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The relationship between renewable energy use, energy efficient building renovation and the role of windows in achieving EU climate targets: A comprehensive scientific review – summary

Conducted for European Trade Association of PVC Window System Suppliers, European Aluminium Association and EuroWindoor

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Content

1 Motivation and objectives

The European Green Deal aims to achieve carbon neutrality by 2050. As buildings account for 43 % of final energy consumption in the EU, mostly for heating, reducing GHG for heating buildings is an important aim of the energy policy in the EU [1].

With the new version of the EPBD (Energy Performance of Buildings Directive [2]), the EU Commission intends to phase out fossil fuel in heating and cooling in new buildings and in buildings undergoing major renovation or heating system replacement. The initial proposal for a recast regulation (Building Energy Act [3]) in Germany, according to which each newly installed heating system must be powered by at least 65 % renewable energy from January 2024, has raised a strong public debate in 2023. The role of energy efficiency measures in the building sector has rarely been explored in this public discussion, even though the Building Energy Act (BEA) not only regulates heating systems, but also the energy efficiency of the building envelope.

This highly politicized debate in Germany has, on the one hand, created the impression that relying solely on new renewable heating systems can drive the decarbonization in buildings. On the other hand, the limited number of heating technologies that meet the requirements of the BEA and different consumer experiences contribute to uncertainty among building owners. This often leads to delays in implementing energy efficiency measures and replacing heating systems, both of which are crucial to achieving the goals of the European Green Deal.

Recognizing that the focus of this discussion should be on scientific facts rather than on any public political awareness, EPPA (European Trade Association of PVC Window System Suppliers), European Aluminium Association and EuroWindoor engaged Fraunhofer IBP to conduct a comprehensive literature review of key research studies addressing the economic, societal and other multiple aspects of energy efficient renovation and the renewable energy use. Additionally, the role of windows in the context of the entire building envelope in energy efficient building renovation is to be identified from the existing research studies.

The first objective of this project is to provide an overview of the state of knowledge on the multiple impacts of energy efficient measures (demand side) and the use of renewable energy (supply side) in the building sector to achieve the zero-emission for heating in buildings.

The second objective of this project is to present a comprehensive literature analysis of the contribution of windows to energy efficient renovations of building envelopes in the EU.

2 Summary of results

2.1 Energy efficient measures (demand side) and the use of renewable energy (supply side) for heating in the building sector

1. What is the current situation of energy supply and energy consumption for heating in the building sector in the EU?

   At EU level, buildings account for 43 % of final energy consumption, of which two thirds is consumed in residential buildings, mostly (78 %) still for heating in 2019 [4]. Since 2000, heating consumption per square meter has decreased due to stricter building codes, financial incentives for retrofitting, and adoption of more efficient heating systems. However, statistics show a slowdown in the improvement of energy efficiency in the building sector in the EU in last 10 years in comparison to the period between 2000 and 2010 [5].

   The analysis of the reduction rates of final and primary energy consumption in the EU for whole sectors reveals that the intensity of energy efficient measures to reduce final energy consumption has remained constant over the past 20 years, while the intensity of renewable energy supply has increased significantly [6]. However, the share of renewable sources for heating and cooling in the EU is still only 23 % in 2021, with large variations between countries [7].

2. What are the available options for reducing energy demands and using renewable energies for heating buildings?

   The heating energy demand in buildings can be reduced by insulating the building envelope, using more energy efficient windows, reducing thermal bridges, increasing air-tightness and insulating pipes. Additionally, implementing heat recovery of ventilated air with a ventilation system, using efficient heating systems and optimizing their control further contribute to energy savings.

   To meet the heating energy needs of buildings, renewable energy sources such as solar, geothermal, biomass, ambient energy and waste heat are utilized to generate heat (see [8] for more information about current renewable heating technologies). In addition to direct use of renewable heat sources, heat pumps and district heating systems must be successively decarbonized through the use and integration of renewable energies. However, the share of renewables in electricity generation is around 38 % in 2021 [9] and even lower with 27 % in district heating in the EU [10]. Approximately 6 % in residential buildings and 12 % of building stocks in the EU are heated by electricity and district heating systems, respectively [11,10].

3. Is there a relationship or link between these two strategies?

   Yes, heat pumps and modern district heating systems are more efficient when operating at lower flow temperatures. This refers to the temperature of fluid,

usually water in the EU, that circulates through pipes and emitters like radiators. To achieve high efficiency of heating systems, buildings should have either relatively good energy efficiency or a large heating emitter area, such as a floor heating system[10,12–14]. A EU-study indicates that heat pumps can be installed in 40 % of all EU dwellings currently heated by fossil fuel boilers without any measures needed at the building envelope. For almost 60 % of dwellings, energy efficiency improvements at the building envelope or adjustments to the heating emitter areas should be conducted to ensure the efficient operation of heat pumps [14]. This study assumed for this estimation a threshold value of 150 kWh/m²a, however, there is a lack of evidence-based values to guide consumers.

4. Between improving energy efficiency on the demand side and increasing the supply of renewable energy, which is the most beneficial strategy from an economic perspective?

   The recent EU research project, ENEFIRST [15], investigated the cost-optimal combination of demand-side and supply-side resources for achieving net-zero GHG emissions in the building sector at the macro-level. This comprehensive study considered the investment as well as operating costs for energy generation, network and storage infrastructures to meet the energy requirement for space and water heating, space cooling, electrical appliances, lighting and cooking in both residential and non-residential buildings. The results show that the total cost of the "highly efficient scenario" with a 35 % energy demand reduction is higher than "low efficient scenario" with 21 % demand reduction, but the cost difference is less than 1 %.

   An international research team of IEA-EBC Annex 56 [16] investigated the question at building level in seven EU countries with different climates.

   The study found that "*a switch to renewable energy systems such as heat pumps and wood-based systems reduces emissions more significantly than energy efficiency measures on one or more envelope elements*" in most of the investigated buildings. However, the cost-effectiveness of renewable heating systems was not clearly demonstrated in the study. A case study employing statistical methods conducted in Switzerland [17] suggest that replacing the heating system is more environmentally and economically advantageous, even at building level.

5. Between improving energy efficiency on the demand side and increasing the supply of renewable energy, which is the most beneficial strategy from a social or other perspective?

   Macro-Level: Creating jobs

   The number of building renovation jobs in the construction sector alone is estimated to be 4.6 million [18]. A 4 % decrease of jobs in the construction sector is expected in next year due to the rising energy and construction material prices in Europe [19]. Available studies [20, 21] indicate that there is a greater

potential for job creation and a construction sector stabilization through investments in energy efficiency measures.

Macro-Level: Health and Well-Being

15 % of the EU population still live in dwellings with problems such as a leaking roof, damp walls, floors or foundations, or rot in window frames or floors, which often result in mold growth [22]. There is evidence of a link between mold and respiratory symptoms, and a significant portion of the EU population is affected by respiratory diseases [23]. The energy efficiency measures have the potential to reduce health costs associated with respiratory diseases and other health conditions related to poor housing conditions in the EU.

Macro-Level: Energy poverty

The percentage of Europeans unable to keep their homes adequately warm increases from 8 % in 2020 to 9.3 % in 2022 due to the high energy prices following the Russian invasion [12]. Energy efficient buildings are less sensitive to energy prices, which can help offset the impact of rising energy costs. This, in turn, contributes to the reduction of energy poverty by lowering the overall energy expenses for households. Utilizing heat pumps and district heating systems can only reduce energy poverty if electricity and district heating prices consistently remain low over the long term. This is because energy consumption is not significantly affected by the replacement of heating systems.

Macro-Level: Electricity systems and demand flexibility

The use of electric-based heating systems can result in a substantial increase in peak electricity demand in winter, which can require a significant increase in investment in the electricity sector and can lead to high energy bills for customers [13]. Flexible demand management is required to avoid peak demand and manage grid overloads, but this can affect the thermal comfort of users. As the room temperature in the poorly insulated dwellings drops much faster than in well-insulated dwellings [24], energy efficiency measures can contribute to increase demand-side flexibility and relieve the distribution grids [13].

Building-Level: Comfort, health and aesthetics

In poorly insulated rooms, the surface temperature is significantly lower than the air temperature. As a result, occupants in such rooms must heat the space to a higher temperature to achieve the same level of thermal comfort compared to well-insulated rooms or must accept the reduced thermal comfort to save on energy costs. Energy efficiency measures can influence the appearance of the building envelope in addition to improving thermal comfort and health, as mentioned at the Macro-Level.

Building-Level: Property of buildings

The impact of high energy efficiency on the property value of buildings is controversially discussed in existing literature. Recent comprehensive studies [25] indicate that it is not the high energy efficiency itself, but rather the low energy efficiency that affects the property value. Low efficiency can lead to a significant discount on the building value, known as "brown discounting" [26].

2.2 Role of windows in the context of the entire building envelope in the energy efficient building renovation

1. How important are windows in the energy efficient building renovation?

   Despite the lower ratio of the windows area compared to walls in residential buildings, the role of windows in improving energy efficiency is crucial. The reason for this is that the difference in thermal insulation values of windows between existing buildings in the EU and currently available on the market is significantly higher compared to other building elements [27]. The greatest savings potential exists in buildings with low thermal insulation values in cold climate zones. The characteristics of a window go beyond just thermal insulation. They also include solar heat gain and light transmission, which have a significant impact on heating, cooling and lighting energy consumption.

   In order to reduce heating energy, it is important to consider the high solar gains in addition to the thermal insulation values [28]. The controlling of the solar gain in the summer plays an important role in reducing cooling energy and providing high thermal comfort, especially in the southern EU and increasingly in the central EU. Solar shading systems are commonly used to reduce the solar gain in the summer and allow high solar gain in the winter. Where solar shading systems cannot be installed for aesthetic or wind speed reasons, high-performance glazing can be used instead, such as switchable glasses that can change their g-values, or solar protection glasses with a low solar gain factor. This, combined with effective daylighting and good thermal insulation, helps to achieve the desired balance between solar control, heating energy efficiency and high levels of visible light.

2. What are the advantages and disadvantages of window replacement compared to other energy efficiency measures, from an environmental, economic, social and other perspectives?

   Evaluating the environmental impact of window replacement compared to other energy efficiency measures in the EU is challenging due to limited case studies and variations in geometry, construction components, and available materials across countries. Nevertheless, available studies [29–31] indicate that the production of windows makes a substantial contribution to GHG emissions compared to typical insulation measures. In addition, new windows with a wooden frame is less cost-effective in typical building stock constructed up to 1975–1980 than other insulation measures in most EU countries [16].

The replacement of single-pane windows proves to be cost-effective through energy savings alone [32]. Nevertheless, an analysis of the thermal properties of the building stock suggests that in certain EU countries such as France, Ireland, Poland, a portion of buildings constructed before 1980 is still equipped with single-pane windows [27]. In such cases, the window replacement will be cost-effective.

However, replacing old windows with new and therefore more airtight windows without renovating the other building envelope areas can lead to mould growth in the absence of adequate ventilation. Therefore, the decision to replace windows should be made considering the entire scope of building energy efficiency measures on the building, such as installation of ventilation systems and insulation of the building envelope. The combined measures of envelope insulation and window replacement will also increase cost-effectiveness.

The main advantage of window replacement compared to other energy efficiency measures lies in its capacity to substantially enhance thermal, visual and acoustic comfort. This improvement results in increased health and well-being, making it a compelling factor for consumers when considering energy efficient retrofitting [25].

Moreover, the replacement of windows contributes to improving the resilience of old buildings against climate-related hazards such as strong wind or rain resulting from the climate change [33].

3 Conclusion

Recently, the intensity of renewable energy supply in the EU has increased significantly. This trend creates optimism about the capacity of renewable energy resources to meet future consumption, without any need for additional energy savings.

However, comprehensive studies [10,13,14] on deploying heat pumps and district heating systems emphasize the importance of energy efficient buildings for achieving high efficiency, reliable functionality and economical use of heating systems based on renewable energy. In addition, this literature study shows that energy efficient measures have a high potential considering multiple aspects such as job creation, health and well-being, reduction of energy poverty and stabilization of the electricity system through demand flexibility. Therefore, key researches suggest that the policy and stakeholders at the building level should acknowledge the correlation between energy efficient measures (demand side) and the use of renewable energy (supply side) in energy planning. Moreover, it is important to consider the additional benefits of energy efficiency measures in the long term and to avoid short-term and short-sighted economic considerations [15,34].

Windows play a crucial role in energy efficient building renovation, considering the low insulation properties of windows in the existing building stock and the

advancements in window technologies over the past 15 years (such as low-e coating and triple glazing).

Assessing the environmental impact of window replacement compared to other energy efficiency measures in the EU is challenging due to differences in geometry, construction components and available materials between countries, as well as the insulation status of the building envelope of the buildings studied. The main advantage of window replacement lies in its ability to substantially enhance thermal, visual, and acoustic comfort. Specifically, it significantly improves thermal comfort in buildings, preventing local thermal discomfort near the windows. Additionally, it contributes to resilience against climate-related hazards such as strong winds or heavy rainfall.

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