

HVAC's Role in the Decarbonisation of the Existing Building Stock - case Finland

Terttu Vainio^{1*}, Eero Nippala², and Timo Kauppinen³

¹VTT, 33720 Tampere, Finland

²Tampere University of Applied Sciences, 33520 Tampere, Finland

³Mutsal Consulting, 90651 Oulu, Finland

Abstract. The Energy Performance of Buildings Directive together with the Energy Efficiency Directive and Renewable Energy Sources Directive define the frame and target state for energy performance of the existing building stock. This should be very energy efficient and decarbonised by 2050. The Finnish target is more ambitious, to achieve the target state already in 2035. In this paper, we discuss and concretise the role of HVAC in overcoming the challenge. Buildings in the Nordic countries are already very energy efficient. Structural improvements of energy efficiency are relatively expensive and have limited potential for energy saving. The best cost-benefit ratio can be obtained by combining HVAC with dynamic building automation systems. Also the EPBD calls for improvement of building automation systems and related measurements in new as well as existing buildings. The performance of buildings can be verified and deviations can be detected by monitoring-based commissioning during their life cycle. This means that special attention must be paid to the instrumentation level and an improved online reporting system for stakeholders. As a conclusion, we see that HVAC systems are in a key role in decarbonisation of existing buildings and a strategic sector on the way to a carbon-neutral society.

1 Background

The Energy Performance of Buildings Directive [1] together with the Renewable Energy Sources Directive [2] and the Energy Efficiency Directive [3] define the frame and target state for energy performance of the existing building stock. The existing building stock in the EU should be highly energy efficient and decarbonised by 2050. The Finnish target is more ambitious: to achieve the target state already in 2035.

The Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC) honour both the long-term commitment to limit and reduce greenhouse gas (GHG) emissions in accordance with agreed individual targets and maintain the global temperature rise below 2 °C [4].

Buildings are crucial to achieve the Union objective of reducing greenhouse gas emissions by 80-95% compared to 1990 by 2050. In connection with the transposition of the Energy Performance of Buildings Directive in Finland, comprehensive requirements were set to renovate the building stock with regard to energy performance [5].

The recast of the Renewable Energy Directive entered into force helping the EU to meet its emissions reduction commitments under the Paris Agreement. The recast directive moved the legal framework to 2030 and set a new binding renewable energy target of a minimum of 32% for the EU by 2030. With the European Green Deal, the EU is increasing its climate ambition and aims

to become the first climate-neutral continent by 2050. To deliver on this, the Commission has pledged to make existing legislation fit for 55% emission reduction by 2030.

2 Introduction

In this paper, we present the long-term renovation strategy of Finland [6]. The strategy was developed in collaboration with ministry officials, researchers and stakeholders. Methodologies of the development work were workshops, statistical analysis and literature studies. We also have a short view on strategies of other Nordic countries. More thoroughly, we address the role of automation and HVAC in overcoming the challenge of decarbonisation. The main data sources of strategy development work in Finland as well as in other countries were the EPC database, official statistics on the building stock, energy consumption models and research results.

3 Long-term renovation strategy of Finland

At the beginning of 2020, the total floor area of Finnish residential and non-residential buildings was 415 million square metres. It consisted of 1.4 million buildings, of which 1.2 million were residential buildings. There were 3 million dwellings in the

* Corresponding author: terttu.vainio@vtt.fi

residential buildings. The long-term Finnish renovation strategy 2020-2050 outlines how the present building stock is transformed to highly energy efficient and almost carbon-free by 2050. Because new construction already meets the requirements, the strategy only focuses on the buildings completed by 2020.

3.1 The main means of strategy

Three primary main means of making the building stock highly energy efficient and decarbonised by 2020 have been identified: (1) demolition of unnecessary heated spaces and the weakest buildings, (2) improvement of energy efficiency in connection with renovations and maintenance, and (3) abandoning of fossil energy sources in energy production (Figure 1). Changes into these directions have been observed due structural changes, development of technology and change of valuation principles. The development will be promoted by means of binding and enabling legislation, government support, investments in competencies and dissemination of information.

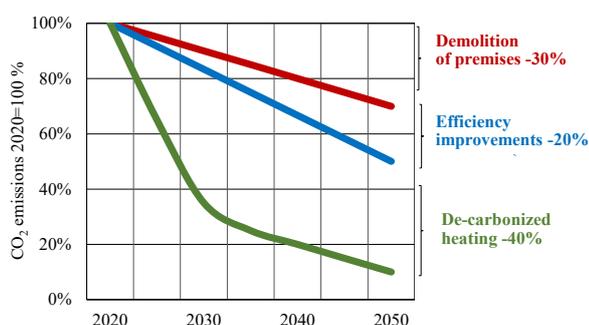


Figure 1. The main means in de-carbonisation of Finnish building stock.

3.1.1 Demolition of unnecessary heated spaces and the weakest buildings

Long-term domestic migration has continued to concentrate the Finnish population into large urban areas of southern Finland. According to the most recent regional projection by Statistics Finland, this trend will continue as the natural population growth takes place and migration is directed to large cities. The population becomes older and smaller in many areas. The population of Finland starts to decrease after 2030.

In addition to vacant buildings, building loss will occur due to technical, functional and financial reasons. The buildings are also decommissioned order to densify the urban structure, provide services more cheaply, or use the facilities more efficiently. Based on the anticipated life cycle of the old building stock and space utilisation trends, only approximately 70 % of all buildings completed by 2020 will remain in 2050.

3.1.2 Systematic maintenance

Regardless of their location, all buildings (in all energy classes and age groups) require sustained and systematic management. As a part of property management, the owner should prepare a property-specific repair strategy or a repair strategy for the entire building stock for the next 15–20 years. The strategy can involve gradual improvement of the building(s) towards the nearly zero-energy level or preparation for demolition of the building(s).

Correct use of facilities and technical systems involves verification of correct adjustments and settings (heating, ventilation, water pressure) and healthy indoor conditions as well as real-time monitoring of water consumption and addressing of any deviations.

3.1.3 Smart HVAC technologies

In the past few years, development of smart technologies has led to changes in renovation projects. New products and new companies that allow improving of the energy efficiency of heating and ventilation systems between renovation cycles have entered the market. The new technologies have increased property owners' interest in realising energy efficiency improvements and heating method changes, such as using heat pumps to boost heat generation and using exhaust air heat pumps to recycle heat. In addition, awareness of the demand response has already been promoted among owners of single-family houses and housing companies.

A common project of the public sector and private enterprises, KIRAdigi, and its follow-up project KIRAHub have speeded up commissioning of smart building technologies. More traditional development work takes place in the Smart Energy programme of Business Finland. The programme studies and tests utilisation of IoT, AI and BIM in management of building energy production and consumption as well as a classification system for smart building solutions (a Smart Readiness Indicator). BIM based digital Twin has been also developed for controlling building energy use and HVAC systems.

3.1.4 Example: The most cost-effective actions in single-family and semi-detached houses

Cost-effective measures in reducing heat loss of old single-family and semi-detached houses that require renovation include adding thermal insulation in roof structures and replacing original windows with new ones. If exterior wall structures require major renovation, adding more insulation in the wall structures is wise. The sealing capacity of the improved building envelope structures must be verified. These and other recommended measures are presented in Table 1.

New single-family houses heated with electricity do not require any structural repairs. The energy efficiency of such buildings and older buildings heated with

electricity should be improved with air source heat pumps and solar panels.

Table 1. As an example, the most cost effective measures for single-family houses. Finnish strategy has similar instructions for all building types.

Building component	Measures
Electricity	Replacing household appliances after their technical service life with new ones that are as energy efficient as possible. Replacing regular light bulbs with LEDs. Acquisition of solar panels.
Ventilation	Replacing old heat recovery units with more energy-efficient ones after the end of their technical service lives.
Domestic hot water	Replacing taps and water fixtures with water-saving ones.
Windows	Repairing and resealing old windows. Replacing windows in poor condition with new and more energy-efficient ones.
Exterior walls	Sealing penetrations. Adding more thermal insulation in connection with a major renovation of the exterior cladding.
Roof	Adding thermal insulation if there is room. In the case of a building with a flat roof, adding thermal insulation when changing the roof type.
Exterior of the building	Adding new frost insulation to the exterior of the building.
Heating system	Direct electric heating: adding an air source heat pump. Electric storage heating: adding an air-water heat pump.
De-carbonisation	Oil heating: replacing the heating system with geothermal heating, an air source heat pump or wood heating. Fireplaces: replacing them with energy-efficient ones, for example replacing an open fireplace with a heat-storing fireplace.

3.1.5 Impacts

Heating energy savings of buildings completed by 2020 consist of building loss and improved space utilisation efficiency as well as improved energy efficiency of buildings as a part of maintenance and renovation projects. Development of the building stock, renovation projects and introduced new means are expected to cut the energy consumption of residential and non-residential buildings by halve by 2050.

Heating-related CO₂ emissions will be further reduced by changing heating methods in both property-specific heating in the burden-sharing sector and in centralised energy production in the EU's ETS sector. Reduction in use of fossil heating fuels will reduce the dependency on imported fuels. Thanks to the valid binding legislation and the plans to be realised, CO₂ emissions of the building stock completed by 2020 will be reduced by 90 % by 2050.

According to the Finnish principles, improvements in energy efficiency are included in normal renovation activities so that the renovations can be performed cost-effectively and in compliance with the principle of material efficiency. Based on the cost-optimal level of the minimum energy efficiency requirements used in renovation projects (2018), implementation of the

Finnish renovation strategy will cost EUR 24 billion in 30 years or EUR 800 million per year. This amounts to 12,000 person-years in construction products industry, service industries and construction sites. The costs will be 6 % of the annual building renovation volume of EUR 13 billion.

4 Strategies of other Nordic countries

4.1 Denmark

Denmark's strategy [8] is based on three different regulatory approaches: normative instruments (e.g. component-specific requirements in connection with renovations), financial instruments (e.g. taxes and grants) and informative instruments (e.g. information for citizens, energy rating of buildings or additional training of tradespeople).

Denmark has stipulated building regulations stating that profitable energy savings must be implemented when the building owner renovates various building elements due to wear and tear. This ensures that energy measures are carried out at the most cost-effective time, i.e. in connection with other non-energy related renovation. Denmark supports purchase of heat pumps, PVs, solar heating and small biomass boilers as well as abandonment of oil boilers.

Denmark focuses on how the potential of data and increasing digitalisation can better be utilised so that energy efficiencies are implemented where they provide most value and in such a way that the transaction costs of energy renovations are reduced. For the purposes, a number of analyses and demonstration projects focus on promoting use of data and digitalisation as the driving forces for achieving energy efficiencies and flexible energy consumption in buildings, including supporting a database-based energy management approach.

4.2 Estonia

Estonia's strategy [9] includes financial measures (loans, guarantees and financial support), development of new technologies (prefabrication, digital tools, simple energy calculators for building owners), awareness raising (guidance materials, advice to property owners), demolition of unused buildings, additional services of the KredEx Foundation regarding investments into residential buildings (renovation and construction of rental buildings) and research and development to ensure knowledgeable and efficient action.

For example, an energy performance assessment tool based on energy costs could be developed for owners of commercial properties. HVAC sector's proposal is to offer general suggestions to reduce energy costs on the basis of the building's general technical specification and the main energy cost component (electricity or heating).

Development of virtual tools for preparing energy labels and energy audits could be the next step in digitalisation of the field. The most important condition for renovating a building is the owner's will to renovate.

Simpler virtual tools would enable building owners to think through the initial versions without any costs.

Due to the limited public-sector resources, financing has to be found in various EU funds (funds managed in Estonia and central funds), revenues from trading GHG emission allowances (the average tax revenue from renovation is 32%), state's other budget resources and private funds through market-based services.

4.3 Sweden

Sweden's energy policy [10] is based on the same three pillars as energy cooperation within the EU. The policy aims at combining environmental sustainability, competitiveness and security of supply.

Many Swedish instruments are complementary and aim at correcting various market failures linked to energy efficiency improvements and renovation, e.g. split incentives and lack of access to information. Instruments may also be aimed at accelerating a trend. Instruments offer incentives to improve energy efficiency in conjunction with renovation.

In practice, the Halvera Mera initiative has been carried out in three stages with the aim of disseminating information and raising awareness of the Rekorderlig Renovering method. The aim of the initiative was to identify cost-effective measures in order to halve the energy consumption of buildings.

The work of "Smart City Sweden" has been developed further. In addition to energy and environmental issues, the platform will address planning and construction, digitalisation, social sustainability, mobility and other issues of relevance to sustainable urban development.

All households and businesses should also be well-placed to make use of electronic public services and broadband services. The Government has developed a broadband strategy for a fully connected Sweden by 2025.

Viable Cities, a strategic innovation programme for smart and sustainable cities, is the largest research and innovation programme ever carried out in Sweden.

Procurement of technology is an aid to promote new technology in Sweden. It is an instrument, which is designed to initiate a market transition and disseminate new and more efficient technologies and methods, such as new products, systems and processes. This is used within areas such as heating and control, ventilation and lighting.

4.4 Norway

Norway does not have plans for renovating the existing building stock towards nZEB but it is already going to the direction [11]. Norway also subsidises the switch from fossil energy sources to electricity, district heating and heat pumps for heating purposes in buildings. Because the electricity supply is almost entirely renewable, greenhouse gas emissions from Norwegian buildings are very low.

5 The role and possibilities of building automation within renovations

5.1 EPBD obligations for automation

The EPBD calls for improvement of building automation systems and related measurements in new as well as existing buildings if their heating power is high enough [1]. In smaller buildings, the requirements can be taken into account on a voluntary basis. The performance of buildings can be verified and deviations can be detected by monitoring-based commissioning (MBCx) during their life cycle. This means that special attention must be paid to the instrumentation level and an improved online reporting system for stakeholders. HVAC and dynamic building automation systems have much more possibilities than before to decrease carbon foot print of buildings.

The changes of EPBD require that for the non-residential buildings, the owner must ensure that the building heating systems with a rated output of more than 290 kW, is equipped with an automation and control system for the building. The automation system must also be able to continuously monitor, record and analyze energy use and enable it to be adapted, make a comparative analysis of the energy performance of the building, detect a decrease in efficiency, to identify opportunities for improving energy efficiency and to enable the technical systems of interconnected buildings to communicate with each other. Interoperability must be ensured between systems regardless of equipment and manufacturers. These regulations also apply, under certain conditions, to existing buildings and buildings undergoing major renovation.

Although the above guidelines only apply to large non-residential buildings, it can be assumed that they will also apply to residential buildings in the future. It must be prepared for in order to evaluate and verify the operation of a renovated building and its systems and also the performance of a new building, sufficiently good procedures and technology must be used. The building should perform "as designed".

5.2 Building commissioning

Building commissioning is a procedure to understand quality control and assurance procedures that cover the entire life cycle of a building. This, of course, requires precise and comprehensive design intent. The set requirements for the building will be monitored and followed during the different stages of the building process by key performance indicators.

Compared to the situation even 10-15 years ago [12], remote monitoring of buildings has developed and especially measurement and data transmission technology has improved. Data can be collected from buildings wirelessly and large amounts of data can be stored in cloud services where they can be analyzed in different ways. Building automation systems control technical systems so that the indoor conditions (the end product of construction) are brought to the planned

level. Building automation systems also involve sensor technology, but there are still shortcomings in the measurement and reporting of existing systems from the perspective of users and property management. Also, different systems may not be compatible in their databases. Modern technology makes it possible to Monitoring Based Commissioning (MBCx), which also enables a service business based on the exploitation of results. In the United States, for example, Building Commissioning (Cx) is a business in which the Cx-Agent is a neutral external actor.

5.3 Performance evaluation by real-time information

A key factor in evaluating the performance from buildings is the acquisition of real-time information about buildings and building systems and how it is passed on to different parties. This can be compared with the quality control in the industry, where product quality is ensured during the production process to meet customer requirements and accepted standards. Technically, the monitoring of buildings is not so challenging than the industrial process monitoring, if we just had better measuring and reporting practices in use. Building automation systems have the key role in this progress. SRI = Smart readiness Index is coming, and the properly planned automation system can be a part to define the SRI-level and to generate an energy label for the building.

6 Summary

De-carbonisation of the Finnish as well as the European building stock means the growing role of electricity. This transition will not only need more and better ways of harvesting electricity from renewable sources but also a variety of solutions to store the renewable electricity for power as well as storages for heating energy

The deep renovations are not an end in itself, but the aim is to reduce greenhouse gas emissions that are harmful to the climate. As much as it is necessary to improve energy efficiency, it is important to exercise restraint and avoid excesses. By rushing, we lose the opportunity to take advantage of new, more efficient technologies and we only produce an unnecessary carbon spike.

In major renovations, the priority is to invest in the abandonment of fossil fuels, i.e. the use of solar and other free energy from the environment with new and efficient technologies. It is from this perspective, i.e. the use of renewable energy, that Nordic countries have taken the lead over the rest of Europe [13]. The share of RES in heating and cooling is in Sweden 66 %, Finland 58 %, Estonia 52 %, Denmark 48 % and in Norway 70 %. They are not in such a hurry to improve energy efficiency because buildings are already heated with renewable energies.

Improvements should be placed at a natural stage in the life cycle of buildings in terms of cost and material

efficiency to avoid unnecessary carbon spike. With smart control systems, it is possible to significantly reduce energy consumption and emissions almost completely without embedded emissions. These measures can be applied to buildings at any time, even between major renovations.

All this means that during the past decade deep renovation strategies of the building stock has changed from building structural energy efficiency renovation to more balanced of three renovation categories: a) building envelope energy efficiency, b) building services and c) heating and cooling fuel. This means that energy efficiency renovation can be carried out at any time, also between major renovations.

Deep renovation has also some barriers. One problem in many countries and in Finland is lack of finance. That is why ESCO Agreements for resident sector, Green Lease and Green Bonds type financing are needed.

References

- [1] Directive 2018/844/EU. Amending Directive of the European parliament and the council on the energy performance of buildings. *Official Journal of the European Union* 19.6.2018
- [2] Directive 2018/2001/EU. Directive of the European parliament and the council on the promotion of the use of energy from renewable sources (recast). *Official Journal of the European Union* 21.12.2018.
- [3] Directive 2018/2002/EU. Amending directive of the European parliament and the council on energy efficiency. *Official Journal of the European Union* 21.12.2012.
- [4] United Nations. *Paris agreement*. United Nations, Climate Change. 2015.
- [5] Asetus 4/2013. Ympäristöministeriön asetus rakennuksen energiatehokkuuden parantamisesta korjaus- ja muutostöistä. *Finlex* 27.2.2013.
- [6] National long-term strategies 2020. Finland. Available: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/long-term-renovation-strategies_en [Accessed 24.1.2021]
- [7] Buildings and free-time residences in Finland. Available: http://www.stat.fi/til/rakke/index_en.html [Accessed 24.1.2021].
- [8] National long-term strategies 2020. Denmark. Available: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/long-term-renovation-strategies_en [Accessed 24.1.2021]
- [9] National long-term strategies 2020. Estonia. Available: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/long-term-renovation-strategies_en [Accessed 24.1.2021]
- [10] National long-term strategies 2020. Sweden. Available: https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/long-term-renovation-strategies_en [Accessed 24.1.2021]

- [11] Better growth, lower emissions - Norwegian Government's strategy for green competitiveness. Available: [Better growth, lower emissions – the Norwegian Government's strategy for green competitiveness - regjeringen.no](https://www.regjeringen.no) [Accessed: 8.3.2021]
- [12] Nykänen, Paiho, Peltonen, Kauppinen, Pietiläinen, Kovanen and Pihala. Systematic process for commissioning building energy performance and indoor conditions. *Proceedings of Clima 2007 WellBeing Indoors*. Available: <http://www.brita-in-pubs.eu/toolbox/> [Accessed 24.1.2021]
- [13] Renewable energy for heating and cooling in EU countries. Available: <https://ec.europa.eu/eurostat/documents/4187653/10321628/renewable+energy+for+heating+and+cooling.png> [Accessed 24.1.2021]