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Review

A Review of Non-Residential Building Renovation and Improvement of Energy Efficiency: Office Buildings in Finland, Sweden, Norway, Denmark, and Germany

Mihkel Kiviste [1,*], Sami Musakka [2], Aime Ruus [1] and Juha Vinha [3]

[1] School of Engineering, Tartu College, Tallinn University of Technology (TalTech), Puiestee 78, 51008 Tartu, Estonia
[2] AINS Group (A-Insinöörit), Renovation Engineering, Puutarhakatu 10, 33210 Tampere, Finland
[3] Building Physics, Civil Engineering, Faculty of Built Environment, Tampere University, Korkeakoulunkatu 5, P.O. Box 600, 33014 Tampere, Finland
* Correspondence: mihkel.kiviste@taltech.ee

Abstract: Existing buildings are a source of great potential for energy efficiency through renovation. In this study, the national energy requirements equivalent for the major renovation of existing non-residential buildings using the example of office buildings in five European case countries are drawn out and discussed. The non-residential building sector has been found to be complex and heterogenous with much less available data than for the residential sector, but having greater average specific energy consumption per floor area. The existing non-residential building stock in the studied countries has been divided into varying amounts of groups and sub-groups. The energy requirements have been shifting from the increasing requirements for the U-values of the building envelope (before the 2000s) towards calculated energy demand for buildings as a whole (currently). The requirements for buildings in the near future will be carbon emission based. The energy efficiency of N-RBs in all of the studied case countries have been steadily improved during different decades of construction. Relatively older office stock combined with the relatively late introduction of national energy requirements was found to have a significantly larger potential for energy savings. Different terms and contents in national requirements were used to describe the principles of "major renovation" as from EPBD.

Keywords: case countries; energy efficiency; major renovation; national requirements; non-residential buildings

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1. Introduction: European Existing Building Stock, Its Energy Performance and Renovation

1.1. EU Requirements for Improving the Energy Performance of Buildings

Buildings and the construction sector together have been found to be responsible for 40% of global energy consumption and 33% of greenhouse gas emissions [1]. Therefore, they are a source of enormous energy efficiency potential. Increasing the energy performance of new and existing buildings is the key to tackle the impacts for climate change. In the EU, the Energy Performance of Buildings Directive (EPBD) [2] and the Energy Efficiency Directive (EED) [3] have been stipulated; however, finding the energy savings of the European buildings has been difficult. At present, approximately 75% of the EU building stock is energy inefficient [4]. The energy efficiency (EE) of new buildings has been persistently improved over time, but the majority of the Europe's existing building stock has not been energy improved. The 2012 EED supplemented major renovations as a requirement for the Member States (MS). Also, MSs had to set strategies for the renovation of national building stocks and for 3% annual renovation of the central government's building stock [3]. MSs have to make sure that a major renovation of a building or its part is functionally, technically, and economically possible and, at the same time, meet the minimum energy performance requirements established in the EPBD [2]. Countries have chosen different ways to define and monitor major renovations. However, the comparison of different EEs of building renovation between countries has been complicated [5].

In 2002, the Energy Performance Certificates (EPC) were introduced [1]. The EPCs show the calculated energy consumption and energy performance rating of a building for all relevant parties during selling or rental. With the EPBD recast in 2010, MSs had to harmonize their national legislation in accordance to the EPC. However, the implementation of the EPCs in MSs is still in progress, dealing with different issues [4]. It should be mentioned that EPBD and EED directives and other building EE related requirements (documents) are being constantly updated and supplemented, which is one of the fastest developing transitions regarding the energy performance of buildings.

A new proposal for the EPBD was introduced by the Commission in December 2021 [6], which, however, is not currently in force for the MSs, yet. The proposal for the new EPBD also includes carbon metrics [7]. The EU has proposed to move from the current definition of nearly zero energy buildings (NZEB) to zero emission buildings (ZEMB) by 2030 [8]. According to a proposal for new energy performance requirements, the meaning of "major renovation" is going to change-before 1 January 2030, buildings or building parts will be transformed into a NZEB, and as of 1 January 2030, into a ZEMB [6].

Across all MSs, most of the floor areas belong to residential buildings, with the share from around 60% to more than 85% [9]. So far, the energy research has mostly been focusing on residential building stock in Europe. This means that, by now, the dataset of information for residential buildings in different European countries is fairly comprehensive [10–15], which, in turn, enables us to make conclusions about the residential sector. However, EU calculations for 2013 [9] indicated an average energy consumption of 250 kWh/m^2 for non-residential and 180 kWh/m^2 for residential buildings, respectively. It is estimated that there are 12 million N-RBs and 24 billion m^2 of non-residential floor space in the EU27, Switzerland, and Norway, increasing at a rate of around 1% per year [16]. However, there is much less data gathered for non-residential stock [16]. This is caused by the large amount of different types of N-RBs and the heterogeneousness of the sector [4]. Within the EU, 42% of N-RBs were constructed before 1970s. Currently, only approximately 9% of the EU N-RB stock has been renovated [9].

1.2. Motivation and Objective of the Research

This research is a part of the *Future Spaces* project, related to the structural renovation of office buildings in five studied countries: Finland, Sweden, Norway, Denmark, and Germany. The motivation for research origins from Finland, where moisture and mold-related problems and deteriorations in the building structures of public buildings (including offices [17]) have been studied comprehensively [18–20] and introduced at the Finnish Parliament [21].

The objective of the research is to present and discuss the energy requirements (as stipulated in the national building codes) equivalent for major renovation of the existing office buildings using the example of five case study countries: Finland, Sweden, Norway, Denmark, and Germany.

1.3. Acquisition of Source Research Data

There are numerous specific national construction databases in the studied countries, however, often with limited or restricted access. The authors had no access to the national databases and, thus, to the information presented in them. No national depositories or archives (except for Finland), were studied by the authors for the acquisition of additional research data.

The information considering national building codes and national strategies for the case study countries was sought using public online web pages. The information sources were sought in relation to the research project Future Spaces [22]. The existing building structures to be renovated in Finland were sought and clarified by a project partner [23]. The current review deals with the information for renovation and improving EE of numerous non-residential and office buildings, which is presented in previous national research reports, journals, and conference papers. A systematic and comprehensive information review was used in the current study. Therefore, no case studies of renovation of N-RBs were reported.

1.4. Existing Building Stock in the Case Study Countries

In Table 1, the information on the existing building stock of studied countries is summarized.

Table 1. Existing building stock in the case study countries.

	Finland	Sweden	Norway	Denmark	Germany
Total number of buildings	Buildings: 1,540,434. Summer cottages: 508,919. Heated N-RBs: 144,700	Buildings: 8,157,403	Buildings: 4,308,490. RBs: 1,592,339. N-RBs: 2,716,152 Heated N-RBs: 754,525	Buildings: 4,811,562	RBs: ca. 19 million Heated N-RBs: ca. 1.98 million ± 0.152 million
Number of groups of buildings or N-RBs	Heated N-RBs: 4 groups	Buildings: 7 groups	N-RBs: 9 groups	Buildings: 9 groups	N-RBs: 8 groups [24], 14 groups [25]
Group of buildings including offices	Office buildings: 10,624	Buildings with business activity: 60,670	Office and business buildings: 38,912	Office, trade, inventory, incl. public admin.: 101,769	Office and admin.: 307,000 . . . 413,000 (323,700) (1.70%)
Source	Statistics Finland (2021) [26–28]	Swedish Real Property Register (2018) [29]	Statistics Norway (2023) [30]	Statistics Denmark (2023) [31,32] Long term renovation strategy (2020) [33]	Federal Statistical Office (Destatis 2021) [34], Hörner and Bischof (2022) [25,35], German Energy Agency [24,36]

Table 1 shows that each studied country has a major challenge to deal with renovating their existing building stock, especially for larger building stock in Germany. Table 1 also shows that the statistical institutions in the studied countries have different approaches dividing the buildings into different building groups (types). Therefore, the number of office buildings in Table 1 are not directly comparable, but gives an overview.

Finland: The number of buildings could be found from the the real estate, building, and spatial information register of the Finnish Digital and Population Data Services Agency (DVV). The data in the register originates from building project notifications and covers 100% of buildings. According to Statistics Finland, in 2021 there were a total of 144,700 heated N-RBs (Table 1) with a floor area of 110 million m^2 in Finland. N-RBs were divided into four groups: (1) commercial, transport, and communications buildings (100,800 buildings, 46.7 million m^2 (40%)); (2) institutional care and educational buildings (18,500 buildings, 32.9 million m^2 (30%)); (3) office buildings (10,800 buildings (0.69% of the total building stock in Finland); 19.7 million m^2 (20%)); and (4) assembly buildings (1600 buildings; 10.6 million m^2 (10%)) [37].

Most of the office buildings in Finland were found to be constructed in the 1980s (21% of office buildings; 20% of floor space), followed by the 1970s (14%; 14% of floor space) and the 2000s (10%; 14% of the floor space). Office buildings in Finland constructed in the period 1950–2019 represent approximately 80% of the total floor area [28,37].

Sweden: According to the data from the real property register of the Swedish mapping, cadastral, and land registration authority ("Lantmäteriet") [38] referred by Statistics Sweden [39], there were over 8 million buildings in Sweden in 2018, divided into seven types. The most common type was (1) complementary buildings, for example, free-standing outbuildings, garages, and storage buildings (4,696,479 buildings in 2018; 58% of the total building stock). The housing and services sector (3,016,677 buildings, 37%) encompassed (2) single houses, (3) apartment buildings and non-residential premises. Non-residential premises (444,247 buildings; 5% of the building stock) consisted of (4) industrial buildings, (5) buildings with a social function, (6) buildings with business activity such as hotels, offices, commerce, restaurants or multi-story car parks, and (7) agricultural buildings [29]. Therefore, offices were included in a sub-group of non-residential premises with business activity (60,670 buildings in 2018, accounting 0.74% of the total building stock in Sweden).

Norway: According to Statistics Norway (February 2023) the building stock consisted of 4.3 million buildings, out of which 2.7 million were N-RBs. N-RBs were divided into nine groups: (1) holiday houses, garages linked to dwellings, etc.; (2) industrial buildings; (3) agricultural and fishery buildings; (4) office and business buildings; (5) transport and communications buildings; (6) hotel and restaurant buildings; (7) buildings for education, research, public entertainment, and religious activities; (8) hospital and institutional care buildings; and (9) prisons, buildings for emergency preparedness, etc.

Offices belonged to the group of "office and business buildings" and amounted 38,912 in 2022 (0.91% of the total building stock) [40]. Around 85% of the total office buildings were constructed in the period 1960–2000. However, very few new office buildings have been constructed in Norway since 2015 [41]. About 64% of office buildings in Norway had a total building area of less than 10,000 m^2. However, the size of office buildings varied greatly. In addition, the available data sources on average size of offices had gaps [41,42].

Denmark: The total number of building stock (according to Statistics Denmark) in Denmark accounted for 4,811,562 buildings in 2023 [31]. The buildings were divided into nine groups of use: (1) detached houses (1,128,851 buildings); (2) terraced, linked, or semi-detached houses (268,017 buildings); (3) multi-dwelling houses (99,916 buildings); (4) other residential buildings (7787); (5) non-residential farm buildings (315,926); (6) factories, workshops, etc. (50,103); (7) office, trade, inventory, including public administration (101,361 buildings (2.13% of the total building stock in Denmark); (8) buildings for education and research (schools, laboratories, etc.) (17,625 buildings), and (9) weekend cottages (230,597) [32]. However, Statistics Denmark has presented only the information for the number of existing buildings for the years starting from 2011 to 2022.

Therefore, the data sample (1,717,580 buildings) of the Central Register of Buildings and Dwellings (as of 13 June 2016) has been used for the analysis of construction periods. The largest areas of Danish trade and service buildings (including offices) were constructed between 1979 and 1998 (24.0% of the total floor area) followed by 1960–1972 (17.4%). For institutions, the largest areas were also constructed between 1960 and 1972 (23.4%) followed by 1979–1998 (17.2%) [22,34].

Germany: The Federal Statistical Office (Destatis) estimated that there are around 19 million residential buildings (43,084,122 dwellings), extrapolated from the results of the 2011 Census of Buildings and Housing [34]. Due to the unsatisfactory body of data and multi-faceted use, the exact number of German buildings has not been determined yet [43,44].

A recent ENOB:dataNWG project estimated that there are a total of 1981 $\pm$ 0.152 million geospatially relevant N-RBs with a gross floor area of 3507 $\pm$ 399 million m^2 in Germany. The variation was included due to the estimation methodology which consisted of basic geospatial data analysis (georeferenced house boundaries), screening (100,000 house surrounds) and a sample survey (100,000 house perimeters stratified by spatial planning region) [25,35,45].

According to Destatis and reported by the German Energy Agency, the N-RBs in Germany have been divided into 8 groups [24]. However, ENOB:dataNWG project (2022) has differentiated German N-RBs into 11 types (8 different types of Service buildings and 3 types of Production and technical buildings [44,46]. A range from 307,000 $\pm$ 45,000 (indicated as a result of a broad survey) to 413,000 ± 23,000 office and administration buildings was found (a result of the screening of mixed-use buildings) [47]. This range fits to the earlier geo-basic data analysis in 2013, which identified a stock of 294,557 "office and administration" buildings [46]. In 2015, the German Energy Agency estimated that there were 323,700 office and administration buildings with a total floor space of 382.4 million square meters (arithmetic mean of 1181 square meters floor space) [24].

According to the study of Deutsche Energie Agentur (Dena) 64% of the office buildings and 53% of the floor space were constructed before 1978 (the first building regulation on EE, Thermal Insulation Ordinance). As the oldest and largest age group, 27% of offices (19% of floor area) have been constructed before 1919. Around half of the office and administration buildings (50.4% usable floor area) to 59.6 percent (number of buildings) were located in the rural districts. The size of the office buildings in Germany varied greatly, from 999 m^2 in the offices located in the rural districts to 1938 m^2 in the large cities (mean values of both groups) [36,48].

Cross country analysis of the results. The studied Nordic countries have official information registers accounting rather accurately the amount of the existing building stock, whereas for Germany, the data from different federal states and different sources has not been aligned yet. The statistical institutions (and other institutions) in each studied country have made efforts to estimate the number of existing buildings as accurately as possible. However, there are differences in approaches for dividing the buildings into the groups of use, which number varies from four to nine. N-RBs as a separate building group are listed in Finland, Norway, and Germany. Denmark has not separated a group of N-RBs in their division. In Sweden, a sub-group of non-residential premises belonged to the Housing and services group, thus also not directly comparable with the other studied countries. The office buildings in the studied countries accounted from 0.69 (Finland) to 2.13% (Denmark) of the total building stock, but was not calculable for Germany. In comparison of the age of the buildings in the case study countries, the oldest office stock was found to be in Germany (a considerable number of offices constructed before 1919), whereas a relatively younger office stock was in Finland, Sweden, Norway, and Denmark, where in general (number, floor areas), the majority of offices were constructed in between the 1960s and the 2000s (also in the 1950s in Finland).

2. Improving the Energy Efficiency of the Existing Non-Residential Buildings in Studied Countries

2.1. Current Regulations and Requirements for Improving the Energy Performance of Existing Office Buildings

The studied countries have different national authorities responsible for the energy use of buildings in the field of construction as described below. The relevant building laws, codes, and guidelines issued by the authorities are listed in Table 2. The national buildings codes are in national languages as they provide information about the national legal framework. The English translations of relevant building laws and codes may not be legally binding and may only be updated at the time of the initial translation. In addition, the authorities of the studied countries have stated their national goals or strategies (Table 2), which follow the national building codes and acts.

Table 2 shows that in one group of the studied countries the building regulations are based on a law referring to separate documents (decrees/acts/ordinances), which deal with the EE of buildings (Finland, Germany). In the other group of countries there is a building code, which has separate chapter(s) dealing with the EE of buildings (Sweden, Norway, Denmark). Each of the studied country also sets goals and reports its progress to the European Commission in national strategies (except the document Implementation of EPBD in Norway in Table 2).

Table 2. A summary of current national building codes and current requirements for energy performance of the existing office buildings in case of major renovations in the studied countries.

	Finland	Sweden	Norway	Denmark	Germany
Building codes/acts	Land Use and Building Act 132/1999 and related decrees	Boverket's Building Regulations (BBR) [49]. Planning and Building Act. Planning and building ordinance [50]	TEK 2017 [51] Building and planning act, Building application regulations [52], SINTEF Building Research Design Guides [53]	BR18 [54]	Federal Public building law: Building Code (BauGB) [55], Federal Land Utilization Ordinance (BauNVO) [56], Technical Building Rules (MVV TB) [57]
National goals/strategies	Long-term renovation strategy 2020–2050 [37], Carbon neutral Finland 2035 (2022) [58]	Sweden's Third National Strategy for EE Renovation (2020) [29]	Norway 2022. Energy Policy Review. [59] Norway's National Plan (2019) [60] Energy 21 [61] Implementation of the EPBD in Norway [62]	National Strategy for Sustainable construction (2021) [63],	Action Programme Climate Protection (AP 2020) [64]. Climate-friendly building and housing National Action Plan on EE (NAPE) [64]
Regulations dealing with the EE of buildings	Decree for EE of new buildings (1010/2017) [65] Decree for EE in building renovation and modification (4/13) [66]	BBR, [49] Chapter 9 Energy Conservation	Regulations on technical requirements for construction works, TEK17 [67]	Energy requirements of BR18 [54]	Energy Conservation Act (EnEG) [68], Energy Conservation Ordinance (EnEV) [69], Renewable Energy Heat Act (EEWärmG) [70]
Indicator of energy performance	(Improved) calculated annual energy consumption per heated net area, [kWh/(m^2·a)]	Primary energy number (EP_{pet}) [kWh/m^2 A_{temp} per year	Total net energy demand [kWh/m^2 heated gross internal area per year]	Total net energy supply and demand [kWh/heated floor m^2], (voluntary)	Primary energy demand or final energy consumption
Energy perf. limit for office [kWh/(m^2·a)]	145 (or 70% of energy consumption before renovation)	80 *	115	A: 71.3 + 1650 C: 135 + 3200	Varying in different federal states

EE–Energy efficiency or energy efficient. * Addition may be made by 70× (q_{medel} − 0.35) when the outdoor air flow in temperature-regulated spaces, for reasons of increased hygiene, is greater, than 0.35 l/s per m^2, where q_{medel} is the average specific outdoor air flow during the heating season and may as a maximum be included up to 1.00 l/s per m^2.

Finland: The Ministry of the Environment prepares new legislation concerning housing and built environment (including land use). Based on the Land Use and Building Act 132/1999 [71] the Ministry has set a decree for the improvement of EE in building renovation and modification (4/13) [66]. The decree has a background in the EPBD 2010/31/EU and was changed in 2017 (among other things) with definitions for the technical, functional, and economic feasibility of major renovations,.

Following the standards set by the decree, there is no need to separately estimate if a renovation is a major renovation or not. The technical requirements/levels for renovation in the decree are cost optimal as the EPBD 2010/31/EU requires. In Finland, it is also common that renovations are done in several phases, which alone do not fulfill, the definition of major renovation.

Sweden: The basis for the work of National Board of Housing, Building and Planning (Boverket) is the Planning and Building Act, parts of the Environmental Code and the Housing Supply Act (all in Swedish). The national building code BFS 2018:4 stipulates, among others, the requirements for EE in case of "the alterations of buildings" [72], the closest possible to "major renovation" in the EPBD. The alterations of a building should meet the requirements for the primary energy number (in Table 2). However, when this is not possible, the set U-values (in Table 2) should be followed (BFS 2017:5; Section 9:2) [73].

Norway: The Norwegian building authority is responsible for implementing current buildings technical regulation, TEK17, to improve the EE of new buildings as well as existing buildings after major renovation. According to TEK17, the building's total net energy requirement should not exceed the energy requirement level (Table 2) and, at the same time, should satisfy the minimum requirements for the U-values of the building envelope. N-RBs are required to have dedicated energy meters for heating and hot water. The installation of fossil-fuel-based heating systems is prohibited. In order to encourage the production of local renewable energy (more than 20 kWh/m^2 of heated gross internal area per year), the specific energy limit (last row in Table 2) could be exceeded by 10 kWh/m^2 per year.

The Norwegian building code (TEK17) has specific energy limits for different types of N-RBs. The requirements are set in kWh/m^2 useful energy demand per year within the building envelope, which takes into account heat recovery from ventilation systems, but not from system losses and energy export. All buildings larger than 1000 m^2 should have flexible heating systems [67].

Denmark: The Housing and Planning Agency is responsible for specifying and updating the requirements of the Building Regulations, currently BR18 is in force [74]. BR18 has a separate chapter for Energy consumption and climate impacts (Ch. 11 § 250–§ 298). Buildings should be constructed so that the calculated energy requirement does not exceed the energy framework, which includes the building's total need for supplied energy for heating, ventilation, cooling, domestic hot water, and lighting. Added energy from different energy suppliers is weighed together using the energy factors. Calculations should be verified according to SBi instruction Buildings' energy needs [75].

The Danish building code BR18 operates with six different types of construction projects: (1) new buildings, (2) change of use, (3) extension, and (4) conversions and other alterations, (5) replacements of building elements and installations, and (6) reparations [54]. In this study "Conversion and other alterations" of the existing buildings are considered as an equivalent of "major renovation" in the EPBD.

In the case of conversions, cost-effective energy savings should be implemented which do not entail a risk of moisture damage. Conversions, where annual savings times lifetime (insulation to structures: 40 years, windows: 30 years, heat systems: 30 years, heat appliances: 20 years, lighting: 15 years, automation: 15 years, joint sealing: 10 years) divided by investment is greater than 1.33, are considered as cost-effective.

According to BR18, there are two methods to fulfill the requirements for *Conversions and other alterations*. The first method is to meet the minimum requirements for the U-values of the building envelope and the linear losses for joints between building elements. The requirements for the linear losses for joints (ψ value) are as follows: for foundations 0.12 W/mK; joints between external walls, windows, external doors, glazed external walls, gates, hatches 0.03 W/mK; joints between roof structure and roof lights or skylight domes 0.10 W/mK [54,76].

There is an alternative method named energy performance framework for existing buildings–also known as renovation classes. To fulfill the requirements set by renovation classes, an energy performance framework must be satisfied as specified in Table 3. The energy demand should be reduced by at least 30 kWh/m^2 per year. Additionally, renewable energy should be present in the total energy supply calculations for the building. In order to reach renovation class 1, the requirements for indoor environmental quality (at least at the satisfactory level) should be met (Table 3) [75,76].

Table 3. Energy performance framework for existing offices, etc. (renovation classes) in Denmark [76].

Offices, Schools, Institutions, Etc.	kWh/m^2 per Year per Heated Floor Area	Energy Label
Renovation class 1	71.3 + 1650	A (2010)
Renovation class 2	135 + 3200	C

Germany: There are numerous laws and codes which regulate the German construction sector. Public building law forms the basis on which the permissible use of land for construction is determined by type and intensity. Urban development planning for the whole Germany is regulated in the Federal Building Code (Baugesetzbuch (in short BauGB) [55] and the Federal Land Utilization Ordinance (BauNVO) [56]. In Germany, the generic requirements for structural works and the use of construction projects are laid down in the Building Codes of the federal states. Where necessary, these generic requirements can be specified by Technical Building Rules. Deutches Institut für Bautechnik (DIBt) publishes the Model Administrative Provisions–Technical Building Rules (MVV TB) [57] on behalf of the federal states. The Energy Conservation Act (EnEG) [68], the Energy Conservation Ordinance (EnEV) [69], and the Renewable Energy Heat Act (EEWärmeG) [70] are managing the energy requirements for buildings. EnEG shows the legal framework of energy transition in buildings and provides justifications for the amendment of EnEV. EEWärmeG obliges to use renewable energy both in new buildings and for major renovations of the public buildings [70].

The German Energy Saving Ordinance (Energieeinsparverordnung, EnEv) states that the minimum energy performance requirements for new buildings are also applicable to existing buildings if, as a result of renovations, the external elements are changed by more than 10% [77].

It can be found that the energy requirements for a new construction as well as for renovation are stated in the same building code in Sweden, Norway, and Denmark. Table 4 shows that the term "major renovation" as in the EPBD is used only in the current Norwegian building regulation TEK17. Finland, Sweden, and Denmark use the term building "alteration" or a term related to it. In Germany there is a "standard renovation" which can be considered as closest to the "major renovation" in the EPBD.

Table 4. Minimum requirements for the U-values of existing building envelope in case of national major renovation or alteration measure considered as closest to "major renovation" in the studied countries.

U-Value [W/m^2 K]	Finland	Sweden	Norway	Denmark	Germany
Type of renovation, Code, chapter	Repair and alteration work 4/13, 1 §	Building alteration, BBR 2017:5	Major renovation, TEK17, Ch.14	Conversion and other alterations, BR18	Standard renovation
U_{roof}	0.09	0.13	≤0.18	0.12	0.20
U_{wall}	0.17	0.18	≤0.22	0.18	0.28
U_{floor}	0.09 (outdoor air) 0.16 (ground) 0.17 (crawl space)	0.15	≤0.18	0.10 (ground slabs) 0.40 (suspended upper floors)	0.35
U_{window}	1.0	1.2	≤1.2	1.4 (new) 1.65 (renovated)	1.30
$U_{exterior\ door}$	1.0	1.2	≤1.2	1.80	1.8

Table 4 summarizes the minimum requirements for U-values for different building components in the studied countries in cases of a major renovation. Table 4 shows that the strictest requirements to the U-values of different structures of the building envelope are in Finland. The minimum requirements for the building envelope in the other studied Nordic countries are also rather strict. In comparison, the strictest requirements for air tightness of the building envelope are set in the Norwegian building code. Considering that Germany is in Central Europe, the requirements for U-values for renovating the envelope of existing buildings still require a considerable increase in EE; however, the U-values are not as strict as in the studied Nordic countries.

2.2. Energy Efficiency and Energy Performance Certificates of Non-Residential Buildings

Energy Performance Certificates (EPCs) are a rating scheme to summarize the EE of buildings regulated the EPBD [2]. EPCs were introduced in 2002, and aspects of quality, harmonization (a scale using letters A to G), and public accessibility were added to the EPBD recast in 2010. With the EPBD recast, the MSs had to revise their national legislation regarding the EPC schemes. Table 5 summarizes the adoption and national legislation managing EPCs in the studied countries.

Table 5. Energy performance certificate (EPC) scheme for buildings in the studied countries.

	Finland	Sweden	Norway	Denmark	Germany
Adopted since. Comments	Developed since 1996. Required since 2008 (binding legislation). Amendment of nZEB since 2018	In effect since 1 October 2007. Certificates made before were not automatically energy-classified. Based on energy bills.	Required from 1 July 2010. Obligatory from 1 Jan 2012 for commercial buildings.	Database since 1997, available for public. Adjusted in 2006 as a result of the EPBD. Different A classes: A2020, A2015, A2010	Since (EnEV) 2014 *, From May 2021 Buildings Energy Act (GEG) [78,79] 2 types: Demand and consumption Certificate.
Based on	Law on building energy certificate [50/2013] [80]	BBR (BFS 2017:10) [73], Hjortling, Björk 2017 [81]	NS-EN ISO 52000-1:2017 [82]	ISO 9001 + Danish Energy Agency	EnEV/GEG [69,79]

* The EnEV EPC database in Germany is accessible only to enforcing authorities and certifying experts. Due to strict data privacy laws, the metadata does not include any information about the energy performance of buildings.

Method of statistical analysis. Assuming that energy classes A–G are ordered by increasing energy consumption, and the energy consumption intervals are equal, the letter designation are replaced with numbers 1–7. This allows the comparison of energy consumption distributions using mathematical methods. A large number of random variables in technology have the normal distribution, in which the average values occur with the highest frequency, which symmetrically decrease to zero towards the extremes. The main statistical characteristics describing the shape of the distribution are the skewness and kurtosis, which in the case of normal distribution are both zero [83].

The EE of N-RBs is described using average heating energy consumption and energy classes from the studied countries as follows.

Finland. The Housing Finance and Development Centre (ARA) maintains the energy certificate system. A total of 7984 EPCs were registered for N-RBs in June 2019, which represented 5.52% of the total N-RB stock [37]. The average heating energy consumption of N-RBs in Finland is presented in Table 6.

Table 6. The average heating energy consumption of N-RBs of different age classes in Finland [37].

Indicator	Unit	Until 1959	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2019
Average heating energy consumption	kWh/m^2	190	160	195	175	170	105	95

Source: Long term development of emissions, Technical Research Centre of Finland (VTT) and the Finnish Environment Institute (SYKE) [84].

Table 6 shows that the EE of the existing N-RBs has been constantly improved since 1970s as the average heating energy consumption has decreased significantly (Table 6). Table 7 shows that approximately 60% of the N-RBs completed before 2010 belong to energy classes C and D. The requirements for EE of buildings in Finland became tighter in the 1980s, and therefore buildings completed after that are included in energy class D or better. The next tightening of EE requirements was in 2010. Thus, the most typical energy class of N-RBs completed after 2010 is B (Table 7) [37]. The distribution of energy classes of the Finnish B-RB-s are presented in Figure 1 and Table 8.

Table 7. Energy class distribution (in percentages) of N-RBs of different ages based on number of buildings. Status in June 2019 [37].

Energy Class	Until 1959	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2019	All N-RB
A	0	1	0	1	0	0	15	2
B	7	8	15	7	9	10	77	16
C	28	40	44	51	34	40	5	36
D	25	31	16	19	24	20	2	20
E	18	8	14	10	15	18	0	13
F	6	6	4	6	9	9	0	6
G	15	5	8	6	10	3	0	8
Floor area shares	19	11	14	18	11	14	12	100%

Source: EPC register 2018, statutory EPCs, ARA.

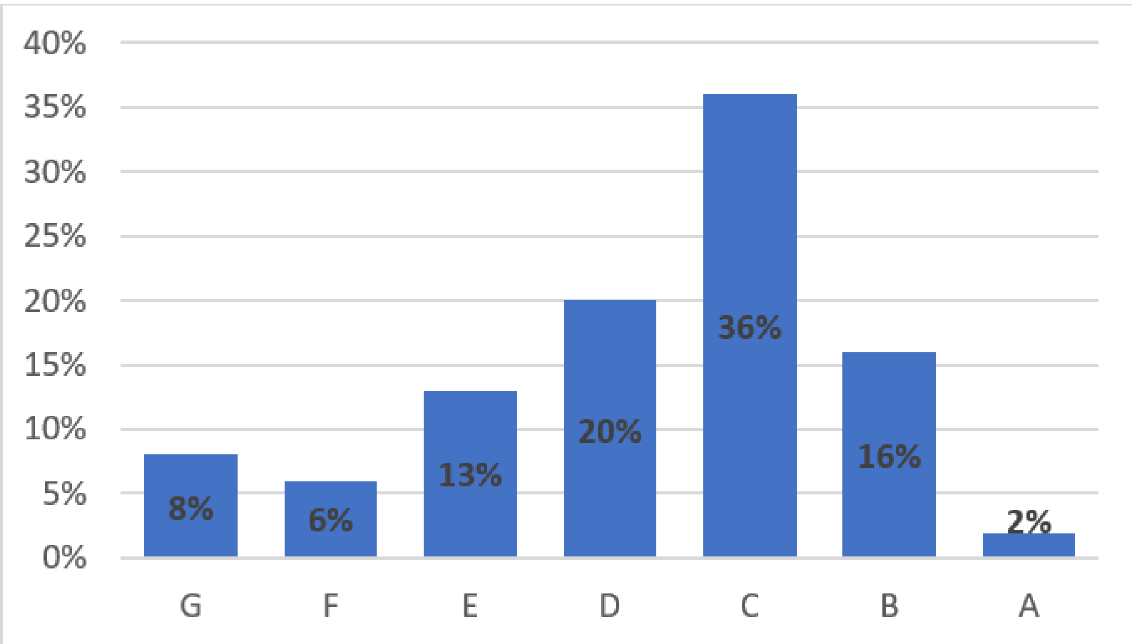

Figure 1. Distribution of energy classes of N-RBs in Finland [37]. Source: Statutory EPC register, 2018, ARA.

Table 8. The average heating energy consumption of non-residential buildings of different age classes in Finland.

Indicators	Until 1959	1960–1969	1970–1979	1980–1989	1990–1999	2000–2009	2010–2019	All N-RBs
New and renovated N-RB: energy classes A, B and C	35%	47%	59%	59%	43%	50%	97%	54%
Worst performing segments of the N-RB: classes F and G	21%	11%	12%	12%	19%	12%	0%	14%

Source: Statutory EPC register 2018, ARA.

Figure 1 and Table 8 show that a bit over half (54%) of the Finnish non-residential building stock is considered new (completed in the 2010s) or renovated (belong to energy classes A, B, and C), and 14% belongs to the worst performing segments (energy classes F and G) [37]. Figure 1 shows the distribution of energy classes with a skewness of 0.69 and a kurtosis of −0.20 which differs considerably from the normal distribution. A positive value of the skewness refers to asymmetric distribution towards to larger energy consumptions (energy classes F and G in Figure 1).

Sweden: In 2017, the housing and services sector accounted for the 39% of end-use energy consumption in Sweden [85]. During the period 1995–2017, temperature-corrected energy consumption for heating and hot water decreased by 33, 22 and 21% for one-family buildings, apartment buildings, and non-residential premises, respectively [29].

The energy performance certificates in Sweden are based on energy bills and compiled by an independent and certified expert. In July 2019, there were 55,675 non-residential premises with energy declarations [29]. The mean specific energy consumption for these buildings was 128 kWh/m^2 A$_{temp}$ per year, and the mean primary energy demand was 186 kWh/m^2 A$_{temp}$ per year [29]. The distribution of declared N-RBs by class is shown in Figure 2.

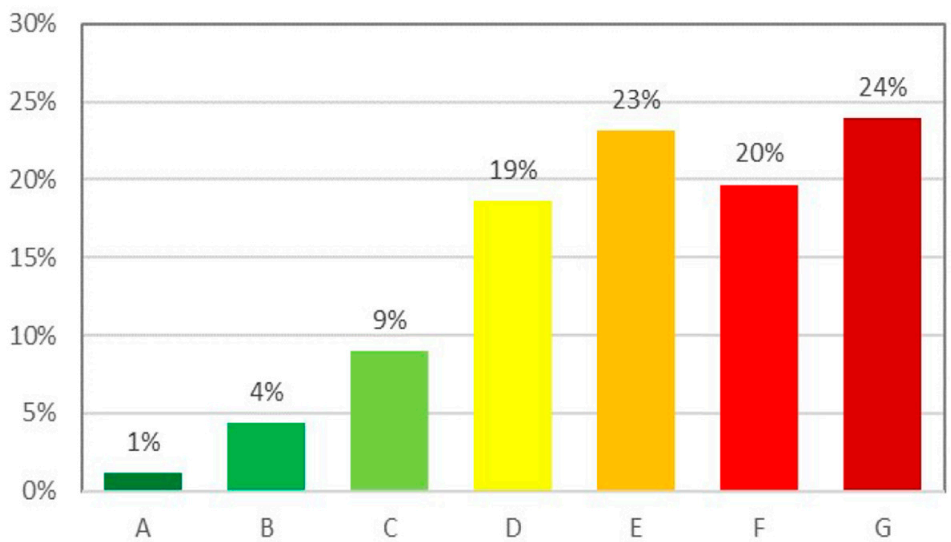

Figure 2. Distribution of energy classes of declared Swedish non-residential premises. Source: Energy Declaration Register of Sweden (1 July 2019).

Figure 2 shows that approximately 14% of the declared non-residential premises belong to energy classes A–C. The distribution of energy classes is described with a negative skewness of −0.46 and kurtosis of −0.52, which differ from the normal distribution. Negative skewness in Figure 2 is asymmetric towards lower energy consumptions (classes A–C). The distribution between the energy classes D, E, F, and G is relatively evenly split (close to uniform distribution), with 19–24% of non-residential premises in each class. Offices (and schools) were found to be the most numerous and most energy inefficient types among the declared non-residential premises. The most energy consuming offices were constructed between 1960 and 1989, belonging to energy classes E–G.

Hjortling et al. [81] studied the 186,021 measured EPCs issued for commercial buildings (355 Mm^2) in Sweden collected by the National Board of Housing, Building, and Planning (Boverket) during 2007–2015. Based on the EPCs the mean energy consumption for rental premises in Sweden (mainly offices, partly stores or shopping malls) was found to be 151.0 kWh/m^2 (standard deviation 61.8 kWh/m^2), with the frequency histogram in Figure 3. The mean energy consumption of Swedish offices found by earlier research (Energy Statistics by the Swedish Energy Agency) was 137 kWh/m^2 [86]. The distribution of energy consumption in Figure 3 has a skewness of 0.96 (asymmetric towards higher energy consumptions) and kurtosis of 1.51 (more extreme values compared to the normal distribution), which indicate lognormal distribution.

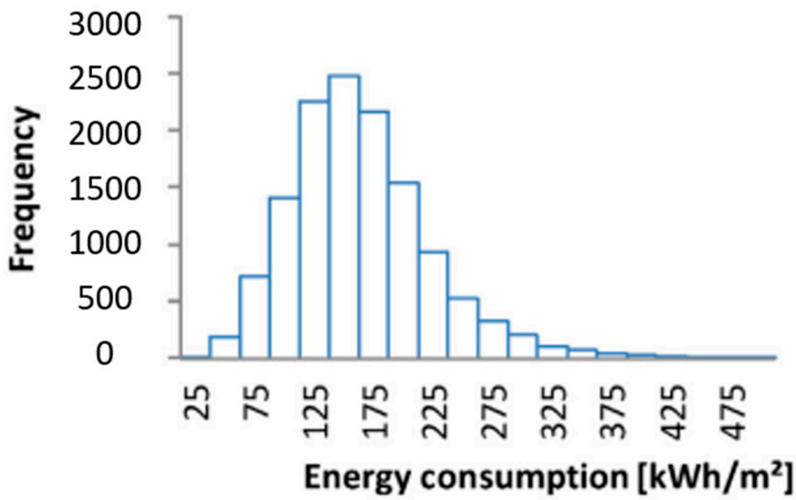

Figure 3. Frequency histogram of the energy consumption [kWh/m^2] of rental premises, mainly offices in Sweden [81].

Due to the changes in Swedish energy performance legislation, three construction periods were analyzed in the Swedish EPCs. The mean energy consumption was 159 kWh/m^2 for offices built before 1979, 137 kWh/m^2 for 1980–2009, and 87 kWh/m^2 for 2010 onwards, respectively. About 57% of the energy in office buildings was spent on heating, 27% on electricity for facility system support, 10% on cooling, and 6% on hot tap water [81].

Norway. The Energy demand of Norwegian building stock constitutes about 40% of the final energy consumption, 22% of which goes to the residential sector and 18% to the non-residential sector [87]. A comparison for energy requirements specified in the building code (TEK) for the selected types of N-RBs in Norway are shown Figure 4.

According to the Thema report, the measured average specific energy use of existing Norwegian office buildings was between 217 and 245 kWh/m^2. The calculated values for energy use deviated from the measured values, and the deviation increased after 1990 [42]. The net energy demand (the term in Table 2) is calculated for model buildings used for defining the building code. Therefore, Figure 5 shows simulated values for representative models of an office building, according to the standard NS 3031 [82].

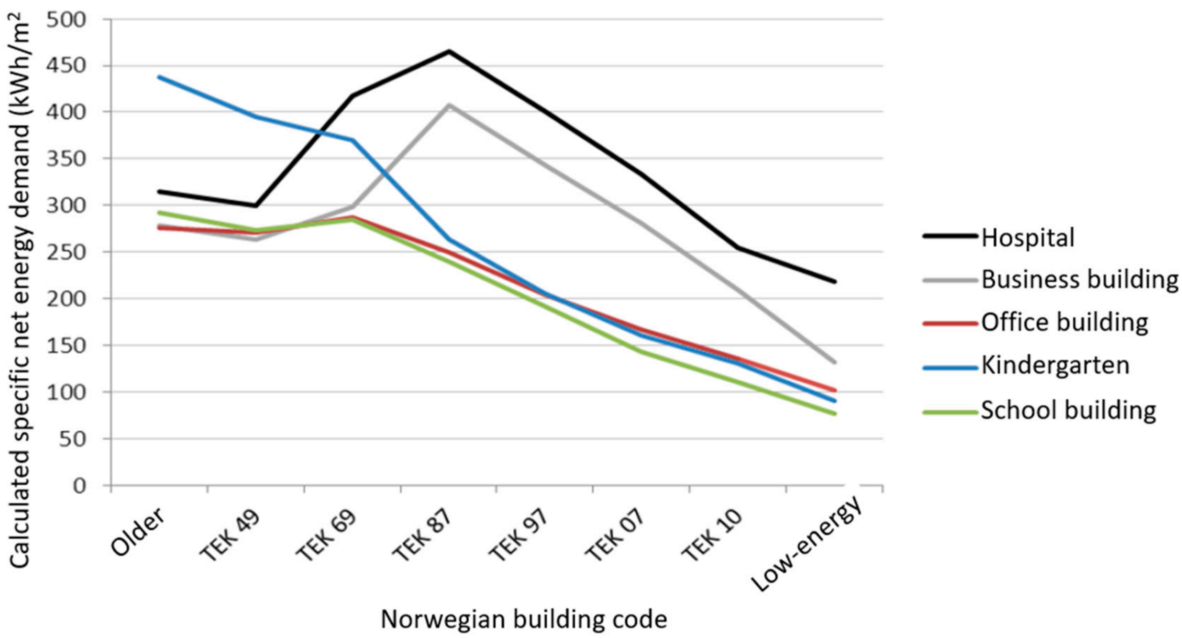

Figure 4. The development of requirements for energy frameworks in various TEK for some types of N-RBs, based on information of Multiconsult and Analyse&Strategi 2011 [88].

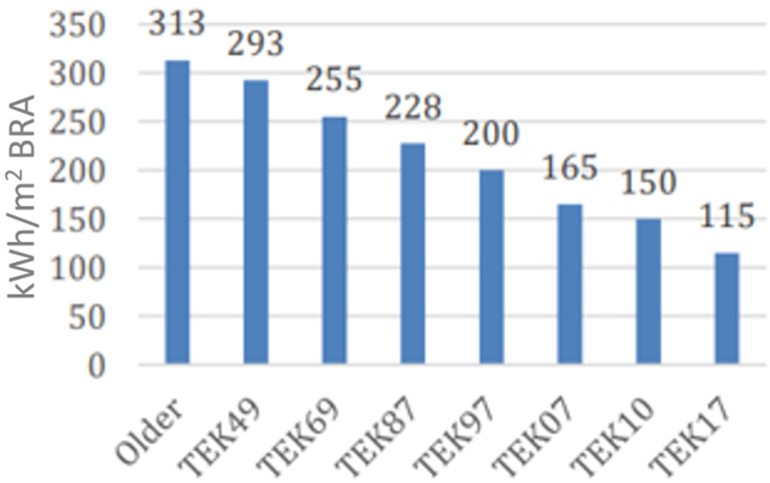

Figure 5. The development of calculated specific net energy demand of Norwegian office buildings based on building code (Multiconsult, simulated in SIMIEN) [88].

Figure 5 shows that changes in the Norwegian building code have consistently resulted in more EE buildings over decades [42]. In Norway, electricity has been the most regular energy carrier especially for office buildings [87]. From 1990 to 2010, the share of electricity varied between 78% and 85%. However, the trend decreased due to the increasing use of district heating by around 19% from 2000 to 2010 [89] and around 39% from 2011 to 2019 [90].

Most of the registered EPCs in Norway cover residential buildings. However, in the non-residential sector (2.7 million N-RBs in total), only approximately 9% of the buildings with a certifying obligation have an EPC (0.25 million N-RBs). The market for energy certification of N-RBs is non-uniform and less developed than for residential sector. Therefore, the number of gathered EPCs for N-RBs in Norway is not sufficient for an analysis and are based on calculations [62].

Denmark. A significant proportion of the total energy consumption (35%) in Denmark is used for heating buildings [33,91]. Since 1976 (first energy plan), there has been a focus on reducing energy consumption for heating. In 2018 the final energy consumption for heating per m^2 of heated area has been reduced by almost 45% compared to 1975 and net heat consumption per m^2 has been reduced by almost 30% [33] (Figure 6). The energy characteristics of the existing buildings in Denmark have been calculated based on a data sample (1,717,580 buildings) of the Central Register of Buildings and Dwellings (as of 13 June 2016, provided by the Danish Energy Agency) and the energy labeling scheme database (527,000 buildings) in 2017 [92], presented in Table 9.

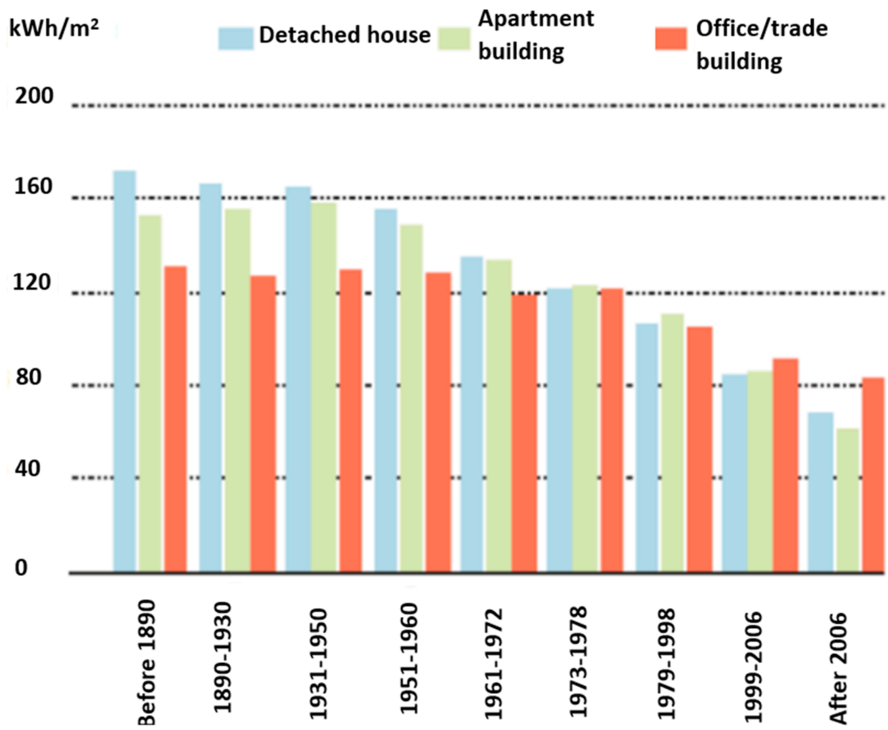

Figure 6. Average net heating demand of Danish buildings in kWh/m^2 (as of 2011) [91,93].

Table 9. Buildings in Denmark (as of 13 June 2016) and their calculated energy consumption (as of 23 January 2017) [33,92].

	No. of Buildings	Area, mm^2	TWh/Year	kWh/Year per m^2	MW
Farmhouse	113,980	22.0	2.77	126	1115
Detached house	1,102,462	162.2	20.50	126	8015
Terraced house	244,885	37.1	4.05	109	1532
Apartment building, etc.	102,558	92.3	10.36	112	4040
Trade and services	109,180	84.4	7.72	91	3868
Institutions	44,515	38.3	3.97	104	1969
Total	1,717,580	436.3	49.37	113	20,539

Table 9 shows that more than half of the energy consumption for heating in buildings was used in single-family houses (detached houses, terraced houses, and farmhouses). The analysis of Danish Building Research Institute concluded that around 80–85% of the potential energy savings associated with renovations lie in buildings constructed before 1979 [92]. More than 70% of the Danish building stock has been constructed before 1979, that is, before any significant energy requirements for buildings [91].

Table 9 and Figure 6 show that the average net heating demand of office and trade buildings is lower (91 kWh/year per m^2 than other types and has been decreasing through different decades of construction.

Germany. N-RBs in Germany are characterized by relatively large floor areas and energy requirements per m^2, which forms 37% of the total energy consumption. A large potential could be assumed for energy and costs savings, particularly in the groups of offices, hotels, and commercial buildings [24].

German energy certificates indicate either the primary energy demand or the final energy consumption [46]. The evaluation is based on the data from 52,100 energy certificates and the energy parameters for heating and hot water [36]. Figure 7 shows the differences between energy demand and energy consumption between the individual building age classes of the office buildings in Germany.

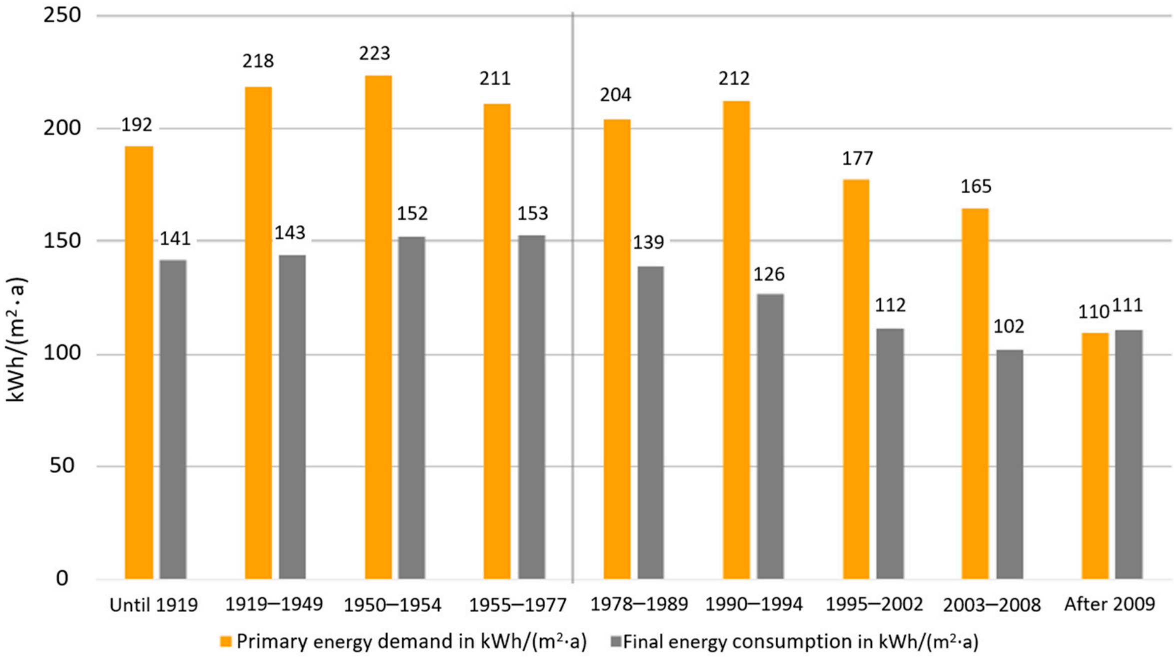

Figure 7. Comparison of the primary energy demand and final energy consumption according to the age of the German office buildings. Evaluation: German Economic Institute (IW), Cologne [48].

An office building has an average primary energy demand of 185 kWh/(m^2 a) and an average energy consumption of 136 kWh/(m^2 a), but for office buildings constructed after 2009, both characteristic values are equal with 110 and 111 kWh/(m^2·a). The quantity model and the evaluated energy indicators for heating and hot water result in a total energy consumption 51.9 TWh/a for office and administration buildings. Overall, the energy consumption of all office and administration buildings for heating, hot water, lighting, and cooling was found to be around 65 TWh/a. This corresponds to the consumption of around 20 percent of all NR-B and around 6 percent of the entire building sector in Germany [48].

2.3. National Levels and Cost-Effective Measures of Renovation of Non-Residential Buildings in the Studied Countries

The national concepts or levels of renovation of the existing N-RBs in the studied countries are summarized in Table 10 and discussed afterwards. Also, possible cost-effective renovation measures for N-RBs are discussed.

Table 10. Current renovation levels for existing N-RBs in the studied countries [29,33,37,43,62].

	Finland	Sweden	Norway	Denmark	Germany
Renovation levels	Nearly zero energy (nZEB)	Level 0: 4%; Level 1: 10% Level 2: 30% Level 3: 50% (40% for offices)	Low energy. Passive. Zero emission (five ambitions).	Light: <30%. Medium: 30–60%. Deep: >60%.	Standard (EnEV). Moderate (KfW 100). Ambitious (KfW 55)

Finland. The cost-effective measures of EE and decarbonization in Finland were found as building loss, space utilization efficiency, EE improvements in connection with renovations and maintenance, and replacing fossil energy sources in heat generation. According to the results of the Ekorem model, the energy consumption of different building components or technical systems of N-RBs were divided as follows [37,94]:

- Ventilation/air-conditioning 45%;
- Lighting, electricity consumers 27%;
- External walls 10%;
- Windows 9%;
- Roof structures 7%;
- Water 2%;
- Base floor 1%.

The renovation actions of building technical systems or components are listed in Table 11.

Table 11. Renovation actions of the technical systems or components of NR-Bs in Finland [37].

Building Component/System	Renovation or Replacing Actions
Ventilation	Instalment of efficient ventilation heat recovery system or replacement of the existing heat recovery system. Applying smart ventilation control system as a replacement for existing system.
Electricity	Replacement the existing lighting with LED lighting. Instalment of movement sensor based lighting system. Instalment of photovoltaic panels for the all-year-use building.
Heating system	Instalment of automation and smart control to the existing heating system. Perform balancing of the upgraded heating system.
External walls	Instalment of additional layer of insulation at the time of replacement of external cladding. Perform sealing of the joints between the building structures.
Roof	Instalment of additional layer of insulation during roof renovation when technically feasible.
Windows	Replacement of energy inefficient windows or windows in a poor technical condition.
Base floor	Replacement or instalment of additional layer of insulation against freezing.
Domestic hot water	Adjustment of the pressure of the water pipe system. Replacement of the existing water fixtures with the water-saving. In case of high volumes of water instalment of heat recovery system from wastewater.
Decarbonised heating and cooling	Abandonment of fossil fuels. Replacement of the fossil fuels with geothermal heating or another carbon emission-free energy source. Replacement of the electrical cooling with district or geothermal cooling system if technically feasible.
Sources	Cost-optimal levels of minimum EE requirements in renovation projects, Ministry of the Environment, Finland

In order to assure the cost and ecological efficiency, the of N-RBs should be renovated comprehensively. Joint procurement processes and voluntary EE agreements have been found as reasonable approaches of investments [37].

Sweden: Since the property owners have varying expectations, it is the function of non-residential premises, which is determining the measures of renovations. Offices should be renovated after 40 years. It was found that a major renovation of offices was necessary within 15 and 20 years for offices from 1981–1990 and from 1960 to 1990, respectively [29]. Chalmers Industriteknik (CIT) has set four levels of renovation by applying the reference scenarios with computer simulation (HEFTIG) [95]. The measures for renovation packages for offices in Sweden are demonstrated in Table 12.

Table 12. Measures and levels of renovation of office buildings in Sweden [29].

	Daily Operation and Maintenance	Light Renovation, (Level 1)	Standard Improvement (Level 2)	Total Renovation (Level 3)
Upgrading ventilation systems	-	-	Yes	Yes
Demand-based and control of ventilation	-	Partially	Yes	Yes
Replacement of windows with more energy-efficient ones	-	-	Yes	Yes
Operational optimisation of cooling	-	-	Yes	Yes
Upgrading lighting in public and office areas	Yes	Yes	Yes	Yes
Additional attic/roof insulation	-	-	-	Yes
Measures around entrances	-	-	-	Yes
Shading	-	-	-	Yes
Hot water measures	-	-	-	Yes
Total energy saving:	4%	10%	30%	40%

Norway: The renovation measures have to be covered by the building regulations and are the same for new and existing buildings. SINTEF has elaborated guidelines for EE concepts on the example of office buildings in Norway (Table 13). The energy savings of each renovation measure are weighed case by case, and an exception from requirements could be given if the measure is proven to be cost-inefficient [96,97].

Table 13. Minimum requirements for renovated building components or technical systems of office buildings in Norway.

Building Components/Air Tightness	Building Components/Air Tightness		
	TEK17	Low Energy Class 1	Passive
Exterior walls, U-value (W/m^{2}K) $\leq$	0.22	-	-
Roof, U-value (W/m^{2}K) $\leq$	0.18	-	-
Exposed floor, U-value (W/m^{2}K) $\leq$	0.18	-	-
Windows, doors, U-value (W/m^{2}K) $\leq$	1.2	1.2	0.8
Thermal bridges $\leq$	-	0.05	0.03
Air tightness, air changes per hour at 50 Pa pressure difference (h^{-1}) $\leq$	3.0	1.5	0.6
Heat exchanger in ventilation system (%) $\geq$	-	70	80
Specific fan power (SFP) for ventilation fans kW/(m^3/s) $\leq$	-	2.0	1.5

In the Norwegian context, five different ambition levels have been defined for the zero emission building (ZEMB) balance during the lifetime of a building, in terms of greenhouse gas equivalents (CO_2 equivalent) [98].

- ZEMB-O(EQ): Net embodied emissions of use of operational energy of a building excluding (including) the energy use for the equipment. These emissions should be balanced by renewable energy production;

- ZEMB-OM(COM): Embodied emissions of use of operational energy use plus embodied emissions from materials, installations (and construction process) of a building. should be compensated by renewable energy production;
- ZEMB-COMPLETE: Embodied emissions of a complete lifecycle of a building, which could include the reuse, recovery and recycling of building materials.

Denmark: The Danish Building Research Institute has prepared and grouped the anticipated renovation depth of the existing buildings in 2020 into the categories presented in Table 14. The heat requirement of buildings is calculated normatively using the energy rating with an indoor temperature of 20 °C including hot water and pipe losses, but excluding conversion and supply losses. Based on the heat requirement data, the buildings in the analysis are grouped according to the magnitude of the calculated heat requirement corresponding to the level of detail in the energy rating scale with the deduction of a typical electricity requirement for building operation of 5 kWh/m^2 (corresponding to approximately 2 kWh/m^2 multiplied by the primary energy factor for electricity of 2.5) [99].

Table 14. Grouping of renovation depth calculated according to energy rating and heat requirement in Denmark [76].

Renovation Depth	Energy Rating	Heat Requirement, kWh/m^2/Reduction of Energy Consumption, %
No renovation	F or G	>235
Light renovation	E or D	135–235/<30%
Medium renovation	C or B	60–135/30–60%
Deep renovation	A *	<60/>60%

* A is the group of the ratings A1, A2, A2010, A2015, and A2020.

The Danish National Strategy for Sustainable Construction aims to phase-in life-cycle assessment (LCA) calculation requirement for new buildings into the building code by 2023. The strategy also introduces threshold limit values for maximum CO_2 emissions for new buildings (more than 1000 m^2) in 2023, and the phasing will take place gradually by 2025 [63].

Therefore, the concepts of ZEMB have been defined in Norway, and the threshold limit values for CO_2 emissions of new buildings will be set in the new Danish building code. The requirements for ZEMB, the carbon emissions, and perhaps the carbon metrics for buildings will be set in the new EPBD. However, currently it is not known whether the requirements for carbon emission will be concerning the major renovation of the N-RBs.

Germany: Three renovation levels: standard, moderate, and ambitious were applied to evaluate the renovation potential of the building envelope. The Energy Saving Ordinance (EnEV) [69] determines the primary energy demand value of existing buildings for major renovation at a standard level. The moderate level of renovation is based on the support program of KfW Efficiency House 100 by the KfW Development Bank. The primary energy demand of a building renovated at ambitious level corresponds to KfW Efficiency House 55 level (Figure 8).

According to the results reported in ENOB:dataNWG: the average annual building renovation rate of 0.7%/a of the building envelope was found to be insufficient to modernize the German building stock by 2045. About 2% of the exterior wall surfaces were renovated each year without being insulated at the same time. It would make a decisive difference in the energetic modernization dynamics if it were possible to couple these opportunities with insulation measures. With a moderate increase in the current modernization rate of 2.3%/a, a large proportion of the heat generators could be replaced again by 2045. The modernization dynamics from 2010 to 2014 shows differences between the different owner categories. During this period, the private institutional owners modernized the exterior walls and windows slightly above average and the main heat generators significantly above average. Public owners modernized the building envelope slightly above average, and significantly below average for the main heat generators. Private persons as owners renovated their N-RBs well below average during this period [25].

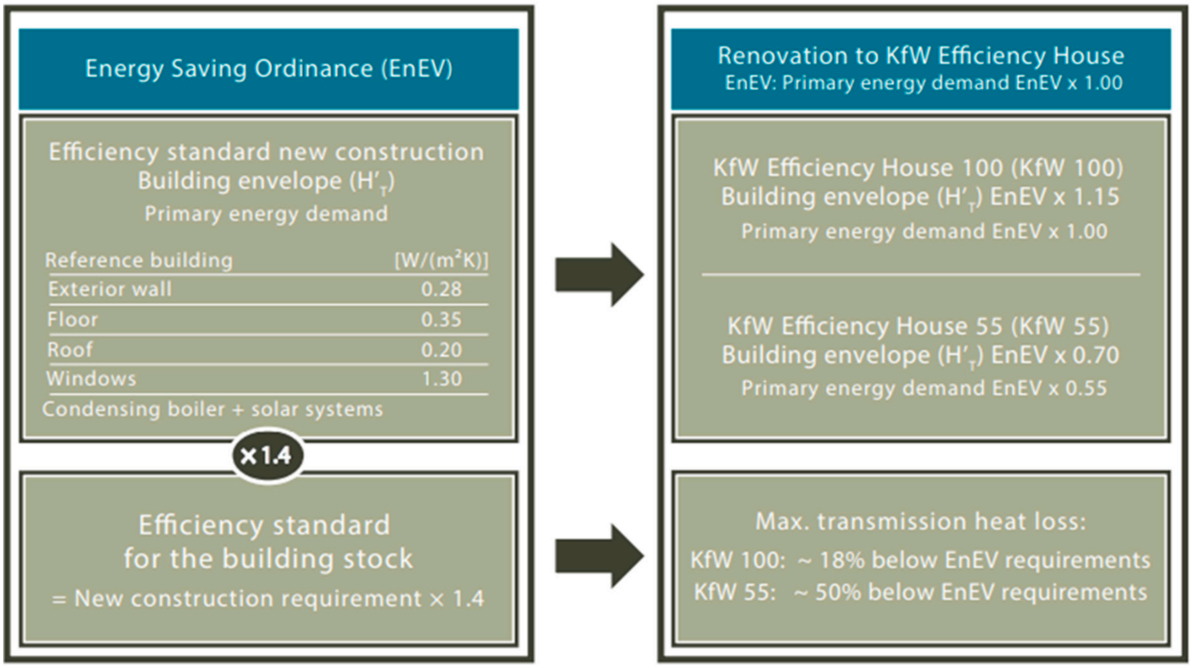

Figure 8. Three efficiency standards for energy renovation of existing German building stock (defined by the German building code and the support programme of kfW. Source: Fraunhofer Institute for Systems and Innovation Research [100].

2.4. Aspects Regarding Building Structures to Be Addressed before Making a Renovation Decision

Before making any decisions regarding renovation, the actual situation and problems should be mapped and the condition of existing structures of the studied building must be assessed. The main aspects, which have to be focused on renovation, is to improve the energy performance, functionality, and architectural solution, which could be solved using multi-objective optimization [101]. However, there are different building physical aspects regarding building structures, for example, thermal bridges, air tightness, moisture and microbial damage, and indoor air quality problems, which have to be considered. Often there are complex problems, and increasing the thermal resistance of the building structure could eliminate both thermal bridges and mold problems. There are also requirements to preserve the cultural value of historical buildings, where, for example, external insulation is not allowed. Sonntag et al. [102] (Germany) have developed a methodology for a renovation concept including the consideration of potentially existing moisture related problems on facades focusing on such sensitive cases as internal insulation of bricks walls. Hansen et al. [103] (Denmark) offered guidelines and introduced a web tool to estimate the risks and benefits of the internal insulation of historic buildings. In order to avoid moisture and mold damage, safety action plans have been developed in different countries: so called Dry Chain in Finland [104] and ByggaF in Sweden [105], also some specifications could be found in the Danish Building Regulations BR18 [54] and in TEK17 in Norway [67]. A database of best practices has been developed within IEA SHC Task 59 project (Renovating Historic Buildings Towards Zero Energy) in participation of the studied countries Sweden, Denmark and Germany [106]. Within the project RIBuild [107] a tool for evaluating whether a building is suitable for internal insulation, evaluation of technical condition, and a calculator for internal insulation were developed.

3. Conclusions

The majority of research attention has focused on the EE of new buildings, and also to the existing residential buildings in the EU, where systematic data has been gathered. The non-residential sector has been found to be very heterogenous associated with higher uncertainties in tracking all different types of N-RBs. Therefore, the data for N-RB stock in the EU is far less covered than that of residential stock. Although, there are less N-RBs, the average specific energy consumption per floor area of the N-RBs is found to be greater than that of the RBs. In this study, the national energy requirements equivalent for major renovation of the existing N-RBs and offices in the five studied countries are drawn out and discussed based on which the following conclusions are drawn:

- The division of the types of buildings in the studied countries was substantially different. The existing building stock has been divided into varying numbers of groups (from four to nine groups, and sometimes sub-groups). Three of the studied countries out of five differentiated N-RBs as a building group (heated/non-heated N-RBs were also differentiated). In the case of a large country, with numerous federal states, the existing building stock has been estimated, whereas in countries with a smaller building stock, the existing buildings have been counted more accurately;
- Office buildings accounted for 0.69 to 2.13% of the total building stock. In comparison of the age classes of the buildings in the studied countries, the oldest office stock was found to be in Germany (a considerable number of offices constructed before 1919), whereas relatively younger office stock was noticed in Finland, Norway, Denmark, and Sweden (the majority of offices constructed between the 1960s and the 2000s). The first national energy requirements for buildings in Finland, Sweden, and Norway were introduced at the end of the 1940s, in Denmark at the start of the 1960s, and in Germany at the end of the 1970s. Therefore, for example, more than half of the existing office stock in Germany was constructed before the introduction of the energy regulations (in 1978) and thus, it has a significant potential for energy savings;
- The EE of N-RBs in all of the studied countries has been steadily improved during different decades of construction. Therefore, the impacts of renovation on improving the energy efficiency of buildings have been confirmed. The reasons were energy crisis (in 1970s), the introduction of first and afterwards more stringent energy requirements for buildings in national codes;
- The energy requirements have been shifting from the increasing requirements for the U-values of the building envelope (before the 2000s) towards the calculated energy demand for a building as a whole (with its technical systems) in the 2000s. The requirements for zero emission buildings, the carbon emissions (metrics) of buildings will be set in the new EPBD. The concepts and ambition levels in terms of greenhouse gas equivalents for ZEB have been already defined in Norway;
- There are comparable minimum requirements for the calculated U-values of building components in the studied countries. The strictest (minimum) requirements for the U-values and air tightness of the building envelope are stipulated in Finland and in Norway, respectively. Considerable increase in EE is required for renovating the existing buildings in Germany as well; however, the U-values are not as strict as in the studied Nordic countries;
- The Nordic countries have set the energy performance value for the renovation of existing buildings. The principles for energy estimation vary from calculating the primary energy number (Sweden), demand (Germany), total net energy demand (Norway, Denmark), or energy consumption (Finland, Germany) per floor square meter (determined by varied methodology) of a building.The term "major renovation" as in the EPBD is also used in the Norwegian building regulation. The term "alteration" or similar to it is used for renovation in the Finnish, Swedish, and Danish regulations. A "standard" type of renovation could be considered as the closest in German regulations;
- The adoption of energy performance certificates (EPC) has added value to the detailed energy data of buildings and also to N-RBs. However, the data gaps, lower certification

of N-RBs (e.g., in Norway) and limited access to data (e.g., in Germany) prevent the exploitation of the full potential of the EPC schemes;
- So far, the previously published information on the energy renovations of the N-RBs and office buildings in the studied countries have been scarcely published in English.

4. Prospects for Future Work

Current work takes into account the data gaps for energy performance related information for non-residential buildings. More detailed information could be acquired in the future as the information gaps will be filled during time. The current review could be used as a basis for a more detailed comparison of energy performance values of renovation of non-residential buildings in the future. The review could be also used as a basis for future developments of national building codes in Europe.

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Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

ARA	Housing Finance and Development Centre of Finland
BauGB	Federal Building Code of Germany (Baugesetzbuch)
BauNVO	Federal Land Utilization Ordinance
BBR	Boverket's Building Regulations (Sweden)
Boverket	National Board of Housing, Building and Planning (Sweden)
BR(18)	Building Regulation of Denmark
CIT	Chalmers Industriteknik (Gothenburg, Sweden)
Dena	Deutsche Energie Agentur
Destatis	The Federal Statistical Office of Germany
DIBt	Deutches Institut für Bautechnik (Germany)
EE	Energy efficiency
EED	Energy Efficiency Directive
EEWärmeG	Renewable Energy Heat Act
EnEG	The Energy Conservation Act (Germany)
EnEv	Energy Saving Ordinance (In German: *Energieeinsparverordnung*), (Germany)
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EU	European Union
EvEV	Energy Conservation Ordinance (Germany)
GEG	Buildings Energy Act (Germany)
HEFTIG	Computer simulation programme (Sweden)

IEA SHC	International Energy Agency Solar Heating and Cooling progamme
IW	German Economic Institute (Cologne)
KfW	German Credit Bank for Renovation (In German: *Kreditanstalt für Wiederaufbau*)
LCA	Life-cycle assessment
MS	Member States
MVV TB	Model Administrative Provisions–Technical Building Rules (Germany)
N-RB	Non-residential building
NZEB	Nearly zero energy buildings
SBi	Danish Building Research Institute
SYKE	Finnish Environmental Institute
TEK(17)	Norwegian Building Code
VTT	Technical Research Centre of Finland
ZEMB	Zero emission buildings

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