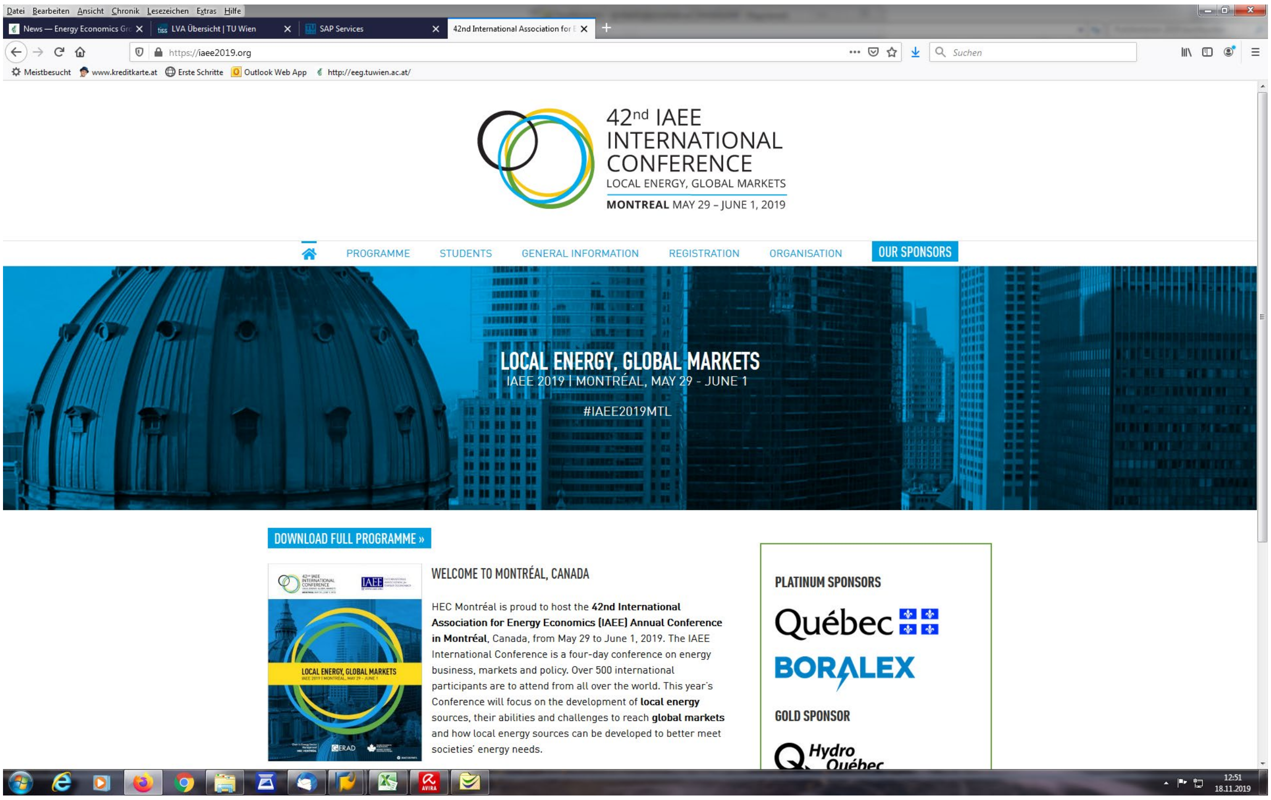

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ACTIVE RETROFITTING FOR MULTI-APARTMENT BUILDINGS: USE CASE ANALYSIS WITH A SPECIAL FOCUS ON PHOTOVOLTAICS AND HEATING SYSTEMS

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Overview

Even though new buildings often meet today's energy efficiency standards [1], energy efficiency measures in those buildings alone will not make a big difference in achieving the goal of reducing CO_2 emissions in the building sector: The European Comission reports that 35% of European building stock is older than 50 years and, thereof, 75% is energy-inefficient [2]. The building sector accounts for 40% of total energy consumption and 36% of CO_2 emissions in the European Union. These numbers emphasize the need for retrofitting the old housing stock in the near future. Due to their high density in cities and due to the fact that half of European housing stock consists of multi-apartment buildings, this building segment is chosen for analysis in this work. Three basic categories of retrofitting a building can be found in literature: (i) passive retrofitting such as insulation of facades and roofs, window change, etc. (ii) passive measures combined with a solar thermal system for meeting hot water demand and (iii) a combination of active and passive retrofitting measures. A thourough literature review revealed a lack of studies focusing on the profitability of different active retrofitting investment options, including investments both in electricity and heating technologies. Furthermore, photovoltaic (PV) systems have not been analysed in sufficient detail. These can not only be implemented building-attached on a building's rooftop but also building-integrated and on different parts of building surface, like the facade or implemented as salient shading elements. Together with the consideration of different heating options and different building characteristics a variety of use cases can be analyzed in terms of profitability.

Methods

In order to be able to examine a variety of use cases a modular approach is used to simulate different building set-ups. This makes the results applicable to a wide range of building types. The model allows to choose from a variety of building characteristics like orientation, location, static heat load, roof pitches, constraints by neighbouring buildings, number of apartments, purely residential building and so on. Additionally, the model makes it possible to choose for analyses electricity and/or heating technologies out of a building energy technology portfolio. For instance, the energy technology portfolio contains such options as building-attached/integrated PV for being implemented on a roof, facade or used as salient shading elements. Named PV systems can be complemented by a battery storage facility. For heating purposes, the technology portfolio holds such options as pellet heating, district heat, mono-/bivalent heat pump.

In order to examine the profitability of investments in active retrofitting measures, a mixed-integer linear programming optimization model is developed. The objective is to maximize the net present value (NPV) over a time horizon of 20 years. With the optimization input parameters of previously selected building characteristics and building energy technologies, the optimization model determines the optimal energy technology capacities to be installed (e.g. optimal size of PV systems, optimal/necessary installation capacity of the heating system) and the resulting energy flows. Since the model is concerned with achieving reasonable long-term investments, the optimal decision can also be not to install a given energy technology. The optimization model is constrained by the main requirement to cover electricity and heat demand at every point in time, besides many more constraints for each technology used in the model. The solar irradiation is calculated according to the building's location, specified by the azimuth and an inclination angle. The heat load is calculated based on a location's outdoor temperature profile and a constant indoor temperature of 20°C. The heating threshold temperature is set to 12°C. For electricity data, real-measured loadprofiles are used. All data comes in 15-minutes' resolution and thus leads to precise results.

Results

As a first step, the financial impact of a heating system change is analysed. As a default setting a stand-alone multi-apartment building with 10 residential units, a roof tilted at 30°, a specific heat load of 145kWh/m^2/yr and gas heating is considered. The optimization model's output shows that, from a financial perspective, other heating systems cannot yet compete with a conventional gas heating. District heating is the cheapest option after gas, followed by pellet heating. Bivalent and monovalent heat pumps are the most costly options. However, once CO_2 emissions are considered, it is recommendable to install pellet heating or a heat pump. An additional battery storage storage facility is unable to reduce costs.

In a second step, the different possibilities of implementing PV systems are investigated. It is positive to see that all kinds of PV systems are able to achive break-even within a time horizon of 20 years. Rooftop building-attached PV systems are the most profitable due to optimal solar irradiation and reasonable prices of 1050€/kW. Costs rise as soon as building-integrated PV systems are implemented, because the building envelope is harmed by such a PV implementation. This causes additional basic roof/façade renovation costs, which have to be factored into the analysis. As a result, additional costs lead to a decrease in the NPV and thus to less profitability. Despite weaker solar irradiation, PV systems on the façade can also achieve break-even. Notably, the optimization model prefers to implent PV systems on South-oriented sides of the building. However, the profitablility of PV systems implemented on East and West-oriented sides of a building is not substantially lower. The North-oriented sides of the building are not considered profitable by the optimization model for installing PV (least amount of solar irradiation).

A sensitivity analysis with a tenant portfolio variation showed that, compared to a purely residential load, including a business on the ground floor of the multi-apartment building has a significant impact on the optimal PV system size. Businesses consume most electricity during the day, meaning that there is a good correlation of the electric load profile with the hours of sunlight. This further leads to an increase in optimal PV system sizes and thus a higher profitability. This statement can be proven by the fact that in case a business is included, the North-oriented part of the building's roof is also considered profitable for implementing PV. A variation of the roof pitch within a small range (20°-40° tilt), on the contrary, does not alter optimal PV system sizes, and thus profitability, significantly.

Last but not least, a sensitivity analysis is conducted by altering the static heat load. In the case of implementing a heat pump in combination with a PV system, one can see that the installed heat pump capacity decreases significantly with increasing building quality. The PV system size, in contrast, only sees a slight decrease. Most electricity is used to cover the electric load, the heat pump capacity decrease therefore affects optimal PV system size insignificantly. When comparing the monetary value of energy savings due to better building standards to passive renovation costs, which are necessary in the first place, it is obvious that passive renovation measures are not profitable. The cost reduction from energy savings cannot compensate for the initial investment of improving the building envelope. However, it can be seen that the profitability gap between passive renovation costs and the monetary value of energy savings is smallest for the buildings with highest quality standards due to their low static heat load.

Conclusions

Results show that building-attached as well as building-integrated PV systems on different parts of the building surface are reasonable investments for an active building retrofit, whereas a change of the default heating system (gas) cannot contribute to saving energy costs. The profitability gap between investments in passive renovation measures and resulting energy cost savings is a topic to be addressed in the future as reasonable building retrofitting should include a combination of passive and active retrofitting measures. Investments in passive building renovation could be triggered by governmental subsidies. Another way would be the introduction of CO_2 taxes or true-cost pricing of CO_2 emissions, which would encourage people to reduce their heat load, which can be realized, among others, by raising building standards.

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