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Complex assessment of reconstruction works on an institutional building: A case study

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ABSTRACT

Energy demands of current buildings present an important problem for building designers and engineers. However, the necessity to retrofit building envelopes and achieve a better thermal performance is substantially limited by the economic viability. Despite of the environmental benefits accompanied with enhanced thermal stability, a complex evaluation of the impact of reconstruction works from various perspectives is still needed. In this paper, a quantification of physical, social, economic, and environmental benefits resulting from the application of exterior thermal insulation system to an institutional building is presented. The temperature profiles in the wall cross-section are used for the assessment of the effect of expanded polystyrene boards. The annual energy consumption and carbon emission production is found to decrease by 46% as the result of better thermal performance. The improved social comfort is confirmed by the evaluation of predicted mean vote characterizing the average heat sensation of building occupants. The carbon payback of 3.24 years refers to low initial environmental burden in proportion to obtained energy savings. However, full investments recovery rate varying from 43 to 60 years in dependence on applied economic scenarios reaches almost the lifetime of used materials, which presents a substantial barrier despite of the discounted cost savings of 180,000 Euros during the 60-year lifespan.

1. Introduction

Global warming and increased concentration of carbon dioxide in atmosphere poses one of the greatest threats for present and future periods. Increased global temperature accompanied with growing concentration of carbon dioxide during last few decades can be, according to the Intergovernmental Panel on Climate Change (IPCC, 2014), attributed to the deforestation and burning of fossil fuels in particular. Nowadays, the concentration of carbon dioxide exceeded 400 ppm, which refers to a substantial increase compared to 280 ppm from the pre-industrial period (Dovie and Lwasa, 2017).

The global concerns related to negative implications of human activities resulted in carbon reduction targets, for example U.S. is required to decrease production of carbon dioxide of about 83% at 2050 relative to the level at 2005 and Europe Union Members aim at 80% carbon emission reduction of 1990 level until 2050 (European Commission, 2010, further refined in Directive, 2012/27/EU, 2012). Similar commitments have been adopted by other main producers of carbon dioxide, such as China, Brazil or India (Melo et al., 2016).

The building sector is responsible, besides industry and transportation, for a significant part of consumed energy and substantial part of emitted carbon dioxide. Moreover, the worldwide development of urbanization further increases energy demands and consequent depletion of fossil fuels (Ali et al., 2011). This trend is more obvious in developed countries, where the major part of population lives in urbanized areas and more demanding requirements on indoor thermal comfort induced an increase of energy consumption (Gao et al., 2015). Taking into account the projected global temperature rise, World Energy Outlook Report (2016) identified four key areas which can successfully face this phenomenon. Huisingh et al. (2015) summarized those strategies to promote suitable climatic interventions. Besides scenarios dealing with carbon emission storage, capturing and more efficient utilization of raw materials, the strategy aimed at decreasing

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energy consumption concluded, that heating and cooling energy loads represent a substantial share of the European Union total energy consumption. The design of new modern buildings emphasizes the application of modern technologies and materials considering environmental and economic implications towards sustainable development principles. However, the most of existing older buildings in Europe do not meet the current criteria from the energy efficiency point of view. Therefore, the maximization of energy efficiency of current buildings has a high priority, also due to expensive maintenance (Croci et al., 2017) or better efficiency of utilizing natural resources (Moreno and Garcia-Alvarez, 2018).

The operation phase of buildings is responsible for a substantial part of consumed energy and thus produced emissions. Therefore, great efforts are made to moderate this negative effect and decrease energy consumption of buildings. While energy requirements for heating of modern buildings vary from 45 to 65 kWh/m^{2}a, for low energy houses the building energy policy is moving rapidly towards more strict regulation levels which are based on net zero energy (Lovell, 2009) and net zero carbon buildings (Berry and Davidson, 2015). The energy declaration proposed by Voss et al. (2011) concluded that older and not refurbished buildings require often more than 200 kWh/m^{2}a. From this point of view, the Europe legislation perceived the institutional and administrative buildings as the leading building segment for accomplishment of international carbon dioxide restriction (European Commission, 2012) and stated that all new buildings shall be nearly net zero energy buildings from 2020 (European Commission, 2010). Therefore, the modern energy declaration is accompanied with the fulfillment of the passive standard. Additionally, the improvements in the field of energy efficiency (BPIE, 2013) are linked with the economic viability to meet economic and environmental perspectives (Rodrigues and Freire, 2017).

The common building decision models are usually based on optimization or minimization of costs. However, these assumptions are not sufficient under the new paradigm of moving towards sustainable society. The economic factors should be evaluated together with environmental issues. For example, the study of Garcia-Ceballos et al. (2018) dealing with the life cycle study of construction solution for building envelopes precisely evaluated environmental issues by LCA; neglecting the economic factors though decreased the relevance of the formulated conclusion. The stakeholders are sensitive to costs related to building retrofitting. The environmental externalities present an important parameter which should be included in the decision processes to achieve environmental sustainability in terms of Europe 2020 strategy and Roadmap to a Resource Efficient Europe (2011). Unfortunately, the excessive focus on the initial expenditures substantially limits the willingness to carry out major renovation works (Mahlia et al., 2011). However, in the long-term perspective the energy inefficient buildings and related high carbon dioxide emissions represent a substantial environmental burden for future periods. According to the World Energy Outlook 2016 (IEA, 2007), almost 40% of energy consumed by buildings can be attributed to maintenance of the required indoor thermal comfort. From this point of view, the emphasis will be put on energy efficient buildings in the subsequent decades. The insufficient thermal performance of old buildings resulting in higher energy consumption can be subjected to additional taxation (Berry and Davidson, 2015).

Moreover, only cost-optimal management used for retrofitting measures is not in compliance with long-term sustainability principles (Ashrafian et al., 2016). Although many studies highlighted the importance of considering the economic benefits in long term runs, the short-term decision models prevailed and direct costs represented a substantial value for the investor focus (Lim et al., 2016). From this point of view, economic factors can be perceived as one of main negative forces limiting more intensive building retrofitting. The compromise between affordability and higher energy efficiency is extensively discussed even in political debates (United Nations, 2016). The importance of national policy intervention was well shown by Lim et al. (2016) where modification of federal taxes for ground source heat pumps substantially shortened average payback period and promoted implementation of this energy efficient technology towards less energy demanding society. The promotion of policies (temperature reduction in residential buildings, banning of residential biomass heating systems, banning of diesel fueled domestic boilers, night-time streets washing, speed limit reduction on highways, circulation restrictions of oldest EURO vehicles, conversion of diesel buses to natural gas, car sharing/biking promotion, particle filters adoption in diesel vehicles, extension of road lanes for urban buses, energy efficiency refurbishment in residential buildings) leading to emission reduction was simulated by Chiesa et al. (2014) and revealed its environmental effectiveness. However, the authors concluded that public acceptance of all these restrictions is problematic.

In the light of this knowledge, multicriterial measures should be appropriately distributed among various criteria, reflecting economic, environmental, social, and physical aspects. Mikucioniene et al. (2014) used multicriterial decision model built on energy efficiency, environmental impact, economical rationality, and comfort as a decision-making tool for selecting the best option during renovation of existing buildings. The decision-making models represent a more optimal way for the assessment, as compared to LCA applied for each building element, even when LCA is combined with LCC (Kneifel, 2010). The viability of alternative environmental solutions in building industry is closely connected with distinct economic consequences, in particular in the private sector where the short cost recovery plays an important role. For example, the study of Liapis and Kantianis (2015) directly points to integrating economic factors into the life cycle assessment (LCA) analyses, which would reduce the importance of LCA for decisions in the private sector. Although life cycle cost (LCC) analysis represents a positive step, which together with LCA allows consideration of the whole sustainability problem, the weak points consist in different conceptual foundation and methodological approaches (Swarr, 2011). The simplification is in case of economic tools, such as Cost Benefit Analysis (CBA) or LCC, accompanied by underestimation of environmental issues and reduction only to monetary dimensions (Aye et al., 2012). On the other hand, the application of biophysical models, such as LCA (Collinge et al., 2013), embodied energy analysis (Chang et al., 2012), exergy analysis, or thermodynamic input-output models (Sharrad et al., 2008), allows only substitution of the same resource but not balancing different kind of quantities.

In the current literature it is possible to find advanced papers dealing with the building retrofit to improve their energy performance. However, many papers are focused only on the definition of optimal decision-making strategy for the building retrofit based on models. The development of new models applicable for the ideal retrofitting strategy, such as those proposed by Seo et al. (2018), Irulegi et al. (2017), Salvalai et al. (2017), or Son and Kim (2018), is of course very important and provides a helpful tool but validity of real outputs from these studies can be disputable without a comparison between modeled values and the real data. There are also many papers based on narrow evaluation procedures. Their authors mostly rely only on environmental aspects, how it can be found, e.g., in AlFaris et al. (2016) or Ritzen et al. (2016). However, once again, without a proper validation of these models or tools it is not possible to provide reliable results (Ma et al., 2012). Despite of the effort paid to this topic, the published papers comparing the preliminary data from the pre-renovation models with the post-renovation real data are scarce. One of the exceptions is the study