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Concept of Building Evaluation Methodology for Gap Estimation between Designed and Achieved energy savings

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Abstract

Nowadays, despite the plethora of existing standards and calculation methodologies, i.e. procedures assessing a building's energy efficiency, it is unfortunately common to monitor significant differences between designed and achieved energy savings in practice. This is a problem that in extremis may lead to contractual and even legal claims, but in any case sheds doubt on the whole energy efficiency approach and finally presents one of the barriers for investments in energy efficiency projects. It should therefore be addressed and in order to achieve this, one has to understand the problem: Numerous and often intertwined factors lead to the aforementioned discrepancy, based on the differences in methodological approaches and standards adopted as well as the boundary conditions they use, they will all be discussed in the paper.

Furthermore, a novel building evaluation methodology will be presented; its conceptual approach addresses the different influences addressed and taken into account, as they can significantly affect the level of achieved energy savings in buildings. In that sense, the main purpose of the proposed methodology is to evaluate in advance, the difference rate between designed and achieved energy savings. This approach can be a useful decision tool in the phase where energy efficiency projects are rated and evaluated for possible investments.

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Keywords: buildings, energy efficiency, energy savings.

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1. Introduction

It is a well-known fact that buildings are responsible for the large part of overall final energy consumption as well as for the approximately same amount of carbon dioxide emissions, [1]. Therefore, the investment potential in buildings is high as the general EU policy is focused on restraining overall energy consumption in buildings and by that reducing harmful emission into the environment [2]. Furthermore, an increase in the share of renewables is also an EU general long term target towards 2050, where it will be challenging to implement them on a desired large scale. Namely, according to the available renewable energy technologies on the market nowadays, it is not a problem to successfully implement them in the case of single building units, as in family houses or in relatively small building residential facilities. However, there is an issue when implementing renewables in the case of condominium building facilities at a sufficient level as we have certain technical constrains. In the case of condominium building facilities, we are generally limited with space for the sufficient implementation of renewables, so the realistic question is whether we can even achieve the desired share of renewables in the case of the considered building facilities. Even though we can have excellent climate characteristics on specific geographical locations, we unfortunately have limited capabilities when implementing renewables for the mentioned building facilities, i.e. limited on-site energy production from renewables. One solution in solving the previous issue is to realize large scale renewable energy plants (electricity, thermal) that will produce a larger share of primary energy demands for certain building facilities (district energy plants based on renewables). However, we need to be clear that in the previously considered case, we are faced with a high investment cost, possible technical limitations and finally with questionable economic viability.

The EU has set a clear target for nZEB which is challenging in the sense of market available energy efficient products, technologies and design issues (guidance plans [3] were provided as each EU member state country should prepare their specific guidance for nZEB). Designers need to be prepared and additionally educated in order to be able to cover the increased design related work load regarding nZEB and finally provide quality projects that will ensure the desired nZEB standards. Hence, to reach nZEB standards, we need to prepare professionals (designers), companies involved in project realization, i.e. a whole chain needs to be prepared in the energy renovation of building facilities. In relation to the previous issue, the PROF/TRAC project [4] was kick started in March of 2015 in order to develop a European Training and Qualification Platform on nZEB design and construction. It is indicative that all professions are included in this project as well as all major, well-known and influential professional associations. There is a clear and serious signal that we need to change the current design paradigm if we want to reach nZEB standards on a large scale. A design paradigm change entails a close and intertwined cooperation between all professions from initial project consideration until its final realization. The current design approach that usually happens is provided in the way that architects set a defined baseline for specific building facilities in advance and all other professions need to integrate their specific part into it. In the previous case, it is hard to build in the most efficient project solution that will lead to nZEB standards (we have a predefined base and basically have limited designer flexibility). Hence, as already mentioned, a close and smooth cooperation between all professions is crucial if we want to achieve nZEB standards and should be the general approach.

One of the crucial problems related to energy efficiency projects in buildings is the validation procedure of achieved energy savings, i.e. there are a lot of examples in practice where we have a significant difference between designed and achieved energy savings. Namely, current designer procedures include a variety of input data where the final output (designed energy savings) is sensitive to the input values and there can be a significant value range in magnitude for the designed energy savings in the final outcome. Furthermore, estimated (designed) energy savings are an important factor for the decision of possible investment in specific building facilities (especially in the case when dealing with investment scenarios such as a combination of grants and other financial instruments). Hence, it would be useful to have a tool where we would be able to at least estimate a possible gap between achieved and designed energy savings. The previous kind of approach would also be a useful tool in detecting potential weak spots inside a specific building facility as those spots can significantly contribute to energy dissipation in buildings (in that manner designers can act in advance in order to prevent the possible degradation of energy savings).

The objective of this paper is to elaborate a novel proposed concept of building evaluation methodology that would be a useful tool when estimating gaps between designed and achieved energy savings in buildings. It would be a certain kind of corrective element in present design procedures where a base energy savings potential would be calculated. However, in this paper we only deal with its conceptual approach as a large number of influential input parameters would obviously occur along with their interconnection (which finally entails a long term research of the proposed concept) and also deal with its early stage research.

Nomenclature

BI	behavioural index for specific building facility,
E_{AS}	achieved energy savings,
E_{DS}	designed energy savings,
α,β	weight factors,
η_{EFBDR}	energy efficiency building dissipation rate,
η	factors related to the specific impact on building energy performance.

2. Impact on energy savings potential in buildings: An overview

It is hard to define all impacts that can affect the potential of energy savings in buildings (i.e. that can affect building energy performance), but we can certainly detect and define the main influential impacts. An additional problem is that besides a relatively large number of impacts, they are usually intertwined with complex causal relations. In general, impacts that can reduce building performance efficiency can be divided into technical and behavioral ones. Technical impacts can be more easily controlled and predicted but on the other hand behavioral impacts are more complex and are hard to control efficiently. The problem with ESCO base investments in buildings is the fact that service providers usually (ESCO companies) need to take risks, i.e. they need to give a guarantee for the achieved energy savings, even though they do not have the mechanisms to control the impact of human behavior on achieved energy savings. The impact on building energy performance caused by behavioral issues can be emphasized and influential especially in the case of buildings that are designed according to rigid modern standards and also in building facilities where we deal with a large number of occupants. In the next sections we will address and discuss technical and behavioral impacts as the base for our proposed building evaluation concept.

1.1. Technical issues

A first technical impact, a base one, can be caused due to building design as itself, [5]. The major problem is in the complexity of prediction and general circumstances that designers need to take into account. The previous means that even though a designer may have skills and practice, a potential oversight is possible. Namely, daily activities and busy schedules in daily designer practice do not allow constant monitoring of novel technologies and energy efficient solutions. Sometimes time is an issue, i.e. there is a lack of time that should be devoted to the specific project and although sufficient skills by the designer exist, in some cases the integration of best solutions is missed. The most important issue that is set nowadays in front of building designers is to take the thermal inertia of specific building facilities into account (building envelope) and which is especially emphasized in the case of warm climates, [6-8]. Hence, to provide a quality building design, we need to ensure a close cooperation of all engineering professions from the beginning of the project and need to ensure a good foundation for other systems, i.e. technologies that can reduce overall energy consumption in building facilities. A major problem with building designs is that hidden flaws are sometimes noticed when the buildings in question are already built, or after the starting period of the operation, so quality supervision during construction phase is extremely important.

Installed equipment can significantly affect building performance, intelligent and more efficient building systems are desired. There is a large number of research studies that analyzed different building energy technologies and their impact on building performance, [9-17]. It is found that the quality of installed equipment is important as well as efficient (smart) equipment management. Namely, having average equipment quality together with proper equipment energy management can achieve better performance in comparison with more efficient equipment and less efficient equipment management. Nowadays, we have a large variety of different equipment options on the market that can have a significant range in retail price and range in level of quality. Proper power management in buildings is important in order to achieve energy savings and finally balance installed equipment towards an efficient operation. Besides the quality of installed equipment, equipment exploitation is also an issue that needs to be addressed as occupants and their habits have a significant impact on equipment exploitation, [18,19] and equipment lifetime.

Legislative also falls into the category of technical impacts that can contribute to the energy performance of certain building facilities. Nowadays, we have several calculation methodologies where we can have a significant difference between achieved and designed energy savings. Furthermore, output in the case of calculation methodologies is sensitive regarding input value as already emphasized. Basically, we can get a wide range of designed energy savings that can be distant from reality. An excellent example of the previously addressed issue is ventilation thermal loss that is extremely sensitive to input value. Unfortunately, because of certain deficiency levels in the existing calculation methodologies, levels of designed energy savings can easily be manipulated (especially in cases where verification of energy savings is obtained by the designed approach and where projects are partially financed by subsides). As a result, legislative is extremely important as it should be an important corrective. Furthermore, a building energy certification (building energy labeling) gives static data regarding overall building energy consumption where we can finally have a significant difference from realistic energy consumption indicators. However, that kind of legislative is usually used in the EU but dynamic data for buildings are needed to get more realistic data related to energy performance of certain building facilities. Hence, we can conclude that energy labeling is useful, but the gained data should also be taken as a rough building energy performance indicator. In the majority of EU countries, maximal U-values for certain building elements (heat transfer coefficient W/m^2K) are regulated. However, the mentioned U-values should certainly be measured after renovations to prove that they are achieved after all. As several published studies have shown, there are quite significant discrepancies between measured and calculated U values, the former being as generally higher than the latter [20]. A reasonable degree of difference can be justified due to the static and single dimensional calculation mode of regulations; however, with increasing design and structural complexity this difference becomes truly important both from Nordic to Mediterranean climate conditions [21, 22].

Finally, there are a large number of other possible technical impacts that can contribute to building energy performance but can be more easily controlled and predicted, which is not the case with behavioral impacts. This will be discussed in the next section of the paper.

1.2. Behavioral issues

Modern building facilities that were built according to current rigid standards (related to the allowed energy consumption of specific building facilities) boosted the impact of occupants on overall building energy performance. Namely, in the case of building facilities with high U-values of construction elements, the behavioral impact was less emphasized then in the case of thermal bridges. Actual building energy performance is extremely sensitive to the behavioral habits of occupants. As already mentioned, one of the major issues regarding ESCO companies is how to take over investment risk in the case where the influence of occupants can strongly affect achieved energy savings (that are for example defined in EPC contracts). It is hard to measure overall occupant influence on building energy performance (i.e. on achieved energy savings) and especially in the case of building facilities with a large number of occupants (administrative buildings, schools, etc.). Occupant influence is complex as it depends from a large number of specific parameters that are related to thermal comfort. Further, psychological and social issues also affect the attitude of occupants regarding general occupant culture and behavior. In recent years, research has provided large efforts in order to develop an evaluation methodology that will be able to quantify behavioral influence on building energy performance. We are dealing with pure technical (physical) parameters, like thermal comfort, and simultaneously with psychological influences that can hardly be expressed by numbers (analytically described). Finally, the previously mentioned physical and physiological influences are intertwined. There are a lot of research studies related to behavioral issues and analysis of their influence on overall building energy performance, [23-29].

Behavioral issues can also be reflected through the maintenance staff that is in charge of regular maintenance for the installed systems and equipment in building facilities. The maintenance staff should have an important role and needs to behave and act proactively besides scheduled maintenance activities. Occupant complaints (poor indoor quality), failure of certain systems or parts of equipment (malfunctioning), reacting for example when lights are turned off etc., falls under the category of their own responsibility. Therefore, prevention can be crucial and there certainly is a benefit related to building energy performance. To enable the previous benefit, O&M staff needs to be educated and needs to have regular, i.e. periodic trainings in order to keep in touch with novel energy efficient products and technologies. Besides O&M staff skill and knowledge, an important issue is also certainly related to the quality of spare parts and quality (or even existence) of proper monitoring. In the case of novel building facilities or retrofit of existing building facilities, an energy consumption monitoring system is ensured in most cases (which is an important base tool for analysis of specific energy systems inside building facilities). One interesting research study reported that a better paid O&M staff entails a better energy performance of the considered building facility, [30]. Unfortunately, in the majority of cases, issues related to maintenance staff is still not sufficiently encouraged, i.e., it is underestimated and this topic certainly needs to be apprehended more seriously in order to achieve more efficient buildings.

Building management also falls under the category of behavioral issues as several studies proved that proper building management can improve and boost building energy performance, [5,31]. An important role of building management is having a proactive energy efficiency policy. A proactive energy efficiency policy, for single building facilities, entails a constant professional education of employees, professional trainings, raise of awareness, strict and clear procedures related to energy efficiency and finally benefits for all employees. It is a well-known fact that a high employee awareness level can reduce overall energy consumption in specific building facilities by a few percent without direct investments. Finally, a smart building management and proactive policy can ensure long term benefits both for employees and owners.

3. Concept of building evaluation methodology

In the previous section we addressed and analyzed the main influences on building energy performance that are generally divided into technical impacts and behavioral impacts. Each building facility is a case for itself and it is difficult to cover all possible impacts, however, it is important that the major impacts (ones that will have major impact on building energy performance) are taken into account. In the proceedings of the paper, we will elaborate the concept of our approach that will be able to give analytical estimation between achieved and designed energy savings for certain building facilities once developed.

The first step of our approach is to analytically connect gained (achieved) energy savings, E_{AS} with designed ones, E_{DS} and they are usually lower when compared with designed ones, respectively,

$$E_{AS} < E_{DS}$$. (1)

The second step is to introduce a correction factor η_{EFBDR} (energy efficiency building dissipation rate) that will take into account all major influences that will cause a gap between designed and achieved energy savings, respectively,

$$E_{AS} = \eta_{EFBDR} E_{DS} \quad (2)$$

Correction factor η_{EFBDR} takes into account a variety of impacts that usually occur in cases of specific building facilities and that reduce levels of designed energy savings. General impacts on the magnitude of the η_{EFBDR} are briefly presented in Fig. 1. Besides all specified general influences in Fig.1., we can have other influences that are specific for certain types of building facilities as already mentioned. Therefore, our approach allows inclusion of any influence that has a potential of impact on η_{EFBDR} magnitude. Finally, the correction factor can be expressed as a sum of factors related to technical, η_{TI} and behavioral, η_{BI} contribution, respectively,

$$\eta_{EFBDR} = \eta_{TI} + \eta_{BI} \quad (3)$$

The overall contribution of the technical impact is expressed through factor η_{TI} and it generally contains an influence of building design, η_D, installed equipment, η_{IEQ}, equipment exploitation, η_{EEQ} and other influences in general that depend from the specific type of building facility. Hence, it could be written as,

$$\eta_{TI} = \eta_{TI}(\eta_D, \eta_{IEQ}, \eta_{EEQ}, \eta_{OTI}) \quad (4)$$

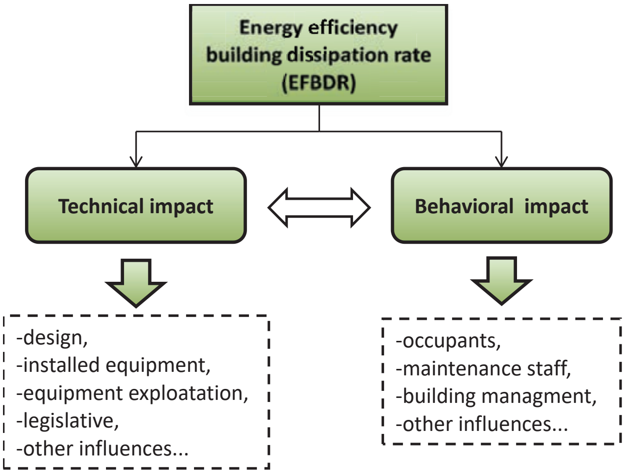

Fig.1 Impacts that affect gaps between designed and achieved energy savings

Behavioural impact is taken within factor η_{BI}, which contains influence of occupants, η_{OC}, influence of maintenance staff and maintenance in general, η_{OM}, influence of building management, η_{BM} and finally other influences related to behavioral issues, η_{OBI}, respectively,

$$\eta_{BI} = \eta_{BI}(\eta_{OC}, \eta_{OM}, \eta_{BM}, \eta_{OBI}) \quad (5)$$

Depending from the type (nature) of specific factor, i.e. specific individual influence, factors will be determined through a specific score system or through a carefully developed evaluation procedure. All influences would finally be scaled via weight factors α and β in order to determine the actual magnitude of factors η_{TI} and η_{BI}. Finally, energy efficiency dissipation rate can be analytically expressed as follows,

$$\eta_{EFBDR} = \alpha\eta_{TI} + \beta\eta_{BI} \quad (6)$$

The value of factors α and β ranges between 0 - 1 and $\alpha + \beta = 1$.

To stress the behavioral issue more, we proposed a behavioral index (BI) for specific building facilities that can be calculated as follows,

$$\mathrm{BI} = \frac{\beta\eta_{BI}}{\eta_{EFBDR}} \quad (7)$$

The behavioural index would be a useful quantitative tool for determining the sensitivity level of specific building facilities in relation to occupant impact and its potential impact on building energy performance.

The conceptually elaborated metodology can be organised in a few crucial steps as follows,

1) Framework definition,
2) Selection of building evaluation criteria,
3) Calculation of weights,
4) Score calculation,
5) Calculation of energy efficiency building dissipation rate.

However, as already mentioned, this paper only presents its conceptual approach as research is still in progress, where methodology, i.e. evaluation procedures and criteria are under development.

4. Conclusions

This paper elaborates the concept of a novel approach related to a specific building evaluation methodology. The final idea of the proposed approach is to determine gaps between designed and achieved energy savings beforehand, i.e. to predict deviation between them. In relation to the previous, an energy efficiency building dissipation rate was introduced as an important factor that defines gap magnitude between designed and achieved energy savings. All major and general influences that can boost the mentioned gap were also addressed, technical and behavioral ones, as they are built in the proposed concept of building analytical evaluation methodology. The herein presented conceptual approach is still under research activity where score procedures and specific evaluation methods would be developed in the future. Finally, the proposed building evaluation methodology is a potential one as it can be a useful tool during techno-economic evaluation of specific building facilities.

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