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A comprehensive cost-optimal approach for energy retrofit of existing multi-family buildings: Application to apartment blocks in Turkey

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ABSTRACT

This research presents a comprehensive cost-optimal approach for existing building retrofits. The approach incorporates energy efficiency measures related to building envelope, building energy systems and renewable energy, all at once. Moreover, the cost-optimal calculation scope is extended through integration of occupant behaviour.

The comprehensive approach is implemented for a reference building which represents high-rise apartment blocks in Turkey; these building types accommodate 4500 families corresponding to 23.1% of the national households. Three different climatic regions, that show significant distinction from each other, were selected for the sample application of the approach in order to refer different climates. Cost-optimal calculations were performed for more than 1300 scenarios. Integration of occupant behaviour into this calculation procedure was demonstrated with sensitivity analyses; the present application of the approach was focused on the use of window openings by occupants.

Results reveal that cost-effective energy saving potential is higher than 70% in high-rise apartments. Moreover, occupant behaviour related to window openings is able to raise this rate above 80%. The findings indicate the necessity of comprehensive approach and demonstrate that integration of occupant behaviour into cost-optimal calculations is fundamental in order to reach significant and stable results.

1. Introduction

Energy efficiency in buildings is accepted as one of the key strategies to achieve intended energy saving in the world since energy consumed in building sector corresponds to one-third of final energy consumption [1]. Accordingly in European Union (EU), building sector is responsible from the largest share as well and leads to 40% of the final energy consumption [2]. Therefore, building energy efficiency targets of EU were set through the recast of Energy Performance of Buildings Directive 2010/31/EU (EPBD recast) [3]. Considering that realization of high energy performance in buildings is not only an energy aspect but also economic practice, EPBD recast introduced “cost-optimality” and “nearly-zero energy building” (NZEB) concepts for building energy performance assessment. According to EPBD recast, Member States are obliged to calculate cost-optimal energy efficiency levels for buildings by adapting the methodology framework provided in EU Regulation No.244/2012 [4,5] and to compare the results with the existing requirements in force. Subsequently, after 2020, the cost optimal energy performance level is expected to meet the NZEB level [6].

In Europe, approximately 40% of the building stock was constructed before 1960s [7] and these existing buildings represent the highest energy saving potential [8]. Therefore, cost-optimality concept of EPBD recast refers not only to new constructions but also to existing building retrofits. Since 75% of the existing buildings in Europe are residential [9], considerable number of the studies focused on the cost-optimal retrofits of national residential building stock as presented below.

In Sweden, Brown et al. investigated residential building stock and suggested to consider also national environmental ratings in order to integrate indoor environmental quality assessment into building energy retrofit process [10]. Liu et al., on the other hand, considered future targets and indicated that although there are challenges, 50% saving potential exists in Swedish multifamily buildings' energy use by 2050 [11]. Bonakdar et al. presented a method for cost optimal analysis of multifamily building retrofits which includes comparison between different financial scenarios and the national building codes of Sweden [12]. In Estonia, as the result of their analyses on wooden apartment buildings, Arumägi and Kalamees [13] declared that in order to ensure cost-effective

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energy savings, envelope retrofits are required to be supported by building service system retrofits. Kuusk et al. [14] investigated the brick apartments and pointed out the necessity of deep renovation perspective and financial support. Eventually these research activities supported the Estonian energy roadmap development, as presented by Kurnitski et al. in [15] and Pikas et al. in [16]. Similar to the procedure followed in Estonia, also in Portugal the research activities on residential building refurbishment resulted with a support to the policy-makers. Brandão de Vasconcelos et al. started from the reference building definition procedure [17] as the first stage and then focused on the whole cost-optimal approach for Portuguese residential building stock [18] until the sensitivity analyses which were concluded with policy implications [19]. The authors reported that envelope measures are required to be combined as packages in order to obtain more benefits and discount rates are one of the major factors affecting the cost-optimal calculations. In Italy, Corrado et al. studied a new procedure for the optimization of the cost optimal levels of an Italian residential reference building [20]. Fabbri et al. [21] identified strengths and weaknesses of the cost-optimal approach through its application to the refurbishment of a residential case study. Desogus et al. [22] investigated existing masonry public dwellings in terms of cost-efficiency with different investment evaluation methods. Becchio et al. highlighted the use of cost-optimal methodology as a decision-making tool for supporting architects in the retrofit energy design of a single family house [23].

The abovementioned studies validate the significance of cost-effective retrofit of existing residential buildings on achieving the ambitious future energy efficiency targets. These recent studies also point out essentiality of examining retrofit measure combinations rather than considering only single measures and moreover emphasise the importance of covering building service system retrofits in addition to envelope retrofits. Nevertheless, as Pombo et al. demonstrated in their review [24], among the research studies on cost-effective retrofit of existing residential buildings, passive strategies are the most commonly addressed measures and there are only limited number of studies combining retrofit measures related to passive strategies, building service systems and renewable energy use all at once. As a consequence of these findings, it is obvious that a comprehensive approach is required for the cost-optimal analyses.

On the other hand, while the cost-optimal calculations for existing building retrofits have still been progressing, new perspectives were introduced. The recent studies in literature indicated the necessity of addressing occupant behaviour within NZEB analyses through cost-optimal approach. As Barthelmes et al. revealed in their research [25], occupant behaviour affects the energy performance of NZEBs more than 150% and accordingly it is needed to be addressed in related studies. Moreover, Becchio et al., drew attention to the importance of regarding the effect of occupant behaviour in cost-optimal analyses in order to actualize future targets based on recently raised concepts such as post-carbon cities as explained in [26]. Therefore, the existing cost-optimal approach is also needed to be extended by regarding effect of occupant behaviour.

Considering the abovementioned gaps and necessities in cost-optimal calculations, the aim of this study is to introduce a comprehensive cost-optimal approach for evaluating existing building retrofits. The approach incorporates three main constituents of a whole building retrofit: envelope, building energy systems and renewable energy use. Moreover, it extends the scope of cost-optimal calculations by integrating effect of occupant behaviour into the energy and economic assessment of building retrofits. In this way the approach regards occupant behaviour as an integral part of cost-effective retrofit of existing buildings to guide actualization of recently introduced future targets.

In line with the aim, this paper demonstrates the proposed comprehensive approach through a sample application for Turkey. This sample application of the approach may refer to the various building refurbishment strategies in Europe as long as Turkey involves different climatic regions that show significant distinction from each other. Although the mild climate is observed in the greater area of Turkey, Turkey's cold climatic region is able to refer Northern Europe since it is characterized by cold, strong and long winter period where the air temperatures are mostly below zero. On the contrary, hot humid climatic region, which appears in the Mediterranean coast of Turkey with hot humid summers and warm wet winters, is indeed able to refer to other Mediterranean countries.

Moreover, in Turkey, similar trends that characterize the European building stock are recognizable since buildings sector is the second biggest energy consumer that is responsible for 30% of total final energy consumption [27] and correspondingly ensuring energy efficiency in buildings is among the future strategic targets of the country [28]. This strategic target is indeed related to recent EU legislation on building energy performance that Turkey follows within the EU harmonization process [29,30]. Since residential buildings represent 75% of the national building stock [31], EPBD recast related research activities in Turkey also focused initially on the residential buildings [32,33]. Findings of these research activities are in line with previously mentioned studies as well, as Ashrafian et al. indicated that it is necessary to develop studies which combine envelope retrofits with mechanical system improvements in order to achieve lower energy consumption levels in building retrofits [34].

Accordingly in this study, a Turkish residential reference building (RB) is examined for the sample application of the proposed approach. The RB is a high-rise apartment building; the choice of this building typology is due to the fact that in Turkey 23.1% of households, which correspond to 4500 families, reside in dwellings which have 6 or more floors [35].

In order to accomplish a complete view, mild, hot-humid and cold climatic regions of Turkey were taken into consideration based on their potentials to refer European climates. These climatic regions are represented respectively by Istanbul, Antalya and Erzurum cities.

In compliance with the cost-optimal methodology framework, retrofit scenarios, consist of energy efficiency measures or packages of measures, were investigated in terms of both primary energy consumption and global cost with the aim of deriving cost-optimal levels.

Energy consumption of the RB is calculated using the detailed dynamic simulation tool EnergyPlus (version 8.2) [36]. Energy consumption of different retrofit scenarios are also evaluated using this tool and converted in primary energy to make a comparative assessment, that considers primary energy consumption for space heating and cooling, domestic hot water production (DHW) and lighting.

Economic calculations of this study are based on the global cost concept of EN15459 standard [37]. Global cost calculations were performed for each scenario considering 30 years calculation period. These calculations mainly consider investment cost, replacement cost, energy cost, maintenance cost and residual value at the end of the calculation period.

The cost-optimal levels of RB retrofits were derived considering a reference occupant behaviour at the beginning. Then, sensitivity analyses on cost-optimal calculations were performed to analyse the effect of occupant behaviour relevant to use of window openings. This extended cost-optimal approach can be widen to all other aspects of occupant behaviour as well. Finally, some observations are deduced from the results of the analyses in order to give useful