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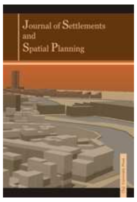

Beyond the Building – Understanding Building Renovations in Relation to Urban Energy Systems

Javier CAMPILLO[1], Iana VASSILEVA[1], Erik DAHLQUIST[1], Lukas LUNDSTRÖM[1], Richard THYGHESEN[1]

[1] *Mälardalen University, School of Business, Society and Engineering, Västerås, SWEDEN*

E-mail: javier.campillo@mdh.se, iana.vassileva@mdh.se, erik.dahlquist@mdh.se, lukas.lundstrom@kfast.se, richard.thygesen@gmail.com

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ABSTRACT

About 35% of Europe's building stock is over 50 years old and consumes about 175 kWh/m^2 for heating, between 3-5 times the amount required by the newly constructed buildings. Annually, between1 and 1.5% new buildings are built and only between 0.2 and 0.5% are removed, therefore the focus needs to be put on the renovation of the existing building stock. The implementation of energy conservation measures (ECMs) in the residential sector becomes a very important strategy to meet the EU´s 20% energy consumption reduction of the 20-20-20 goals. The main challenge, however, is to determine which of the ECMs strategies are the best to provide not just with the best energy consumption reduction, but also with the best environmental impact and economic benefits. This paper addresses this issue and analyses the impact of different ECMs by focusing not only on the buildings themselves, but on the energy supply network and the overall energy system as a whole. To achieve this, we review five case studies in Sweden that use different ECMs as well as other alternatives, such as: distributed generation (DG) and energy storage. Results suggest that although there is no standard protocol that would fit all renovation projects, the existing methodologies fall short to provide the best overall impact on the energy system and that a broader analysis of the local conditions should be carried out before performing large building renovation projects.

1. INTRODUCTION

The buildings sector in Europe is responsible for about 40% of the final energy consumption and 36% of the EU's total CO_2 emissions [1]. This corresponds to the annual unit consumption per m^2 for buildings of 220 kWh/m^2 in 2009, with a large gap between residential (200 kWh/m^2) and non-residential (300 kWh/m^2) use.

One critical issue is that about 35% of EUs buildings are over 50 years old and require an average of 175 kWh annually for heating alone [2]. In contrast, new buildings only require between 35 and 58 kWh/m^2 [1]. The construction of new buildings represents between 1-1.5% of the building stock while removed buildings represent only about 0.2-0.5%. Assuming that this trend will continue, the focus needs to be put on renovation of existing buildings in order to achieve a substantial impact in terms of energy savings and greenhouse gases (GHG) reduction. Taking into account that the number of refurbishments accounts for about 2% of the housing stock per year, it is possible to estimate that around one million dwellings are refurbished every year.

Adopting effective energy conservation measures (ECMs) in the residential buildings sector is an important strategy to meet one of the EU's 20-20-20 goals: 20% energy consumption reduction. Mass adoption of this strategy could help reduce the use of non-renewable primary energy resources between 5% and 6% and reduce CO2 emissions by 5% [1]. Some of these ECMs are explained in more detail in section 2.

Sweden has developed policy incentives to reduce energy use in buildings that have been in place since the mid-1970s. Sweden has adopted EUs 20-20-20 goals for reducing 20% of the energy use in the residential sector by 2020, and by50% in2050 using the consumption levels in 2008 as a baseline [3], [4].

Out of the existing building stock in Sweden, a large share was built between the 1960s and the 1970s under the so called *"Million Programme"*, that had the main objective of reducing the existing housing shortage [5]. These buildings were built very fast and with low energy efficiency standards, compared with the existing ones today and represent almost 25% of the total number of multi-family buildings in Sweden [6]. Moreover, these buildings are between 45-55 years old and while they have received upgrades over time, most of them still fall far below today's energy efficiency construction standards [7].

The challenge, however, is that in every city, including both in municipality owned and private enterprises, investments in renovations should provide the best profitability. It is therefore, critical to determine the best way to use these investments, so that it also provides the highest impact on energy efficiency.

When performing building upgrades, particularly those that involve renovating large areas of a city, it should consider all the aspects around the area in order to determine the best ECMs to implement. Since there is no general consensus about what is the best strategy to carry out when undertaking these renovation works, different methods are used. An extensive literature review was carried out in Prombo et al. [8], who performed a critical review of different energy-efficiency strategies and summarized the assessment methods applied in building retrofits, the authors concluded that a lot of the studied methods lack a proper life cycle approach.

Additionally, B. Tan et al (2015), carried out a comprehensive analysis of different ECMs and developed a mixed integer programming algorithm to select the best combination to maximize the financial savings and minimize environment [9]. Similarly Mata et al, developed a bottom-up methodology to assess energy efficiency and carbon dioxide (CO_2) mitigation strategies in the existing building stock and successfully validated their method in 1400 buildings in Sweden [10]. The work presented in Campos et al. [11] takes a slightly different approach, where the building's consumption is modelled to estimate de energy performance after adopting the best combination of different ECMs, that are obtained from an analytic hierarchy process. According to Campos et al (2010), between 15-30% overall energy savings were obtained by using this method as compared to others [11].

Most of these methodologies aim at selecting the best renovation strategy that would improve the energy performance of each building as a single entity or as the entire building stock. However, other issues have to be taken into account, for instance, the impact of these renovations on the energy supply system [7], [12], the indoor thermal and air quality [13], and the social issues between tenants and landlords [14],among others.

Furthermore, while the use of district heating networks (DH) adds more complexity to the energy supply network, it provides with a large potential for using renewable sources (e.g. biomass, waste, etc.) for heating. However, the increased adoption of ECMs and the construction of low-energy buildings affects the cost-effectiveness of traditional DH-systems [15].

Additionally, the existing building code in Sweden, allows for installing solar PV panels and heat pumps when performing renovations. These modifications, when adopted at a large scale, can positively benefit renewable energy usage in the energy mix, especially, when installed together [16]. The benefits can be extended even further when energy storage is included to maximize the self consumption of solar electricity [17] while also minimizing the use of DH, especially in low-energy buildings.

Mass adoption of solar PV systems together with other distributed generation (DG) units (e.g. micro CHP) also provide with a good technical and economical alternative, under the right circumstances, to increase the use of renewable energy sources in local distribution grids and help reduce distribution losses by providing energy closer to the consumption loads, while also increasing demand response and provide with additional load balancing support [18].

Nevertheless, large DG penetration requires the adoption of smart power flow management in order to maximize efficiency and renewable energy use, without compromising network reliability and production costs. This will also play a critical role with the upcoming penetration of electric vehicles (EVs) in the network, that could increase the nightly peak power consumption in densely populated residential areas and therefore, have a high impact on urban power distribution systems [19].

The purpose of this paper is to present different ECMs and evaluate their impact not only on the buildings themselves, but also on the energy supply network and the overall energy system as a whole in Sweden. Other alternatives, such as distributed generation (DG) and energy storage are looked into as well, in order to provide a critical view on conventional methods for selecting ECMs in renovation processes, so that policy makers and city planners should have a broader perspective, to make better decisions when selecting technologies for performing the renovation of areas of a city, not just in Sweden but also in other European mid-sized cities.

The paper is organized as follows: in section 2, the theoretical background for different technologies and ECMs is presented, as well as the methodology used to evaluate them. Section 3 outlines the results of five case studies where several of the ECMs and technologies presented in section 2 have been analyzed and it summarizes their impact on buildings and on the energy supply system. Finally, section 4 summarizes the most relevant results and presents the conclusions.

2. THEORY AND METHODS

In this section, we make a brief description of different ECMs adopted in building renovation projects, as well as different technologies for improving energy efficiency and maximize renewable energy penetration.

Additionally, we analyse five cases in which some of the ECMs have been implemented. In the first case study, the heat demand profiles and electricity-to-heat factors of different ECMs simulated in two existing multi-family residential buildings in the Lagersberg district in Eskilstuna, Sweden, are evaluated from a system perspective approach, in order to determine the impact on efficiency and greenhouse gas emissions on the district heating system (DHS).

In the second study, a building located in Västerås, Sweden, is modelled and simulated with a PV system, a ground sourced heat pump (GSHP) and two types of storage, electric and thermal, in order to determine which system provides the best PV self-consumption and better economic benefits.

The third case study evaluates a renovation process carried out in Allingsås, Sweden, where 16 buildings were renovated by adding 45-50 cm of insulation and replacing existing windows with argon-filled two-glass windows with a silver layer.

The forth study evaluates the energy impact on a group of buildings of the *“million programme”* in Eskilstuna, Sweden, where energy advisors visited the households to explain in detail the different renovation techniques and technologies installed in the apartments, and how to use them in order to increase the efficiency of water and energy consumption.

Finally, the fifth case study, evaluates the impact on the electricity consumption from mass adoption of GSHP in the region of Sollentuna in Sweden.

These cases were selected based on the data available for the projects, technologies used, ECMs impact on the energy-supply network and the population in the cities where the projects were carried out, so that they could be compared with other mid-sized cities in Europe (with less than 500,000 inhabitants) [20].

2.1. Envelope insulation

Improving the building’s envelope insulation includes multiple measures that reduce the building’s heat loss factor for transmission, such as additional insulation of external walls and attic, improved glazing and reduced thermal bridges. These kinds of measures are desirable from the supply point of view as the building becomes less dependent of the outdoor temperature, thus having a more even heat load (which requires less capacity on the supply side). The choice of glazing the windows also affects the amount of solar radiation reaching through, subsequently reaching balance for both heating and cooling.

2.2. Heat and energy recovery ventilation systems

Modern heat recovery ventilation (HRV) employs counter-flow heat exchangers that recover sensible heat from the outbound airflow. While energy recovery ventilation (ERV) systems also recover latent heat, most of the common systems use a rotary enthalpy wheel. HRV systems require a frost protection mechanism to prevent ice formation in the heat exchanger, thus losing in efficiency at lower outdoor temperatures, while ERV systems are able to work with much lower exhaust air temperatures without freezing. A heat pump can also be used to recover energy in the outbound airflow, to provide more flexible energy recovery with the trade-off of increased electricity consumption.

2.3. High-efficient lighting

One of the most cost-effective ways to reduce energy consumption and CO2 emissions is to adopt existing efficient lighting technologies where savings of up to 50% can be obtained [21], [22].

Although there are several lighting technologies available for residential use, in terms of energy efficiency and future improvements, Light-emitting diode (LED) technology offers the greatest potential. In the last six years, the cost of LED lighting has dropped by 90 percent [23] and efficiencies of over 300 lm/W have already been achieved [24]. In comparison, the average efficiency of conventional fluorescent technologies, largely used in existing residential buildings, is of 80-100 lm/W, but more importantly, its lifespan oscillates between one-third and one-fifth of that of LEDs [25].

Furthermore, in a detailed Life-cycle assessment (LCA)comparison between LED lighting technology and conventional fluorescent lamps carried out by Principi and Fioretti (2014) it was found that LED lighting can reduce the environmental impact between 31-50% [26]. Additionally, the use of LED provides a 41 to 50% reduction in mercury emissions.

While replacing conventional lighting fixtures with LEDs is a strongly recommended practice, natural lighting should also be used whenever possible, not just to reduce the energy requirements for artificial lighting, but also because natural daylight creates a more visually stimulating and productive environment for building occupants.

In Sweden, over a whole year, lighting is the largest user of domestic electricity in houses connected to the district heating network, with a contribution share of 26%, and the second largest in multi-dwelling apartments with a contribution share of 16% [27]. Improvements in this area can lead to significant energy consumption reduction, so, when performing large-area renovations, if possible, existing exterior street lighting should be replaced with LED technology. Street lighting commonly uses high-intensity discharge lamps, in particular high-pressure sodium (HPS) lamps, that offer higher operation costs, shorter lifetime, inferior colour rendering index (CRI) and offer less possibilities for smart operation control (e.g. brightness adjustment).

2.4. Building automation

Building automation and control systems (BACS) use the principles of linear control theory to monitor and control the equipment that interact with the multiple subsystems involved in building operations. Some of these subsystems include HVAC, lighting, access control and lifts systems. BACS ensure safe and efficient building operations while reducing operation costs, improve building management and provide increases security for people and equipment [28].

Modern BACSs include a strong ICT integration and more recently, wireless sensors networks provide real-time mobile remote access, instant notifications, and online data access where real-time electricity price and weather forecast can be used for scheduling HVAC control in order to reduce operation costs [29].

One of the main challenges to successfully adopt BACS is the installation and communication standards among different vendors. A new European Standard, the EN15232 – *"Energy performance of Buildings – Impact of Buildings Automation, Control and Building Management"* was developed to tackle this issue. This standard specifies methods to assess the impact of (BACS) and Technical Building Management (TBM) functions on the energy performance of buildings and a method to define the minimum requirements of these functions [30].

2.5. Solar photovoltaics

Solar photovoltaic (PV) is a technology where light is converted directly into electricity and is considered an energy efficiency measure in Sweden. PV-systems are mainly used to reduce the need for purchased electricity in buildings and due to the Swedish electricity cost structure this is also wise from a profitability standpoint.

However, the reduction in purchased electricity usually only makes a small impact on the energy used for heat and domestic hot water. In Sweden, PV-systems are mainly used to reduce the electricity consumption of the building services (fans etc.) since by law, these systems cannot be used directly to lower the tenants' household electricity demand. If storage systems are not used, all the excess power from the PV-systems has to be fed and sold back to the grid.

2.6. Heat pumps

As PV-systems, heat pumps are also considered an ECM in Sweden. Heat pumps can be divided into different sub-categories depending on the low-grade heat source it uses. The most common subcategories are Air/air-, Air/water- and Water/water-heat pumps.

Heat pumps transfer heat form a low temperature source to another with higher temperature. This is can be done by heating and compressing a refrigerant that has a low temperature boiling point. The heat from the refrigerant is then released to the heat sink, via a heat exchanger, when the refrigerant is condensed. Heat pumps are very efficient, and in Sweden, the common seasonal coefficient of performance (SCOP) for water/water heat pumps is of about 3. This means that for every kWh of electricity used by the heat pump, it supplies 3 kWh of heat energy. Additionally, the thermodynamic cycle can be inverted and use the same machine for cooling, which is not just useful for providing with the cooling requirements over summer, but if a GSHP is used, the heat directed to the ground provides a better heating performance over winter, thus serving as seasonal thermal storage.

The major drawback of installing heat pumps is the high initial capital cost, especially if GSHPs are used, when the installation of deep boreholes is required.

2.7. Micro CHP

CHP microturbines are small energy generators that range from 15 to 300 kWe and are based on the operation principle from open cycle gas turbines [31]. Microturbines in general offer different features, for instance: high-speed operation, high reliability, low maintenance and low NOx emissions [32].

Electric conversion efficiency is of around 30% for most systems, however, microturbines are usually coupled with a heat exchanger to use the exhaust energy for combined heat and power (CHP) applications. Conversion efficiencies above 80% are common using this scheme [33].

Additionally, while the most common fuel used for microturbines is natural gas, they accept most commercial fuels, both gaseous and liquid. Finally, the included power electronics onboard coupled with the electric generator, allows for off-grid and grid-tied operations. For all this, microturbines are the one of the most promising technology for distributed generation applications, especially when both power and heat are required.

When a microturbine is connected to the main distribution grid, it can operate in thermal-priority mode or in electric priority mode. In the first one, electricity production is adjusted to control the heat output using measured water inlet, outlet or external temperature control signal. In the second mode, the electricity output is either controlled by the connected load, a fixed operation point or at a custom power production scheme.

On the contrary, when a microturbine is operating in off-grid mode, it can only operate in electric-priority mode with load-following operation to supply with the required electric power and the heat output varies accordingly.

2.8. Energy storage

Energy storage is one of the most important technologies to help increase the installation of distributed energy resources, especially those relying on renewable energy sources. Energy storage can be placed between the generation and the load, helping balance the discrepancies that exist between energy availability (e.g. sun power) and consumption, by storing energy when is highly available and supplying to the load when the energy production has stopped (e.g. overnight).

Energy storage systems are usually described as thermal or electrical. The first one uses the sensible or latent heat of different material to provide with heating or cooling when required. The second one is more complex; the connection interface is electrical and it usually comprises a wide range of technologies, including kinetic storage (e.g. flywheels), electrochemical systems (e.g. flow-batteries) and potential energy (e.g. pump-up hydro) [34].

There is a large range of different technologies used for energy storage, for instance: Lithium-ion batteries, flywheels, flow batteries, superconducting material energy storage, compressed air, pump-up hydroelectric, hot and cold water storage, phase changing materials (PCM), among others.

Unfortunately there is no one-size-fits-all technology and it greatly depends on the application; for instance, the environmental conditions (e.g. operating temperature, indoor or outdoor, etc), storage capacity (months, days, hours, minutes, seconds, milliseconds), instant power, cycling capability and last but not least, cost per kWh.

2.9. Appliance control & consumer behaviour

When implementing building renovation and ECMs, the end-users' engagement plays a very important role. The incorrect use of the implemented energy saving strategies might have a very low impact if they are used in an incorrect way.

For most consumers energy is *"invisible"* and it is difficult for people to connect specific activities to energy consumption [35]. For instance, due to lack of information regarding efficiency, some consumers tend to ventilate their homes by opening the windows with low outdoor temperatures, instead of simply using the thermostats installed with their heating systems.

Several studies have proven the efficacy of providing people with information and feedback regarding their consumption, achieving energy reductions of up to 20% in some cases [36], [37]. These savings are however, dependent on factors such as the consumers' interest, the type of information and also the devices and the frequency used to provide it, among others. The lack of involvement of the consumers in the development process or the information provided in combination with other services based on the consumers' characteristics and interests (options for energy storage; appliances control; security and remote monitoring) are also contributing to customers' lack of interest in demand flexibility, as mentioned by Heiskanen and Matschoss (2011) [38].

Additionally, Swedish consumers are typically used to high indoor comfort, with overall little focus on environmental impact of energy consumption, explained by abundant and cheap renewable sources that suppress the consumers *"guilt"* when consuming high amounts of energy [39]. On the other hand, the implementation of large-scale ECM is typically followed by an increase in the monthly rent (which includes hot water and heating consumption) that end-users pay to landlords or the companies in charge of the buildings. This could potentially create conflicts between the two parties since landlords claim that end-users would be the main beneficiaries of the ECM, but the end-users see the investment only as an extra economic burden [14]. Furthermore, it is important to include the *"rebound effect"* in ECM implementations and energy saving estimations [40]: the increase in energy efficiency might be reduced if there is an overconsumption from the users' side when they consider that they are paying too much for it.

3. RESULTS AND DISCUSSION

3.1. First case-study: ECMs impact on DH networks and primary energy usage

In this study, Lundström and F. Wallin (2016) studied the heat demand profiles and electricity-to-heat factors of different ECMs were simulated in two existing multi-family residential buildings in the Lagersberg district in Eskilstuna, Sweden [12].

The impact of these ECMs was evaluated from a system perspective approach, in order to determine the impact on efficiency and greenhouse gas emissions on the district heating system (DHS).

In this study, seven ECMs were analysed: improving the building envelope, installing a heat recovery ventilation system, reduce household electricity, reduce domestic hot water, use exhaust air heat pumps, improve operational optimization and use thermal solar.

Results obtained from the seven simulated ECMs, showed that if biomass fuels are not considered as residual (e.g. waste) and a primary energy (PE) factor of 1.1. is used, then, all the studied ECMs increase PE efficiency. However, if residual biomass fuels are used, as it is expected in most future DHS, reducing the electricity consumption and improving the buildings envelopes are the only ECMs favourable for improving the primary efficiency and reducing GHG in the DHS.

3.2. Second case-study: energy storage for maximizing self-consumption of PV systems

This study was carried out by Thyghesen and Karlsson (2014) where a building located in the city of Västerås in central Sweden, was modelled and simulated. The building model included a 5.19 kWp PV system and a ground sourced heat pump (GSHP). Two type of storage systems were added and tested: the first one was a lead-acid based battery storage with 48 kWh capacity with a maximum depth-of-discharge (DoD) of 50%. The second was a hot water storage tank with an inner volume of 185 lts.

This work concluded that the electric storage provided the highest level of PV self-consumption but also offered the highest levelized cost of electricity. The hot water tank offered a levelized cost of electricity that was less than half of the one obtained in the first case and a self-consumption level close to the one obtained using the electric storage system [41].

The reason for the latter was mainly the high capital cost for the electric storage system and its short lifespan. Moreover, the self-consumption of PV electricity per battery capacity starts declining after 10 kWh, suggesting that when adding this type of storage, careful sizing has to be taken into consideration in order to minimize the system's cost.

3.3. Third case-study: Renovation to passive-standard

This case evaluates the renovation carried out in Allingsås, Sweden, where 16 buildings were renovated by adding 45-50 cm of insulation and replacing the existing windows with argon-filled two-glass windows with a silver layer.

Additionally, new heat recovery ventilation systems with a rated efficiency of 88% were installed. The full renovation cost per apartment was of approximately 120,000€ out of which 40,000 €/apartment corresponded to improvements in the building envelope [42].

Additional ECMs included the installation of solar collectors for production of hot tap water, new heat exchangers on the buildings' district heating connection point and the use of ceramic plates as outer surface coating.

All these measures brought the buildings to near-zero passive building standards, with an average investment of 133-570 €/m^2 and expected savings of 62 - 85%.

3.4. Fourth case-study: The consumer perspective on ECMs adoption

The involvement of the consumer throughout the entire duration of the renovation activities was taken into account in the "million program" areas (characterized by high unemployment, consumer with people with foreign background, usually not speaking Swedish) in Eskilstuna, Sweden.

The approach used in those areas, included overall sustainability issues targeting improvements in waste recycling, use of organic products for cooking, workshops where experts in different topics were invited to present and discuss with the consumers questions regarding the different topics (e.g. energy bills). Additional practices focused on finding ways to increase employment rates and possibility for development through increased understanding of different cultures and background with special focus on the children.

Energy advisors working for the municipality visited the households to explain in detail the different renovation techniques and technologies installed in the apartments, and how to use them in order to increase the efficiency of water and energy consumption.

The changes in electricity consumption in some of the apartments in the area, reached savings of up to 33%, reaching a total average saving of 1745 kWh/month for the 3-year period, as shown by Vassileva et al (2015) [43].

3.5. Fifth case-study: GSHP impact on electricity distribution networks

In this study carried out by Campillo et al (2012), 322 households located in Sollentuna, near Stockholm, were studied in order to evaluate the impact on the electricity consumption from installing GSHPs. Additionally, theimpact on electricity costs, taking into account the pricing scheme used in Sollentuna was also studied. A comparative energy analysis was performed for four years: two years before and two years after the installation of the GSHPs [44].

This result concluded that GSHPs combined with dynamic pricing contracts achieved electricity consumption reductions up to 58% in detached houses where direct electric heating was used before. GSHP make it as the best option for these types of households; however, it is important to consider that high-peak electricity price conditions usually happen during cold winters, when GSHP offer their lowest efficiency and are required the most.

For this, the adoption of smart thermostats and automated HVAC control is recommended. In multi-dwelling buildings located in areas with access to DHS, these systems are expected to maintain their predominant position for heating purposes.

4. CONCLUSION

Implementing energy conservation measures (ECM) in the residential sector is one of the most effective alternatives to reach Europe's 20% energy consumption reduction goal. The main challenge, however, is to determine what are the best ECM strategies to provide not just with the best energy consumption reduction, but also with the best environmental impact and economic benefits for the system as a whole and not just in the buildings where the ECMs are implemented.

This paper presented a theoretical background of different ECMs that can be implemented when performing building renovations and reported five case studies where ECMs were evaluated from a different perspective to the conventional one, which usually considers the impact on the buildings themselves.

From the results of the case studies, it is important to consider the characteristics of the existing energy networks that supply the buildings before undertaking large renovations. It can help city planners decide in which areas, the different ECMs would have a higher system impact on energy efficiency and greenhouse gases reduction. Additionally, it is important to consider additional measures, besides conventional building envelope improvements, such as building automation, distributed generation (e.g. solar thermal, PV, micro CHP etc.), efficient outdoor lighting and energy storage.

From the consumers' perspective, it is important to involve the end-users in the renovation strategies and technologies that will be implemented in their homes. Providing the consumers with information combining overall sustainability issues in order to increase their awareness and engagement while obtaining long-lasting effects can improve even further the estimated efficiency results.

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