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Strategies for cost efficient refurbishment and solar energy integration in European Case Study buildings

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ABSTRACT

There are numerous residential building typologies in Europe, which require differentiated strategies for building rehabilitation to obtain the lowest payback and highest energy savings. Building integrated renewables can provide some or most of the building energy demand with a strong dependency on climatic conditions. Within the project "holistic energy-efficient retrofitting of residential buildings" (HERB) in the European Union seventh framework program, the most appropriate way of saving energy and supplying building integrated renewables in 7 European countries is sought. This study presents an energetic and economic comparison between energy efficient refurbishment of the building envelope and the integration of renewable solar energy technologies for different climatic conditions.

A range of dynamic multi-zone simulation runs were done in EnergyPlus increasing the thermal resistance of the building envelope elements from the national reference energy standard up to a low energy standard. For the given energy demand, the solar energy integration potentials providing electricity and heat are investigated using the simulation environment INSEL. Finally, cost analyses are done to find the financially optimum strategy for saving energy with building rehabilitation or producing energy with renewable technology integration.

It could be shown that building rehabilitation becomes less cost and energy efficient with decreasing geographical latitude while renewable integration increases in relevance. Building insulation measures offer much higher savings than renewable production in more Northern locations even though with slightly higher specific costs. The measures suggested are now implemented in 12 building projects within the European project focusing especially on innovative materials and renewables.

1. Introduction

Comprising different dwelling types such as detached, semi-detached, terrace houses and apartment blocks, the residential floor space constitutes 75% of the EU building stock. Within the EU-28, the residential stock is responsible for 26% of the total final energy consumption and 13% of the CO_2 emissions by 2012 [1]. Therefore, the reduction of CO_2 emissions through refurbishment of residential buildings has a significant share in the construction sector for moving to a low carbon economy up to 2050. Although it is mentioned in the EPBD recast that new buildings will have to consume nearly zero energy as of 2020 [2], there is no specific target for refurbishment of existing buildings. Besides, there are several national energy agencies, academic institutes and non-profit associations focusing on energy efficiency refurbishment of existing building stock for the European Union 2050 target.

Undertaking energy efficiency refurbishment is a complex process comprising different phases and many stakeholders. Occupants influence the building usage, investors and professionals from different disciplines are involved who may not see the building as a whole and the municipality administration is concerned with policy making for the entire rental housing stock. Therefore, to develop best practices and improve their effectiveness, understanding the actors' strategy and the dynamics of barriers is necessary. Political and normative, behavioural, technical and financial barriers have been identified as the main five barriers [3]. Besides, in the decision making process, multi-variant design and multiple criteria analysis as an holistic approach to the refurbishment process determine the strongest and weakest points of each building's refurbishment project. The main factors are the cost of refurbishment, the annual energy saving after refurbishment, tentative pay-back time, harmfulness to health of the materials used, aesthetics, maintenance properties, functionality, comfort, sound insulation and longevity, etc. [4].

Regarding the choice between reuse and replacement of existing buildings, studies show that refurbishment rather than demolition

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is more effective on the basis of time, cost, community impact, prevention of sprawl, reuse of existing infrastructure and protection of existing communities [5]. Also, the environmental impact of life cycle extension by renovation and reuse of existing stock is generally more sustainable than demolition [6,7]. Furthermore, studies point out the relevance of life cycle assessment within the scope of refurbishment interventions and renewable technology integration in order to ensure a balance between energy saving and environmental benefits by considering operational, embodied and demolition energy before and after retrofit actions [8–10]. In fact, shifting from existing houses to low energy buildings and to net zero energy buildings might end up with increased embodied energy even higher than the energy savings in operation [11]. As a holistic approach, the principles that should be taken into account in the whole refurbishment process include energy demand reduction, thermal comfort, climate issues, design parameters, appropriateness and economics. Furthermore, there are several measures to be applied for energy efficiency refurbishments, which are either construction or building service related measures [12].

The European building stock is dominated by houses built before 1975 and after World War II with poor thermal properties and usually no insulation [13]. The energy efficiency potential from the refurbishment of existing residential buildings in the EU shows about 40,000 kilotons oil equivalent energy saving for space heating which corresponds to the expected amount of renewable energy resources from the 2020 target [14]. Also a Danish study shows that a profitable space heating saving potential of about 80% has been identified within the Danish residential building stock built before 1979 up to year 2050 [15]. Some European case studies show that the most significant benefits concerning energy savings are related to the thermal improvement of the building envelope [16–18]. The most significant issue is to find economically feasible ways and means to choose between insulation measures, better glazing, building service installation measures and renewable energy systems such as solar collectors and PV modules. A study shows the optimal hierarchy of the most effective and durable energy-saving measures for refurbishment as the insulation of the roof, insulation of the floor, thermally better performing glazing, more energy efficient heating system and renewable energy system integration, respectively [19]. Another study shows that retrofitting the building fabric, the building service and metering systems requires less investment costs and more environmental benefits as compared to using renewable energy technologies [20]. However, most of the cited literature excludes a detailed investigation of the shift when thermal insulation becomes less efficient in warmer climates.

The current work is conducted within the "holistic energy-efficient retrofitting of residential buildings" (HERB) project financed by the European Union seventh framework program. The project aims to establish new and innovative energy efficient technologies and solutions for retrofitting older buildings to be developed and demonstrated for different building types, climates and socio-economic conditions in various European countries. The retrofit technologies can be categorized into three groups, supply side management, demand side management, and change of energy consumption patterns, i.e. human factors [20]. Within this study, demand side and supply side measures are both taken into account by investigating the appropriate ways of energy demand reduction and energy production with renewable technologies for three residential units in Almada – Portugal, Bologna – Italy and Nottingham – UK.

This study presents an energetic and economic comparison between energy efficient refurbishment of the building envelope and the integration of renewable solar energy technologies for different climatic conditions. The aim of this paper is to present the results obtained to guide the professionals in the choice of energy efficiency refurbishment strategies and/or renewable integration. To obtain this goal, firstly energy demand reduction potentials are investigated via architectural interventions such as building envelope retrofits. Secondly, according to demand data obtained from simulations, renewable technology integration such as photovoltaic (PV) system for electricity and solar thermal system for heating and domestic hot water (DHW) demand are investigated. Finally, a cost benefit analysis is performed for the demand and supply side measures. The results enable to comprehend which investment is more effective in the considered climate regions and constitutes an economic optimum for further decision making on the building envelope or renewable system implementation process.

2. Case study buildings within the European HERB project

Within the scope of this study, three of the building projects in three climate regions were chosen. The buildings located in Almada (Portugal) and in Bologna (Italy) are multi-family residential buildings, the UK building in Nottingham is a single family residential building.

The investigated building in Almada is one of the buildings of a larger L-shaped block of five similar buildings included in a large social housing area (361 ha and 13 500 inhabitants), see Fig. 1. The housing area is mainly managed by the National Housing Institute of Portugal, although some are managed by the Municipality of Almada as the one chosen for the HERB project. The building with 10 apartments is representative of multi-family apartment buildings built in the 80s/90s which comprise a significant share of the total housing stock in Portugal. It was built in the early 90's after the first Portuguese legislation regarding the energy performance of buildings.

The five-story plus basement building with 1296 m^2 total floor area is constructed with brick masonry with concrete columns and slabs. The main façades are NW/SE oriented with the main front oriented at an azimuth angle of 157.5° to SSE. The main entrance floor is 1.2 m above ground and stairs are providing access to this floor. The basement floor has high windows all along the back façade and small ones along the front façade. The overall quality of the building envelope is relatively low, with no insulation and low efficiency single glazed windows. As there is no heat distribution system in the building, in each apartment an electrical heater is occasionally used. The usage level is very low (1 h a day during winter months according to information received from the survey done with the occupants). Water heating is done with a low efficiency gas boiler situated in the basement and a gas cooker is used.

Fig. 2 shows the location of the investigated multi-family house in the city of Bologna which is a multi-family house with six apartments. The principal part of the building, namely that with the same floor plan at the first, second and third floor, was constructed between 1930 and 1940. An extension of the first floor was constructed between 1960 and 1970. The total floor area of the building is 474 m^2 with 282 m^2 of conditioned area. The two roof surfaces are oriented to Southeast and Northeast.

Some divisions of the internal spaces were modified around 1980 to increase the number of apartments. Space heating was provided by a gas boiler and DHW by electric water heaters, as in the present state. Recently, starting from 2000, occupants of several apartments changed building envelope components by renewing the single glazed windows and insulating some problematic areas. In some apartments, windows were replaced with double glazed windows with aluminium frame and unheated basement areas were insulated. The status of the years 1980–2000 when the building has the current partitioning and no occupant has interfered with