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ENERGY AND COST PERFORMANCE MODELLING OF A REFERENCE COASTAL HOUSE TOWARD NEARLY ZERO ENERGY STANDARDS

Summary

This study presents an annual thermal performance and cost analysis of a reference single family building, representative of typical residential construction in coastal Croatia during the second half of the 20th century. The objective of this study was to evaluate the energy performance under various renovation scenarios, aiming to reduce annual energy consumption through improved building envelope and HVAC systems in order to move the building toward nearly zero energy standards. A number of cases were simulated, varying in envelope insulation thickness and HVAC configurations, including both traditional and renewable energy systems. Although the initial building exhibited poor thermal efficiency and high energy consumption, results showed that strategic upgrades could significantly reduce energy demand, confirming that even outdated, energy-inefficient buildings can be transformed into low-energy homes through targeted renovations.

Keywords: Dynamic modelling, HVAC, Nearly zero energy building, renewables, TRNSYS.

Field of application for the findings: Energy Efficient Buildings

Addressed audience: Researchers and HVAC experts

1. Introduction

Improving energy efficiency is a key strategy to reduce primary energy consumption in the European Union (EU). Buildings in the EU account for over 40% of final energy use and about 35% of total CO_2 emissions, with heating and cooling systems responsible for roughly half of this consumption. Since the majority of existing buildings show poor energy performance, renovating existing buildings is essential for the transition to a low-carbon energy sector. According to the EU Energy Performance of Buildings Directive, all new buildings and those undergoing major renovations must meet nearly zero energy building (nZEB) standards. To be cost-effective, renovations should reach a cost optimal level that minimizes total costs over the system's lifetime. Nearly zero energy buildings (nZEBs) are highly energy-efficient buildings that cover most of their energy needs from renewable sources. This transition is directly aligned with the United Nations Sustainable Development Goals, which aims to ensure universal access to affordable, reliable, sustainable and modern energy services, while promoting an increased share of renewable energy and improved energy efficiency performance as core mechanisms for the decarbonization of the global energy system. Various studies have been conducted in order to evaluate the energy performance and environmental impacts of HVAC systems under different building configurations (Hamdy et al., 2013; Barthelmes et al., 2015; Ascione et al., 2019; Eksi and Ozcan, 2025). The objective of this study is to define, for a given building, the appropriate systems for heating, cooling, ventilation, and domestic hot water production, and to perform annual simulations in order to calculate costs, CO_2 emissions and energy consumption up to the level of primary energy. Meteorological data for the reference location were based on the climate conditions of Rijeka, Croatia. The building under study is a single-family house with a basement, ground floor, and first floor, designed in the second half of the 20th century, a type that exists in large numbers along the Croatian coast in similar form and size. For this reason, the analysis and results obtained can be considered representative for a wide range of comparable buildings.

2. Model description

The building under consideration consists of three floors, which can be considered as three separate apartments and represent the heated part of the building. The heated zones of the building include the basement, ground floor, and first floor, while the unheated zones comprise the garage, three storage rooms, the ground-floor and first-floor porches, and the attic. The building model was created in *Google SketchUp* with the *TRNSYS3D* plug-in to ensure compatibility for subsequent thermal property calculations. Firstly, the building was analyzed in its existing and renovated states with varying envelope insulation thicknesses, without considering heating, cooling, or ventilation systems. After defining the building 3D model and the envelope insulation thickness that satisfies current regulation requirements, an insulation thickness of 8 cm was chosen and applied in the subsequent system simulations. The simulations were conducted using TRNSYS Simulation Studio software. Nine different HVAC system variants were simulated to identify the most energy-efficient and cost-effective configuration. Both fuel and energy costs, as well as investment costs for envelope retrofits, insulation, and system installation, are evaluated to enable a comprehensive comparison of the scenarios. The considered systems included oil and gas boilers, condensing gas boilers with solar DHW production, mechanical ventilation with heat recovery, heat pumps with auxiliary electric heating, and purely electric heating coupled to photovoltaics. Table 1 represents a summary of the system variants considered in this study.

Tab. 1: System variants component summary

Syst.	Envelope	Heating	Cooling	DHW	Ventilation
S1	Original uninsulated	Oil boiler, radiators	Split system	Oil boiler	Natural
S2	8 cm insulation	Gas boiler, radiators	Split system	Gas boiler	Natural
S3	8 cm insulation	Gas boiler, radiators	Split system	Gas boiler	Heat recovery
S4	8 cm insulation	Gas boiler, radiators	Split system	Solar, gas boiler	Heat recovery
S5	8 cm insulation	Heat pump, FCUs	Heat pump	Electric heater	Natural
S6	8 cm insulation	Heat pump, FCUs	Heat pump	Electric heater	Heat recovery
S7	8 cm insulation	Heat pump, FCUs	Heat pump	Heat pump	Heat recovery
S8	8 cm insulation	Electric heater + PV	Split system	Electric heater	Natural
S9	8 cm insulation	Electric heater + PV	Split system	Electric heater	Heat recovery

3. Energy and economic analysis

After defining all system variants, annual dynamic simulations were conducted to determine the delivered energy demand of each HVAC system for the same thermally insulated building. Apart from the delivered energy of each considered system variant, primary energy and carbon dioxide emissions were also calculated to enable a consistent and objective comparison. Figure 1 presents the delivered energy of each analyzed HVAC system variant, categorized according to the energy source used. The results show a clear trend of decreasing total delivered energy as the systems become more advanced and energy-efficient. System variants S8 and S9 represent an exception to this trend; however, the integration of photovoltaic panels reduces the amount of supplied grid electricity, consequently improving their overall energy performance.

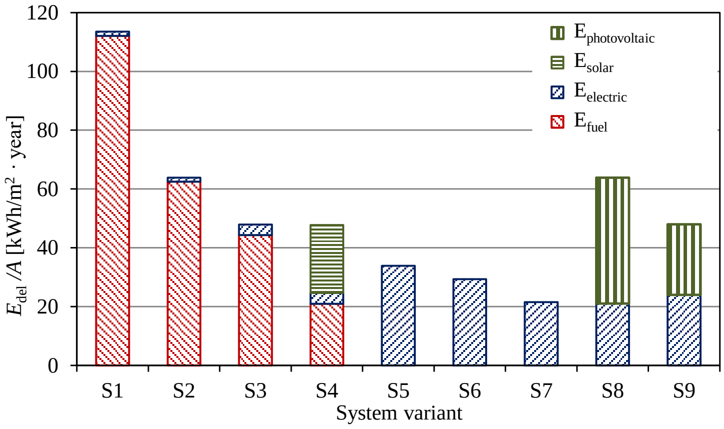

Fig. 1: Annual delivered energy from different sources

As part of the overall analysis, economic indicators were also considered in the present study. Both investment and operating costs were evaluated using the global cost approach, representing the total expenditure over a 20-year period. Figure 2 illustrates the relationship between the cost indicator C_I calculated for a period of 20 years and the annual primary energy consumption (E_{prim}/A) for the evaluated HVAC system variants (S1–S9). The results indicate that only systems S4, S7, S8 and S9 comply with the 35 kWh/m² primary energy requirement. These systems exhibit superior energy performance, resulting in a significant reduction in annual operating costs, even though their investment costs are comparatively higher in relation to conventional systems.

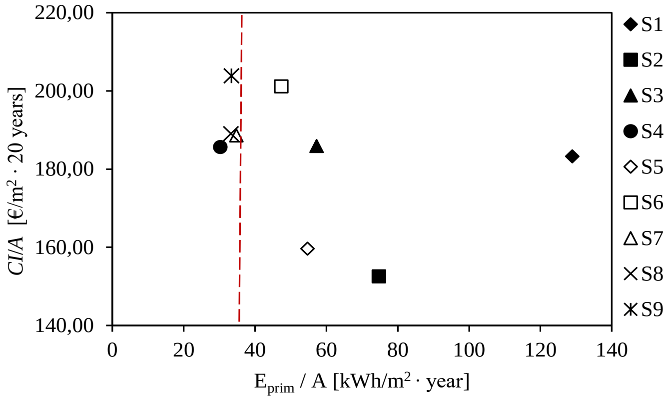

Fig. 2: Cost indicators for investment and operation over a 20-year period

4. Conclusion

This study investigated the impact of thermal insulation thickness and various HVAC system configurations on the energy and economic performance of a typical single-family residential building representative of the Croatian coastal region. From an energy and economic perspective, the condensing gas boiler system with solar collectors (S4) and the heat pump system (S7) demonstrated the lowest primary energy consumption while maintaining moderate overall costs. Both S4 and S7, as well as S8 and S9, meet the nZEB requirement that at least 30% of annual delivered energy must come from renewable sources. System variants that employ electric heating coupled with photovoltaics (S8 and S9) showed performance comparable to that of S4 and S7. The study also shows that domestic hot water (DHW) production should be supplied by a heat pump or solar system to comply with maximum primary energy standards. From a CO_2 emissions perspective, system variants S4, S7, S8 and S9 are the most favorable, each achieving a reduction of approximately 85% compared to the uninsulated baseline system variant S1. The presented methodology and results may serve as a guideline for similar retrofit projects aimed at achieving cost optimal and regulation compliant energy performance levels in the residential building sector, especially in Mediterranean areas with comparable climate to the one considered in this study.

5. References

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