HEAT PUMPS AND COST OPTIMAL BUILDING PERFORMANCE

Henrik Gjerkeš, PhD
University of Nova Gorica, Slovenia
Marjana Šijanec Zavrl, PhD
Gašper Stegnar, MS
Building and Civil Engineering Institute ZRMK, Ljubljana, Slovenia

Abstract

Slovenia has established comparative methodology framework for the minimum energy performance requirements on the basis of article 5 of the Directive EPBD – Recast (2010/31/EU) and in accordance with Annex III, differentiating between different categories of buildings. Choosing a single family house, energy performance of the buildings was calculated with IDA Indoor Climate and Energy as a whole year detailed and dynamic multi-zone simulation study of indoor climate and energy use. The minimum energy performance requirements are represented by the area of the cost curve that delivers the lowest cost for the end-user and society. The results demonstrate that the minimum requirements set for new single family houses in national building codes in force are more severe than the minimum requirements corresponding to the cost optimal level, mainly due to the national energy and climate policy targets in the building sector. Among systems, heat pumps proved to be important competitors in seeking the cost optimal building performance.

It was shown, that heat pumps are environmentally acceptable and economically efficient way of heating with plausible positive social multiplied effects. Heat pumps have support of local economy and are based on well-established technology, their operational is efficient, reliable and are suitable for almost all buildings. In the future it is expected to reach higher coefficient of performance (COP), especially at lower temperatures. Higher COP, together with further increase of renewables share in national electrical power system is making heat pumps important foundation for further sustainable development in line with sustainable principles.

Keywords: Nearly zero energy buildings,Cost optimality, Renewable energy sources, Sustainability, Heat pump

Introduction

Directive EPBD – Recast (2010/31/EU) require very high energy performance for nearly zero energy buildings (nZEB) while nearly zero or very low energy demand must be covered to a very significant amount by energy from renewable energy sources (RES). By 2020 (by 2018 for public buildings) all new buildings will have to correspond to the national nZEB definition. The EU overview of the drafted nZEB regulation prepared under IEE CA EPBD III project showed that crucial question in formulation of nZEB criteria is how to define “nearly” zero energy demand (Maldonado, 2012). Nevertheless, the energy efficiency minimum requirements of the building codes must be based on cost effectiveness from the life-cycle perspective and the requirements may only go beyond the threshold of cost effectiveness.

Renewable energy is an integral part of fight against climate change and is crucial in sustainable growth, job creation and increase of local energy security, therefore plays at most important role in formulation of nZEB criteria. By 2020 renewable energy should account for 20% of the EU's final energy consumption. To meet this common target, each Member State (MS) needs to increase its production and use of renewable energy in electricity, heating and cooling and transport. The renewables targets are calculated as the share of renewable consumption to gross final energy consumption. Renewables consumption comprises the direct use of renewables (e.g. biomass, syngas, biofuels) and the part of electricity and heat that is produced from renewables (e.g. hydro, biomass cogeneration, solar power plants), while final energy consumption is the energy that households, industry, services, agriculture and the transport sector use. Slovenia started with 16 % in 2005 and has target to reach 25% utilization of RES in final energy consumption by 2020 (EC-Directorate General for Energy and Transport, 2008).

In Slovenia the potential of solid biomass is high, with over 55 % of land covered with forests. Secondary wood is used mainly for heating by firing in individual furnaces and is prevailing fuel in household sector. It is local RES and is relatively cheap fuel, but could have also side effects, especially emission of PM10 hard particles, which becomes significant problem for Slovenia. In looking for more appropriate energetic utilization of high potential of wooden biomass, the innovative technologies developing and some already emerging on market (e.g. gasification with poly-generation) seems to be right direction, having in mind district heating systems, local energy self-supply and increase of RES level in national electrical power system. Considering sustainability circumstances, together with regional resources, the potential of heat pumps in residential sector was analysed in context of cost optimal nZEB performance.

Cost optimal building performance

Slovenia has implemented EPBD (European Commission, 2013) based minimum requirements for energy efficient buildings in the year 2002, and accepted two revisions in 2008 and 2010 building codes. The process of setting national minimum requirements was based on the advanced but market available technologies for energy efficient buildings and defined in accordance with the national targets and obligations set by the 20-20-20 policy.

Methodology allows the MS to complement the framework methodology in certain elements. Economic lifecycles of the building and building elements are assumed in line with findings of IEE LCC DATA project, national regulation on maintenance of buildings and building elements and EN 15459: 2007 (for energy systems). The comparison with related EU studies on LCC showed that the lifetime of building elements may differ in a significant range. The discount rates of 3% and 5% (required in the national procurement documentation) are taken in the consideration. The cost categories for LCC are based on the prEN 15643-4 (and standardization from CEN/TC 350) with consideration to the Annex I of methodology framework (i.e. disposal costs were excluded, the costs that are the same for all variants and costs that have no influence on energy performance of a building were also omitted). Primary energy factors are determined in the national regulation, i.e. building code PURES 2010. Energy performance is determined according to the national calculation methodology which is based on EN ISO 13790 and CEN EPBD standards (European Commission, 2013). The climate in central Slovenia may be considered relevant for the majority of settlements in the country, only the small coastal area has milder, Mediterranean climate (Šijanec Zavrl et al, 2013).

In order to investigate the cost optimality of minimum requirements in Slovenian building code the national study was initiated based on the EC comparative methodology framework for calculating cost optimal levels of minimum energy performance requirements for buildings and its elements (Šijanec Zavrl et al, 2012a). Firstly the effort was focused on the cost optimality at financial level (with consideration of the end consumer perspective), aiming at definition of cost optimum minimum requirements for new single family houses, which are the most numerous and represent 75% of the residential sector floor area, and 55% of the entire Slovenian building sector.

In continuation, Slovenia has established comparative methodology framework on the basis of article 5 of the Directive EPBD – Recast (2010/31/EU) and in accordance with Annex III, differentiating between different categories of buildings (single-family houses, block of flats and office buildings), Figure 1. Fifteen reference buildings that were taken into study reflect national building stock, since they are classified into residential and non-residential buildings and adequately cover the age of construction of the building. Reference buildings were chosen on the basis of the EU project IEE Tabula (Diefenbach et al, 2012), which already dealt with the issue of the reference residential buildings and Registry of Real Estates (managed and updated by Geodetic Administration of the Republic of Slovenia).

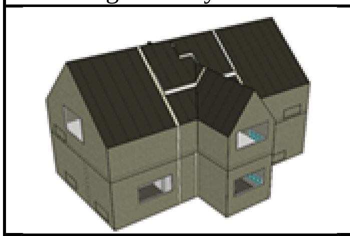
Single-family house	Multi-family house	Office building
		

Figure 1: Example of three reference buildings

Energy performance of the buildings was calculated with IDA Indoor Climate and Energy as a whole year detailed and dynamic multi-zone simulation study of indoor climate, and energy utilization. From the variety of specific results for the assessed measures (single measures and packages/variants of such measures), a cost curve has been derived, shown in Figure 2.

Assessed measure is marked with a unique code, in order to differ from the others. E.g. W.0,28_R.0,20_Win.1,3_HP.a-w_AHU stands for a package of measure, where the thermal conductivity of the wall(W) is 0,28 W/m2K, roof(R) 0,20 W/m2K and windows(Win) 1,3 W/m2K. The envelope description follows heat generator – Heat pump (HP) and the possible use of the mechanical ventilation with heat recovery (AHU – Air Handling Unit).

The lowest part of the curve in Figure 2 represents the economic optimum for a combination of packages. To establish a comprehensive overview, all combinations of commonly used in practise and advanced measures should be assessed in the cost curve. The packages of measures range from compliance with current regulations and best practices to combinations that realise nearly zero-energy buildings (Constantinescu et al., 2010). The minimum energy performance requirements are represented by the area of the curve that delivers the lowest cost for the end-user and/or for the company or society. Potentially, these requirements could prove to be more effective and efficient than current national requirements, at less or equal cost. The area of the curve to the right of the economic optimum represents solutions that underperform in both aspects (environmental and financial). In figure 2, the distance to target for new buildings, so they are "nearly zero-energy buildings" as from 2021, is made visible on the left side of the cost-optimal levels interval (green marked area).

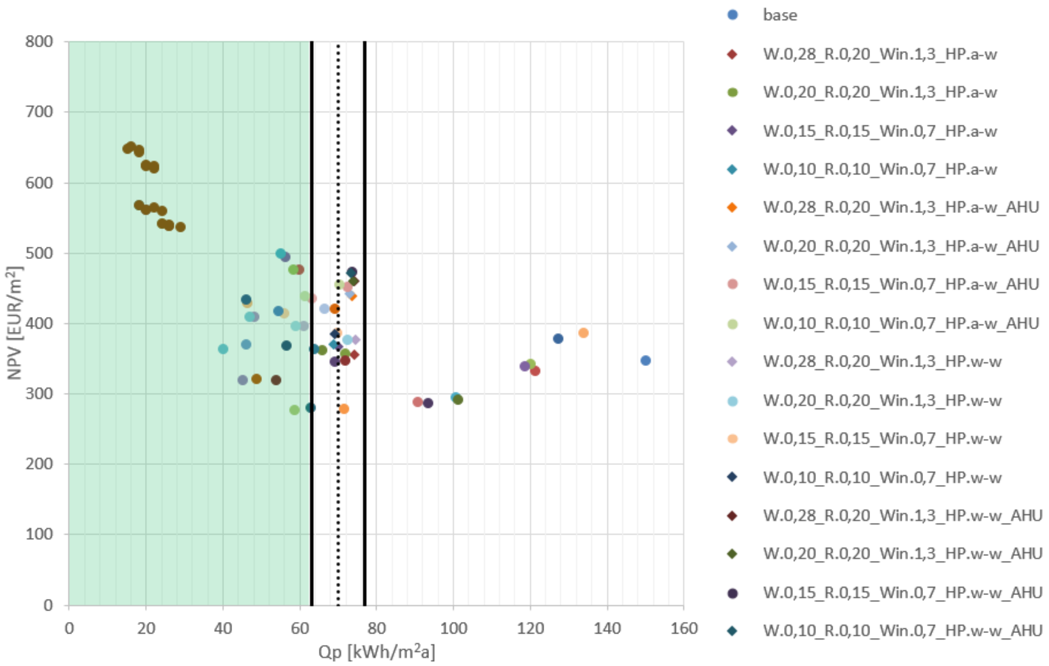


Figure 2: Cost curve for reference single-family house, built in 1960. Qp – Primary energy; NPV – Net present value

The results also demonstrate that the minimum requirements set for new residential buildings – single family houses - in PURES 2008 and PURES 2010 national building codes are more severe than the minimum requirements corresponding to the cost optimal level, mainly due to the national energy and climate policy targets in the building sector. Variants in compliance with the 2010 national building codes are based on the implementation of insulation levels and windows resulting in the overall specific transmission heat losses of the envelope Ht' bellow 0,4 W/m2K, use of condensing gas boiler and solar collectors for DHW and other systems like hat pump or biomass boilers that lead to the share of over 25% of RES in delivered energy (Šijanec Zavrl et al, 2012b).

Due to the relatively flat cost optimality curves the final conclusion on cost optimal combination of envelope insulation level and energy systems is still pending and needs additional sensitivity analyses of core parameters. In this stage, heat pumps in variants with very good envelope insulation (around 20 cm), windows with double low-e glazing, natural ventilation demonstrated very good cost-optimal performance. Heat pumps proved to be important competitors among nZEB systems and considering other, especially environmental sustainability effects, were chosen for more comprehensive analysis.

RES based electricity generation

Renewable based generation share of the electricity fed into the grids increases the cumulative share of RES in heat pump operation. Due to the relatively cold climate (3300 DD) heating is still the main part of energy use in Slovenian building sector. In year 2012, households in Slovenia used 13.804 GWh of energy, most of it, i.e. 11.250 GWh, for heating and domestic hot water (DHW). The most common energy source for heating were wooden fuels with 51 % share, followed by fuel oil with 20 % and natural gas with 12 %. With 11,6 %, electricity becomes important energy source for space heating (652 GWh) and DHW (615 GWh), which together represents 40 % of electricity, used by households (Statistical Office of the Republic of Slovenia, 2013).

The share of renewable energy sources (RES) in total use of final energy is increasing, especially with different forms of wooden fuels and with rising of the number of district heating systems. The role of heat pumps, which transform renewable energy from environment (sun, ground), is increasing and became important energy source in sector heating. Therefore, from the sustainability point of view, the trends of the share of RES in power generation on national level are very important for meeting the targets of nZEB and sustainable building.

Renewable based generation accounted for 22,3% of the electricity fed into the grids of the European Union in 2012, a year-on-year increase of 7%. By the end of the decade renewables are predicted to be the second largest component of the EU energy mix, accounting for 34% of the total generation, Figure 3 (EURELECTRIC, 2013).

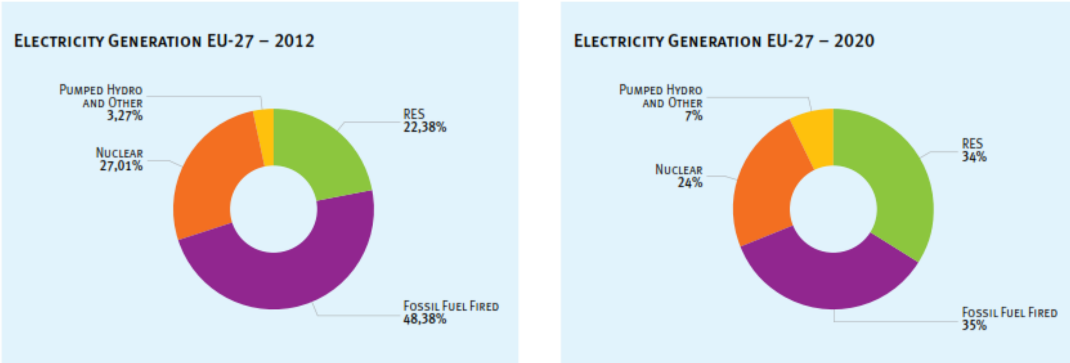


Figure 3: Electricity generation shares in the EU27 countries, 2012 and prediction for 2020.

Increase of RES based electricity generation share in energy mix from 2004 to 2012 is shown in Figure 4. The share of renewables in gross electricity consumption in Slovenia, which as a result of very favourable hydrological conditions in 2009 grew to more than a third, dropped substantially by 2011. In 2009 electricity from renewables accounted for 36.8% of total electricity generated in Slovenia (Eurostat, 2013). Even though the hydrological conditions were still relatively favourable, the share declined to 33,8 % in 2010 because of higher economic activity and hence higher electricity consumption. With much lower water levels of rivers and thus lower hydro-energy production in 2011, the share dropped to 30,8 %. However, it was still above the EU average (21,7 %), where in the past few years the share of renewables in electricity production has been gradually growing.

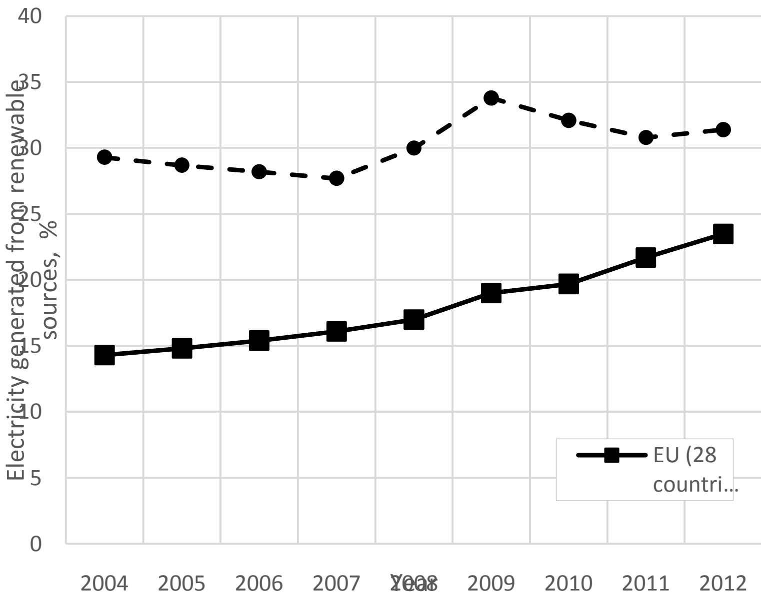


Figure 4: RES based electricity generation share in energy mix

With the increase in production in hydroelectric power plants and stagnation of gross electricity consumption, in 2012 the share of renewables in electricity production in Slovenia increased to 31,4 % (IMAD, 2013). Slovenia reached 28,50 % share of RES in reference year 2005 and the target in this sector is 39,30 % of RES in electric energy mix by year 2020, which will require more diversification of power generation from RES as well as improved management of electricity use.

Cost and environmental efficiency of heat pumps

Heat pumps are an attractive option for reducing GHG emissions caused by buildings. Heat pumps are based on well-established technology and nearly half a million systems have been installed worldwide.In Slovenia heat pumps have demonstrated that they can provide ample heat in the most challenging environment. Heat pumps exploit primarily the energy of sun, heating the air, but also from soil, as about 50% of solar energy that falls on the earth's surface is absorbed by it and represent an energy reservoir.

The technology of heat pumps is well developed and their operational is efficient, reliable and are less vulnerable to changes in weather than majority of other low-energy and renewable systems. Heat pumps use the refrigeration cycle to upgrade low-grade environmental energy collected from sources such as air, ground or ground water into energy for use in hot water supply, space heating or cooling.

In Slovenia, an air-source heat pump (a/w) achieves a typical annual average coefficient of performance (COP) of 3,5, which means that 350 % the energy, put into the process in the form of electric energy, is generated as heating energy at appropriate temperature level for low-temperature heating systems in buildings. A soil/water (s/w) and water/water (w/w) heat pumps achieve in Slovenia an annual average coefficient of performance of 4,5 and 5, respectively (Gjerkeš et al., 2011).

In assessment of economic effects of different heating sources, the already presented cost-optimum methodology represent the most comprehensive approach, but also a direct operational cost comparison could give a fast overview about the cost effectiveness of different energy sources for building heating. Operational cost comparison is shown in Figure 5 on the example of single family house with annual consumption of 18,3 MWh of final energy for space heating ($T_{heating\ water}$ = 35 °C) and domestic hot water (DHW, T_{DHW} = 55 °C). For the analysed systems, typical efficiency data were taken, together with fuel and energy prices from the beginning of 2014.

It is clearly shown, that comparing the various heating systems, the heat pumps outperforms other systems considerably from the operating cost point of view. Still widely used oil boiler is as much as 188 % more expensive to use as the most common air/water heat pump.

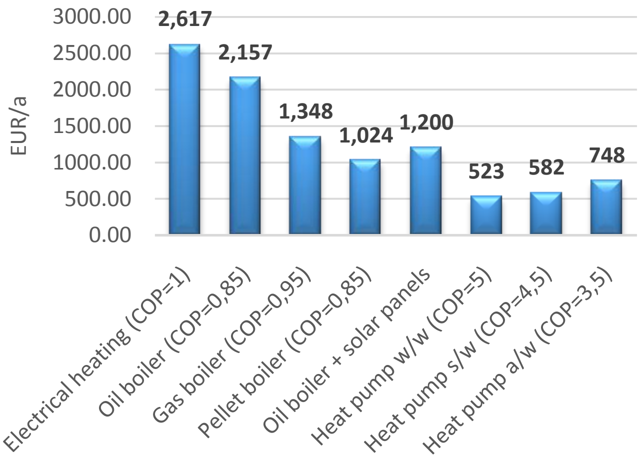


Figure 5: Annual fuel/energy costs for different heating systems in single family house with annual energy demand of 18,3 MWh

In assessment of environmental effects of different heating sources, the use of primary energy was compared and shown in Figure 6, and standard emission of CO_2 in Figure 7 using the coefficients as determined in the national regulation, i.e. building code PURES 2010. These coefficient imply the actual share of RES in national electric energy mix.

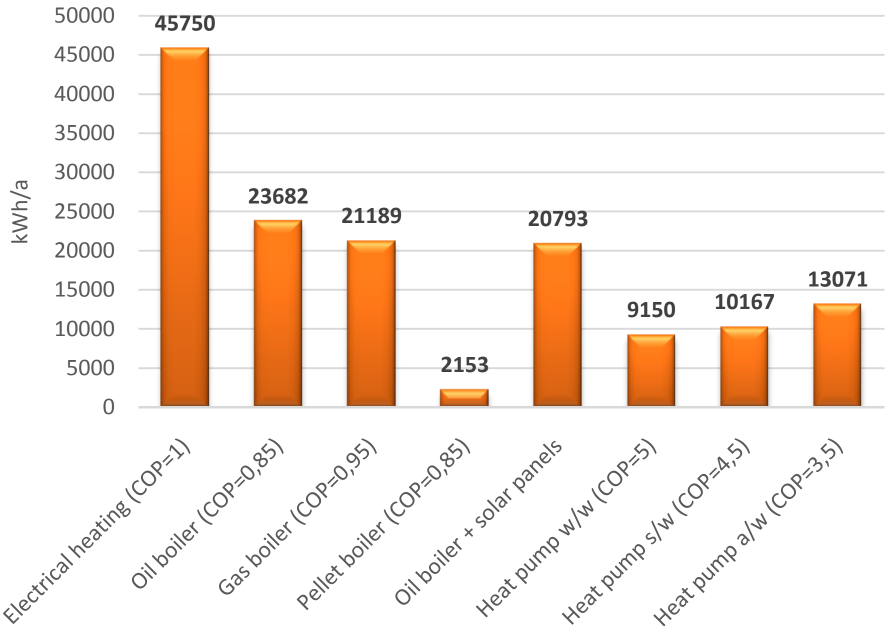


Figure 6: Annual use of primary energy for different heating systems in single family house with annual energy demand of 18,3 MWh

Also in primary energy use and CO_2 emission, the heat pumps outperform other systems, except system on wooden biomass, which on the other side in small individual boilers can cause already mentioned burning issue in Slovenia with emission of PM10 hard particles. Comprehensive estimation of effects therefore makes heat pump very competitive heating system also in environmental point of view. Their competitiveness will increase even more with higher COP, especially at lower temperatures, and with increase of the share of renewables in electricity production in Slovenia.

The share of RES utilized by heat pump with COP = 3,5 is 71,4 %, if there is no RES based electricity generation (EE) share in national energy mix, and increases to 80 % with 30

% of RES based electricity generation, and up to 88,6 % with 60 % of RES based electricity generation, as in Sweden, as shown in Figure 8.

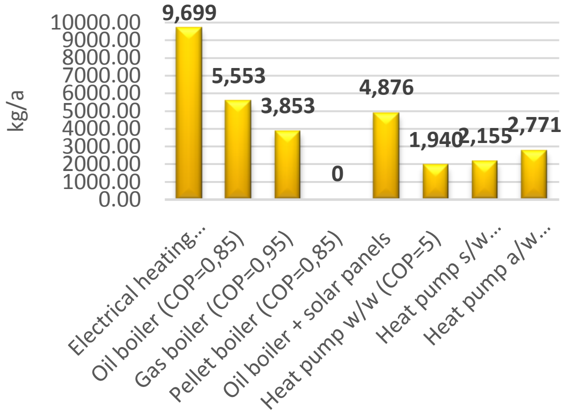


Figure 7: Annual CO_2 emission for different heating systems in single family house with annual energy demand of 18,3 MWh.

In 2012, in Slovenia, the share of RES in national electric energy mix amounted to 31,4 %, so heat pump with COP of 3,5 utilized 80,4 % of renewable and 19,6 % of non-renewable energy. Reaching the goal in 2020 with 39,3 % share of RES in in national electric energy mix, the same heat pump will utilize 82,7 % of renewable energy.

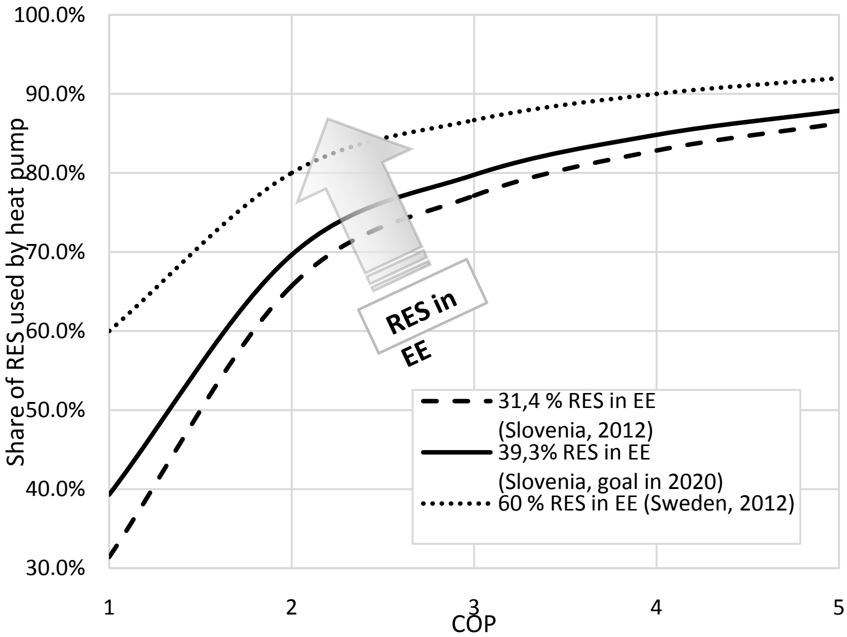


Figure 8: Impact of COP on the share of RES utilized by heat pump, operating at different COP.

In general, both the COP and the share of renewables in electricity production have impact on the share of renewable energy, utilized by heat pump. Both of these factors will increase with heat pump technology development and with fulfilment of EU 2020 commitments, which makes heat pump important system not only in cost optimal building performance methodology, but also as an important foundation for further sustainable development, considering that the potential of the Slovenian heat pump industry is growing, having renowned producers with long tradition and competitive products.

Conclusion

Slovenia has established comparative methodology framework for the minimum energy performance requirements on the basis of article 5 of the Directive EPBD – Recast (2010/31/EU) and in accordance with Annex III, differentiating between different categories of buildings. Choosing a single family house, energy performance of the buildings was calculated with IDA Indoor Climate and Energy as a whole year detailed and dynamic multi-zone simulation study of indoor climate, and utilization of energy. From the variety of specific results for the assessed measures (single measures and packages/variants of such measures), a cost curve has been derived. The minimum energy performance requirements are represented by the area of the curve that delivers the lowest cost for the end-user and/or for the company or society. Potentially, these requirements could prove to be more effective and efficient than current national requirements, at less or equal cost. The results demonstrate that the minimum requirements set for new single family houses in national building codes in force are more severe than the minimum requirements corresponding to the cost optimal level, mainly due to the national energy and climate policy targets in the building sector. Among systems, heat pumps proved to be important competitors in seeking the cost optimal building performance.

In Slovenia, the heat pumps in addition to wooden biomass (and potential waste) represent the greatest potential for sustainable increase of the renewables in the heating and cooling sector. It was shown, that heat pumps are environmentally acceptable and economically efficient way of heating with (potentially) positive social multiplied effects if the domestic manufacturers of equipment and systems will have appropriate conditions for further development. Heat pumps are based on well-established technology, their operational is efficient, reliable and are less vulnerable to changes in weather than majority of other low-energy and renewable systems, and are suitable for (almost) all buildings. Development continues and we can expect even higher COP, especially at lower temperatures. Higher COP, together with further increase of renewables share in the Slovenian electrical power system is making heat pumps important foundation for further sustainable development in line with sustainable principles.

References:

Constantinescu Tudor et al.. Cost optimality – Discussing methodology and challenges within the recast Energy Performance of Buildings Directive. Brussels: BPIE, 2010.

Diefenbach, N., Loga, T., Dascalaki, E., Balaras, C., Šijanec Zavrl, M., Rakušček, A., Corrado, V., Corgnati, S., Ballarini, I., Renders, N., Vimmr, T., B. Wittchen, K., Kragh, J., Application of Building Typologies for Modelling the Energy Balance of the Residential Building Stock – TABULA Thematic Report N° 2 – ISBN 978-3-941140-23-3, Februar 2012

EURELECTRIC - Union of the Electricity Industry, Power Statistics & Trends, Brussels, 2013

European Commission, Directorate General for Energy and Transport. Slovenia – Renewable Energy Fact Sheet, 2008

European Commission. Implementing Energy Performance of Buildings Directive (EPBD), (http://www.epbd-ca.eu/), 2013

Gjerkeš, Henrik, Papler, Drago, Šijanec-Zavrl, Marjana. Sustainable development of power generation in Slovenia. V: GOLOBIČ, Iztok (ur.), CIMERMAN, Franc (ur.). Development and implementation of enhanced technologies 2011 : proceedings of the 3rd AMES International Conference, Ljubljana, Slovenia, November 29th-30th, 2011. 1st ed. Ljubljana: Association of Mechanical Engineers of Slovenia - AMES, 2011

IMAD – Institute of Macroeconomic Analysis and Development, Development Report, Indicators of Slovenia's development, 2013

Maldonado Eduardo. Member states approaches EPBD, World Sustainable Energy Days 2012, Nearly Zero Energy Buildings Conference, Wels, March 1, 2012

Statistical Office of the Republic of Slovenia, Energy consumption in households, Slovenia, 2012 - final data, http://www.stat.si/eng/novica_prikazi.aspx?id=5803, 2013

Šijanec-Zavrl, Marjana, Skubic, Marta, Rakuščček, Andraž, Gjerkeš, Henrik, Potočar, Erik. Practical implementation of coast-optimal regulation for establishing national minimum requirements of Slovenia. V: World Sustainable Energy Days, Wels, 29 February - 2 March , 2012. Proceedings. Wels: [O. Ö. Energiesparverband, Linz], 2012a, [13] 3 pp.

Šijanec-Zavrl, Marjana, Gjerkeš, Henrik, Tomšič, Miha. Integration of nearly zero energy buildings : a challenge for sustainable building stock. V: World Engineering Forum, 17-21 September 2012, Ljubljana, Slovenia. Sustainable construction for people. Ljubljana: Inženirska zbornica Slovenije, 2012b.

Šijanec-Zavrl, Marjana, Gjerkeš, Henrik. Sustainable energy networks: a hub for nearly zero energy buildings : presented at 3rd International Exergy, Life Cycle Assessment, and Sustainability Workshop & Symposium (ELCAS-3), 07-09 July, 2013, Nisyros, Greece. Nisyros: ELCAS-3, 2013