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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.

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 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.

Many studies with different aims have been reported related to energy efficiency in buildings. 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

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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, and 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., based on interviews and surveys 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 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, 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 ranging from methods including economic and environmental parameters [13], cluster method [3] or Life-Cycle Cost analysis combined with a Mixed Integer Linear Programming [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 the lack of monitored building performance data in the documentation of the energy savings [10] and due to fact that the measured performance of the certified buildings had little correlation with the certification level [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 use increases during the first four years of operation by 36% compared to the design predictions [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, such as difficulties in the understanding of the energy label [18,19] and a low implementation rate of the energy-efficiency measures one year after the energy assessment [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 calculated and real 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