

PAPER • OPEN ACCESS

Analysing energy upgrading projects of single-family houses towards a Norwegian nZEB level

To cite this article: R Moschetti *et al* 2021 *J. Phys.: Conf. Ser.* **2069** 012112

View the [article online](#) for updates and enhancements.

You may also like

- [Awareness, benefits and drawbacks of net zero energy building practices: construction industry professional's perceptions](#)
D O Nduka, A N Ede, K D Oyeyemi et al.
- [Dormitory thermal retrofitting to nZEB standard](#)
J Kwiatkowski, J Sowa, A Trzski et al.
- [Business models for nZEB renovation of small wooden buildings](#)
Ann Kristin Kvellheim, Sigrid Damman and Anne Gunnarshaug Lien



The Electrochemical Society
Advancing solid state & electrochemical science & technology

241st ECS Meeting

May 29 – June 2, 2022 Vancouver • BC • Canada

Extended abstract submission deadline: Dec 17, 2021

Connect. Engage. Champion. Empower. Accelerate.
Move science forward



Submit your abstract



Analysing energy upgrading projects of single-family houses towards a Norwegian nZEB level

R Moschetti¹, B Time¹, L Gullbrekken¹, V Heide², L Georges² and Anne G Lien¹

¹ SINTEF Community, Postboks 4760 Torgarden, 7465 Trondheim, Norway

² Department of Energy and Process Engineering, Faculty of Engineering, Norwegian University of Science and Technology (NTNU), Kolbjørn Hejes vei 1a, 7034 Trondheim, Norway

E-mail: roberta.moschetti@sintef.no

Abstract. As the existing building stock is responsible for high energy use and greenhouse gas emissions, energy upgrading projects have been acknowledged as crucial for the energy performance improvement of existing buildings, as well as for environment preservation and rational use of resources. The aim of this article is to investigate the definition of a nearly zero-energy building (nZEB) level for the energy upgrading of single-family houses. In particular, the findings from a research project, i.e., “energy upgrading of wooden dwellings to nearly zero energy level” (OPPTRE), are presented and discussed. A core task of OPPTRE was to carry out an architectural competition, where six interdisciplinary teams proposed innovative solutions for upgrading to a nZEB level representative Norwegian wooden single-family houses, from the period 1950-1990. The upgrading measures proposed in the OPPTRE competition focused on several aspects, such as architectural quality, indoor thermal environment, energy use/generation, carbon footprint, and cost effectiveness. General principles for a nZEB level achievement in upgrading projects are discussed in this article, as deduced from the evaluation of the results of the OPPTRE architectural competition. In particular, the focus is on examining the solutions proposed for upgrading building envelope and technical building systems. Energy use, energy generation, investment costs, and CO₂ emissions are examined across the various OPPTRE projects, striving to define a trade-off among different parameters for the achievement of a nZEB level. The findings of this paper support the creation of knowledge in nearly zero-energy upgrading of wooden single-family houses, aiming to a more systematic definition of a nZEB level in such projects. This can be relevant for several stakeholders, such as governmental institutions, homeowners, builders, and private or public decision makers, towards the market uptake of nZEB upgrading by 2030.

1. Introduction

Existing buildings are highly responsible for energy use and green-house gas (GHG) emissions [1]. The energy upgrading of the existing building stock is therefore needed to reduce the environmental impacts of buildings and to achieve positive economic and social effects, such as the reduction of future energy-related costs and the improvement in the indoor thermal environment. Energy upgrading projects imply the use of energy-efficiency measures for the building envelope and/or the technical building systems. To achieve the energy and emission reduction targets, the concept of zero-energy building (ZEB) was explored in Europe aiming to buildings with a very high energy performance and a very low or nearly zero amount of delivered



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

energy¹ [2]. Norway has lately strengthened the target of reducing GHG emissions of at least 50% by 2030, compared with the 1990 level [3]; this brings focus on the energy upgrading of existing buildings. The Norwegian dwelling stock is primarily made of wooden single-family houses, which were built in the period 1950-1990 and are now reaching the phase when major upgrading is needed [4]. However, only half of the upgrading projects of Norwegian existing buildings also performs an energy upgrading; one reason for this is an insufficient energy advice [5].

One of the main challenges in the implementation of deep energy upgrading projects is the lack of standardised guidelines and strategies. Therefore, the main objective of this article is to discuss the definition of a nearly zero-energy building (nZEB) level for the upgrading of Norwegian single-family houses, by presenting and reviewing the findings of a Norwegian research project, i.e., “energy upgrading of wooden dwellings to nearly zero energy level” (OPPTRE). The focus in this article is on examining heat losses, energy use, energy generation, investment costs, and CO₂ emissions across the various projects in OPPTRE, striving to define a trade-off among different parameters for the achievement of a nZEB level. The remainder of the paper is organised as follows. Subsection 1.1 presents a literature review of energy upgrading strategies towards a nZEB level in Europe and Norway. In section 2, the OPPTRE research project is introduced, together with the case study buildings. Then, in section 3, the main findings are presented and discussed. Finally, conclusions and future outlooks are drawn in section 4.

1.1. Building energy upgrading to nZEB level: state of the art

In Europe, the energy performance of buildings directive (EPBD) recast [2] and the amending Directive 2018/844 [6] stated that each European country should establish a long-term renovation strategy to support the upgrading of existing buildings towards a highly energy efficient and decarbonised building stock by 2050. This would also facilitate the cost-effective transformation of existing buildings into nZEBs.

Policies and measures needed to be strengthened by all countries to successfully support an economic and energy efficient upgrading of existing buildings. The integration of cost-optimal energy efficiency and nZEB concepts was investigated in several research works, such as [7, 8]. The main goal of these studies was to support the development of national nZEB definitions in building upgrading, under the framework of the EPBD recast. The importance of an overall performance assessment in nearly zero-energy upgrading projects was also recognised as a key step for a broader market uptake of nZEBs towards 2030, as pointed out in [9]. The latter concluded that the market success for zero-energy renovation of dwellings depends on the homeowners’ priorities for improved home qualities, based both on quantitative indicators for environmental and economic performance, and on qualitative indicators for social aspects and usability. Furthermore, as demonstrated in [10], the whole life cycle of buildings should be considered when upgrading towards the zero-energy level, to achieve a balance of the operational and embodied energy. In nZEBs, the energy use during the operational phase generally assumes less significance than the embodied energy during the construction phase, which instead becomes particularly relevant; this is also evident in ambitious energy upgrading projects.

The nZEB definition given in the EPBD recast allowed different European states to freely define some aspects, such as type and period of energy balance, energy uses, renewable energy sources, normalisation and conversion factors. This led to different energy requirements around Europe for nZEB levels in new and existing buildings [11]. An attempt of benchmarking the Nordic countries’ nZEB requirements against the European Commission (EC)’s recommendations is shown in [12]. The results illustrated that the national values could

¹ Amount of energy delivered to the building without adjustment for any energy loss in the generation, transmission, and distribution of that energy to the building

not be directly compared because of differences in primary energy factors, energy flows included, and input data; therefore, a reference building was needed for the comparison, but only one Nordic country's nZEB requirement complied with the EC specifications.

In Norway, Killingland et al. [13] suggested that nZEBs should have an energy use that is 70% lower than the energy requirement in the national building code at that time, calculated as net delivered energy². A revised nZEB level definition was provided in [14], where the energy requirements in the current Norwegian building code (TEK17) [15] were considered, but the nZEB level was also defined in relation to different building categories. The target value for the yearly net delivered energy given in [14] for residential buildings was 40 kWh/m².

2. Methods

To investigate the definition of a nZEB level for the energy upgrading of single-family houses, the results from the architectural competition in the OPPTRE research project were analysed and systematised in this article.

2.1. The OPPTRE research project

OPPTRE is a research project (2018-2021) [16] supported by the Research Council of Norway, a Norwegian government enterprise (Enova), and other partners. The project has also the goal of proposing a target level for the upgrading of Norwegian single-family houses to nZEBs. One of the main steps of OPPTRE was an architectural competition among six project proposals for the energy upgrading of representative Norwegian wooden single-family houses. Six interdisciplinary teams were involved in the competition, where the focus was on several aspects, such as architectural quality, building physics, indoor thermal environment, energy use, energy generation, carbon footprint, and cost-effectiveness.

During the architectural competition two workshops were held, focusing on architectural and housing quality, energy use, embodied energy in materials, and ventilation solutions. The six teams could rely on the support of experts in building physics for the choice of the building envelope measures, and they received a handbook about building practices according to Norwegian requirements. Furthermore, all project teams were provided with an excel-based tool for the life cycle assessment (LCA) evaluations, which contained an extensive material database and a standard analysis layout that allowed an easier comparability of results. The CO₂ emissions were calculated in a 60-year perspective and with the Norwegian electricity mix, which is characterised by only 25 g CO₂ eq./kWh due to the predominant electricity generation from hydropower. For the energy calculations, the project teams could freely choose the tool to use; SIMIEN, IDA ICE, and TEK-sjekk [17] were the main programs employed. Almost all the projects had available data for the measured delivered energy in the previous years. Furthermore, all the teams made a calculation of the energy demand³ of the existing buildings before the implementation of the upgrading measures. All the LCA, energy, and cost calculations carried out by the six project teams were double checked by different experts involved in OPPTRE.

The nZEB goal in the OPPTRE architectural competition included the following main points:

- (i) Satisfy the energy requirements of the Norwegian building code, TEK17. According to TEK17, the total energy demand for single-family houses should not exceed the energy limit of $(100 + 1600/A^2)$ kWh/m² per year, where A^2 expresses the heated floor area of the house. Note that in OPPTRE, the energy target for the upgraded buildings was less ambitious than in TEK17 and was set in terms of net delivered energy; therefore, the energy requirements given in TEK17 for the net energy demand had to be fulfilled by the net delivered energy.

² Amount of delivered energy with the deduction of the energy supplied to the building by renewable energy technologies

³ Electrical and thermal energy needed by the building, without taking into account system losses and conversions from one energy type to another

- (ii) Comply with the minimum requirements given in TEK17 for building components (i.e., U-value limits for external walls, windows, roof, and floor on ground/unheated zone) and for building airtightness. However, exceptions were possible where practical conditions could be of a hindrance, as for instance in the insulation of the floor against the ground and the airtightness requirement achievement.

2.2. Systematisation of OPPTRE findings

The OPPTRE architectural competition led to several different findings, but the focus in this article was on examining the solutions proposed for upgrading the building envelope and the technical building systems, as well as the energy use/generation, the investment costs, and the CO₂ emissions. Therefore, representative results obtained for the six analysed projects were assessed and weighed against each other, striving to define a trade-off among different indicators for the achievement of a nZEB level.

3. Results and discussion

Table 1 shows a summary of general information on the projects, together with the features of building envelope and technical building systems before and after the upgrading projects, as provided by the OPPTRE architectural competition teams. Note that the name of each project includes a reference to the specific geographical location; the dwellings are placed throughout Norway and are characterised by typical Norwegian climate conditions.

Table 1. Main features of the six OPPTRE projects.

		Nesodden 1972		Malvik 1957		Hamar 1963		Malvik 1989		Kristiansand 1972		Sandefjord 1972		
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After	
General information	Heated floor area (m ²)	120	142	127	127	175	175	274	278	196	210	192	192	
	Heated floors (No)	2	2	2	2	2	2	3	3	2	2	2	2	
	Dry-bulb temperature, yearly average (°C)	6.4		5.5		4.3		5.5		7.5		7.1		
Building envelope	U-value (W/m ² /K)	External walls	0.29	0.13	0.44	0.17	0.35	0.14	0.35	0.21	0.58	0.18	0.55	0.27
		Roof	0.18	0.09	0.27	0.14	0.12	0.07	0.21	0.18	0.40	0.10	0.11	0.11
		Floor on ground, unheated room	0.23	0.10	1.49	0.21	3.2	0.09	0.24	0.24	1.24	0.23	0.29	0.26
		Windows	3.06	0.64	2.80	0.80	2.9	0.90	2.10	0.90	2.61	0.80	2.23	1.20
		Airtightness at 50 Pa (h ⁻¹)	4	0.3	6	0.3	3	1.8	4	2.5	7	2	4.3	2
Building systems	Heating system	EH	EH+WBS	EH+FP	EHP, EH, WBS, FP	EH	EHP, WBS, EH	HP+EHF	HP+EHF	EH+FP	EH+FP	EH	EHP, EH, WBS	
	Ventilation system	NV	CHP	NV	BMV	NV	CHP	NV	BMV	NV	BMV	NV	CHP	
	Renewable energy generation	20 m ² PVs				40 m ² PVs				8 m ² STs				

EH: electric heater; WBS: water-borne system; FP: fireplace; EHP: exhaust heat pump; EHF: electric heating floor; BMV: balanced mechanical ventilation with heat recovery; NV: natural ventilation; CHP: Compact heat pump with BMV and EHP; PVs: photovoltaics panels; STs: solar thermal collectors.

The U-values of the building components in the OPPTRE projects satisfied the TEK17 value limits, with some few exceptions. The airtightness values after the upgrading measures given in some projects, such as Nesodden 1962 and Malvik 1957, were considered unrealistic. Achieving such a low airtightness value in this kind of upgrading projects is challenging; a complete sealing of the existing floor towards basement is, for instance, very difficult to realise especially in presence of a vertical ventilation shaft.

Figure 1 illustrates the energy use for all the single-family houses, as measured in the last years and as calculated before and after the upgrading projects. All the proposals showed a significant improvement in the energy performance after the upgrading project and were generally within the OPPTRE competition target. The only exception was the "Malvik 2020" project with the net delivered energy slightly above the energy target. For almost all the projects, the delivered energy measured before the upgrade (131-184 kWh/m² per year) was significantly lower than the calculated delivered energy (183-356 kWh/m² per year). This can be explained by the prebound effect related to the occupant use of the buildings, which can lead to an overestimation of the real

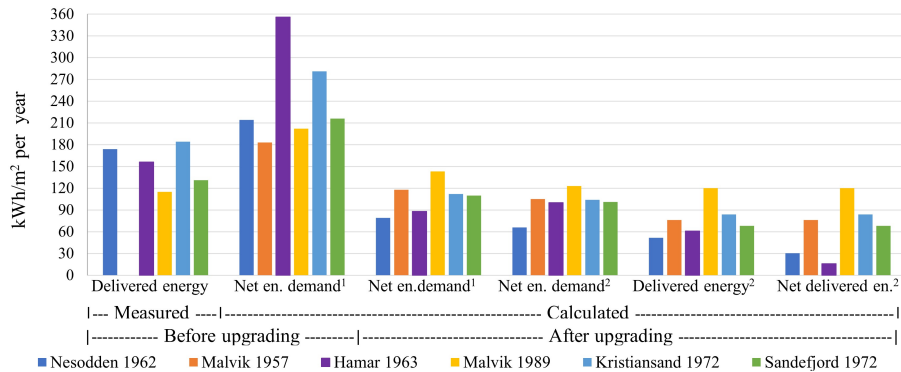


Figure 1. Energy use for the six OPPTRE projects before and after the energy upgrading.

¹ Standardised calculation according to TEK17 parameters, including the use of Oslo climate file.

² Calculation where realistic parameters were used, including the actual climate files for the project locations.

potential for energy savings. The calculated delivered energy, excluding the energy generated by photovoltaics (PV), was generally as low as 50-120 kWh/m² per year. The two projects with PV panels (PVs) showed a very low net delivered energy, i.e., 16 and 30 kWh/m² per year.

In Figure 2, the net delivered energy of the six proposals is plotted against the CO₂ emissions.

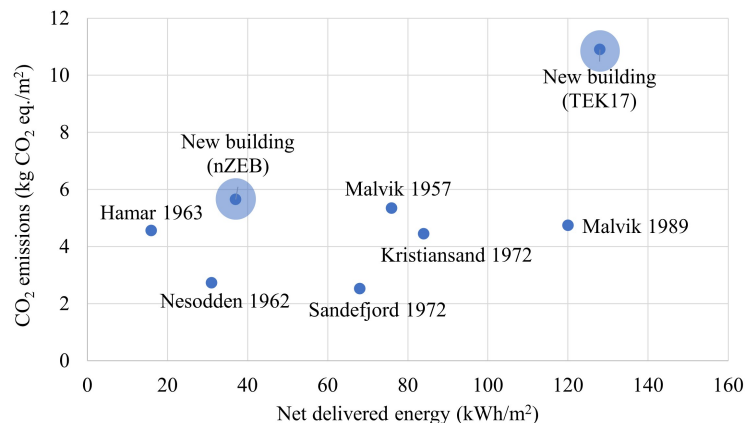


Figure 2. Yearly CO₂ emissions vs. yearly net delivered energy in the OPPTRE projects after the energy upgrading.

The blue circle around New building (nZEB) and New building (TEK17) represents the value uncertainty.

Both the CO₂ emissions and the net delivered energy in the OPPTRE projects were lower than those of a typical new single-family house built according to TEK17. Furthermore, all the projects had lower CO₂ emissions than a new nZEB; however, the net delivered energy of the proposals was generally higher than that of a new nZEB. This is because a new building built to the zero-energy level generally provides the use of PVs for the energy generation, but in OPPTRE, PVs were only adopted in two projects. Furthermore, the LCA results reflected the different environmental ambitions of the proposals, as for instance in the choice of materials with very low emissions. The main contribution to CO₂ emissions was, in fact, from the material production and replacement in all the projects. For a new TEK17 building, the total CO₂ emissions were calculated as the sum of 8.1 kg CO₂ eq. per m² per year for material production [18] and approximately 2.8 kg CO₂ eq. per m² per year for the energy use during the operation phase (25 g CO₂ eq./kWh * ca. 110 kWh/m², where 25 g CO₂ eq./kWh refers to the Norwegian

electricity mix and 110 kWh/m^2 is approximately the TEK17 energy limit). Note that the LCA assessment for the new TEK17 building was simplified and the system limits were not identical to the OPPTRE projects' ones; the construction phase was, for example, not included in this simplified evaluation. Typical values for delivered energy in a new TEK17 building were instead defined based on Norwegian energy label statistics [19]. For a new nZEB building, representative data for both CO_2 emissions and delivered energy values were deduced from [20].

Figure 3 illustrates the investment costs for the existing building envelope upgrading, expressed in Norwegian kroner (NOK⁴) per heated floor area, plotted against the difference between the specific heat loss before and after implementing the upgrading measures. Note that the heat loss was evaluated through external walls, windows, roof, and floor on ground/unheated zone and was normalized by the building heated floor area. As shown in Figure 3, the Δ heat loss was not directly proportional to the investment costs for the existing building envelope measures in the OPPTRE projects. Malvik 1957 was, for instance, the project with the highest investment costs for building envelope upgrading, but with an average value of the Δ heat loss among the other projects. This was because Malvik 1957 had relatively high heat loss in the current condition and, even implementing costly measures, the total heat loss remained relatively high. Note that the original conditions of the analysed houses were not completely comparable, and this led to the choice of different measure and costs for the building envelope upgrading.

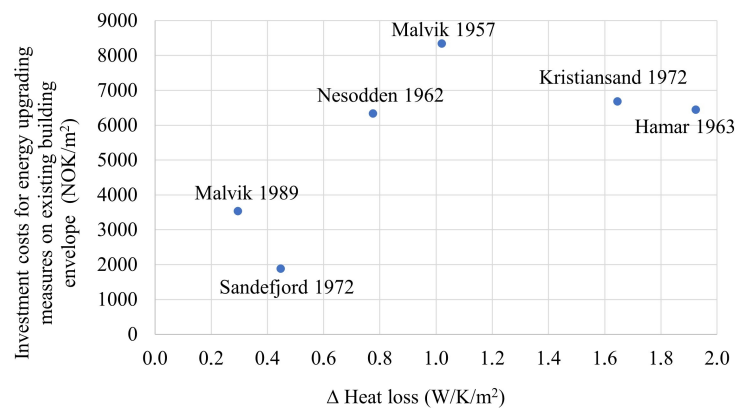


Figure 3. Investment costs for building envelope upgrading vs. Δ specific heat loss in the OPPTRE projects.

Figure 4 shows the net delivered energy plotted against both the investment costs for upgrading the existing building systems (a) and the investment costs for upgrading the existing building envelope (b). The graph in Figure 4 (a) points out that, in all the projects, the higher the investment for upgrading the existing building systems, the lower the net delivered energy. Hamar 1963 and Nesodden 1962 achieved the lowest net delivered energy with the highest investment costs due to the PVs. However, higher investment costs for the building envelope renovation were not necessarily associated to lower delivered energy, as shown in Figure 4 (b). Furthermore, the investment costs for building envelope upgrading were generally higher than those for technical building systems, but there was no inverse proportionality between these two cost categories, i.e. higher costs for the building envelope did not lead to lower costs for the building systems. The teams focused separately on building envelope and building systems to achieve a total energy use reduction; therefore, a trade-off between different appropriate measures on the building envelope and the building systems was generally not pursued.

⁴ 1 NOK=0.098 EUR at the time of writing

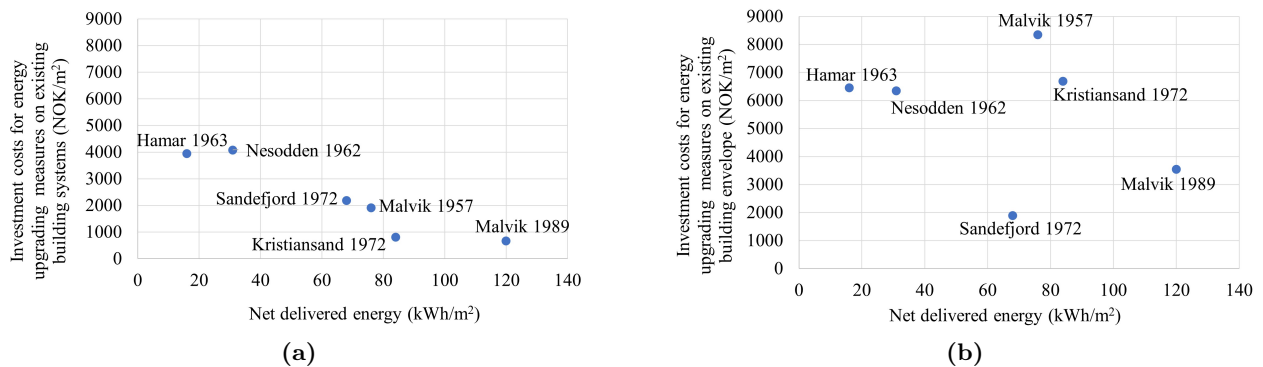


Figure 4. Yearly net delivered energy in the OPPTRE projects vs.: (a) investment costs for upgrading the existing building system; (b) investment costs for upgrading the existing building envelope.

Figure 5 illustrates the energy balance for the six projects, in terms of yearly energy use and energy generated. Energy use is meant as the energy demand, considering also the efficiency of the technical building systems. The blue area in the graph of Figure 5 denotes a nZEB based on the definition of the OPPTRE competition. Almost all the projects fall within the nZEB area as their energy use is lower than the limit value; however, Hamar 1963, Nesodden 1962, and Kristiansand 1972 are not placed on the edge of the blue area since they also generate energy.

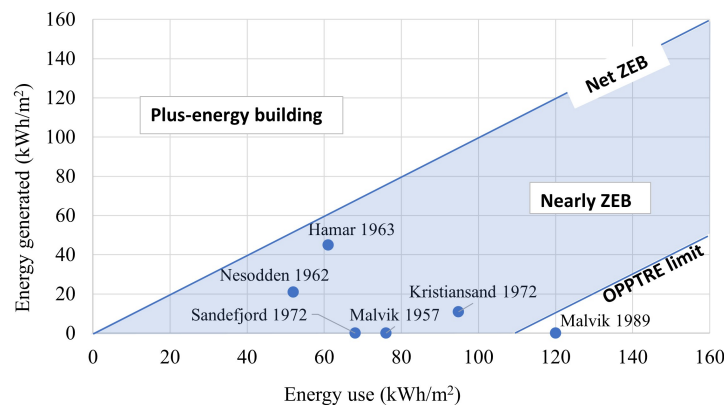


Figure 5. Energy balance for the OPPTRE projects in terms of energy use and energy generated.

4. Conclusions

This article investigated the definition of a nearly zero-energy building (nZEB) level for the energy upgrading of Norwegian wooden dwellings. The findings from an architectural competition in the research project “energy upgrading of wooden dwellings to nearly zero energy level (OPPTRE)” were systematised and discussed.

The results of the OPPTRE architectural competition showed that a substantial reduction of the net delivered energy was feasible through specific upgrading measures on the building envelope and/or the building systems. In particular, the measures on the latter resulted to be even more economically viable than those on the building envelope in all the projects. However, building materials contributed most to the total CO₂ emissions in all the projects, so the choice of

materials to employ in the upgrading measures should be carefully thought from different points of view. The architectural competition also showed that the teams considered energy measures on the building envelope and systems separately and not in a holistic way, as proposed by the EPBD methodology. As regards the building envelope, almost all the building components in the OPPTRE projects were upgraded to a level fulfilling the Norwegian building code (TEK17)'s requirements. However, the addition of insulation was not always feasible, especially for the floor on ground/unheated room, leading to higher building heat losses and airtightness. As deduced from OPPTRE, upgrading single-family house to a high-energy efficiency level can be more economically and environmentally feasible than building a new house according to the current Norwegian building code. CO₂ emissions and net delivered energy in all the OPPTRE proposals were, in fact, lower than those of a new building built according to TEK17. However, a more detailed analysis that also includes the demolition and waste handling phases should be carried out for an overall assessment.

The findings of this article contribute to the creation of knowledge for nearly zero-energy upgrading of dwellings, aiming to a more systematic definition of a nZEB level in such projects. The results of the article can be relevant for several stakeholders, including private and public decision makers, such as governmental institutions, homeowners, and builders, towards the market uptake of nZEB upgrading projects by 2030.

5. Acknowledgements

This paper was written within the Norwegian research Project “Energy upgrading of wooden dwellings to nearly zero energy level” (OPPTRE). The authors gratefully acknowledge the support from the Research Council of Norway, Enova, and the other OPPTRE partners.

References

- [1] Nejat P, Jomehzadeh F, Taheri M M, Gohari M and Abd Majid M Z 2015 *Renew. Sustain. Energy Rev.* **43** 843–62
- [2] European Commission 2010 Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (EPBD recast)
- [3] Department for Climate Change 2020 Submission by Norway to the ADP Norway's Intended Nationally Determined Contribution (updated 2020)
- [4] Gullbrekken L and Time B 2019 *SACE* **25** 35–42
- [5] Risholt B 2013 *Zero energy renovation of single family houses* PhD-thesis Department of Architecture and Design. NTNU
- [6] European Commission 2018 Directive (EU) 2018/844 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency
- [7] Ferreira M, Almeida M and Rodrigues A 2016 *Energy Build.* **133** 724–37
- [8] Semprini G, Gulli R and Ferrante A 2017 *Energy Build.* **156** 327–42
- [9] Risholt B, Time B and Hestnes A G 2013 *Energy Build.* **60** 217–24
- [10] Brambilla A, Salvalai G, Imperadori M and Sesana M M 2018 *Energy Build.* **166** 271–83
- [11] D'Agostino D and Mazzarella L 2019 *J. Build. Eng.* **21** 200–12
- [12] Kurnitski J 2019 *REHVA Journal* **56** 8–12
- [13] Killingland M, Lånke A F, Monsen Ragnøy M, Aga P, Smits F, Andresen I, Elvebakk K and Holthe F 2013 Nearly zero energy building - proposal for a national definition. (in Norwegian) Tech. rep.
- [14] Andersen I, Dokka T H and Skregelig Johansen V 2018 Criteria for nZEB for FutureBuilt projects (in Norwegian) Tech. Rep. 01-2018 URL <https://www.futurebuilt.no/0m-oss>
- [15] Directorate for Building Quality 2017 Norwegian building code, TEK17 (in Norwegian)
- [16] OPPTRE, Energy upgrading of wooden dwellings to nearly zero energy level URL <https://opptre.no/>
- [17] Commercial software for energy simulations in the Nordic countries URL <https://ibpsa-nordic.org/commercial%20software/>
- [18] Wiik Kjendseth M, Selvig E, Fuglseth M, Resch E, Lausset C, Andresen I, Brattebø H and Hahn U 2020 Climate gas requirements for use of materials in buildings - Development of a baseline for setting absolute requirements for greenhouse gas emissions from material use in norwegian buildings (in Norwegian) Tech. Rep. 24 Research centre on zero emission neighbourhoods in smart cities
- [19] Norwegian energy label statistics (in Norwegian) URL <https://www.energimerking.no>
- [20] Wiik Kjendseth M, Fufa S, Kristjansdottir T and Andresen I 2018 *Energy Build.* **165** 25–34