because many barriers have been met in their implementation. The motivation for this study came from the fact that more practical studies, and documentation of them, are necessary to increase the level of confidence in the energy efficiency measures.

The analysis was performed by evaluation, verification, and monitoring of the energy savings induced by implementing energy efficiency measures. The building database of 41 buildings was developed in a generic way, so that it was simple to compare the results. The building database included: hotels, schools, office buildings, shopping malls, health centers, and sport centers. All the buildings included in the study had available energy monitoring systems. The regression analysis and stock diagrams were used to analyze the data. To identify the success factor of the energy efficiency measures, the parameter called bias, p, was introduced to compare the assumed and achieved energy use. To estimate and present the persistence of the energy efficiency measures, the method based on the stock diagrams was introduced.

In the current study, most of the buildings had a specific energy use lower than 600 kWh/m^2. The assumed annual energy savings varied from a few to 200 kWh/m^2 or about 30 % of the total energy use on average. The results of the real achieved energy use showed that the buildings with lower energy use achieved lower energy savings than the buildings with higher energy use. The reason for this could be that the energy savings were overestimated in buildings with low energy use, because of the difficulties in finding profitable measures. One of the most important conclusions from this study related to the measurement persistence. The analysis of this showed that the persistence of the energy efficiency measures was influenced by the achieved savings in the first year, the guaranty period, and the implementation of the *operation measures*. Finally, the uncertainty analysis showed that the uncertainty due to lack of information or from not delivering the *operation measures* was about 20 %.

The results showed a great need for detailed measurements, verification, and the documentation of the energy efficiency measures to realize the expected results. Therefore, new standards and requirements should set a high requirement level for the documentation of the expected results in energy efficiency in buildings. The conclusions from this study could be used to emphasize the factors that contribute to the successful realization of the energy efficiency measures in reality, even though these factors might not be technical. The results from this study could be used for a brief estimation of the economic benefit of the energy efficiency measures and associated uncertainty.

Appendix A. Building data

Table A. 1. Technical data about hotels

Name	Heated area (m²)	Building year	Investment cost (NOK)	Energy use in the basis year (kWh/m²a)	Assumed energy savings (kWh/m²a)	Number of measures
H1	8 200	-	524 702	312	55	7
H2	20 584	2001	2 850 772	369	111	5
H3	6 600	2000	993 069	286	89	6
H4	21 326	1917	3 343 149	368	99	7
H5	3 983	1929	183 272	220	15	2
H6	5 952	1916	483 586	254	43	7
H7	4 939	1983	331 241	289	50	6
H8	5 440	1853	603 652	269	48	8
H9	2 200	1945	545 263	373	82	6
H10	7 347	1921	371 136	252	22	5
H11	13 300	1985	2 641 820	419	85	4
H12	7 587	-	248 947	221	34	2
H13	2 725	2006	303 781	385	97	5
H14	4 814	-	508 440	279	43	5
H15	5 923	2001	877 188	246	94	8
H16	12 100	-	421 976	286	44	3
H17	8 500	1876	764 911	384	69	6
H18	4 000	-	304 478	346	59	6

Table A. 2. Technical data about schools

Name	Heated area (m²)	Building year	Investment cost (NOK)	Energy use in the basis year (kWh/m²a)	Assumed energy savings (kWh/m²a)	Number of measures
S1	4 350	1977	147 022	211	47	6
S2	2 200	1983	125 314	185	58	7
S3	650	1987	62 010	212	26	1
S4	675	1972	40 778	314	21	3
S5	6 900	1965	848 937	212	19	6
S6	2 003	1975	131 643	215	17	2
S7	4 876	1976	59 098	164	4	1
S8	2 720	1982	37 982	59	4	2
S9	1 107	1976	133 209	266	88	4
S10	437	1996	53 022	566	38	3

Table A. 3. Technical data about office buildings

Name	Heated area (m²)	Building year	Investment cost (NOK)	Energy use in the basis year (kWh/m²a)	Assumed energy savings (kWh/m²a)	Number of measures
O1	6 773	1928	1 352 639	321	63	6
O2	3 350	1930	1 584 193	791	197	6
O3	16 000	1992	2 303 338	360	42	5
O4	6 500	1970	1 818 258	442	106	9
O5	414	1921	44 532	251	50	2

Table A. 4. Technical data for the shopping malls

Name	Heated area (m²)	Building year	Investment cost (NOK)	Energy use in the basis year (kWh/m²a)	Assumed energy savings (kWh/m²a)	Number of measures
SM1	32 000	1988	786 750	134	13	5
SM2	17 766	1998	1 667 592	169	40	3

Table A. 5. Technical data for the health centers

Name	Heated area (m²)	Building year	Investment cost (NOK)	Energy use in the basis year (kWh/m²a)	Assumed energy savings (kWh/m²a)	Number of measures
HC1	1850	2003	209 975	286	25	4
HC2	1907	-	880 162	538	193	8
HC3	534	2001	250 714	398	117	3
HC4	979	1972	27 963	59	3	2

Table A. 6. Technical data for the sport centers

Name	Heated area (m²)	Building year	Investment cost (NOK)	Energy use in the basis year (kWh/m²a)	Assumed energy savings (kWh/m²a)	Number of measures
SC1	2 650	2003	508 842	231	53	4
SC2	1121	1967	2 001 871	1640	534	8

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