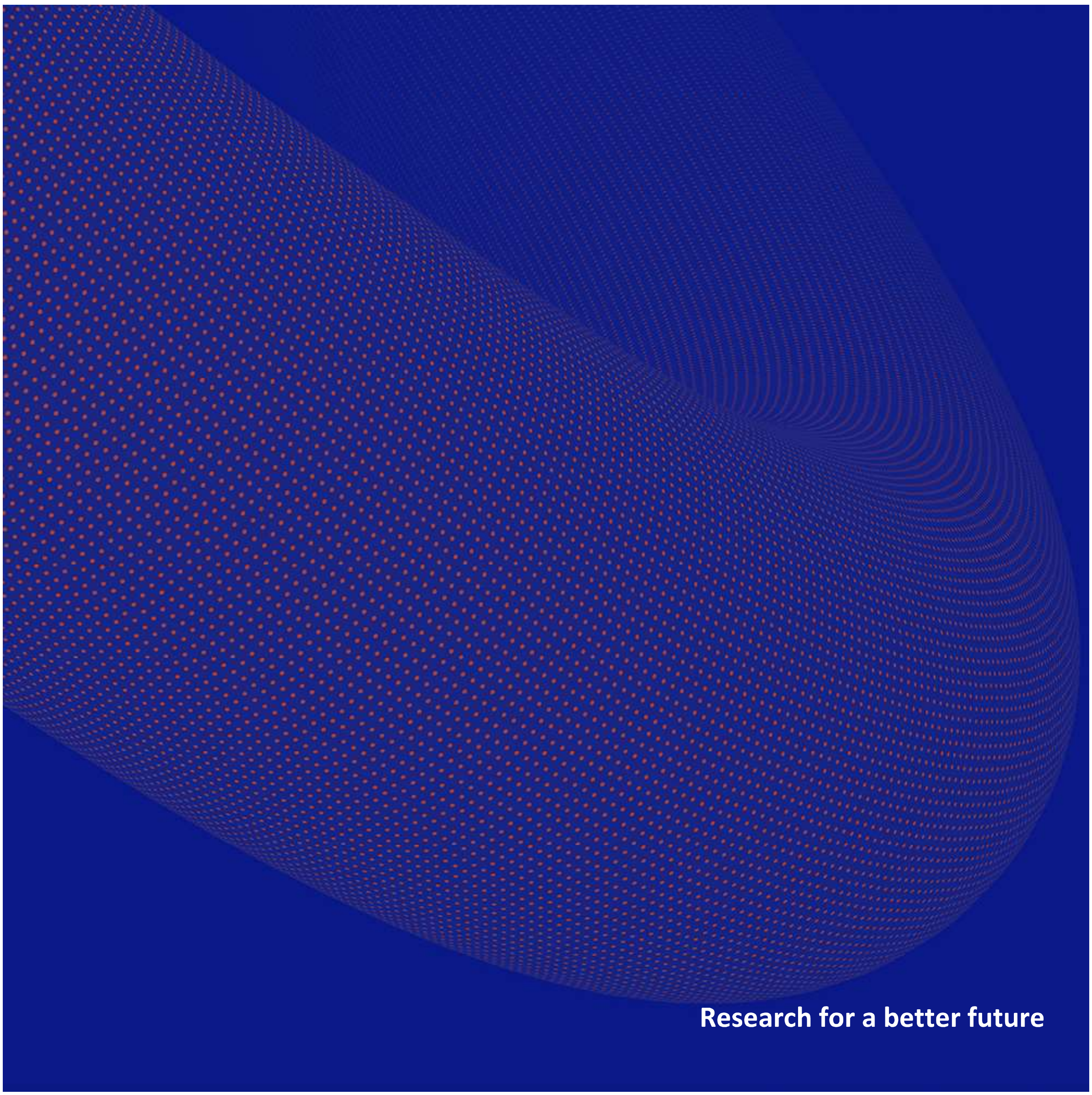
Building energy efficiency measures in Norwegian energy system analysis

IFE/E-2023/007



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Title:
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Summary:

This report is a part of the project "Role of energy behaviour in the low carbon transition", BEHAVIOUR, that is a research project financed by the Norwegian Research Council. The primary objective of BEHAVIOUR is to map how the energy behaviour of private households can, and needs, to be changed to support a desirable development of a low-carbon energy system, and how this complex system of behaviours can be included in energy system modelling.

This report presents background data for the potential of energy efficiency measures in Norwegian buildings and how it is adjusted to fit in with the energy system model IFE-TIMES-Norway. It is based on data from previous work of NVE and Multiconsult in 2020 and the data is further processed for adaption in energy system analyses.

The technical energy efficiency potential is calculated to 37 TWh in 2025 for all buildings. It is divided in 18 TWh in single-family houses, 3 TWh in multi-family houses and 17 TWh in non-residential buildings. This represents 43% of total energy demand in single-family houses, 36% of total demand in multi-family houses and 53% of total demand in non-residential buildings.

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Contents

1 Introduction

Upgrading the building mass to a higher energy standard, also called building retrofit, is an energy efficiency measure that can significantly contribute to lower the energy demand. This report derives and presents the potential, and corresponding costs, of energy efficiency measures related to upgrading of existing Norwegian buildings. The analysis builds on data that is provided by the Norwegian Water and energy Directorate (NVE), that is based on a study by Multiconsult in 2020 [1]. The potential and cost data are split between climate regions, building standards, and building types. The derived energy efficiency data will be used as model input to the to the Norwegian energy system model, IFE-TIMES-Norway [2], to analyse the role of energy efficiency in the energy system transition.

This report is a part of the project “Role of energy behaviour in the low carbon transition”, BEHAVIOUR [3], that is a research project financed by the Norwegian Research Council. The objective of BEHAVIOUR is to map how the energy behaviour of private households can, and needs, to be changed to support a desirable development of a low-carbon energy system, and how this complex system of behaviours can be included in energy system modelling. The data derived in this report is a first and necessary step, to analyse the value and energy system impact of building mass upgrades. The cost data of this report is conservative as it includes the whole cost of upgrading the building mass. The cost can be lower if the upgrades are done at the same time as other upgrading needs of a building, for example when changing windows.

BEHAVIOUR [3] targets three different types of behaviors from households; 1) building mass upgrades, 2) installation of PV and 3) flexible energy use. This report focuses presents the techno-economic assumptions that is used related to the first type of behaviour, building mass upgraded.

The report is structured as follows. First, we describe energy system model, followed by the background data from the study of NVE and Multiconsult. Then, the adoption of the data is described in chapter 4, followed by the implementation to the energy system model, IFE-TIMES-Norway, in chapter 5, and further work in chapter 6. More details are provided appendices; the %-savings per measure, building type, building standard and region in Appendix A, and LCOE (Levelized Cost of Energy) per measure, building type, building standard and region in Appendix B

2 Energy system model – IFE-TIMES-Norway

2.1 Model description

The TIMES modelling framework is developed within the ETSAP (the Energy Technology Systems Analysis Program) IEA implementing agreement during several decades [4]. TIMES is a bottom-up framework that provides a detailed techno-economic description of resources, energy carriers, conversion technologies and energy demand. The framework is mainly used for medium and long-term analysis on global, national and regional levels, including the Energy Technology Perspectives [5] and World Energy Outlook [6] of IEA. TIMES models minimise the total discounted cost of the energy system to meet the demand for energy services for the analysed model horizon.

IFE-TIMES-Norway is a technology-rich model of the Norwegian energy system divided into five regions corresponding to the current electricity market areas. The model provides operational and investment decisions from the starting year, 2018, towards 2050, with model periods for every fifth year from 2020 to 2050. To capture operational variations in energy generation and end use, each model period is divided into 96 sub-annual time slices, where the four seasons are represented by one day of 24 hours in each season. IFE-TIMES-Norway minimizes the total discounted cost of the energy system in meeting the Norwegian demand for energy services for the period 2018-2050. The energy system cost includes investment expenditures in supply and demand technologies, storage technologies and transmission lines, operation and maintenance costs, and costs of net electricity imports [2].

The model has a detailed description of end-use of energy, and the demand for energy services is divided into numerous end-use categories within manufacturing, buildings, and transport. Note that energy services refer to the services provided by consuming a fuel and not the fuel consumption itself. Each energy service demand category can be met by existing and new technologies using different energy carriers such as electricity, biofuel, hydrogen, and fossil fuels. Other input data include fuel prices, electricity prices in countries with transmission capacity to Norway, renewable resources, and technology characteristics such as costs, efficiencies, and technology learning curves. The discount rate used is 4 percent and the monetary unit of the model is Norwegian kroner (NOK) with an exchange rate of 1 NOK = 0.1 €.

The use of electricity, hydrogen, district heating and biofuels are examples of operational decision variables. Consequently, the marginal prices of these energy carriers are a model result. Petroleum products and imported biofuels are examples of energy carriers that are determined outside the model, i.e., exogenously.

The building sector of TIMES-Norway is divided in residential single-family and multi-family houses and in non-residential/commercial buildings for each of the model regions [2]. All buildings are divided in existing and new buildings. The existing buildings have a stock of equipment in the start year. The end-use demand is divided in central heating (HC), point source heating (H), hot water (W) and electricity specific demand (E). Heating is divided in central heating (water borne system) and "point source" heating. Buildings with central heating can be connected to a district heating grid, but due to high costs it is assumed that single-family houses don't connect to district heat [7].

Norway is divided into five electricity price regions, NO1-NO5, in the model. When site specific data such as temperatures are needed, the following cities represents these regions: Oslo (NO1), Kristiansand (NO2), Trondheim (NO3), Tromsø (NO4) and Bergen (NO5).

2.2 Modelling of energy efficiency

The model is driven by end-use demand of energy services. Energy efficiency measures can be included in the demand projection or be part of the optimization model. IFE-TIMES-Norway normally includes regulations in the demand projection and end-use technologies, e.g., heat pumps is always a part of the optimization, see Figure 1. Conservation measures, e.g., improved insulation can either be a part of the demand projection or be modelled as technology options and be part of the optimization. Behavioural measures are difficult to include.

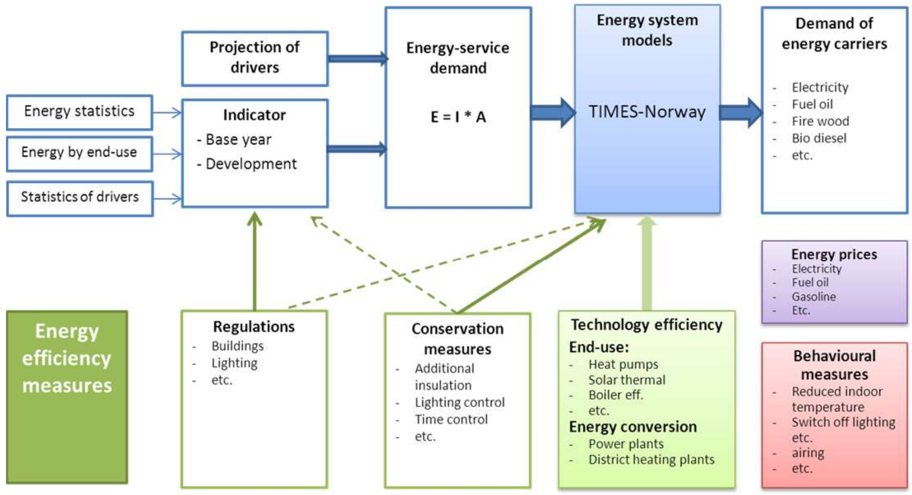

Figure 1: Schematic overview of modelling of energy efficiency in IFE-TIMES-Norway

In this study, regulations such as improved building standards of new buildings are included in the projection, while conservation measures and end-use technologies are modelled as technology options. This endogen modelling of energy efficiency includes data on investment costs (NOK/kWh), lifetime (years) and maximum potential (upper bound on activity in kWh/year) for each geographical region and model year.

The end-use demand projection is based on work in the research project FlexBuild [8], corrected for no energy efficiency improvement in existing buildings, since it is modelled explicitly as investment options in our study. Figure 2 presents the model input on energy service demand of existing and new single-family, multi-family and non-residential buildings for the years 2018, 2030 and 2050 and divided into end-use of specific electricity use, space heating and tap hot water heating,

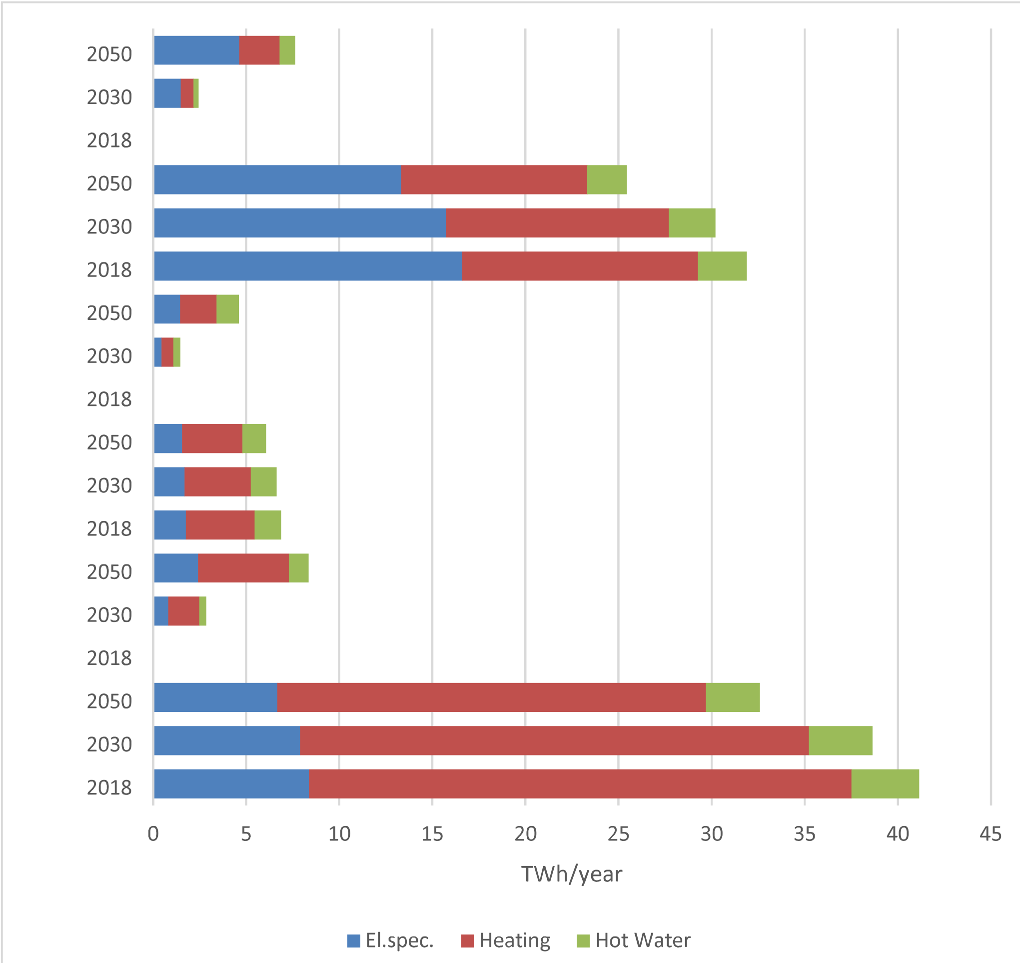

Figure 2: End-use demand projection in buildings in IFE-TIMES-Norway (TWh/year)

3 Background data

In 2021, the Norwegian Water and Energy Directorate (NVE) and the Norwegian Building Authority (DiBK) delivered a report as a support to a long-term strategy for energy efficiency in combination with renovation of buildings to the Ministry of Local Government and Regional Development and to the Ministry of Petroleum and Energy [9]. The reported technical potential for energy renovation of buildings was calculated to 26 TWh in single-family houses, 4.3 TWh in multi-family houses, and 18.5 TWh in non-residential buildings, in total 48.8 TWh. This report was built on a detailed study of potentials and costs made by Multiconsult on behalf of Norwegian Water and Energy Directorate (NVE) in 2021 [1]. This study covers 13 energy efficiency measures in 13 building categories that are listed below. The data from this work is further processed in our work, to fit in with the energy system model IFE-TIMES-Norway.

Measures:

1. Insulation of walls
2. Insulation of roof
3. Insulation of floor
4. New windows and doors
5. Reduced indoor temperature at nights and weekends
6. Improved heat recovery in ventilation
7. Improved power efficiency
8. Improved ventilation regulation
9. Lighting regulation
10. Energy efficient lighting
11. Automatic sun protection
12. Demand controlled ventilation (DCV)
13. Energy management systems

Building categories:

1. Single-family houses
2. Multi-family houses
3. Kindergarten
4. Offices
5. Schools
6. University/higher education
7. Hospitals
8. Nursing homes
9. Hotel
10. Sports
11. Wholesale and retail
12. Culture
13. Light industry / workshop

Further, the energy efficiency data is split by four different building standards (TEK97, TEK87, TEK69 and TEK49 or older) and five climatic zones (Bergen, Kristiansand, Oslo, Tromsø and Trondheim). The building standard TEK49 was in use from 1949 until the next building standard came in 1969, and so on. The oldest houses are built before 1969 and are based on TEK49 or older standards. As shown in Figure 3, the building standard has a significant impact on the demand for energy services of buildings per square meter, in particularly on the space heat demand.

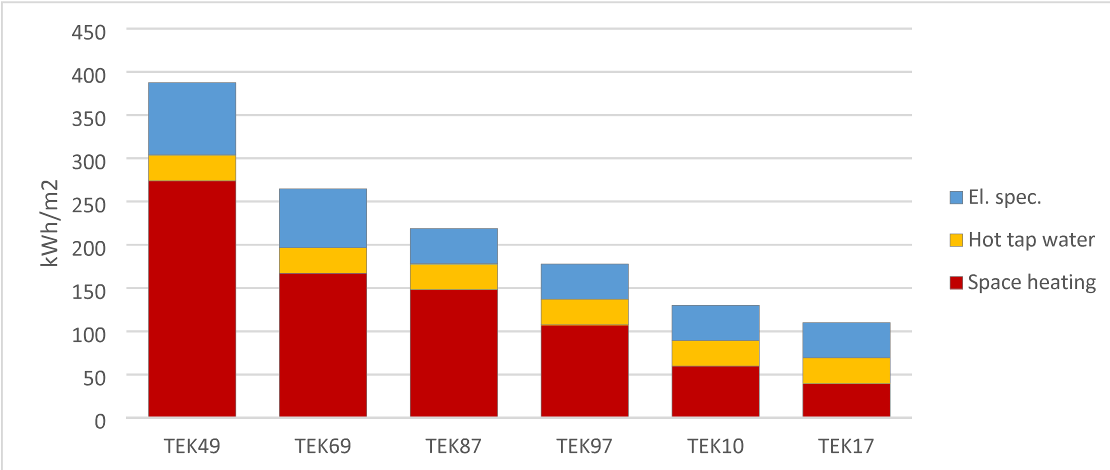

Figure 3: The energy service demand split by building standards (TEK) for single-family houses in Oslo, kWh/m2.

The energy efficiency measures are calculated individually with the SIMIEN program, and the results gives savings in kWh/m^2 and as % of energy demand. The %-savings are presented in Appendix A in tables A1-A7.

The area per building type, building standard and region is provided by the inhouse model of NVE, BEMA, and is illustrated in Figure 4. In the figure, data for several non-residential buildings are aggregated in “other”, but separate data are available in the data source. The share of area per building standard (TEK) is presented in Figure 5.

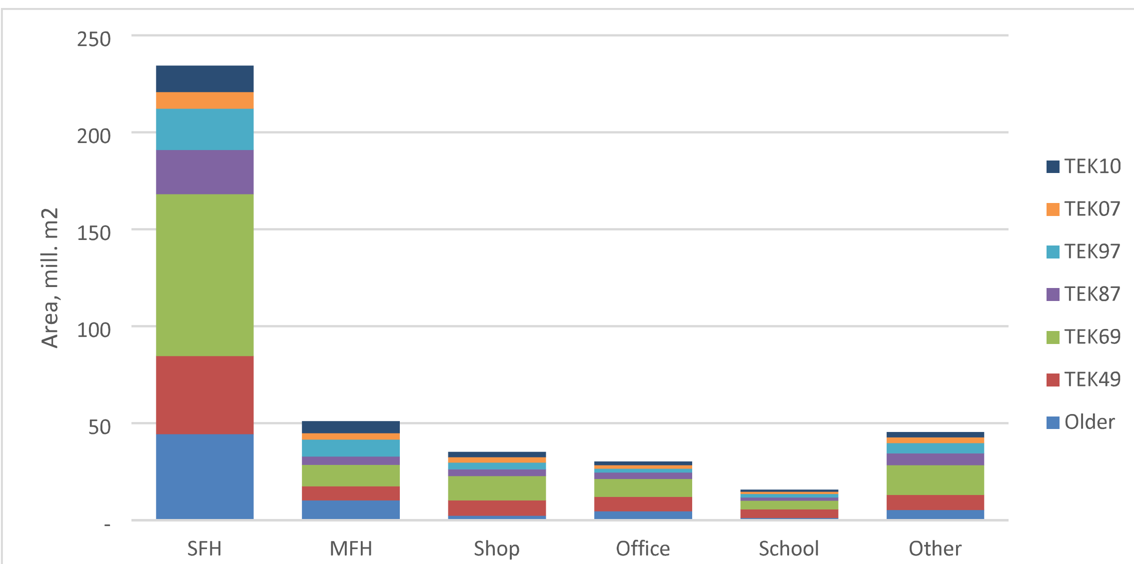

Figure 4: Area per building type and building standard (TEK) in Norway, million m2. SFH is Single Family House, MFH is Multi Family House, and Other includes other non-residential buildings.

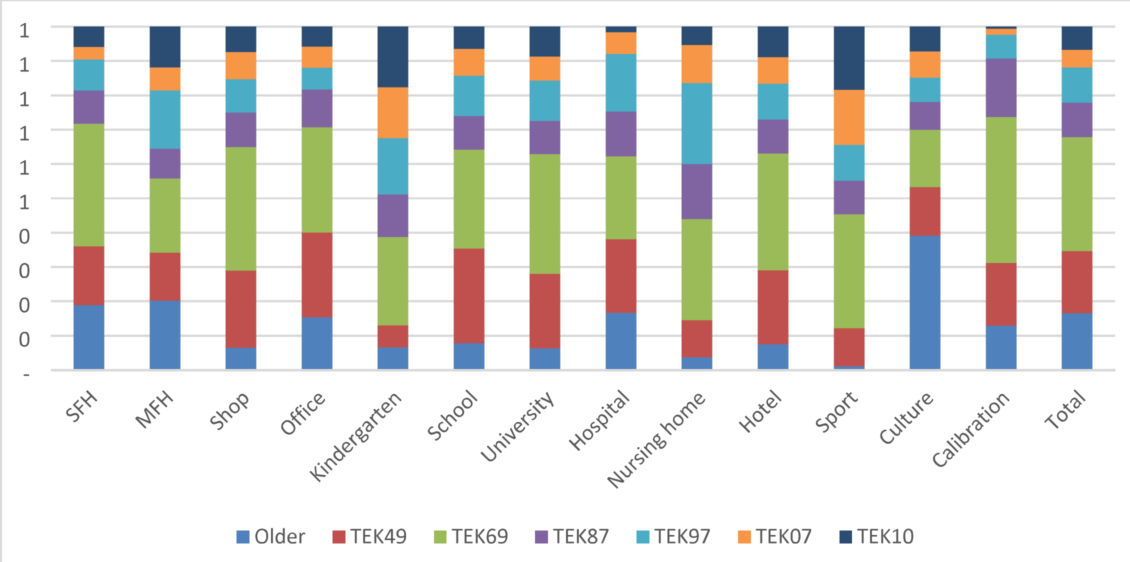

Figure 5: Area share by building standard (TEK) and building category in Norway. SFH is Single Family House and MFH is Multi Family House.

The energy demand is divided in demand for space heating, hot tap water and electricity specific use for each building type, building standard, and region. An example of data for residential houses in Oslo is presented in Figure 6.

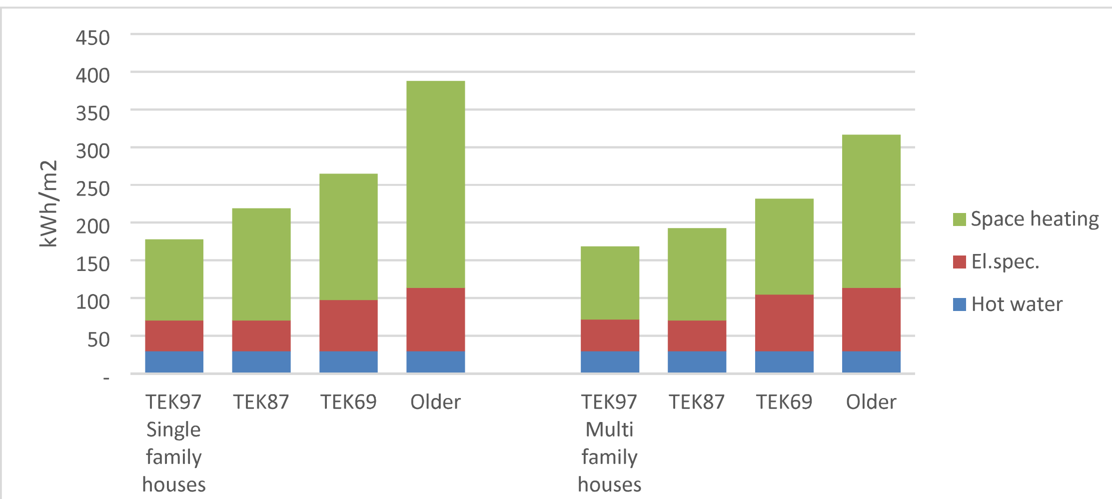

Figure 6: Energy demand by building standard for single- and multi-family houses in Oslo, kWh/m2

The application of the measures by building type, building standard and end-use is schematically presented in Table 1.

Table 1: Measures and the appliance on sector, building standards and end-use sector (X=relevant, (x)= relevant to a smaller extent, - = not relevant)

Measure	Resi-dential	Non-resi-dential	Building standard	End-use			
				Heat	Hot water	El.spec	Cooling
Insulation of walls	X	X	Not TEK97	X	-	-	(x)
Insulation of roof	X	X	Not TEK97	X	-	-	(x)
Insulation of floor	X	X	Not TEK97	X	-	-	(x)
New windows and doors	X	X	Not TEK97	X	-	-	(x)
Reduced indoor temperature at nights and weekends	X	X	All	X	-	-	(x)
Improved heat recovery in ventilation	X	X	All	X	-	-	-
Improved power efficiency		X	All	(x)	-	X	X
Improved ventilation regulation		X	All	X	-	X	X
Lighting regulation		X	All	X	-	X	X
Energy efficient lighting	X	X	All	X	-	X	X
Automatic sun protection		X	Not TEK97	X	-		
Demand controlled ventilation (DCV)		X	All	X	-	X	X
Energy management systems	X	X	Not TEK97	X	X	X	X

The calculations of energy savings per measure, building and building standard are based on the original building standard, but some are renovated and thus the building standard is improved. No statistics exists of to what degree this is done and therefore, background experience was used to estimate to what degree simple energy efficiency measures (e.g., weather stripping), renovation (with improved building insulation) or both has been done and thereby reduced the energy use. The following factors was in [9] used to compensate for improvements of different building segments (resulting in decreased energy use per building):

- Simple energy efficiency measures 0.8
- Renovation 0.7
- Both renovation and energy efficiency measures 0.65

The saving potential was further reduced by use of a factor of 0.89 to compensate for internal dependence of measures.

The technical lifetime of the energy efficiency measures is presented in Table 2.

Table 2: Technical lifetime of the energy efficiency measures (years)

Measure	Lifetime (years)
Insulation of walls	60
Insulation of roof	60
Insulation of floor	60
New windows and doors	30
Improved heat recovery in ventilation	20
Improved specific fan power (SFP)	20
Demand controlled ventilation DCV	20
Red. indoor temp. nights/weekends	15
Energy efficient lighting	15
System for lightning control	12
Energy Monitoring System	10
Building management system (SD)	15

The levelized cost of energy (LCOE) for all measures and building types with different hurdle rates, where calculated, where examples of LCOE is presented in Appendix B tables B1-B3 and in Figure 7.

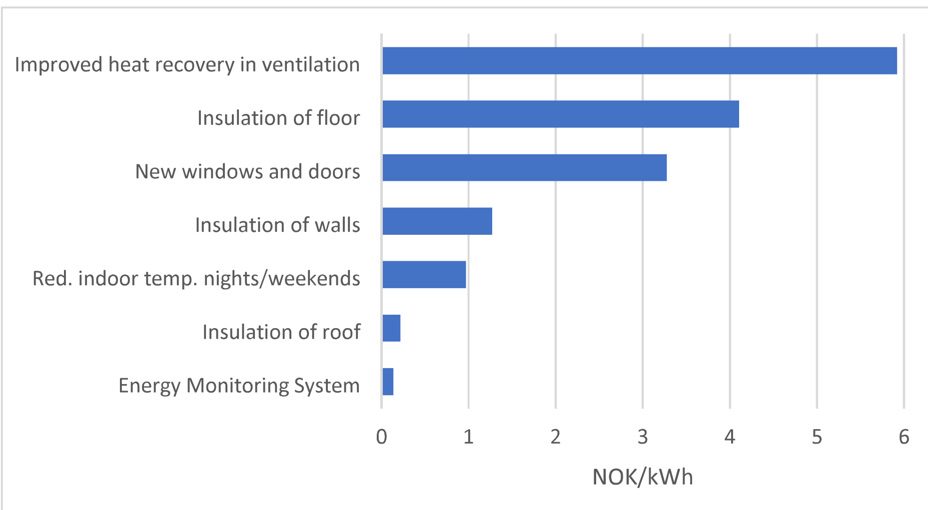

Figure 7: Levelized cost of energy (LCOE) for energy efficiency measures in old single-family houses in Oslo with 6 % hurdle rate and incl. Value Added Tax, NOK/kWh

The annual technical energy efficiency potential is calculated to 26 TWh in single-family houses, 4.3 TWh in multi-family houses and 18.5 TWh in non-residential buildings, in total 48.8 TWh [9]. In these calculations, it is taken into account that some buildings already have implemented measures and further reduced the potential by 10% to compensate for overlapping measures [9].

4 Adaptation of data

4.1 Reason for adaptation of data

The study by Multiconsult focus on the energy savings of each individual measure and does not explicitly capture how a combination of several measures lowers the energy service demand. If all the measures in the study by Multiconsult is aggregated directly, the potential for energy efficiency savings becomes unrealistic high. An example of this is shown in Figure 8 for old single-family houses in price region NO1. The total energy demand for space heating is calculated to 5.7 TWh/year and the total savings if all energy efficiency measures are aggregated are 9.9 TWh/year. In this previous study, the potential was reduced to 6.6 TWh/year by adjusting for already implemented renovations as shown in the middle column of Figure 8. It was further adjusted for internal dependence of measures by use of a factor of 10%, but instead of using this method the adjustment used in our study is described in section 3.2 and 3.3.

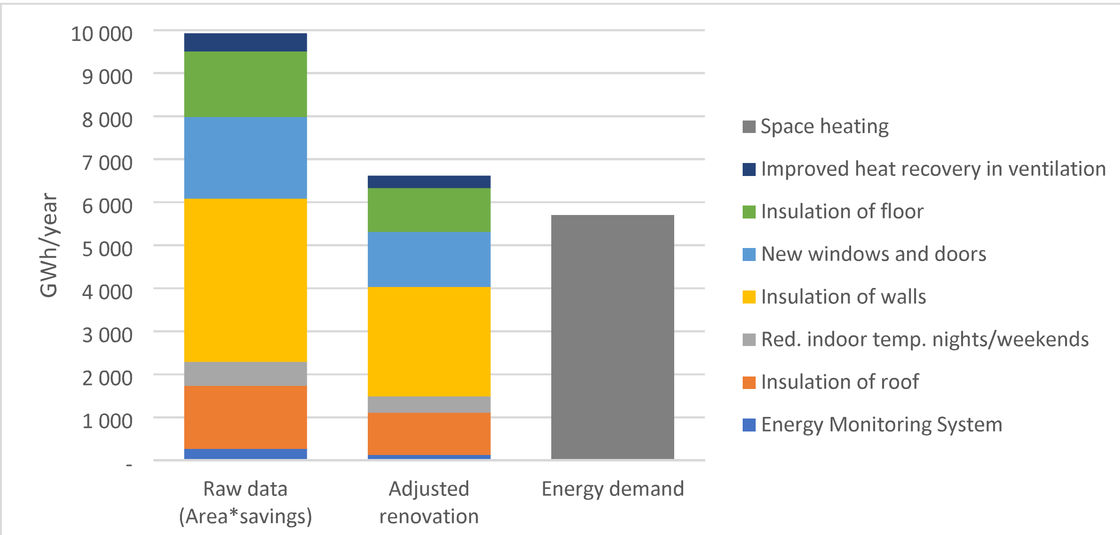

*Figure 8: Energy demand, energy savings based on area * savings (m2 * kWh/m2) and adjusted for earlier renovations, for old single-family houses in NO1 (GWh/year).*

The focus of the Behaviour project is on dwellings and therefore the focus on the adaption of the data has been on the residential sector, and non-residential buildings are of less importance.
We focus on the impact of space heat demand and does not consider the impact of energy efficiency on the cooling demand.

An example is improved insulation of walls, that according to the raw data, has an impact on both space heating and cooling, but in Norwegian conditions, the impact on cooling is rather low, particularly in dwellings, and therefore only the reduced heating demand is included in the data used in IFE-TIMES-Norway. Similarly, the measure "Automatic sun shading" is not included in the model, since it only impacts buildings connected to a local cooling system and this is only a small share of Norwegian buildings.

We consider the raw data to have an unrealistic high potential for the "Energy efficient lighting" measure, as it according to our estimates save more energy than the electric specific demand. Further, for use in IFE-TIMES-Norway, we assume that there is a 10% savings in electric specific demand when efficient lighting is applied.

4.2 Calibration

The original data of the Multiconsult study is calculated for single houses/buildings per m2 and if this data is aggregated to total energy use, it differs from the statistics. The base year of IFE-TIMES-Norway is 2018 and the energy demand of buildings is calibrated with the energy balance of Statistics Norway in 2018. The energy efficiency potential also must be calibrated with the statistics and the following calibration factors are used:

- Single-family houses 0.87
- Multi-family houses 0.82
- Non-residential buildings 1.15

4.3 Correction due to inter-dependence

When a measure is implemented, the energy savings of the next measure is reduced measured as kWh/dwelling (or m2) and therefore all measures cannot be added directly. The potential energy savings of measures must be reduced based on previously implemented measures.

The order of implementation influences the energy savings of each measure. One way of ranking the implementation of the measures is to assume that the most profitable measures is implemented first. This is consistent with the investment strategy of a techno-economic model such as IFE-TIMES-Norway. The LCOE of each energy efficiency measure is used to rank the measures per building type and region. Note that this ranking is not necessarily applicable for real-life analysis, as households can have other preferences than least cost.

Energy saving potentials are calculated for each measure by multiplying the end-use demand by the %-savings in the study of Multiconsult. The energy saving per measure is reduced if other measure(s) already is implemented and thus reducing the end-use demand. This is handled by first ranking the measures based on the calculations of LCOE in the background data (using data with 6% rate, with VAT for single-family houses and without VAT for multi-family houses and non-residential buildings). Second, the end-use demand is successively reduced when a measure is implemented. The LCOE for single-family houses, multi-family houses, shops and offices is presented in Tables B1-B3 in Appendix B.

An example of energy efficiency heat measures in old single-family houses in Oslo (NO1) is presented in Table 3 and Figure 9. The measures are sorted by increasing LCOE. Raw data is calculated as %-saving multiplied by area. Then the savings are adjusted for degree of renovation (multiplied by 0.67 for old single-family houses) and calibrated with statistics (multiplied by 0.87). The energy demand for space heating in old single-family houses in NO1 adjusted for degree of renovation and calibrated to the energy balance 2018 is calculated to 5693 GWh/year. The last line of Table 3 presents the remaining demand for space heating if all measures are implemented. Without adjusting for inter-dependence of the data, and only adjust for degree of renovation and additional calibration, gives a negative demand for space heating, meaning that the sum of measures is greater than the demand for space heating. When correlating also for the interdependence of measures, the remaining space heating demand is 2091 GWh/year or 37% of the total space heating demand. The energy demand can theoretically be reduced by 63% in old single-family houses in NO1.

The savings when taking interdependence between measures into consideration is calculated by reducing the savings once a measure is implemented. The cheapest measure is EMS (Energy Monitoring System) and it is assumed that this is implemented first with is full potential. The second cheapest measure is roof insulation. The potential of this measure is reduced by the savings of measure #1 (=(5693 - 114)* 15% = 857):

*Savings measure #2 = (Heat demand – savings measure #1) * % saving measure #2*
*Savings measure #n = (Heat demand – Σsavings measure #1-(n-1)) * % saving measure #n*

Table 3: Example of savings of heat by energy efficiency measure in old single-family houses in NO1

	LCOE	Savings	Energy savings per measure (GWh/year)				
	NOK/kWh		Raw data	Adjusted renov.	Adjust & Calibrated	Inter-dependence	Energy demand
Energy Monitoring System	0.14	2 %	269	130	114	**114**	
Insulation of roof	0.22	15 %	1 463	983	860	**857**	
Red. indoor temp. nights/weekends	0.97	6 %	563	378	331	**279**	
Insulation of walls	1.27	40 %	3 789	2 545	2 226	**1 745**	
New windows and doors	3.27	20 %	1 901	1 277	1 117	**432**	
Insulation of floor	4.11	16 %	1 519	1 021	893	**167**	
Improved heat recovery in ventilation	5.92	6 %	421	283	247	**9**	
Sum savings		105 %	9 925	6 617	5 787	**3 602**	
Space heating demand							5 693
Space heating demand after energy efficiency			-4 232	-924	-94	**2 091**	

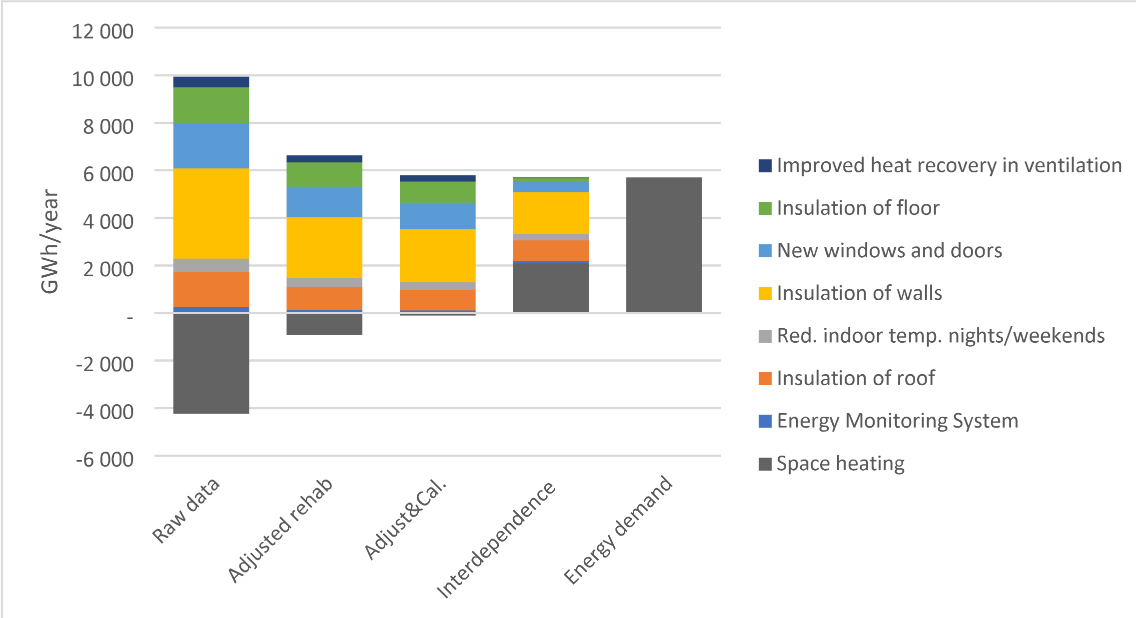

Figure 9: Example of savings of heat by energy efficiency measure in old single-family houses in NO1.

The total technical potential for energy savings is not affected by the sequence of measures, but the energy savings of the individual measure is affected.

4.4 Investment costs

The investment costs are given in NOK/m2 in the background data. The input data to IFE-TIMES-Norway is investment costs in NOK/kWh saved and derived by dividing the raw data with the reduced energy use per measure. Since this is the reduced energy depends on the order of measures, the investment costs in NOK/kWh saved is also affected. The same principle as for the technical potential is used, i.e. the cost is divided by the reduced energy use per measure.

The investment cost for some energy efficiency measures can also be considered as an increased cost, due to e.g. extra insulation of walls, roofs, floors. This is not included here but can be used in further work. The investment costs used here can be considered as a conservative estimate that does not underestimate the costs of implementing energy efficiency measures.

5 Implementation to IFE-TIMES-Norway

5.1 Measures

In IFE-TIMES-Norway, buildings are divided into single family houses, multifamily houses and commercial (non-residential) buildings. They are further divided in energy use by end-use of heat used in point sources, heat in central heating systems, hot tap water and electricity specific use. The categorization differs from the one used by the study of NVE/Multiconsult and some 'translations' have been made to ensure consistency at a more or less aggregate level. The more detailed building classification of the NVE study is kept as it is, while the division in heating system (point sources or central heating) assumes that the energy efficiency potential is the same for both systems (the potential is calculated as the share of point sources and central heating, respectively).

Table 4: Energy efficiency measures in IFE-TIMES-Norway (BS=Building Standards, HS =Heating System)

Measure	Single-family houses	Multi-family houses	Non-residential buildings	Total incl. 5 regions
Insulation of walls	3 BS * 2HS	3 BS * 2HS	3 BS * 2HS * 11 building types	78*5=390
Insulation of roof	3 BS * 2HS	3 BS * 2HS	3 BS * 2HS * 11 building types	78*5=390
Insulation of floor	3 BS * 2HS	3 BS * 2HS	3 BS * 2HS * 11 building types	78*5=390
New windows and doors	3 BS * 2HS	3 BS * 2HS	3 BS * 2HS * 11 building types	78*5=390
Reduced indoor temperature nights and weekends	3 BS * 2HS	3 BS * 2HS	3 BS * 2HS * 11 building types	78*5=390
Heat recovery in ventilation	4 BS * 2HS	4 BS * 2HS	4 BS * 2HS * 11 building types	104*5=520
Energy Monitoring System	4 BS	4 BS	4 BS * 11 building types	104*5=520
Energy efficient lighting	4 BS	4 BS	4 BS * 11 building types	104*5=520
Lighting regulation	-	-	4 BS * 10 building types	80*5=400
Better specific fan power (SFP)	-	-	4 BS * 11 building types	88*5=440
Demand controlled ventilation (DCV)	-	-	4 BS * 11 building types	88*5=440
Energy management systems ("SD-anlegg»)	-	-	3 BS * 11 building types	66*5=330
Total number of measures (incl. 5 regions)	230	230	3335	3795

All the measures are presented in Figure 10 - Figure 12. The energy savings and LCOE are calculated based on the adjusted data used in IFE-TIMES-Norway and with a discount rate of 4%.

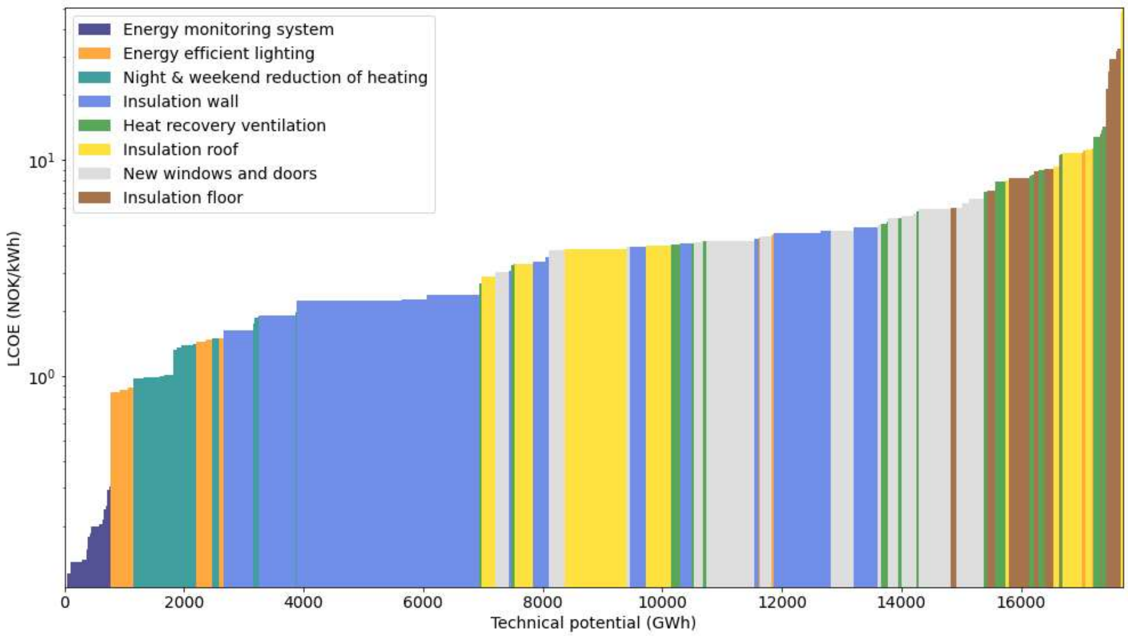

Figure 10: Technical energy efficiency potential by levelized cost of energy (4% discount rate) in the single-family houses in Norway in 2025 (NOK/kWh)

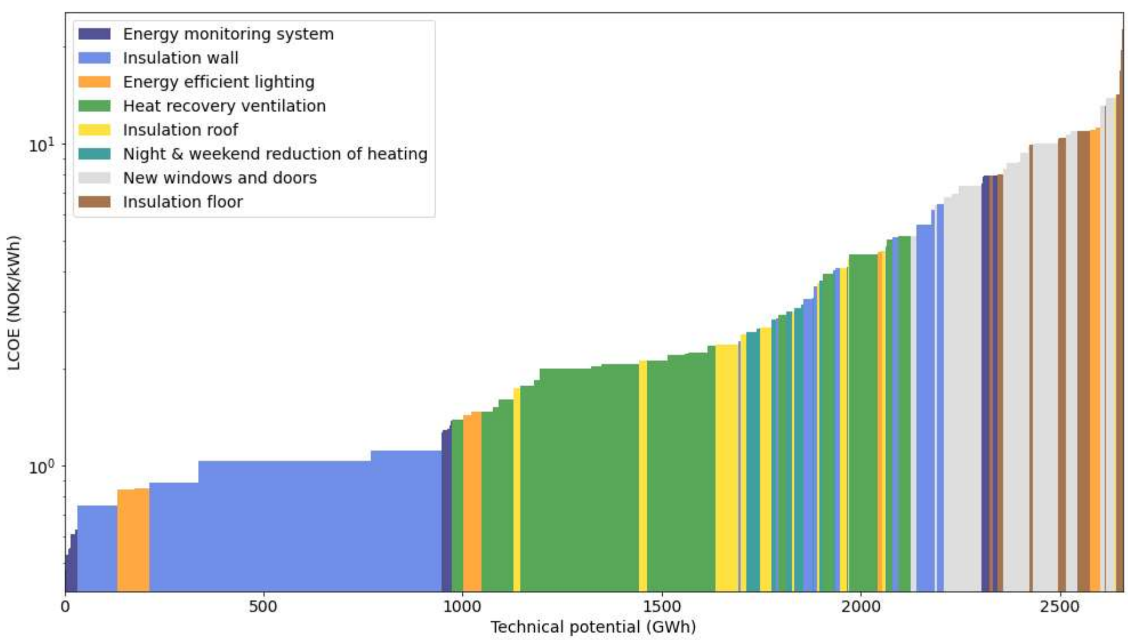

Figure 11: Technical energy efficiency potential by levelized cost of energy (4% discount rate) in the multi-family houses in Norway in 2025 (NOK/kWh)

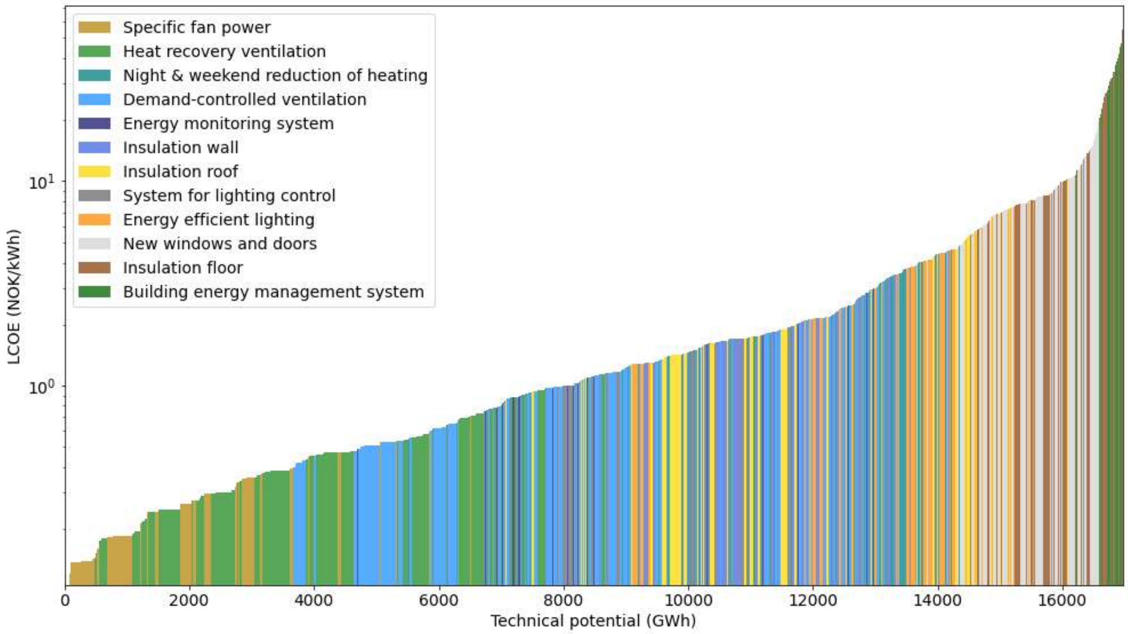

Figure 12: Technical energy efficiency potential by levelized cost of energy (4% discount rate) in non-residential buildings in Norway in 2025 (NOK/kWh)

5.2 Total energy efficiency potential

The energy demand by end-use for the three building categories single-family houses, multi-family houses and non-residential buildings is compared to the total technical energy efficiency potential in Figure 13. For all buildings, the technical potential is calculated to 37 TWh in 2025 and in 2050 it has decreased to 30 TWh. The potential is lower in 2025 than 2025 due to demolition of buildings.

The total technical energy efficiency potential for single-family houses is 18 TWh/year in 2025 or 43% of total energy demand. Most of the potential is connected to space heating, which can be reduced by 57%. The corresponding potential for reduced electricity specific demand is 11% and for hot tap water 2%. The technical potentials of multi-family houses are calculated to 3 TWh or 36% of total, 54% of space heating, 9% of electricity specific demand and 2% of hot tap water. For non-residential buildings the total savings are 17 TWh or 53%, space heating 78% and electricity specific demand 34%. The technical potential for savings of space heating in non-residential buildings is very high, and it might be necessary to further adjust these measures.

The adjusted technical energy efficiency potential is 77% of the previous total calculated potential [9]. The difference is higher for residential houses (68% for single-family houses, 62% for multi-family houses) than for non-residential buildings (92%). Note that the calibration of the energy use with the energy balance as described in paragraph 4.2 decreased the potential of dwellings by about 15% and increased the potential of non-residential buildings of about 15%.

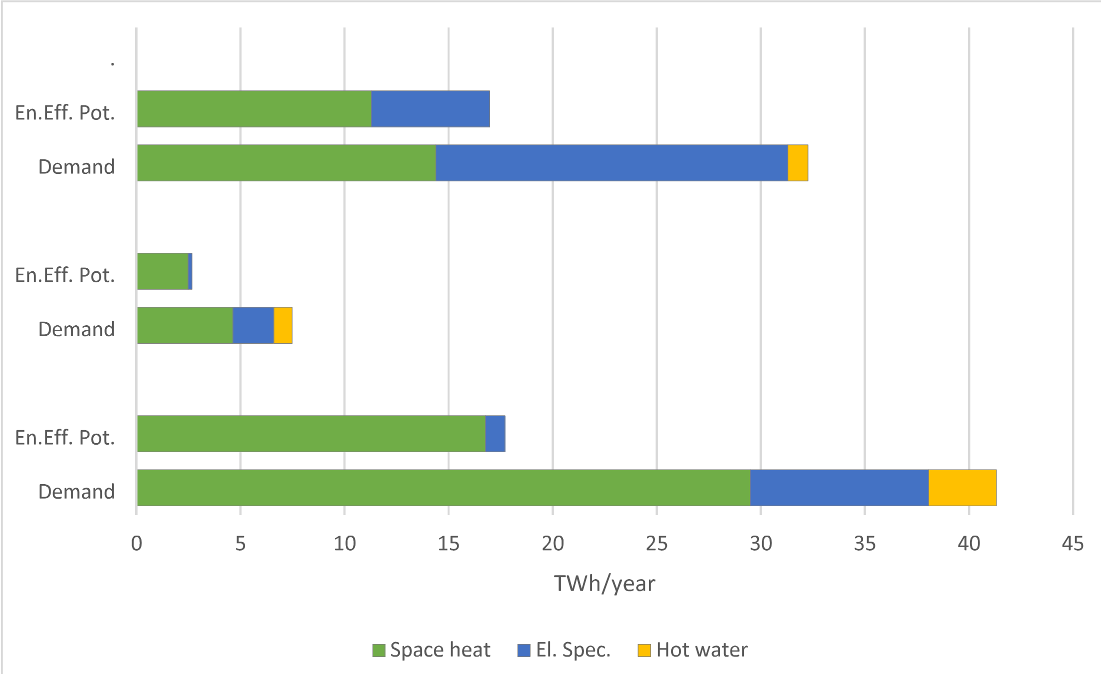

Figure 13: Energy demand by end-use and technical energy efficiency potential of buildings in 2025, TWh/year

Table 5: Energy efficiency potential per region and building type in 2025, GWh/year

Building type	End-use	Region					Sum
		NO1	NO2	NO3	NO4	NO5	
Single-family houses							
	heat	7 100	3 600	2 500	2 000	1 700	16 800
	appliances & lighting	400	200	100	100	100	900
	sum	7 500	3 800	2 600	2 100	1 800	17 700
Multi-family houses							
	heat	1 100	500	400	300	200	2 500
	appliances & lighting	80	40	20	20	20	200
	sum	1 180	540	420	320	220	2 700
Commercial buildings							
	heat	7 400	3 700	2 400	1 800	1 700	17 000
	El.specific demand	5 700	2 800	1 900	1 500	1 300	13 100
	sum	13 100	6 500	4 300	3 300	3 000	30 100
All buildings							
	heat	15 500	7 800	5 200	4 100	3 600	36 200
	El.specific demand	6 200	3 000	2 000	1 600	1 400	14 300
	sum	21 700	10 800	7 200	5 700	5 000	50 500

6 Further work

This work is the first step of the energy analyses in the Behaviour project of Work Package (WP) 5. It will be used in combination with the work done by other disciplined that is executed in the other work packages:

- WP1: Psychology, Consumer decision strategies
- WP2: Socio-technical analysis
- WP3: Panel Survey
- WP4: Agent Based Modelling (ABM)
- WP5: Energy system analysis

Trough interdisciplinary collaboration, the project will address how the energy behaviour of private households can, and needs to, be changed to support a desirable development of a low-carbon energy system, and how this complex system of behaviours can be included in energy system modelling.

The purpose is:

1) to provide knowledge on the main drivers and barriers for sustainable implementation of energy efficiency, flexible energy use, and new technology in private households,

2) to develop a methodology for modelling the complexity of the consumer side in relation to energy system models,

3) to quantify the impact of consumer energy behaviour,

4) to address the value and impact on the Norwegian energy system.

Further works includes to analyse the energy system value and impact of the derived energy system measures of this report. Further, it is planned to quantify under what conditions energy efficiency will be implemented from agent and societal perspective and combine this with insights from energy system analysis. An agent based (ABM) model is currently developed in the BEHAVIOUR project, several case studies has been executed and a survey of Norwegian households was carried out in May 2023.The knowledge created from case studies and a survey will be transformed into an agent-based model to simulate the actions and interaction of individual and collective entities. Thereafter, the agent-based model will be linked to Norwegian energy system, IFE-TIMES-Norway, to quantify the role of energy behaviour in the transition of the energy system.

7 References

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Appendix A Energy efficiency measures, % savings per measure

Table A1 Energy savings in residential sector

			Single family houses					Multi-family houses				
TEK	**Measure**	**End-use**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**
Older	Insulation of walls	Heat	40%	42%	41%	39%	42%	42%	45%	44%	42%	46%
	Insulation of roof	Heat	15%	16%	16%	15%	16%	12%	13%	13%	12%	13%
	Insulation of floor	Heat	16%	17%	16%	16%	17%	12%	13%	13%	12%	14%
	New windows and doors	Heat	20%	20%	20%	20%	21%	20%	20%	19%	20%	21%
	Red. indoor temp. nights/weekends	Heat	6%	7%	6%	5%	7%	6%	8%	7%	5%	8%
	Heat recovery in ventilation	Heat	6%	6%	6%	6%	6%	18%	19%	18%	18%	19%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
TEK69	Insulation of walls	Heat	25%	26%	25%	24%	26%	17%	19%	18%	17%	19%
	Insulation of roof	Heat	7%	8%	7%	7%	8%	7%	8%	8%	7%	8%
	Insulation of floor	Heat	7%	8%	8%	7%	8%	6%	7%	7%	6%	7%
	New windows and doors	Heat	33%	35%	33%	33%	35%	31%	33%	32%	32%	34%
	Red. indoor temp. nights/weekends	Heat	6%	7%	6%	5%	7%	6%	8%	7%	6%	8%
	Heat recovery in ventilation	Heat	11%	12%	11%	11%	12%	29%	31%	30%	29%	32%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
TEK87	Insulation of walls	Heat	16%	17%	16%	15%	16%	12%	13%	13%	12%	13%
	Insulation of roof	Heat	2%	3%	3%	2%	3%	2%	2%	3%	2%	3%
	Insulation of floor	Heat	6%	7%	7%	6%	7%	3%	4%	4%	3%	4%
	New windows and doors	Heat	28%	28%	27%	27%	28%	25%	25%	25%	25%	26%
	Red. indoor temp. nights/weekends	Heat	6%	7%	6%	5%	7%	5%	7%	6%	5%	7%
	Heat recovery in ventilation	Heat	12%	12%	12%	12%	11%	33%	34%	34%	33%	34%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
TEK97	Insulation of walls	Heat	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of roof	Heat	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of floor	Heat	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	New windows and doors	Heat	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Red. indoor temp. nights/weekends	Heat	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Heat recovery in ventilation	Heat	16%	16%	17%	16%	16%	42%	44%	44%	41%	44%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%

Table A2 Energy savings in kindergartens and offices

			Kindergarten					Office				
TEK	**Measure**	**End-use**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**
Old	Insulation of walls	Heat	19%	20%	20%	19%	20%	24%	26%	25%	24%	27%
	Insulation of roof	Heat	24%	25%	25%	23%	25%	20%	22%	21%	20%	23%
	Insulation of floor	Heat	25%	26%	26%	24%	26%	21%	22%	22%	21%	23%
	New windows and doors	Heat	13%	13%	12%	13%	14%	22%	23%	21%	23%	25%
	Red. indoor temp. nights/weekends	Heat	10%	12%	10%	9%	12%	11%	14%	12%	10%	16%
	Heat recovery in ventilation	Heat	15%	16%	16%	16%	16%	27%	29%	28%	27%	29%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	13%	13%	13%	13%	13%	11%	11%	11%	11%	11%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	10%	10%	10%	9%	10%	9%	9%	10%	10%	11%
	System for lightning control	El.spec.	14%	14%	14%	14%	14%	12%	12%	13%	12%	12%
TEK69	Insulation of walls	Heat	14%	15%	14%	13%	15%	23%	25%	24%	23%	26%
	Insulation of roof	Heat	11%	12%	12%	11%	12%	7%	8%	7%	7%	8%
	Insulation of floor	Heat	13%	14%	14%	13%	14%	6%	7%	7%	6%	7%
	New windows and doors	Heat	24%	24%	23%	24%	26%	35%	37%	34%	35%	39%
	Red. indoor temp. nights/weekends	Heat	9%	11%	10%	9%	12%	11%	13%	12%	10%	15%
	Heat recovery in ventilation	Heat	16%	17%	17%	17%	17%	24%	26%	25%	24%	26%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	12%	12%	11%	12%	12%	9%	9%	9%	9%	9%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	15%	15%	14%	13%	14%	9%	8%	9%	11%	10%
	System for lightning control	El.spec.	13%	14%	14%	14%	14%	11%	12%	12%	12%	12%
TEK87	Insulation of walls	Heat	12%	12%	12%	11%	13%	15%	17%	16%	15%	18%
	Insulation of roof	Heat	6%	6%	6%	5%	6%	3%	4%	3%	3%	4%
	Insulation of floor	Heat	16%	17%	16%	16%	17%	9%	10%	10%	9%	11%
	New windows and doors	Heat	28%	28%	27%	27%	28%	42%	46%	43%	41%	47%
	Red. indoor temp. nights/weekends	Heat	9%	11%	10%	9%	12%	10%	14%	12%	10%	16%
	Heat recovery in ventilation	Heat	9%	10%	10%	10%	10%	17%	18%	17%	16%	18%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	10%	10%	10%	10%	10%	7%	7%	7%	7%	7%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	17%	17%	16%	15%	17%	15%	13%	15%	16%	14%
	System for lightning control	El.spec.	12%	12%	12%	12%	12%	9%	10%	10%	10%	10%
TEK97	Insulation of walls		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of roof		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of floor		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	New windows and doors		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Red. indoor temp. nights/weekends		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Heat recovery in ventilation	Heat	13%	13%	11%	13%	14%	23%	25%	23%	22%	25%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	8%	8%	7%	8%	8%	6%	6%	6%	6%	6%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	18%	18%	16%	17%	18%	12%	9%	11%	14%	10%
	System for lightning control	El.spec.	13%	14%	14%	14%	14%	10%	11%	11%	11%	11%

Table A3 Energy savings in schools and universities

			Schools					Universities				
TEK	**Measure**	**End-use**	**NO 1**	**NO 2**	**NO 3**	**NO 4**	**NO 5**	**NO 1**	**NO 2**	**NO 3**	**NO 4**	**NO 5**
Old	Insulation of walls	Heat	19%	20%	20%	19%	21%	22%	24%	24%	23%	25%
	Insulation of roof	Heat	23%	24%	24%	23%	25%	19%	20%	20%	19%	21%
	Insulation of floor	Heat	23%	25%	25%	23%	26%	19%	21%	20%	19%	22%
	New windows and doors	Heat	18%	18%	16%	18%	19%	22%	23%	21%	22%	24%
	Red. indoor temp. nights/weekends	Heat	11%	14%	12%	10%	15%	10%	13%	11%	10%	15%
	Heat recovery in ventilation	Heat	26%	28%	27%	26%	28%	33%	35%	34%	32%	36%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	15%	15%	15%	15%	15%	12%	12%	12%	12%	12%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	15%	16%	15%	14%	16%	12%	11%	12%	13%	13%
	System for lightning control	El.spec.	11%	11%	11%	11%	11%	11%	11%	11%	11%	11%
TEK69	Insulation of walls	Heat	20%	22%	22%	20%	23%	21%	23%	22%	22%	25%
	Insulation of roof	Heat	9%	10%	10%	9%	10%	7%	7%	7%	7%	8%
	Insulation of floor	Heat	8%	9%	8%	8%	9%	6%	7%	6%	6%	7%
	New windows and doors	Heat	28%	29%	26%	28%	31%	33%	35%	32%	33%	38%
	Red. indoor temp. nights/weekends	Heat	10%	13%	12%	10%	15%	10%	13%	11%	10%	14%
	Heat recovery in ventilation	Heat	25%	26%	25%	24%	25%	30%	32%	30%	29%	31%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	13%	13%	13%	13%	13%	10%	10%	10%	10%	10%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	19%	19%	18%	17%	19%	12%	10%	12%	14%	12%
	System for lightning control	El.spec.	11%	11%	11%	11%	11%	10%	10%	11%	11%	11%
TEK87	Insulation of walls	Heat	16%	17%	17%	16%	19%	14%	16%	15%	14%	17%
	Insulation of roof	Heat	4%	4%	4%	4%	4%	3%	4%	3%	3%	4%
	Insulation of floor	Heat	11%	12%	11%	11%	13%	9%	10%	9%	9%	11%
	New windows and doors	Heat	36%	38%	35%	34%	38%	40%	44%	41%	39%	45%
	Red. indoor temp. nights/weekends	Heat	11%	14%	13%	11%	16%	10%	13%	12%	10%	16%
	Heat recovery in ventilation	Heat	16%	16%	15%	15%	16%	21%	22%	21%	20%	22%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	10%	10%	10%	10%	10%	8%	8%	8%	8%	8%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	23%	23%	22%	21%	23%	18%	17%	19%	21%	19%
	System for lightning control	El.spec.	9%	9%	9%	9%	9%	8%	9%	9%	9%	9%
TEK97	Insulation of walls		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of roof		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of floor		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	New windows and doors		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Red. indoor temp. nights/weekends		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Heat recovery in ventilation	Heat	20%	22%	20%	20%	21%	27%	30%	28%	26%	30%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	9%	9%	9%	9%	9%	7%	7%	7%	7%	7%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	24%	23%	23%	23%	23%	15%	12%	15%	18%	13%
	System for lightning control	El.spec.	10%	10%	10%	10%	10%	9%	10%	10%	10%	10%

Table A4 Energy savings in hospitals and nursing homes

			Hospitals					Nursing homes				
TEK	**Measure**	**End-use**	**NO 1**	**NO 2**	**NO 3**	**NO 4**	**NO 5**	**NO 1**	**NO 2**	**NO 3**	**NO 4**	**NO 5**
Old	Insulation of walls	Heat	15%	17%	17%	16%	18%	14%	16%	15%	14%	16%
	Insulation of roof	Heat	13%	14%	14%	14%	15%	17%	19%	18%	17%	20%
	Insulation of floor	Heat	13%	15%	14%	14%	16%	18%	20%	19%	18%	20%
	New windows and doors	Heat	15%	15%	14%	15%	17%	12%	12%	11%	13%	14%
	Red. indoor temp. nights/weekends	Heat	5%	7%	6%	5%	8%	5%	7%	5%	4%	7%
	Heat recovery in ventilation	Heat	53%	58%	55%	52%	59%	42%	44%	42%	40%	43%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	16%	16%	16%	16%	16%	18%	18%	18%	18%	18%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	18%	18%	19%	20%	20%	18%	19%	19%	19%	20%
	System for lightning control	El.spec.	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
TEK69	Insulation of walls	Heat	15%	16%	16%	15%	18%	15%	16%	15%	15%	17%
	Insulation of roof	Heat	5%	5%	5%	5%	6%	6%	7%	7%	6%	8%
	Insulation of floor	Heat	4%	5%	5%	4%	5%	6%	6%	6%	6%	7%
	New windows and doors	Heat	21%	23%	21%	22%	25%	20%	21%	19%	21%	23%
	Red. indoor temp. nights/weekends	Heat	5%	7%	6%	5%	8%	5%	7%	6%	5%	7%
	Heat recovery in ventilation	Heat	50%	54%	51%	48%	55%	40%	42%	40%	38%	42%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	13%	13%	13%	13%	13%	15%	15%	15%	15%	15%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	20%	20%	21%	23%	22%	21%	21%	22%	23%	23%
	System for lightning control	El.spec.	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
TEK87	Insulation of walls	Heat	10%	12%	11%	10%	13%	8%	9%	9%	8%	9%
	Insulation of roof	Heat	2%	3%	2%	2%	3%	3%	3%	3%	3%	4%
	Insulation of floor	Heat	6%	7%	7%	6%	8%	9%	10%	9%	9%	10%
	New windows and doors	Heat	27%	30%	28%	27%	32%	28%	30%	28%	27%	31%
	Red. indoor temp. nights/weekends	Heat	6%	8%	7%	5%	9%	5%	7%	6%	4%	7%
	Heat recovery in ventilation	Heat	35%	39%	35%	33%	39%	27%	29%	26%	25%	28%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	10%	11%	11%	11%	11%	12%	12%	12%	12%	12%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	29%	28%	29%	30%	29%	30%	30%	31%	31%	31%
	System for lightning control	El.spec.	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%
TEK97	Insulation of walls		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of roof		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of floor		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	New windows and doors		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Red. indoor temp. nights/weekends		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Heat recovery in ventilation	Heat	40%	45%	40%	38%	46%	30%	32%	29%	28%	32%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	9%	9%	9%	9%	9%	11%	11%	11%	11%	11%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	26%	33%	27%	28%	25%	28%	19%	30%	31%	29%
	System for lightning control	El.spec.	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%

Table A5 Energy savings in hotels and sport centers

			Hotels					Sport centers				
TEK	**Measure**	**End-use**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**
Old	Insulation of walls	Heat	17%	18%	18%	17%	19%	22%	24%	23%	22%	24%
	Insulation of roof	Heat	20%	22%	22%	20%	23%	25%	27%	27%	25%	28%
	Insulation of floor	Heat	21%	23%	22%	21%	24%	26%	28%	27%	26%	29%
	New windows and doors	Heat	15%	15%	14%	16%	16%	15%	14%	13%	15%	15%
	Red. indoor temp. nights/weekends	Heat	5%	6%	5%	4%	7%	11%	14%	12%	10%	16%
	Heat recovery in ventilation	Heat	32%	34%	32%	31%	33%	14%	14%	14%	13%	14%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	16%	17%	17%	16%	18%	10%	10%	9%	8%	10%
	System for lightning control	El.spec.	10%	10%	11%	10%	11%	5%	5%	5%	5%	5%
TEK69	Insulation of walls	Heat	17%	19%	19%	17%	20%	23%	24%	24%	22%	25%
	Insulation of roof	Heat	8%	9%	8%	8%	9%	21%	22%	22%	20%	23%
	Insulation of floor	Heat	7%	8%	7%	7%	8%	8%	9%	9%	8%	9%
	New windows and doors	Heat	25%	26%	23%	25%	28%	22%	22%	20%	22%	23%
	Red. indoor temp. nights/weekends	Heat	5%	6%	5%	4%	7%	10%	13%	12%	10%	15%
	Heat recovery in ventilation	Heat	31%	33%	31%	30%	32%	12%	12%	12%	12%	11%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	14%	14%	14%	14%	14%	13%	13%	13%	14%	13%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	19%	19%	20%	20%	20%	12%	12%	11%	10%	12%
	System for lightning control	El.spec.	10%	10%	10%	10%	10%	5%	5%	5%	5%	5%
TEK87	Insulation of walls	Heat	14%	15%	15%	14%	16%	21%	23%	22%	21%	23%
	Insulation of roof	Heat	3%	4%	3%	3%	4%	4%	5%	5%	4%	5%
	Insulation of floor	Heat	9%	10%	10%	9%	11%	13%	14%	13%	13%	14%
	New windows and doors	Heat	31%	33%	31%	30%	33%	31%	33%	31%	30%	32%
	Red. indoor temp. nights/weekends	Heat	5%	6%	5%	4%	7%	10%	13%	12%	10%	15%
	Heat recovery in ventilation	Heat	19%	20%	19%	18%	19%	8%	8%	8%	8%	8%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	11%	11%	11%	12%	11%	11%	11%	11%	11%	11%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	26%	26%	26%	26%	27%	15%	15%	14%	13%	15%
	System for lightning control	El.spec.	9%	9%	9%	9%	9%	4%	4%	4%	4%	4%
TEK97	Insulation of walls		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of roof		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of floor		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	New windows and doors		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Red. indoor temp. nights/weekends		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Heat recovery in ventilation	Heat	24%	25%	23%	22%	25%	11%	11%	10%	10%	10%
	Energy Monitoring System	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	El.spec.	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	All	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	26%	25%	26%	27%	26%	16%	15%	15%	14%	15%
	System for lightning control	El.spec.	10%	10%	10%	10%	10%	5%	5%	5%	5%	5%

Table A6 Energy savings in shopping and culture buildings

			Shops					Culture				
TEK	**Measure**		**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**
Old	Insulation of walls	**End-use**	17%	19%	19%	17%	20%	19%	21%	20%	19%	21%
	Insulation of roof	Heat	15%	16%	16%	15%	17%	23%	25%	25%	23%	26%
	Insulation of floor	Heat	15%	16%	16%	15%	17%	24%	26%	26%	24%	27%
	New windows and doors	Heat	16%	16%	14%	16%	17%	15%	14%	13%	16%	15%
	Red. indoor temp. nights/weekends	Heat	8%	11%	9%	7%	11%	10%	13%	11%	9%	13%
	Heat recovery in ventilation	Heat	44%	47%	44%	43%	46%	21%	21%	21%	20%	21%
	Energy Monitoring System	Heat	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	All	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	El.spec.	18%	18%	18%	18%	18%	15%	16%	16%	16%	16%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	20%	20%	21%	20%	22%	13%	14%	13%	12%	14%
	System for lightning control	All	0%	0%	0%	0%	0%	5%	5%	5%	5%	5%
TEK69	Insulation of walls	El.spec.	10%	11%	11%	10%	12%	20%	22%	21%	19%	22%
	Insulation of roof	Heat	6%	6%	6%	6%	7%	9%	10%	9%	9%	10%
	Insulation of floor	Heat	5%	6%	5%	5%	6%	8%	8%	8%	8%	9%
	New windows and doors	Heat	25%	26%	25%	25%	29%	25%	26%	24%	26%	28%
	Red. indoor temp. nights/weekends	Heat	8%	10%	9%	7%	11%	9%	11%	10%	8%	12%
	Heat recovery in ventilation	Heat	42%	45%	43%	41%	44%	20%	20%	20%	19%	20%
	Energy Monitoring System	Heat	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	All	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	El.spec.	15%	15%	15%	16%	15%	13%	13%	13%	14%	13%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	23%	23%	24%	25%	25%	16%	16%	16%	16%	17%
	System for lightning control	All	0%	0%	0%	0%	0%	5%	5%	5%	5%	5%
TEK87	Insulation of walls	El.spec.	12%	14%	13%	12%	15%	15%	16%	16%	15%	17%
	Insulation of roof	Heat	2%	3%	3%	2%	3%	4%	4%	4%	3%	4%
	Insulation of floor	Heat	7%	8%	7%	7%	8%	10%	11%	11%	10%	11%
	New windows and doors	Heat	28%	31%	28%	27%	32%	31%	32%	30%	30%	32%
	Red. indoor temp. nights/weekends	Heat	9%	11%	9%	7%	12%	9%	11%	10%	8%	12%
	Heat recovery in ventilation	Heat	27%	28%	27%	26%	28%	12%	12%	12%	11%	12%
	Energy Monitoring System	Heat	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	All	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	El.spec.	12%	13%	13%	13%	13%	11%	11%	11%	11%	11%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	32%	32%	32%	32%	33%	21%	21%	21%	20%	22%
	System for lightning control	All	0%	0%	0%	0%	0%	4%	4%	4%	4%	4%
TEK97	Insulation of walls	El.spec.	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of roof		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Insulation of floor		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	New windows and doors		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Red. indoor temp. nights/weekends		0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Heat recovery in ventilation		32%	34%	32%	30%	34%	16%	16%	15%	15%	15%
	Energy Monitoring System	Heat	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Energy efficient lighting	All	10%	10%	10%	10%	10%	10%	10%	10%	10%	10%
	Improved specific fan power (SFP)	El.spec.	11%	11%	11%	11%	11%	10%	10%	10%	10%	10%
	Energy management system	All	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%
	Demand controlled ventilation	All	30%	29%	31%	32%	30%	21%	21%	21%	21%	22%
	System for lightning control	All	0%	0%	0%	0%	0%	5%	5%	5%	5%	5%

Appendix B LCOE (Levelized Cost of Energy)

Table B1 LCOE for single family houses with 6% hurdle rate and incl. VAT (NVE [10])

	Measure	Oslo	Kristiansand	Trondheim	Tromsø	Bergen
Old	Energy efficient lighting	4.7	4.8	6.3	9.0	6.6
	Energy Monitoring System	0.1	0.2	0.1	0.1	0.2
	Improved heat recovery in ventilation	5.9	7.3	5.4	4.2	7.0
	Insulation of floor	4.1	4.6	3.8	3.3	4.5
	Insulation of roof	0.2	0.2	0.2	0.2	0.2
	Insulation of walls	1.3	1.4	1.2	1.0	1.4
	New windows and doors	3.3	3.8	3.2	2.6	3.6
	Red. indoor temp. nights/weekends	1.0	1.0	0.9	0.9	1.0
TEK69	Energy efficient lighting	5.2	6.0	4.7	3.8	5.5
	Energy Monitoring System	0.2	0.2	0.2	0.2	0.2
	Improved heat recovery in ventilation	6.7	6.9	9.2	15	9.9
	Insulation of floor	15	17	14	12	16
	Insulation of roof	1.0	1.1	0.9	0.8	1.1
	Insulation of walls	2.6	2.9	2.4	2.1	2.8
	New windows and doors	3.2	3.7	3.1	2.5	3.5
	Red. indoor temp. nights/weekends	1.6	1.6	1.5	1.4	1.5
TEK87	Energy efficient lighting	54	58	75	126	84
	Energy Monitoring System	0.2	0.3	0.2	0.2	0.3
	Improved heat recovery in ventilation	3.8	4.5	3.6	3.0	4.3
	Insulation of floor	6.3	7.1	6.0	5.1	6.8
	Insulation of roof	4.1	4.7	3.9	3.3	4.4
	Insulation of walls	1.7	1.9	1.5	1.3	1.8
	New windows and doors	4.4	5.1	4.2	3.4	4.7
	Red. indoor temp. nights/weekends	1.9	1.9	1.8	1.7	1.8
TEK97	Energy efficient lighting	54	58	75	126	84
	Energy Monitoring System	0.3	0.3	0.3	0.3	0.3
	Improved heat recovery in ventilation	3.8	4.5	3.6	3.0	4.3

Table B2 LCOE for multi-family houses with 6% hurdle rate and excl. VAT (NVE [10])

	Measure	Oslo	Kristiansand	Trondheim	Tromsø	Bergen
Old	Energy efficient lighting	3.0	3.1	4.7	6.6	4.7
	Energy Monitoring System	7.3	8.2	7.1	6.1	8.0
	Improved heat recovery in ventilation	1.5	1.8	1.4	1.1	1.7
	Insulation of floor	3.7	4.2	3.3	2.9	3.9
	Insulation of roof	1.0	1.2	0.9	0.8	1.1
	Insulation of walls	0.7	0.8	0.7	0.6	0.8
	New windows and doors	3.6	4.3	3.5	2.7	3.9
	Red. indoor temp. nights/weekends	1.3	1.3	1.2	1.2	1.2
TEK69	Energy efficient lighting	3.9	4.0	6.2	10.6	6.4
	Energy Monitoring System	1.2	1.3	1.2	1.0	1.3
	Improved heat recovery in ventilation	1.2	1.4	1.1	0.9	1.3
	Insulation of floor	5.3	6.2	4.8	4.0	5.7
	Insulation of roof	1.5	1.7	1.3	1.1	1.5
	Insulation of walls	2.4	2.7	2.2	1.8	2.5
	New windows and doors	3.5	4.2	3.4	2.7	3.9
	Red. indoor temp. nights/weekends	2.2	2.2	1.9	1.7	1.9
TEK87	Energy efficient lighting	29.7	31.7	52.8	95.0	59.4
	Energy Monitoring System	0.4	0.5	0.4	0.4	0.5
	Improved heat recovery in ventilation	1.1	1.3	1.0	0.9	1.2
	Insulation of floor	9.8	11.2	8.9	7.4	10.3
	Insulation of roof	3.8	4.5	3.5	2.9	4.0
	Insulation of walls	1.0	1.2	0.9	0.8	1.1
	New windows and doors	4.7	5.6	4.6	3.5	5.1
	Red. indoor temp. nights/weekends	2.6	2.5	2.1	2.0	2.2
TEK97	Energy efficient lighting	29.7	31.7	52.8	95.0	59.4
	Energy Monitoring System	0.5	0.6	0.5	0.4	0.5
	Heat recovery in ventilation	1.1	1.3	1.0	0.9	1.2

Table B3 LCOE for shops and offices with 6% hurdle rate and excl. VAT (NVE [10])

		Shops					Offices				
TEK	**Measure**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**	**NO1**	**NO2**	**NO3**	**NO4**	**NO5**
Old	Insulation of walls	0.7	0.9	0.7	0.5	0.8	0.9	1.1	0.8	0.6	1.0
	Energy efficient lighting	1.4	1.5	2.1	3.5	2.1	3.2	5.6	4.7	7.9	4.7
	Energy Monitoring System	0.4	0.5	0.4	0.4	0.5	0.6	0.7	0.6	0.6	0.7
	Energy management system	7.4	9.0	8.0	6.9	9.3	12	15	13	11	16
	Insulation of roof	0.4	0.5	0.4	0.3	0.4	0.5	0.6	0.4	0.3	0.5
	Insulation of floor	3.5	4.2	3.1	2.5	3.7	4.2	5.3	3.8	2.8	4.6
	New windows and doors	3.7	4.7	4.2	3.0	4.5	2.8	3.5	3.5	3.0	3.9
	Red. indoor temp. nights/weekends	1.2	1.2	1.1	1.1	1.1	1.3	1.3	1.2	1.1	1.2
	Improved heat recovery ventilation	0.2	0.2	0.2	0.1	0.2	0.4	0.5	0.4	0.3	0.5
	Improved specific fan power (SFP)	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.2
	Demand controlled ventilation	0.2	0.3	0.2	0.2	0.2	1.1	1.3	1.1	0.9	1.2
	System for lightning control						1.1	1.1	1.4	2.6	1.5
TEK69	Insulation of walls	1.6	1.9	1.4	1.1	1.7	1.2	1.6	1.2	0.8	1.4
	Energy efficient lighting	1.6	1.6	2.1	3.6	2.3	3.5	3.5	4.5	7.6	4.8
	Energy Monitoring System	0.4	0.4	0.4	0.4	0.4	0.5	0.6	0.5	0.5	0.6
	Energy management system	9.5	11	11	9.2	12	15	18	17	15	20
	Insulation of roof	1.8	2.0	1.5	1.2	1.8	1.4	1.8	1.3	0.9	1.5
	Insulation of floor	15	17	13	10	15	20	23	18	12	19
	New windows and doors	3.2	4.0	3.5	2.7	3.9	2.4	2.8	2.8	2.6	3.3
	Red. indoor temp. nights/weekends	1.9	2.0	1.7	1.6	1.7	1.7	1.7	1.6	1.5	1.7
	Improved heat recovery ventilation	0.3	0.4	0.3	0.2	0.4	0.7	0.8	0.7	0.5	0.9
	Improved specific fan power (SFP)	0.1	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.3
	Demand controlled ventilation	0.2	0.3	0.3	0.2	0.3	1.3	1.6	1.4	1.1	1.5
	System for lightning control						1.1	1.0	1.3	2.1	1.4
TEK87	Insulation of walls	0.5	0.6	0.4	0.4	0.5	0.7	0.9	0.6	0.5	0.8
	Energy efficient lighting	4.1	4.1	6.5	13	6.0	8.8	8.8	12	18	12
	Energy Monitoring System	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.4	0.5
	Energy management system	11	14	13	11	15	20	25	23	20	27
	Insulation of roof	4.6	5.3	3.7	3.2	4.3	1.8	2.3	1.7	1.3	2.1
	Insulation of floor	4.4	5.1	3.8	3.2	4.6	5.1	6.5	4.7	3.6	5.9
	New windows and doors	4.0	5.0	4.1	3.4	4.9	3.8	4.6	4.0	3.4	5.0
	Red. indoor temp. nights/weekends	2.2	2.2	2.0	2.0	2.1	2.8	2.8	2.4	2.1	2.5
	Improved heat recovery ventilation	0.6	0.7	0.6	0.5	0.7	1.4	1.7	1.4	1.1	1.8
	Improved specific fan power (SFP)	0.2	0.2	0.2	0.2	0.2	0.4	0.4	0.5	0.5	0.4
	Demand controlled ventilation	0.2	0.3	0.2	0.2	0.3	1.1	1.4	1.1	1.0	1.3
	System for lightning control						2.0	1.9	2.6	3.8	2.5
TEK97	Energy efficient lighting	4.1	4.1	6.5	13	6.0	8.8	8.8	12	18	12
	Energy Monitoring System	0.3	0.4	0.4	0.4	0.4	0.5	0.6	0.6	0.5	0.6
	Improved heat recovery ventilation	0.6	0.7	0.6	0.5	0.7	1.4	1.7	1.4	1.1	1.8
	Improved specific fan power (SFP)	0.2	0.2	0.3	0.3	0.2	0.5	0.6	0.6	0.7	0.6
	Demand controlled ventilation	0.3	0.3	0.3	0.3	0.3	1.5	2.4	1.7	1.3	2.3
	System for lightning control						2.0	1.9	2.6	3.8	2.5

Tittel: Building energy efficiency measures in Norwegian energy system analysis

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